Effects of dental loss and senescence on aspects of adult mandibular morphology in South Africans

Submitted by:

Anna Catherina Oettlé

A thesis submitted to the Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria in fulfilment of the requirements for the degree

Of

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Supervisor: Prof Maryna Steyn

Declaration

I, Anna Catherina Oettlé declare that this dissertation is my own work. It is being submitted for the degree of PhD in Anatomy at the University of Pretoria. It has not been submitted before for any degree or examination at this or any other Institution.

Sign:……………………………………………………………………………….

This 31st day of October 2014

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

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INVESTIGATOR	**Principal Investigator:** Dr. A. C. Oettlé
SUBINVESTIGATOR	Prof. M. Steyn
SUPERVISOR	Prof. M. Steyn
DEPARTMENT	**Dept:** Anatomy **Phone:** 012 319 2430 **Fax:** 086 516 2987 **Cell:** 079 500 6079 **E-Mail:** anna.oettle@up.ac.za
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Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

◆Tel:012-3541330 ◆Fax:012-3541367 / 0866515924 ◆E-Mail: manda@med.up.ac.za
◆Web: //www.healthethics-up.co.za ◆H W Snyman Bld (South) Level 2-34 ◆P.O.BOX 667, Pretoria, S.A., 0001

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To my loving husband, my dearest mother and

my four gifts from heaven

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Abstract

Changes occur to the mandible with dental loss and senescence. However, the influence that these changes have on sex and ancestry estimations remains unclear. The purpose of this study was to investigate the influence of dental loss and senescence on changes in mandibular morphology. The outcome has implications for both forensic anthropology and restorative dentistry. The study sample consisted of 717 mandibles consisting of both male and female South Africans of African (SAA) and European ancestry (SAE). To minimise the effects of variation in dentition amongst sex-ancestry groups, the sample included individuals with a spectrum of tooth loss patterns, namely efficient and inefficient occlusions as well as no occlusions. Dentition was considered efficient when the remaining teeth in occlusion were evenly distributed between the sides. Linear measurements as well as geometric morphometric shape analyses were performed. Shape analyses of the complete mandible were performed on models from digitised landmarks by using a MicroScribe G2. Detailed shape analyses of the ramus and chin area as well as measurements of the cortical thickness at specific sites were executed on images generated by cone beam computed tomography (CBCT). A comprehensive assessment of changes in shape, size and cortical thickness of the mandible with age and dental loss were made. Shape and size differences of the mandible were evaluated for discriminant abilities between sex and ancestry groups. Although most dimensions decreased with tooth loss, the greatest impact was noted in the loss of alveolar bone. The mandibular angle increased minimally in size when a few teeth were lost, but recovered to some extent with further tooth loss. The cortical thicknesses at the mental foramen lingually as well as in the midline in females, were relatively spared with tooth loss. Male individuals of SAA were often the most resilient to tooth loss. In general external linear dimensions were maintained with age despite tooth loss. Conversely, measurements of cortical bone thickness decreased slightly, but could have been influenced by dental loss. The shape of the chin and gonial area was more affected by aging in SAE. The sex and ancestry discriminant ability of the linear dimensions when considered collectively approximated 90%, in general improving further when tooth loss was taken into account. All linear measurements were smaller in females and in general tooth loss accentuated sex differences. SAA exhibited greater dimensions, apart from maximum ramus height, bigonial breadth and cortical thickness at the gonion. The mental tubercles were more prominent than the pogonion in SAE (square chin) and vice versa in individuals of SAA (pointed chin). The gonial area in individuals of African ancestry was broad and more convex and the gonial eversion more prominent with a more upright ramus. Discriminant qualities of the gonial shape for sex in individuals of African ancestry reached 90% within dentition groups. Ramus flexure and chin shape were not found to be useful in sex estimation. In conclusion, this research elucidated the effects of tooth loss and senescence on the morphology of the mandible for the forensic anthropological setting.

Key words:

Aging; Tooth loss; Cone beam computer tomography; Shape analysis; Cortical thickness; Chin shape; Gonial eversion; Ramus flexure; Sex estimation; Ancestry estimation

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Psalm 23 King James Version

1 The LORD is my shepherd; I shall not want. 2 He maketh me to lie down in green
pastures: he leadeth me beside the still waters. 3 He restoreth my soul: he leadeth me in the
paths of righteousness for his name's sake. 4 Yea, though I walk through the valley of the
shadow of death, I will fear no evil: for thou art with me; thy rod and thy staff they comfort
me. 5 Thou preparest a table before me in the presence of mine enemies: thou anointest my
head with oil; my cup runneth over. 6 Surely goodness and mercy shall follow me all the days
of my life: and I will dwell in the house of the LORD for ever.

Chapter 1: INTRODUCTION

The shape and internal structural changes of the mandible with the advancement of age and dental loss has implications for forensic anthropology and for clinical dentistry. Many shape characteristics of the mandible such as the mandibular angle, gonial eversion, ramus flexure and chin morphology are used to estimate sex (De Villiers 1968; Acsádi et al. 1970; Novotny et al. 1993; Loth & Henneberg 1996; Ohm & Silness 1999; Galdames et al. 2009) and to a lesser degree ancestry (Tobias 1974), in unknown skeletons. It is uncertain to what extent dental loss and senescence would influence these characteristics that sex and ancestry estimations are based on.

As diet and dental care may influence postnatal development of the mandible, sex and ancestry specific features may not be fixed (Oettlé et al. 2009a). For instance, fluctuating changes in diet and dental care with time within a group could have an effect on dental patterns, which in turn could influence the mandibular characteristics that are used to estimate sex and ancestry. If a relationship exists between these mandibular shape features and senescence or tooth loss, it would need to be considered with regard to the use of these traits in forensic anthropology.

Knowledge of the determinants of the variations in external and internal structure of the mandible also has implications for dentistry when restorative procedures are planned. With this research, new insights into the mechanisms underlying the development of the mandible shape will be provided along with the masticatory function that needs to be optimised in dental care (Zachow et al. 2006). The effects of tooth loss on cortical thickness in specific regions of the mandible need to be considered when tooth extractions, dental implants or sagittal osteotomies for correcting facial abnormalities are planned and performed.

The presence or absence of teeth as well as the distribution of remaining teeth when tooth loss is present have profound effects on the mechanism of chewing and therefore the action of muscles of mastication on the shape of the jaw (Kasai et al. 1996; Loth 1996; Kohakura et al. 1997; Oettlé et al. 2009b). Individuals with a greater occlusal area and therefore more and/or more functionally arranged teeth are capable of producing a greater bite force. Partial dentition where sufficiently remaining teeth are present and in occlusion could contribute to a stable occlusal relationship and efficient mastication, contrary to situations where partial teeth are insufficient or not in occlusion with teeth of the upper jaw (Kasai et al. 1994; Kohakura et al. 1997; Pileicikiene & Surna 2004).

The maximum tooth loss pattern still conducive for efficient mastication will depend on whether or not posterior and anterior teeth are in occlusion and whether they are evenly distributed between the left and the right sides of the jaw (Kasai et al. 1994; Kasai et al. 1996; Kohakura et al. 1997; Ceylan et al. 1998; Pileicikiene & Surna 2004; Knezović-Zlatarić & Čelebić 2005; Yanıkoğlu & Yılmaz 2008; Oettlé et al. 2009b). In this study the maximum tooth loss pattern associated with efficient mastication as reflected in the size of the mandibular angle will be evaluated. This validated maximum tooth loss pattern will then be used as a criterion to classify mandibles.

Each of the muscles of mastication act on the underlying bone to create mechanical stress during the forces of mastication. The posterior aspect of the mandible is said to be particularly sensitive to changes in the forces of mastication as the muscles of mastication attach to this area (Kasai et al. 1994; Xie & Ainamo 2004; Knezović-Zlatarić & Čelebić 2005; Enomoto et al. 2010). The masticatory muscles all have insertions on various sites on the ramus of the mandible and could be responsible for influencing the shape of this area.

Masticatory muscles change in function and structure with advancing age in edentulous subjects and they have been shown to have lower muscle density than dentate subjects. Masticatory muscle atrophy may be one of the factors resulting in change in the shape of the mandible (Xie & Ainamo 2004). This observation is in accordance to Wolff's law which states that as loading on a particular bone increases, the bone will remodel itself over time to become stronger so as to resist that sort of loading. The internal architecture of the trabeculae undergoes adaptive changes, followed by secondary changes to the external cortical portion of the bone, perhaps becoming thicker as a result. The converse is true as well. Similarly the action of the muscles of mastication induces remodelling of the mandible in a particular way so as to resist loading (Wolff 1986; Maki et al. 1999).

The highest mineralised cortical bone in the mandible indicated the highest correlations with cross-sectional area of the masseter muscle. The impressions of the aforementioned researchers suggest that mandibular bone growth and remodelling are affected by masticatory muscles to change its shape and/or mechanical properties. The adaptive procedure of the skeleton to masticatory muscle function is associated with structural deformation and qualitative changes.

Senescence has a general effect on the skeleton and specifically on the morphology of the mandible (Hu et al. 2006). The effects of aging on the cortical thickness of the mandible cannot be ignored as a correlation between aging and cortical thickness and density has been found in past research. It was noted by some researchers that the mandible continues to mature and increase in cortical thickness through 40 to 49 years of age and then decreases in thickness after this period (Swasty et al. 2009). Hobson (1998), in contrast, studied 23 specimens and found no age-related differences.

It is not clear whether these aging effects are isolated from the change in dentition which often accompanies senescence. There also seem to be sex and ancestry group variations in the effects of increasing age on the cortical thickness of the mandible. Dutra et al. (2005) studied panoramic radiographs and concluded that there is a continuous remodelling in the mandibular cortex with increasing age and this is influenced by dental status and sex.

The purpose of this study is to investigate how dentition and senescence influence the external and internal morphology of the mandible within sex-ancestry groups: male South Africans of African ancestry; female South Africans of African ancestry; male South Africans of European ancestry and female South Africans of African ancestry.

Various methodologies ranging from osteometric to three dimensional techniques are employed to evaluate and visualise these structural changes in their entirety. In this way specific characteristics, such as gonial eversion, ramus flexure and the mandibular angle will be viewed as part of the overall shape changes in the mandible.

The interrelationship between various features of the mandible and their association with an increase in age and decline in masticatory efficiency (as reflected by the number of teeth) will be addressed. This has implications for both forensic anthropology and restorative dentistry.

The specific objectives of this project are:

1. To note the number, placement and occlusions of the mandibular teeth with the corresponding maxillary teeth among the sex-ancestry groups in the complete sample.

2. To define three tooth loss subgroups in each sex-ancestry group on the basis of criteria established from published guidelines: efficient mastication (group 2): individuals with enough posterior and anterior teeth remaining in occlusion and evenly distributed between the sides; inefficient mastication (group 1): individuals with limited occlusions and lastly individuals with no occlusions (group 0). Therefore 12 sex-ancestry-dentition subgroups may be identified.

3. To measure the size of the mandibular angle on the complete sample. Measurement of the mandibular angle is done in an attempt to confirm whether the guidelines for the maximum tooth loss pattern associated with efficient mastication holds true as reflected in the size of the mandibular angle, contrary to situations where patterns do not meet this criteria. The direct measurement of the mandibular angle is chosen as it is a well-known parameter with an established simple technique representing the influence of biomechanical factors on the morphology of the mandibular angle.

4. To determine the influence of dental loss and senescence as it affects aspects of the morphology of the mandible. A attempt will be made to distinguish between changes due to advancing age per se, and those caused by dental loss. In an attempt to minimise the effects of variation in dentition amongst sex ancestry groups, the sample will be selected to comprise individuals with a spectrum of tooth loss patterns. Mandibles of individuals will be chosen to represent each tooth loss pattern in each sex-ancestry group as defined in 2 and confirmed in 3.

4.1 Perform manual linear measurements.

4.2 Create three-dimensional models for shape analysis of the complete mandible from digitised landmarks.

4.3 Create three-dimensional models for detailed shape analysis of the ramus and chin area by incorporating images generated by cone beam computed tomography.

4.4 Analyse the cortical thickness at specific sites by incorporating images generated by cone beam computed tomography.

5. To use the information on size and shape, obtained through all the methods mentioned above, in order to make a comprehensive assessment of the change in shape, size and cortical thickness at specified sites with age and changes in dentition within sex-ancestry groups.

6. To assess whether the shape and size differences of the mandible can be used to determine sex and ancestry, especially in older individuals and where a number of teeth have been lost.

Chapter 2: LITERATURE REVIEW

A complex combination of a number of interrelated factors affects mandibular form (Nicholson & Harvati 2006). In order to understand the impact of senescence and tooth loss on mandibular shape and size, the other determinants that also influence the shape and the size of the mandible need to be considered, including sex and ancestry. Quantification methods of mandibular morphology include linear dimensions, morphological features and cortical thickness. Special attention is given to the mandibular angle as it is a pivotal feature that is often measured. The technologies employed to evaluate the three dimensional aspects include geometric morphometrics by microscribe digitisation and digitisation of cone-beam-computer-tomography-derived images (CBCT).

2.1 Basic anatomy, embryology and growth of the mandible

2.1.1 Anatomy

The mandible is one of the most durable bones in unfavourable conditions, as it is the largest and strongest bone in the face (Oettlé et al. 2009b). It has a curved body supporting the teeth within the alveolar process and two broad rami that ascend posteriorly.

Anteriorly, on the external surface the site of the fused symphysis menti may be indicated by a faint median ridge inferiorly dividing to enclose a triangular mental protuberance and raised on each side as a mental tubercle (Standring ed. 2008). The mental protuberance and mental tubercles constitute the chin (mentum osseum) (Fig. 2.1). Immediately above the protuberance is a marked hollow – the incurvatio mandibularis. This hollow deepens on either side of the midline into the fossa mentalis (Parr 2005) or incisive fossa (Standring ed. 2008) for the attachment of mentalis muscle. The depressor labii inferioris has a long, linear origin between the symphysis menti and the mental foramen. The depressor anguli oris has a long, linear origin from the mental tubercle of the mandible and its continuation, the oblique line, below and lateral to the depressor labii inferioris (Figs. 2.2 and 2.3) (Standring ed. 2008).

Near the inner midline on each side is a rough digastric fossa, which gives attachment to the anterior belly of the digastric muscle. The rest of the internal surface of the mandible is divided by an oblique mylohyoid line that gives attachment to the mylohyoid muscle and posteriorly to the superior pharyngeal constrictor, buccinator, and the pterygomandibular raphe. Above the anterior ends of the mylohyoid lines, the posterior symphysial aspect bears a small elevation, often divided into upper and lower parts – the mental spines (genial tubercles). The upper part gives attachment to genioglossus, the lower part to geniohyoid.

The mandibular ramus is quadrilateral and has two surfaces (lateral and medial), four borders (superior, inferior, anterior and posterior), and two processes (coronoid and condylar). The condylar process articulates with the adjacent temporal bone at the temporomandibular joint.

The inferior border is continuous with the mandibular base and meets the posterior border at the angle, which may be everted or inverted to varying degrees. The thin superior border bounds the mandibular incisure, which separates the coronoid process anteriorly from the condylar process posteriorly. The thick, rounded posterior border extends from the condyle to the angle. Superiorly it is convex and inferiorly it is concave to various degrees and constitutes the well described ramus flexure (e.g. Koski 1996; Loth 1996).

The ramus and its processes provide attachment for the four primary muscles of mastication as well as the sphenomandibular and stylomandibular ligaments. The masseter muscle inserts on the lateral aspect of the mandibular ramus. The superficial-, middle- and deep layers of the masseter insert in sequence from the angle and lower posterior half, the central part and upper part of the mandibular ramus, and onto its coronoid process. The medial pterygoid inserts on the postero-inferior part of the medial surface of the ramus.

The temporalis is attached to the medial surface, apex, anterior and posterior borders of the coronoid process and to the anterior border of the mandibular ramus almost up to the third molar tooth. The lateral pterygoid inserts onto the pterygoid fovea, a depression on the front of the neck of the mandible. The stylomandibular ligament attaches to the angle and posterior border of the mandible (Standring 2008).

2.1.2 Embryology

The mandible forms in dense fibromembranous tissue by ossification from a centre that appears near the mental foramen about the sixth week prenatally. From this site, ossification spreads medially and posterocranially lateral to the inferior alveolar nerve and its incisive branch, and also in the lower parts of Meckel's cartilage to form the body and ramus and then spreads upwards for the developing teeth. The Meckel's cartilage is a prominent rod that is derived from the neural crest cells of the first pharyngeal arch, which serves as the cartilaginous scaffold from which the bone of the mandible is to develop (Standring 2008; Hutchinson 2011).

Secondary cartilages appear later from the invasion of mesodermal cells from the first two pharyngeal arches. These are the condylar cartilage, which extends from the mandibular head downwards and forwards in the ramus and contributes to its growth in height, as well as the coronoid cartilage along the anterior coronoid border. One or two cartilaginous nodules also occur at the symphysis menti. At about the seventh month prenatally these may ossify as variable mental ossicles in symphysial fibrous tissue; they unite with adjacent bone before the end of the first postnatal year (Standring 2008; Hutchinson 2011).

2.1.3 Growth of the mandible after birth

At birth the two halves of the mandible are united by a fibrous symphysis menti at their anterior cartilage-covered ends. As ossification extends into the median fibrous tissue, the symphysis fuses. The fusion starts on the outer inferior surfaces and proceeds towards the inner superior surfaces (Scheuer & Black 2000a).

To maintain a functional relationship between all components of the mandible, as well as with changes in the dimensions of the cranial base throughout growth, the mandibular dimensions develop accordingly (Hutchinson et al. 2012). The body elongates, especially behind the mental foramen, providing space for three additional teeth. Growth occurs through the coordinated activity of two cellular groups, osteoblasts forming bone on one surface (bone deposition) and osteoclasts removing bone (bone resorption) on the opposite surface (Martinez-Maza et al. 2013). This elongation is of the body of the mandible and is therefore accomplished by deposition of bone on the posterior surface of the ramus and coronoid process and concomitant compensatory resorption on the anterior surface of the coronoid and condylar processes.

Increase in height of the body of the mandible is achieved primarily by formation of alveolar bone associated with the developing and erupting teeth, although some bone is also deposited on the lower border as well. Increase in width of the mandible is produced by deposition of bone on the outer surface of the mandible and resorption on the inner surface. The resultant effect is an increase in the comparative size of the ramus compared with the body of the mandible (Standring ed. 2008).

This deposition and reabsorption on the mandibular ramus coupled with the postnatal increase in body length influences the angle of the mandible. At birth the mandibular angle ranges from 135° to 150°. This angle changes with the eruption of deciduous dentition to 130° (140°) and further to 120° (130°) after the eruption of the second molar (Scheuer & Black 2000a; Scheuer & Black 2004). As the mandibular angle decreases, the height of the ramus increases and results in the condyle being at a higher level than the occlusal plane of the teeth (Hutchinson 2011).

Condylar growth and remodelling has been shown to be influenced significantly by local factors such as movement and loading of the temporomandibular joint and to a far lesser extent by systemic influences. With changes in dentition throughout life, continuous adaptation of the temporomandibular articulation is required in order to maintain functional occlusal alignment between the upper and lower arches of teeth. This adaptation is thought to be largely the result of ongoing condylar remodelling (Scheuer & Black 2000b; Standring 2008; Hutchinson 2011).

During growth, the position and direction of the opening of the mental foramen changes. The mental foramen points anteriorly at birth and progresses to a more posterior position with the neurovascular bundle occupying a posteriorly placed groove. The mental foramen lies below a line connecting the canine and the first deciduous molar until 36 months (Hutchinson 2011). In dentulous adults, the mental foramen appears midway between the upper and lower borders. As teeth are lost, alveolar bone becomes resorbed so that the mental foramen comes to lie much nearer to the superior border and progressively exposes the inferior alveolar and mental nerve (Standring ed. 2008).

2.2 Mandibular angle

The mandibular angle, also called the gonial angle, is considered to be formed by the ramus line (the tangent to the posterior border of the mandible) and the mandibular line (the relatively straight portion of the inferior border of the mandible (Jensen & Palling 1954; Ohm & Silness 1999).

The size of the mandibular angle is influenced by the action of the masseter, anterior temporal and medial pterygoid muscle. For this reason a greater muscular force would result in a more acute angulation of the mandibular angle, while the angulation in response to a lesser force would be more obtuse. The mandibular angle may be considered to be modelled and formed by the action of the masseter and medial pterygoid muscles that insert into it

(Potgieter et al. 1983; Franklin et al. 2008b). Dentate subjects are considered to have small mandibular angles and edentulous subjects more obtuse angles (Acsádi et al. 1970; Xie & Ainamo 2004).

In physical anthropological assessments of human remains, the mandibular angle has been shown to display statistical differences between sexes and ancestry groups and along with other linear measurements may be used to discriminate among the groups (De Villiers 1968; Xie & Ainamo 2004; Parr 2005; Franklin et al. 2008b). For instance, the mandibular angle is considered less obtuse (under 125°) in male individuals and in South Africans of African ancestry (SAA) in general (Krogman & İşcan 1986; Parr 2005). In these assessments dental pattern is not always considered. It is thought that sex- and ancestry group-specific mechanical forces involving the masticatory apparatus (e.g. whether cultural or dietary in origin) could directly influence the development of the muscles of the lower jaw and, by consequence, their underlying skeletal structures (Franklin et al. 2008a).

2.2.1 Dentition

The mandibular angle becomes more obtuse with tooth loss (130.5° versus 124.5°) and for this reason it correlates with the function of the jaw-closing muscles of mastication (Keen 1945; Ohm & Silness 1999).

Dentate subjects have strong masseter and anterior temporal muscles and small mandibular angles (Keen 1945; Yanıkoğlu & Yılmaz 2008). In a study by Ceylan (1998) et al. no significant difference was found between the dentulous group and those with unilateral and posterior tooth loss, but Oettlé et al. (2009a) found that a unilateral loss of molars may have an even greater effect than bilateral loss. When all molar teeth were present or the loss of teeth was bilateral, a more efficient chewing mechanism was created with a more optimal action of the masticatory muscles, inducing the more acute angle of the ramus of the mandible (Oettlé et al. 2009b).

Kasai et al. (1996) considered at least two incisor or canine teeth and four premolar or molar teeth per side in occlusion as sufficient remaining dentition to maintain a stable occlusal relationship and effective mastication. Even, simultaneous and bilateral tooth contacts in the intercuspal position are assumed to provide a balanced distribution of occlusal force (Pileicikiene & Surna 2004). A decrease in muscle mass, volume or their attachments may be indicative of substantial missing dentition and therefore a decreased bite force. The occlusal surface in an individual determines the capacity of the bite force perpendicular to the occlusal plane (Ceylan et al. 1998).

Potgieter et al. (1983), considered the mandibular angle as an anatomical feature that would be unaffected by the loss of teeth (in the short term) but with time would be subject to modification by the effect of muscular force with time. In edentulous people, changes in the mandibular bone after tooth extraction include a chronic and progressive resorption of the residual ridge and may also present as a widening of the mandibular angle (Kohakura et al. 1997). However, not all authors agree with the idea that the mandibular angle is influenced by tooth loss (Israel 1973; Enlow et al. 1976). Xie and Ainamo (2004), for instance, found no association between angle size and duration of edentulism.

The size of the mandibular angle is influenced by the action of the masseter, anterior temporal and medial pterygoid muscle. A greater muscular force would result in a more acute angulation of the mandibular angle, while the angulation in response to a lesser force would be more obtuse. The mandibular angle may be considered to be modelled and formed by the action of the masseter and medial pterygoid muscles that insert onto it (Potgieter et al. 1983; Franklin et al. 2008a).

This widening of the mandibular angle may be explained in the edentate subject either by the absence of the molar buttress or by disequilibrium between the elevator and depressor muscles of the mandible which favour toward the depressors (Yanıkoğlu & Yılmaz 2008). In the absence of teeth, the action of the masseter and medial pterygoid muscles at the angle is not opposed by the contact of the whole biting surface of the teeth of the mandible with that of the maxilla, but only anteriorly by the alveolar processes. The muscles of mastication will thereafter tend to mould the mandible in such a way so as to restore the parallelism of the biting surfaces, which involves an increase in the angle of the mandible (Keen 1945).

It was thought that rehabilitation of the masticatory system after tooth extraction by denture wearing prevented the widening of the mandibular angle (Keen 1945). In the study performed by Yanıkoğlu and Yılmaz (2008), the mandibular angle returned to the dentulous state in individuals who wore complete dentures.

2.2.2 Sex

The mandibular angle is usually considered to be less obtuse in men because of greater masticatory forces than women (Xie & Ainamo 2004; Williams & Rogers 2006; Yanıkoğlu & Yılmaz 2008; İşcan & Steyn 2013). Jensen and Palling concluded that in all ancestral groups studied, the mean angle in females is 3° to 5° higher than in males (Jensen & Palling 1954). Acsádi et al. (1970) scored the degree of development of sexually differentiated characteristics in one of five categories – from the most feminine to the most masculine. According to this method, the most feminine category of the mandibular angle is rounded with an angle of more than 125° (Acsádi et al. 1970). De Villiers (1968) found the mandibular angle in male SAA to be 120.6° (range 103°–135°), which is significantly different to that of female SAA of 125.0° (range 115°–138°).

In a study by Oettlé et al. (2009) it was found that, although statistically significant differences between sexes were present in their overall sample, these differences became insignificant when the groups with retained molars were compared. Statistically significant differences, however, were present when groups without molars were compared. The authors suggest that this findings could be dependent on the sex differences in the time elapsed from loss of molars to time of death. With the course of time, if molars were lost, the mandible would remodel to a greater extent. It was concluded that it is not possible to predict an individual's sex based on this angle because of the large overlap between groups. This impression is confirmed on a Lebanese sample of ages between 17 and 26 years, where no statistically significant differences of the mandibular angle were detected between sexes (Ayoub et al. 2009). This finding was contradictory to that found by Yanıkoğlu and Yılmaz (2008), who concluded that dentulous women have greater mandibular angles than dentulous men, in both young and older dentulous group.

The mandibular angle is obtuse at birth. During childhood, as teeth are added and growth takes place, it becomes more angulated; i.e., the angle becomes smaller. At puberty, under the influence of hormones, these changes accelerate. The changes in the mandible are more pronounced and occur for a longer time period in males (Walker & Kowalski 1972). For this reason, the male mandible is considered to be more angulated than the female mandible.

2.2.3 Aging

Although senescence has a general effect on the skeleton and specifically on the morphology of the mandible (Doual et al. 1997), the size of the mandibular angle in the adult sample studied by Oettlé et al. (2009) did not change with age per se. This finding is in agreement with those of other researchers (Keen 1945; Jensen & Palling 1954; Israel 1973), although the literature indicates no general consensus on this matter. Jensen and Palling (1954), for instance, found that with old age, the angle regresses to between 120° and 150° and becomes more similar to the infantile angle of 135° to 150°. It is not clear in Jensen and Palling's (1954) study whether these changes were because of aging per se or concomitant tooth loss. Xie and Ainamo (2004) reported that elderly edentulous people had significantly larger mandibular angles (128.4° ± 6.6) than young (122.4° ± 6.6) and older dentate subjects (122.8° ± 6.6).

2.2.4 Ancestry

As osteometric standards are specific to a group with common ancestry, it can be anticipated that the mandibular angle differs between various ancestral groups. Reasons for this can include the fact that specific evolutionary processes on various continents have resulted in craniometric differences (İşcan & Steyn 1999), such as the presence of prognathism in some groups. Mbajiorgu and Ekanem (2002), in their study of 60 dried adult mandibles from Nigeria, record an average mandibular angle for both sexes of 118.75°. The trend of the Nigerian sample group toward a smaller mandibular angle is also mirrored in the SAA group if compared with the South Africans of European ancestry (SAE) (Jensen & Palling 1954; Oettlé et al. 2009b). As most of the previous metric studies on the mandibular angle were not done on dried bones but on radiographs, the method of measurement of the mandibular angle should be taken into account when results are compared (Jensen & Palling 1954; Israel 1973; Doual et al. 1997; Ohm & Silness 1999; Xie & Ainamo 2004; Merrot et al. 2005; Oettlé et al. 2009b).

The mandible of SAA, for instance, is large, well developed, wide, and low, whereas the ramus is fairly broad compared with that of "Caucasiform" (Tobias 1974; Loth 1996). Conversely, in a study by Oettlé et al. (2009), no statisticial significant differences between ancestral groups were present when ancestry groups with retained molars were compared.

The dietary discrepancies between ancestry groups could also contribute to the differences in the mandibular angle (Antón 1996). According to Moore et al. (1968), the modern European type of diet is so soft that its mastication fails to provide an adequate mechanical stimulus to the growth of the facial skeleton. In the past diets of SAA, contained a lot of fibre that required a great deal of mastication (Moore et al. 1968; Lubbe 1971; Van Der

Waal 1977; Nicholson & Harvati 2006) and therefore provided a greater mechanical stimulus for growth of the facial skeleton.

2.2.5 Facial form

The interaction between the masticatory muscles and the craniofacial skeleton has been widely recognised as important for the control of craniofacial growth. In particular, many reports exist of the relationship between the masseter muscle and craniofacial morphology (Kohakura et al. 1997). The muscles have been shown to differ in shape between groups with different skeletal forms. Jaw-closing muscle activity is said to be greatest in subjects with large posterior facial height, small anterior facial height, broad face, long mandible, flat mandibular plane, and small mandibular angle as opposed to those with a long and narrow face (Tallgren 1972). A mandible with a broad and solid ramus has a smaller mandibular angle than a mandible with a slender ramus (Jensen & Palling 1954). Temporal and masseter cross-sectional areas are larger in subjects with larger facial widths, while masseter and pterygoid muscles' cross-sections are greater when the mandibular length is larger. These relationships are independent of overall size and their specificity argues for differences in the tension-generating capacity of muscles according to facial type (Kasai et al. 1994).

2.2.6 Cortical thickness

Osato et al. (2012) reflected that mandibular cortical width can show significant differences according to the mandibular angle. Mandibular angle size was negatively correlated with buccal cortical bone thickness at the second premolar and first molar sections (Kohakura et al. 1997) and the buccal and lingual cortical bone thickness in the region of the second molar (Ogawa & Osato 2012). Xie and Ainamo (2004) found the angle size to be negatively related to cortical thickness at the gonion region only among elderly edentulous women.

2.2.7 Muscles of mastication

The differences in the size of the mandibular angle with aging, loss of teeth, sex and ancestry group, facial form and cortical thickness have been attributed to the function of the muscles of mastication. The main elevator muscles of the mandible – the masseters and the medial pterygoids – act together as a sling about the angle of the jaw to lift the mandible and to close the space between the upper and lower jaws. Other forces lifting the mandible include the temporal muscles via the insertions onto the coronoid processes and the effect of negative pressure in the mouth. Opposing these elevating forces are the depressor muscles of the mandible. The digastrics tend to pull the mandible towards the hyoid bone, which in turn is braced by the infrahyoid muscles. The influence of the platysma, the limiting mass of the tongue within the mouth and the effect of gravity further increase the space between the upper and lower jaws. The power muscles of the mandible are capable of overriding the forces opposing them so as to lift the mandible in occlusal contact (Potgieter et al. 1983).

2.2.8 Summary

The size of the mandibular angle is often measured and is regarded by many to reflect the effectiveness of masticatory function as determined by the dental pattern. As masticatory function influences other aspects of the morphology of the mandible, the size of the mandibular angle may be associated with other metric and morphological differences in the bone. The presence of anterior teeth, molars (unilateral or bilateral); a combination of anterior and posterior teeth in occlusion as well as the presence of third molars have been associated with the effectiveness of mastication and the size of the mandibular angle.

2.3 Effectors of mandibular morphology

Apart from the mandibular angle, other aspects of the morphology of the mandible are considered as well as the factors influencing them. The morphological differences among sexes and ancestral groups need to be explored in order to appreciate the effect of dental pattern and aging in each group. In addition, tooth loss and senescence may have an impact on sex and ancestral traits used to identify unknown remains.

2.3.1 Sexual dimorphism

Some researchers consider the mandible as the most sexual dimorphic part of the skull (St Hoyme & İşcan 1989), including in South Africans (De Villiers 1968; Parr 2005). Sexual dimorphism though, is ancestry group specific (Garvin & Ruff 2012) and develops during adolescence. Changes in adolescence are apparently restricted to boys, with females retaining the more or less juvenile form. These changes are mediated by hormones acting on a genetic substrate (St Hoyme & İşcan 1989; Galdames et al. 2009; Bejdová et al. 2013).

2.3.1.1 General mandibular appearance

Size differences account for much of the sexual dimorphism seen in the mandible, with males having larger, more robust jaws and more developed muscle attachment sites (St Hoyme & İşcan 1989). Apart from being heavier, the male mandible is also broader with a more laterally everted, anterior and higher placed gonion landmark. The chin height and the degree of development of the chin are greater in males and therefore the chin appears square shaped with larger mental eminences. The height and width of the ramus as well as the height of the mandibular body and the size and position (inclined medially and anteriorly) of the condyles are also greater in males (De Villiers 1968; Acsádi et al. 1970; Krogman & İşcan 1986; Novotny et al. 1993; Parr 2005; Garvin & Ruff 2012; Bejdová et al. 2013).

By means of geometric morphometric shape analysis, males are shown to have a relatively more acute mandibular angle, anterior relocation of the condyle, an increase in relative ramus height and breadth, and height of the posterior corpus. The heads of the condyles are relatively more medially relocated in the male. In the female, the coronoid process is displaced antero-inferiorly and the sigmoid notch is relatively broader and shallower. These sexual dimorphic features appear to be population-specific (Franklin et al. 2008a).

The conclusions of De Villiers (1968) and Bejdová et al. (2013) are in agreement that sexual dimorphism has to do with the more powerful masticatory apparatus of the male, having its main effect on size differences. The increased bite force in males, especially has an effect on the coronoid process, gonion and ramus of the mandible and so influences the appearance of these features of the mandible. The reason for the most pronounced sexual dimorphism in this region is that the stronger muscles in males (compared to muscles in females) produce greater forces and thus rougher surfaces of muscle attachments. The masseteric tuberosity for instance is marked, whereas the corresponding area in the female is smooth. The gonion therefore lies more laterally in male, than in female mandibles (Novotny et al. 1993; Bejdová et al. 2013).

2.3.1.2 Gonial eversion

The gonial eversion is considered as the raised edge or turned out everted bony prominence of the gonion region where the ramus and the body of the mandible meet projecting laterally from the rest of the ramus (White et al. 2011).

Gonial eversion is a trait that has traditionally been associated with males (Acsádi et al. 1970; Ferembach et al. 1980; Novotny et al. 1993; Parr 2005), although not all researchers agree that this is a useful trait for estimating sex. According to Acsádi et al. (1970) and Novotny et al. (1993), this trait has been firmly established as a sex marker for adults. Ferembach et al. (1980) also consider gonial eversion as a male characteristic. Contradicting these assumptions, Loth and Henneberg (2000) propose that the gonial form has a high heritable component that appears to be associated with overall facial architecture rather than sex. The manifestation of gonial eversion is thought to be influenced by selective muscle development or imbalance rather than overall robusticity, which may be confused as a male trait. These last mentioned authors and Kemkes-Grottethaler et al. (2002) found low accuracy using this trait. When this feature was assessed by means of geometric morphometrics (Oettlé et al. 2009b), it was also found that the overlap between the sexes was too large to make it usable in single forensic cases.

This two dimensional geometric morphometrics study demonstrated that the gonial eversion involves a greater aspect of the ramus in males while in females it was concentrated in a small, lower section of the ramus. The extent of these differences was not adequate to predict the sex of a single individual as only 71.4% of females and 73.9% of males could be accurately sexed (Oettlé et al. 2009b). More recently Bejdová et al. (2013) in their three dimensional (3D) geometric morphometric analysis of surface models of mandibles found the relatively wider mandible with the associated more laterally placed gonion in males, the most constant shape trait for showing sexual dimorphism across all ancestry groups studied.

2.3.1.3 Ramus flexure

Loth and Henneberg (1996) describe a distinct angulation of the posterior border of the mandibular ramus at the level of the occlusal surface of the molars in adult males. In most females, the posterior border of the ramus retained the straight juvenile shape. If flexure was noted, it was found to occur either at a higher point near the neck of the condyle or lower in association with the gonial eversion.

Koski (1996) concludes that the relationship between the ramus and the condylar process appears to depend on the functional environment of the lower jaw. The direction of the condyle is approximately perpendicular to the lateral skull base. In varying functional instances the ramus must be the adapting part between the articulating condyle and the toothbearing body of the jaw. This leads to flexures of different degrees and the location between the lower ramus and the condylar process. In Koski's experience the flexures occur in most individuals, be they male or female, young or adult. Loth and Henneberg (1996) in their review of the biological reasons for the sexual diversity in mandibles thought that the mandible is shaped in response to hormonal influences and both directly and indirectly by the muscle development thus stimulated. The possible dimorphism seen may arise in response to sex-specific hormones.

When the ramus flexure was first introduced as a morphological feature by Loth and Henneberg (1996), they suggested that this trait on its own could be used with 94% accuracy. They found a clear angulation to be present at the posterior border of the ramus at the level of the occlusal plane in males, whereas in females it was said to retain its straight juvenile shape. This feature was tested by numerous researchers, most of whom found the trait not to be reliable (Koski 1996; Donnelly et al. 1998; Kemkes-Grottenthaler et al. 2002; Hu et al. 2006). Donnelly et al. (1998), for example, showed only a 63% - 69% accuracy for this trait and concluded that the association between ramus flexure and sex is weak and that it is difficult to identify flexure reliably and consistently. Similar to what was found by Balci et al, (2005), it seems that fairly high accuracies for this trait can be found in males but not in females. Geometric morphometric assessment confirmed these observations (Oettlé et al. 2005). In this study on South Africans, female shape was very variable, whereas males were found to have a more constant shape. However the overlap seems to be too large to make it usable in a forensic setting (Oettlé et al. 2005).

In an Indian population the presence of the ramus flexure was evaluated visually using the original description by Loth and Henneberg (1996). Though inter- and intraobserver errors were present it could be minimised with extended practice. Accuracies on average up to 82% were reported (Saini et al. 2011). More recently the sex-discriminant potential of the mandible ramus flexure was tested with the use of linear measurements and angles on three-dimensional (3D) mandible models from computer tomography (CT) images in a Korean sample. It was concluded that the upper ramus above the flexure holds more potential than the mandibular ramus flexure itself for predicting sexes (Lin et al. 2014).

Although there is still no general consensus on the reliability of this method it seems that it is a trait that requires considerable experience to deliver repeatable results. More studies regarding the upper ramus above the flexure are needed to confirm the results of Lin et al. (2013).

2.3.1.4 Chin

The shape of the chin is influenced by a combination of factors, including the development of the ossification of a number (usually three) of small cartilages and intensive growth remodelling. In contrast, a symphysis with a prominence at its base but no real chin may be achieved by compensatory resorptive activity of the alveolar component. Resorption occurs as a means of reducing the predominant forward and downward movement of the symphyseal region produced by growth of the ramus (Rosas & Martinez-Maza 2010).

The relative development of usually three components (mental protuberance/mental eminence and mental tubercles) of the trigonum mentale and of the fossa mentalis (incisura mandibulae anterior) determines the shape of the chin (Fig. 2.1). The distinction between the types is based on the degree of development of the bony prominences. When there is equal development of both protuberance and tubercles, a round chin is formed. A square shaped chin is seen when the mental tubercles show a marked degree of development with a noticeable fossa mentalis. A pointed chin includes those mandibles in which there is a marked development of the mental protuberance/mental eminence (Acsádi et al. 1970; Loth & Henneberg 2001; Garvin & Ruff 2012). A significant sex difference was found in the incidence of a slight protuberance and marked tubercles as seen in the square shaped chin which is rare amongst females (4.2%) but occurs in 25.6% of males (De Villiers 1968; Parr 2005).

Sex differences exist at birth and during the later postnatal stages, which indicates dimorphic prenatal development of the face (Loth & Henneberg 2001; Coquerelle et al. 2011). Mandibular form variation is closely associated with dental mineralisation until the full emergence of deciduous dentition. This association declines during later developmental stages and results in a relatively similar development until adolescence (Scheuer & Black 2000a; Franklin et al. 2007). No apparent sexual dimorphism exists in the patterns of activation involved in speech and mastication until puberty. Children up to puberty therefore have small rounded chins, so that alternative forms appear in males at adolescence (St Hoyme & İşcan 1989; Hu et al. 2006; Coquerelle et al. 2011). These findings are in contrast to those of Loth and Henneberg (2001), who noted that the adult chin shape was also observed in older juveniles (6 to 19 years), with a discriminative accuracy of 67% in males and 73% in females.

After puberty, the difference between the sexes increases as males exhibit an extended ontogenetic trajectory compared to that of females. Adult dimorphism is partly similar to that observed at early postnatal stages; it is further characterised by a mental region, which projects downwards in males and upward in females (Coquerelle et al. 2011). Sheng et al. (2009) demonstrate that in adult females the hyoid bone is positioned more superiorly relatively to the inferior border of the mandible than in adult males. This may lead to an upward positioning of the basal symphysis, responding to both the spatial packing of the tongue and the suprahyoid muscles, as well as to the mechanical demands of the oro-motor functions (Ruff et al. 2006; Sheng et al. 2009).

2.3.2 Ancestry

One of the three most vital determinations that must be made when skeletal remains are dealt with is ancestry group (sexual dimophism has been considered in the previous section and aging is covered in the following). It would be nearly impossible to attempt to identify or reconstruct the face of an individual without this information. These factors have a significant bearing on appearance and also serve to narrow the range of possible matches. In this section the possible effects ancestry group have on the features of the mandible that might be confused with the effects of aging and tooth loss are considered.

In the South African context, forensic anthropologists are frequently required to give a social classification, such as Black, White, Indian or Coloured, from unidentified remains (L'Abbé 2011). Although membership of a social class was previously a legal definition, it is now based on law enforced self-perception and self-classification (Patterson et al. 2010). For readers not acquainted with the complex heterogeneous nature of the South African nation, the terms SAA and SAE will be used throughout this study, as previously defined.

SAA groups possess relatively larger jaws with well-developed rami that are longer and broader (Tobias 1974). Extreme forms of gonial eversion may be seen in SAA, which was thought to be due to stronger muscle attachments at the site. Individuals of European ancestry including those from the Pretoria Bone Collection present with shorter and wider mandibles reflected in larger bigonial widths regardless of the often smaller gonial eversion found. The mandibular angle is more obtuse and the mandibular ramus width is thinner. Muscle attachments are more gracile (Parr 2005).

Ancestry further also significantly affects chin shape. According to De Villiers (1968) in SAA groups the visually assessed shape of the chin is most commonly pointed in just over half of the mandibles (marked development of the mental protuberance/mental eminence) (50.7% in males and 56.1% in females). A rounded contour is the next most common (33.4% and 39.7% of males and females respectively). St Hoyme & İşcan (1989) and Parr (2005) who did not differentiate between round and pointed chins found that a round chin was more common in Africans. Incidences reported by Parr (2005) were 63% in Africans and 39% in Europeans. This is in agreement with the findings of Walker (2008), who found with his scoring system (1 to 5) higher scores for the degree of prominence of the mental eminence in Americans of African ancestry as compared to those of European ancestry and English specimens. Europeans in contrast had a high incidence of square chins (38%), whereas only 18% of Africans displayed a square chin (De Villiers 1968; Parr 2005). More recently, with 3D surface laser scans of the chin, the converse was demonstrated on a group of American individuals. It was found that individuals of African ancestry displayed greater relative projection of the lateral tubercles contributing to a more squared appearance (Garvin & Ruff 2012).

The mentioned ancestry group differences may also be expressed as the differences between the prognathic and the orthognathic mandible (Garvin & Ruff 2012). A relatively short (antero-posteriorly) and wide (medio-laterally) mandible of the orthognathic mandible is found in the temperate and cold-climate groups, and a long (antero-posteriorly) and narrow (medio-laterally) prognathic mandible in the tropical and subtropical ancestry groups (St Hoyme & İşcan 1989; Novotny et al. 1993).

2.3.2.1 Summary

In general SAA groups have a narrower, longer prognathic mandible, more acute mandibular angle, and wider and longer rami in comparison to SAE. Muscular markings may be more prominent and may present with extreme expressions of gonial eversion. Chin shape is considered one of the more ancestry-specific morphological traits. The majority of SAA have a prominent mental protuberance but slight mental tubercles giving rise to a pointed shaped chin or a round chin but seldom a square shaped chin, which is more commonly found in SAE.

As some of the ancestry group or sex-discriminating dimensions might be sensitive to tooth loss and aging, the degree of tooth loss and age needs to be considered when an attempt is made to identify unknown remains.

2.3.3 Remodelling of the mandible with aging

When an attempt is made to identify an unknown individual, characteristics of aging should be taken into consideration as these may have an effect on the estimation of sex or ancestry (Acsádi et al. 1970; Koski 1996; Parr 2005).

The cranial skeleton, which is the basis of metric and morphological analysis, continues to change throughout adulthood because of remodelling as it participates in the overall metabolism of the organism in progressive and regressive processes. Aging features may present in various patterns and at different rates due to culture and lifestyle (environment, gender, nutrition, working conditions) and biology (sex, ancestry or genetics, trauma and disease) as well as features such as frequency and extent of facial expressions (Acsádi et al. 1970; Albert et al. 2007; Martinez-Maza et al. 2013). Aging, therefore, is characterised not so much by the number of years that have passed since birth but, instead, by the condition of the individual as influenced by the before-mentioned factors (Acsádi et al. 1970; Albert et al. 2007)

Age changes beyond puberty in the mandible may be difficult to distinguish from the effects of poor oral health, tooth loss or tooth attrition and could account for some of the variations in the literature reviewed. For instance, the alveolar bone remodels after tooth loss and the vertical height of the face decreases. Masticatory muscle atrophy associated with tooth loss in elderly individuals also potentiates cortical porosity (Von Wowern & Stoltze 1978; Taister et al. 2000; Xie & Ainamo 2004; Dutra et al. 2005; Albert et al. 2007). Some features may make the effect of others less noticeable, for instance the continued eruption of teeth may compensate for the effects of normal attrition to a certain extent.

In general the mandible increases horizontally in size and vertically in the height of the anterior face during the maturation process (24 – 38 years) (Martinez-Maza et al. 2013). Specific areas of resorption and deposition contribute to the overall size and shape remodeling of the mandible. The specific areas include the symphyseal region: resorptive activity on the buccal side in the alveolar bone only. The rest of the symphysis and the anterior region of the corpus is mainly depository. The resorptive activity on the lingual side of the symphyseal region is related to the attachments of the digastric, genioglossus, geniohyoideus, and the anterior part of the mylohyoideus muscles. The specific areas also include the region of the corpus and the ramus: the buccal side shows resorptive fields covering the posterior region of the corpus and the anterior region of the ramus, whereas the resorptive fields of the lingual side are located in the submandibular fossa of the corpus and in the coronoid region and the lower half (gonial area) of the ramus.

These regions of deposition and resorption result in a forward growth direction of the symphysis and a lateral growth of the molar region of the corpus, whereas the anterior region of the ramus grows in a posterior and medial direction. The posterior region of the ramus experiences complex growth dynamics characterised by a lateral growth of the gonial area, a medial growth of the mandibular notch area, and a lateral and medial growth of the condyle area. These growth directions indicate that the lower part of the ramus is taking or maintaining a vertical position while the upper area increases in width and grows backwards (Martinez-Maza et al. 2013).

The whole mandible grows with the main forward direction and a downward growth direction that increases in height as it grows forward in order to maintain the occlusal plane with the maxilla. For this reason during senescence, chin prominence is much increased. In the study by Parr (2005) up to 86% of the individuals in the 80 – 89 age range displayed chin prominence. Alveolar resorption and recession accompanying loss of teeth further contribute to the appearance of a more prominent chin (Parr 2005).

Vertical facial heights seem to increase more in individuals with healthy dentitions from the average age of 25 to 45 years. The vertical development of the dentition is not limited to teeth eruption alone, but also involves their investing tissues, including the alveolar bone. It could be that minor periosteal bone deposition during a long period may be sufficiently great to cause vertical face changes (Forsberg et al. 1991). The lateral growth of the ramus indicates how the ramus grows to maintain contact with the cranial base through the temporomandibular joint (Martinez-Maza et al. 2013). The bicondylar distance will therefore increase in size with age and peak in breadth in the 60 – 69 age category (Parr 2005).

Changes in the dimensions of the mandible continue throughout life, but are of a relatively small magnitude (changes are in the order of 1 mm or 1° in 10 or 20 years' time) (Bishara et al. 1994; Bondevik 1995; Akgül & Toygar 2002). In general the following changes can be expected from 20 years and beyond: slight increase in anterior, mostly lower face height (20 – 30 years) (Forsberg et al. 1991; Bondevik 1995; Albert et al. 2007); mandibular corpus length and maximum length increase (20 – 40 years) (Enlow et al. 1976; Sarnäs & Solow 1980; Bishara et al. 1994; Bondevik 1995; Albert et al. 2007); dental alveolar regression (Bondevik 1995; Albert et al. 2007); dental eruption progression (Enlow et al. 1976; Sarnäs & Solow 1980; Bishara et al. 1994; Bondevik 1995; Albert et al. 2007); dental arch lengths and widths decrease (20 – 50 years) (Bishara et al. 1994; Bondevik 1995; Akgül & Toygar 2002; Albert et al. 2007); alveolar bone remodelling and possible dental attrition affecting vertical face height (50 years and beyond); as well as possible temporomandibular joint arthritis and joint flattening and diminished jaws (60 years and beyond) (Bishara et al. 1994; Bondevik 1995; Albert et al. 2007).

The effects of the changes in the mandible involve changes in face height and level of prognathism. Bishara (1994) found an increase of anterior (nasion to gnathion) and posterior face height (sella turcica to gonion) in both sexes in individuals examined at 25 and 46 years. In the study by Bondevik (1995) on individuals from 22 to 33 years of age, it was found that the anterior face height increased more than the posterior face height in females and the opposite in males. In general females showed more increase in vertical dimensions than males. Akgül and Toygar (2002) report that the total anterior face height increased in both sexes, while the lower anterior face height increased significantly in the female group (22 – 32 years) only.

Reich and Dannauer (1996) and Sarnäs and Solow (1980) found that with increasing age between 21 and 26 years, prognathism tended to increase in degree, while Bondevik (1995) found that mandibular prognathism decreased significantly in females and insignificantly increased in males. The most inferior measurement across the ramus showed a significant increase in males (Bondevik 1995).

Mandibles of younger individuals are more gracile and then become more robust as they grow older. However, in very old age, this robusticity begins to decrease, perhaps due to resorption associated with tooth loss (Parr 2005).

2.3.4 Dental pattern

The presence or absence of teeth, their distribution and the wearing of dentures (partial removable or complete) may have profound effects on the mechanism of chewing and therefore the action of muscles of mastication on the shape of the jaw (Kasai et al. 1996; Loth & Henneberg 1996; Kohakura et al. 1997; Pileicikiene & Surna 2004; Oettlé et al. 2009b; Ozan et al. 2013). Individuals with a greater occlusal area and therefore more and/or more functionally arranged teeth are capable of producing a greater bite force. The presence of anterior dentition or third molars for instance within the mandible probably contributes to higher chewing forces and stronger masseter contraction, as well as consequently higher strain forces of the masseter attachment to the cortex of the mandible (Knezović-Zlatarić & Čelebić 2005).

In this section the biomechanical effects of the presence of dentition are considered and then more specifically the effect of third molars, the consequences of loss of teeth and the use of dentures.

2.3.4.1 The influence of dentition and muscles of mastication

The influence of dentition and muscles of mastication on growth and shape of the mandible is in accordance with Wolff's law that states that as loading on a particular bone increases, the bone will remodel itself over time to become stronger enabling it to resist that type of loading. The internal architecture of the trabeculae undergoes adaptive changes, followed by secondary changes to the external cortical portion of the bone, perhaps becoming thicker as a result. The converse is true as well: as loading on a particular bone decreases, the bone will remodel and become thinner and weaker. Similarly would the action of the muscles of mastication induce remodelling of the mandible in a particular way to resist loading (Wolff 1986; Maki et al. 1999). The most mineralised cortical bone is highly correlated to the cross-sectional area of the masseter muscle. These findings suggest that mandibular bone growth and remodelling are affected by masticatory muscles to change their shape and/or mechanical properties.

Each of the muscles of mastication acts on the underlying bone to create mechanical stress during the forces of mastication. The posterior aspect of the mandible is particularly sensitive to changes in the forces of mastication as the muscles of mastication attach to this area (Kasai et al. 1994; Xie & Ainamo 2004; Knezović-Zlatarić & Čelebić 2005; Enomoto et al. 2010). The masticatory muscles all have insertions on various sites on the ramus of the mandible and could be responsible for influencing its shape.

Enlow et al. (1976) describe certain specific remodelling variations occurring in several major regions of the mandible. As the anterior and posterior border of the ramus is resorptive, the postero-anterior dimension of the ramus become reduced and narrowed with time and the resorption of the anterior border of the ramus adds length to the corpus. Because the masseter and medial pterygoid muscles insert onto the region of the gonial angle, the contractile power also influences the shape of the mandibular base (Xie & Ainamo 2004).

2.3.4.2 Presence of mandibular third molars

The eruption and presence of third molars are associated with a horizontal and vertical increase in the dimensions of the mandible (Al Ali et al. 2008; Ogawa & Osato 2012). In the study performed by Al Ali et al. (2008), both vertical dimensions measured, namely the corpus height at the mandibular second molar and the coronoid height dimensions, were significantly greater in girls with mandibular third molars, than those without. The mandibular angle was similar between groups.

In another study by Ogawa and Osato (2012) on the change in dimensions of the mandible with the eruption of third molars, the largest significant change in the mandibular body morphology was an increase in the horizontal dimension - inferior mandibular cortical width at the level of the mental foramen - followed by vertical dimension - total height of the mandibular body around the mental foramen. The mandibular angle decreased significantly by 6.72°. Mean values for cortical bone mineral content and trabecular basal bone mineral content increased significantly and so did the posterior mandibular body length (mental foramen to gonion) and the distance between the midpoints of the inferior borders of the mental foramen.

2.3.4.3 Tooth loss

Following tooth loss, the mandible shows an extensive loss of bone in some individuals. As severe alveolar ridge resorption may occur even when the bone status in the rest of the skeleton is good and vice versa, it is concluded that local functional factors are of paramount significance (Knezović-Zlatarić & Čelebić 2005). Most of the bone loss occurs in the first year after extraction, with the highest rate being in the first few months. However, continued bone loss from the mandible can still be detected up to 25 years post-extraction (Kingsmill 1999). Resorptive fields underlying the alveolar regions on both the lingual and buccal sides, develop as a result of tooth loss as expected (Enlow et al. 1976). The rest of the deposition and resorptive fields are similar to that of the growth fields normally seen in adults (Martinez-Maza et al. 2013).

Apart from the loss of alveolar bone, other morphological changes are expected in the mandible with tooth loss. In edentulous individuals a relationship between altered masticatory function and the morphology of the areas of major muscle insertion (i.e. coronoid process and gonial angle) would be expected. In the study done by Kasai et al. (1994), coronoid height and the distance between the anterior margin of masseter muscle and gonion in the dentate group were significantly larger than in the edentulous group. In edentulous subjects the superficial masseter muscle is narrower and more posteriorly located in relation to the gonion point (Kasai et al. 1994).

Masticatory muscle atrophy may be one of the factors resulting in change in the shape of the mandible. Masticatory muscles change in function and structure with advancing age in edentulous subjects and have been shown to have lower electromyographic activity and lower muscle density in computed tomography compared with Figures for dentate subjects (Kingsmill 1999; Xie & Ainamo 2004).

The resorption of the residual ridges and the changes in jaw and occlusal relationships show great individual variation. Those individuals with an upright ramus, a more acute gonial angle, and a greater angle from the mandibular base to the condyle measured at the anterior midline (features more frequently associated with patients with a small lower face height) show a significantly greater amount of resorption than long-faced individuals (Tallgren 1972).

Little change is thought to occur in the region of the superior genial tubercles or the mylohyoid and external oblique ridges, which become increasingly prominent. The mylohyoid muscle, the buccinator muscles, and the additional muscles that surround the mandible are among the factors that limit chronic bone resorption in the edentulous jaw, more anteriorly. These muscles provide physiological stimulation of the edentulous area and thus prevent bone resorption. Clear changes, though, have been noted for the position of the attachments of mentalis and buccinator muscles as the ridge recedes (Knezović-Zlatarić & Čelebić 2005).

2.3.4.4 Dentures

The rehabilitation of the masticatory system after tooth extraction by prosthetic treatment prevents the widening of the gonial angle (Yanıkoğlu & Yılmaz 2008). Ceylan et al. (1998) found that although the gonial angle was larger after 6 months of denture wearing post extraction of teeth, the gonial angle slowly returned toward the initial value.

To be rehabilitative, dentures need to be designed with care. If the level of occlusal contact is too low, it will subject the underlying supporting structures to all the force of an insufficiently attenuated set of power muscles. The result will be traumatised mucosa and an ongoing process of alveolar resorption, which will proceed until a proper free-way space has been re-established – at the expense of the alveolar bone (Potgieter et al. 1983; Knezović-Zlatarić & Čelebić 2005). These shortcomings of dentures were confirmed by other researchers who found that denture wearers have smaller dental arches than non-wearers (Pietrokovski et al. 2003; Pietrokovski et al. 2007; Chrcanovic et al. 2011). Ozan et al. (2013) state that dentures can induce alveolar bone resorption rather than preserving the edentulous area even in wearers of removable partial dentures.

Conversely if the level of occlusal contact of the dentures is set too high, it will place the muscles of the mandible at a serious disadvantage. The muscles will be compelled to function in such a shortened state that they will scarcely be able to produce any power at all (Potgieter et al. 1983). Generally, it has been observed that removable denture wearers have significantly reduced bone in the molar region when compared with the premolar region horizontally (Ozan et al. 2013). Patients with dentures can apply only one-eighth to one-sixth of the bite force that is possible by patients with natural teeth. Both physical and social factors may reduce customary bite force, and a reduction in the activity of the muscles of mastication may be seen within as few as four weeks after the insertion of new dentures. The increased horizontal bone resorption in removable partial denture wearers may further be due to the dentures covering the basal area, which limits masticatory efficiency (Ozan et al. 2013). These reasons for reduced muscle activity may be correlated with bone resorption (Warner et al. 2006; Ausk et al. 2012).

In contrast in the case of removable partial dentures, occlusal forces are transmitted also to the periodontal membrane of the abutment teeth through the indirect rests, and in this way decrease alveolar overload and resorption of alveolar ridge under the distal extension saddles. Stronger chewing forces are therefore possible, and alveolar crest overload is decreased. Stronger masseter contraction and higher strain forces at the masseter attachment to the mandibular cortex follow which prevents cortical resorption and stimulates bone growth (Knezović-Zlatarić & Čelebić 2005).

2.4. Quantification of mandibular morphology

Shape and size variations of the mandible may be assessed metrically or scored according to morphological features. Metric parameters are usually straightforward as numerical results are obtained that are easy to measure and interpret. Many characteristics, however, can be assessed only morphologically, but may present certain difficulties such as inter- and intraobserver repeatability, problems with classification of morphological characteristics and statistical analysis. The experience and interpretation of the observer also plays a role (Pretorius et al. 2006). To evade these difficulties, geometric morphometrics may be applied to quantify morphological characteristics (Pretorius et al. 2006; Bidmos et al. 2010).

2.4.1 Linear dimensions

Linear measurements are often used in assessment of sex of unknown skeletal remains (Moipolai et al. 2003; Nissan et al. 2003; Dayal et al. 2008; Robinson & Bidmos 2009; Da Costa De Sousa et al. 2013) but studies regarding the variations between ancestral groups are limited (Ribot 2004; Parr 2005; Umar et al. 2006). The use of the metric approach in the estimation of sex is more structured and may even be more accurate than morphological methods alone and do not require vast experience on the part of the scientist. The assessment of linear measurements is usually straightforward as numerical results are obtained that are easy to measure and interpret. Linear measurements reduce the subjectivity of estimations and enables statistically quantified classifications (Dayal et al. 2008; Kimmerle et al. 2012). Furthermore, linear measurements can be repeated to validate the obtained results. However, inter- and intraobserver errors are well documented with the use of the metrical method and therefore landmarks on which measurements are based should be carefully chosen to ensure consistency (Bidmos et al. 2010; İşcan & Steyn 2013).

2.4.1.1 Data types

Two main types of data are used in metric analyses. These are the traditional linear inter-landmark distance measurements obtained by the use of a calliper, or landmark coordinate data derived distances. Linear interlandmark distance measurements are simple distances defined by anatomical landmarks. Discriminant function analysis may be used to determine the sex of an unknown individual by comparing these measured linear distances with the recorded data for that specific population (İşcan & Steyn 2013).

The collection of 3D Cartesian coordinate data requires the use of a digitiser e.g. MicroScribe Series G2, which collects the x, y, and z coordinates of anatomical landmarks (Franklin et al. 2006; Dayal et al. 2008; Franklin et al. 2008a) or digitisation of landmarks on CBCT derived images (Ludlow et al. 2009). The data collection computer software ThreeSkull written by Stephen D. Ousley, is then commonly used (although not in this study), because of its ability to simultaneously compute the traditional calliper derived interlandmark distance measurements while capturing 3D coordinate point data (Ross et al. 2010). The anatomical 3D Cartesian coordinate landmark data that are collected by the digitiser correspond with the endpoints of the linear interlandmark distances from which the callipers are placed (Kimmerle et al. 2012). Franklin et al. (2006 & 2008) established that 3D landmark coordinates can be successfully transformed for use in traditional linear dimension studies (Franklin et al. 2006; Franklin et al. 2008a). Linear dimensions obtained in this manner are comparable with the large collection of traditional anthropological data available in the literature (Dayal et al. 2008).

Franklin et al. (2008) used distances derived from landmark coordinate data collected by a digitiser and developed discriminant function analyses for mandibles of SAA. Dayal et al. (2008) took measurements with a calliper on the same population and got similar results to those of Franklin et al. İşcan and Steyn (2013) caution that measurements taken with traditional methods as compared to a digitiser may vary slightly and it should therefore be ascertained that the landmarks were exactly the same before a function is calculated.

2.4.1.2 Applications of linear dimensions

Much of our understanding of modern human skeletal variation in southern Africa is derived from anthropological techniques based on the traditional linear metrical system (De Villiers 1968). De Villiers' research demonstrated that sexual dimorphism in the skull of indigenous South Africans appeared to be associated mainly with the mandible for linear measurements (the degree for sexual dimorphism when using morphological features are discussed in the appropriate section). This finding has been confirmed more recently in South Africans and in other groups (e.g. Barthélémy et al. 1999; Franklin et al. 2006).

Linear measurements are also used in clinical dentistry, where measurements are often recorded from radiographs. Radiograph tracings are then transferred to a computer with a digitiser and angles and measurements taken. Often the gonial angle size, as a measure of efficiency of mastication, is compared to various other dimensions to establish relationships e.g. (Moipolai et al. 2003; Nissan et al. 2003; Xie & Ainamo 2004; Yanıkoğlu & Yılmaz 2008; Osato et al. 2012; Da Costa De Sousa et al. 2013). For instance, the gonial angle, area of the mandible and the length of the mandible are of concern in constructing dentures (Moipolai et al., 2003). While the correlation of gonial angle size with cortical thickness, height of the mandibular residual body, and duration of edentulism will be more important for implant dentistry and extractions (Nissan et al. 2003; Xie & Ainamo 2004).

In forensic anthropological research where sexually dimorphic characteristics are assessed (Franklin et al. 2006; Franklin et al. 2008b; Bidmos et al. 2010; Zhuang et al. 2010) edentulous subjects are not specifically included. Barthélémy et al. (1999), however, included some with a degree of tooth loss as their criteria were set not to exclude those with only incisors and canines. In contrast, studies in the dental field often use edentulous subjects to evaluate the effects of edentulism with or without dentures. Nissan et al. (2003) for instance involved only edentulous individuals awaiting construction of replacement dentures. Although studies in the dental field are not designed to comment on sexual dimorphism, findings of these studies, which include edentulous individuals, might give new insights for the forensic anthropologist when sex traits are assessed.

As significant effects of tooth loss and to a lesser extent aging on linear measurements of the mandible have been described (and are dealt with in 2.3.3 Remodelling of the mandible with aging and 2.3.4 Dental pattern sections of this literature review), the degree of tooth loss and aging need to be considered when linear measurements are used in the estimation of ancestry and sex (Acsádi et al. 1970; Parr 2005). The size of the gonial angle for instance, which has been used in the differentiation of sex and ancestry, may be influenced by the degree and duration of tooth loss.

2.4.1.3 Assessment of sex

In general the mandible has larger dimensions in males and their gonial angles are also considered to be less obtuse (İşcan & Steyn 2013). Linear measurements may be used to quantify these size differences between the sexes. Metric standards in sex determination are popular because they provide a high degree of expected accuracy and are less error -prone than subjective nonmetric visual techniques (Franklin et al. 2006). Giles (1964), who used the Terry collection, reported eight measurements of the mandible that were useful for sexing an individual. These measurements were: symphysis height, body height, body length, body thickness, minimum ramus breadth, maximum ramus breadth, ramus height, and bigonial diameter (Giles 1964). In considering SAA, all mandibular measurements were significantly affected by the sex of an individual. For each measurement taken, males were larger than females (Parr 2005).

Franklin et al. (2006; 2008b) established metric discriminant function standards for sex estimation on the mandible in SAA. Seven of the 10 measurements examined were found to be sexually dimorphic and of these the dimensions of the ramus and corpus lengths were most dimorphic. The sex classification accuracy of the discriminant functions ranged from 70.7% to 77.3% for the univariate method, 81.8% for the stepwise method, and 63.6% to 84% for the direct method. It was concluded that the mandible in SAA displays a high degree of sexual dimorphism that may be useful in the identification of sex by metric analyses

(Franklin et al. 2006; Franklin et al. 2008b). These findings were confirmed by Dayal et al. (2008) who used traditional linear measurements.

2.4.1.4 Assessment of ancestry

In the study by Ribot (2004) to differentiate modern sub-Saharan African populations, group differentiation was the highest when all 12 craniometric variables for both vault and face were used. Group differentiation decreased markedly when mandibular variables only were used. Various reasons could have caused the lack of discrimination and include traits that may not have been very representative of the complex morphology of the entire bone. It is also considered that alternative factors in comparison to the rest of the skull could have shaped the mandible, e.g. a higher biomechanical load.

In a more recent study, 921 individuals including individuals from the Pretoria Bone Collection were examined (Parr 2005). Ancestry significantly affected the following linear measurements of the mandible: bigonial width, mandibular length, mandibular angle, and minimum ramus breadth. Europeans tended to have a slightly larger bigonial width than Africans, although the more extreme forms of gonial eversion were more common in Africans. This discrepancy was thought to be the result of Africans having stronger muscle attachments at the gonia and for this reason creating more eversion, while Europeans had generally wider mandibles, regardless of gonial eversion. Africans had a longer mandible, smaller (more acute) gonial angle, and wider minimum ramus width in comparison to those of Europeans. In contrast, Europeans had a shorter mandible, more obtuse gonial angle, and a thinner mandibular ramus width than Africans. These measurements could be used to generate discriminant functions that can distinguish between different ancestral groups.

As some of the population or sex discriminating dimensions might be sensitive to tooth loss and aging, the degree of tooth loss and age needs to be considered when an attempt is made to identify unknown remains by metric analyses.

2.4.2 Morphological features

Specific morphological features of the mandible - for instance in the gonial, ramal and chin region, have been described as sex or ancestral traits or may even show features of aging. The ramus flexure (Loth & Henneberg 1996) and gonial eversion (Acsádi et al. 1970; Ferembach et al. 1980; Novotny et al. 1993), for instance, are two mandibular shape features situated around the posterior aspect of the mandible which have been investigated in sex determination. These characteristics cannot be metrically assessed, and are therefore assessed morphologically. Morphological traits may be visually scored or geometric morphometrics may be applied to quantify and facilitate shape variations.

The morphology of the mandible is influenced by the dental pattern. Enlow et al. (1976), for instance, commented that tooth loss accounts for the greatest shape changes in the mandible. Loth and Henneberg (1996) suggest that the loss of even one molar may result in a change of mandibular shape. As teeth are lost, the mandible enters a state of resorption where the corpus becomes remodelled (Atkinson & Woodhead 1968). Additionally, the lateral portion of the ramus becomes resorbed with age, while the mandibular corpus increases in length (Enlow et al. 1976).

Population-specific shape features of the mandible described by many authors (e.g. Antón 1996; Loth & Henneberg 2000; Viðarsdóttir et al. 2002) may not be fixed as diet and dental care may influence postnatal development of the mandible (Oettlé et al. 2009b). For instance, fluctuating changes in diet and dental care with time within a group could have an effect on dental patterns, which in turn could influence the mandibular characteristics that are used to estimate sex and ancestry. If a relationship exists between these mandibular shape features and senescence or tooth loss, it would need to be considered with regard to the determination of sex and ancestry in forensic anthropology.

In the assessment of sex of unknown individuals a scoring system may be used for classification of the general morphological features of the mandible: the range of the body of the mandible from very narrow (hyperfeminine) to very thick (hypermasculine); the range of the trigonum mentale from rounded smooth (hyperfeminine) to displaying bilateral protruberances (hypermasculine); the range of the mandibular angle area from smooth (hyperfeminine) to demonstrating strongly marked eminences and being laterally directed (hypermasculine); and the head of the mandible being very small (hyperfeminine) to very large (hypermasculine) (Acsádi et al. 1970).

The Acsádi coding system, however, was developed specifically for sexing people of European ancestry and does not encompass the full range of human variation (Walker 2008). A new scoring system for the *Standards for Data Collection from Human Skeletal Remains* that encompasses the extremes observed in a worldwide sample of skulls in museum collections has been developed. Diagrams were produced for each feature on a scale from 1 to 5 instead of - 2 to + 2. The 1 to 5 scale generalises the system and removes the assumption that a zero value is the optimal cut-off point between male and female. Yet it is often considered that 1 is definitely female, 2 is probably female, 3 is ambiguous, 4 is probably male and 5 is definitely male (Buikstra et al. 1994).

For the mental eminence, minimal expression (score = 1), means that the area of the mental eminence is smooth and there is little or no projection of the mental eminence above the surrounding bone. Maximal expression (score = 5), indicates a massive mental eminence that occupies most of the anterior portion of the mandible.

Walker (2008) assessed these five features used by Buikstra and Ubelaker (1994) on Europeans and Americans of European and African ancestry. He combined these five characteristics in logistic regressions and found accuracies of approximately 80%. Combinations of characteristics involving the chin area included the following: glabella, mastoid and mental areas: 87.4%; glabella and mental areas: 84.4%; mental and mastoid areas: 81.8%; orbital margin and mental areas: 78.0%. These accuracies are considered valid only for the populations studied (İşcan & Steyn 2013).

Other forensic anthropological assessments of the chin region include photographic scoring of the mental eminence (Perrot 1996), classification by chin shape types (De Villiers 1968) and more recently, digitising traced outlines of the chin (Thayer & Dobson 2010) and 3D surface laser scans of the chin (Garvin & Ruff 2012).

As the morphological features of the ramus and gonion are mainly related to sex and ancestry group identifications these features have been discussed in greater detail in the appropriate sections. The features of the chin were covered in the sections dealing with the impact of sex, ancestry, aging and dental patterns.

Morphological traits may be modulated by functional forces. From a biomechanical viewpoint, these morphological traits observed in the mandible may be considered as being formed in response to muscular forces of mastication acting in on them. Thus the gonial region may be considered as modelled and formed by the action of the masseter and medial pterygoid muscles that insert onto it (Potgieter et al. 1983; Maki et al. 1999; Swasty et al. 2009). The same would apply to the posterior ramal border and the shape of the chin. This shaping in response to functional force is prescribed by Wolff's Law which states that 'every shape in the use or static relations of a bone leads not only to change in its internal structure and architecture but also to a change in its external form and function' (Wolff 1986).

Although sexual dimorphism in the shape of the mandible has been confirmed in many populations (De Villiers 1968; Parr 2005; Bejdová et al. 2013), the usefulness of mandibular sex traits for identifying unknown individuals especially if considered in isolation is doubtful (Krogman & İşcan 1986; Galdames et al. 2009; Bejdová et al. 2013; İşcan & Steyn 2013).

Maat et al. (1997) for instance scored four mandibular features (robustness, shape of mentum, prominence and shape of angle, robustness of inferior margin) and found very poor results.

2.4.2.1 Advanced assessments of shape: Geometric morphometrics

Traditionally, morphometric studies of the variation in morphological features among individuals outlined before have relied on statistical analysis of distances, angles or ratios (Pretorius et al. 2006). One of the major limitations of metric analyses is that the measurements or angles are ultimately based on the positions of anatomical landmarks, by which they are defined, yet they encode only incomplete information about the relative positions of these defining points (Ross et al. 2010). Also, many characteristics can only be assessed morphologically; e.g. ramus flexure, gonial eversion, and chin shape in the case of the mandible. These morphological characters of the skeleton are often difficult to assess, because of a number of factors such as inter- and intraobserver errors, problems with classification of morphological characteristics (e.g. wide, narrow, intermediate) and statistical analysis. The experience and interpretation of the observer also plays a role (Pretorius et al. 2006).

The newer morphometric methods using three-dimensional landmark coordinates can provide considerably more anatomical information than their traditional counterparts (Ross et al. 2010). Hennessy and Stringer (2002) consider geometric morphometrics very useful for enhancing and understanding results of more traditional morphometric studies. What may have been missed in the absolute morphological scoring system for gonial eversion were picked up by geometric morphometrics, using seven landmarks and detecting finer variations in shape and not size (Oettlé et al. 2009b).

In recent years, geometric morphometric methods have become increasingly more common for studying human skeletal biology in both physical and forensic anthropology (Hennessy & Stringer 2002; Pretorius et al. 2006; Franklin et al. 2007).

In 2008, Franklin et al. examined 225 mandibles of SAA ancestry with geometric morphometrics and were able to demonstrate sexual dimorphism of the studied landmarks, with the condyle and ramus being the most consistently dimorphic part of the mandible. The cross-validated sex classification accuracy in the pooled data (83.1%) was similar to that presented by Steyn and İşcan (81.5%) using traditional linear metrical methods.

Geometric morphometrics provide a mechanism to quantify morphological characteristics. It allows for a detailed assessment of the areas in which morphology differs between various skeletons and may provide some statistics that can be used to interpret findings (Lynch et al. 1996; Hennessy & Stringer 2002; Franklin et al. 2007).

Geometric morphometrics is used to compare the shapes of biological objects. It is based on the analysis of the relative position of specific homologous points recognisable on all specimens in the study (called “landmarks”) identified over the surface of the object itself and in this way representing its shape. Shape can be defined as what remains when location, size and rotational effects are eliminated from a landmark configuration of a certain object. An additional advantage of geometric morphometrics is that these morphological shape variations can be visualised (Webster & Sheets 2010).

Coordinates of the landmarks are used in a Procrustes analysis to correct for size and orientation differences and thereafter a Principal-Component Analysis may be conducted. Principal-Component Analysis allows the principal components of variation between specimens to be examined. As the first two components usually exhibit the greatest variation, the first principal component of shape variation is plotted against the second. Further comparisons of other principal components are considered if they contribute substantially to the shape variation detected (Bookstein 2008). The distribution of the variation in shape amongst individuals can then be visualised graphically. Additional analysis involving the visualisation of shape variations may be calculated with the use of thin plate splines through a deformed Cartesian transformation grid.

Bookstein (1993) describes the combined use of Procrustes superimposition, multivariate statistical analysis and thin plate splines (TPS) visualisation as morphometric synthesis, which is outlined in the following sections.

2.4.2.1.1 Procrustes analysis

A Procrustes shape analysis is performed to eliminate the non-shape variation in the sample so that shape differences may be appreciated (Franklin et al. 2007). Procrustes superimposition removes differences in size, rotation and translation in Kendall's non-Euclidean shape space. The procedure of translating all landmark configurations to a common location, rescaling all to unit centroid size, and rotating all into an optimal least-squares alignment with a recurring estimated mean reference form is called "Generalized Procrustes Analysis". The centroid of a shape is its centre or the mean values of the x- , y- and z- coordinates for all landmarks in the shape and the centroid size is the square root of the sum of the squared distances between each landmark and the centroid of the form (Webster & Sheets 2010). The unit centroid size is used as a biologically meaningful expression of the overall size of the landmark configuration (Franklin et al. 2007).

When a full Generalised Procrustes Analysis is performed reflection is possible as well. After full Procrustes superimposition, the objects will exactly coincide if their shapes are identical. As all differences in location, scale, and orientation have been removed by this procedure, any differences in coordinates of corresponding landmarks between configurations must be the result of differences in shape between those configurations. Variability is represented by the scatter of points at each landmark or the wireframe models of each sample studied. Wireframe models represent lines connecting landmarks in a specified sequence (O'Higgins & Jones 1998; Webster & Sheets 2010).

A potential drawback of Procrustes superimposition is that the orientation of biologically relevant axes is not respected during rotation. Procrustes superimposition may result in considerable variation in relative orientation of the axis of symmetry within a sample. This variation is inconvenient if differences in shape are to be described in terms of landmark locations relative to the axis of symmetry (Webster & Sheets 2010). Procrustes analysis is further also susceptible to the "Pinocchio Effect", in which large differences or variances at one or a few landmarks are effectively smeared out over many landmarks by the least-squares rotation (Webster & Sheets 2010).

Procrustes analysis forms the basis for subsequent operations; e.g. Principal-Component Analysis.

2.4.2.1.2 Principal Component Analysis

A full tangent space projection is performed, which entails the projection of the scatter of points representing the specimens from Kendall's non-Euclidean shape space into a Euclidean space tangent to the shape space at the reference form. This is necessary because most statistical methods are based on Euclidean relationships between variables (Franklin et al. 2007; Webster & Sheets 2010).

A series of Principal Component Analyses may then be used to explore the relationships between groups. As the first two components exhibit the greatest variation, the first principal component of shape variation is plotted against the second. Further comparisons of other principal components may be considered to establish if they contributed substantially to the shape variation detected. The distribution of the variation in shape amongst individuals can then be visualised on the principal components analyses, plots, wireframes, and thin plate spline grid deformations. The name "thin plate spline" refers to a physical analogy involving the bending of a thin sheet of metal in the XY or XZ or YZ planes.

2.4.2.1.3 Repeatability tests

As geometric morphometric methods rely on the accurate identification and quantification of landmarks on biological specimens, reliability tests should always be performed to ascertain whether digitisation of landmarks is repeatable amongst observers and when repeated by the same observer (Von Cramon-Taubadel et al. 2007).

The process of extracting landmark coordinates will always be associated with some degree of measurement error. This error can result from inconsistent tilting of specimens relative to the plane of digitisation, non-coplanarity of landmarks, and/or difficulty in pinpointing the landmark locus (Webster & Sheets 2010). Configurations employed in morphometric analyses often comprise landmarks of differing identification precision. Some landmarks are easily identifiable while others are more ambiguous and determined indirectly by other factors (Von Cramon-Taubadel et al. 2007). Further complicating repeatability is the fact that a Procrustes analysis is susceptible to the "Pinocchio Effect" as explained earlier (Webster & Sheets 2010).

The methods currently employed to assess measurement error in geometric morphometrics include Generalised Procrustes Analysis to superimpose repeatedly digitised landmark configurations (Franklin et al. 2007); an alternative approach involves employing Euclidean distances between the configuration centroid and repeat measures of a landmark to assess the relative repeatability of individual landmarks. Shape differences between individual specimens or groups of specimens are analysed as the perceived relative displacement of individual landmarks within the configuration. Results can be tested univariately (i.e., on a variable-by-variable basis) and multivariately. A third approach to assessing error follows the principle of repeatedly digitising landmarks on one or more specimens by several observers, while keeping the digitiser and the specimen in a constant orientation relative to each other (Von Cramon-Taubadel et al. 2007). Each landmark can then be evaluated as repeatable or not.

A new method for assessing landmark precision suggested by von Cramon-Taubadel et al. (2007) involves a partial superimposition of, for instance, three reference landmarks spread across the configuration to superimpose the repeat trials and thereafter estimate residual error of the nonreference landmarks (Von Cramon-Taubadel et al. 2007).

Various methodologies including the use of a digitiser or cone-beam-derived computer images may provide spatial information in the form of landmarks about a three-dimensional object to a computer system for geometric morphometric analyses.

2.4.3 Cortical thickness

The dense outer sheet of compact bone from periosteum to the inner trabecular (cancellous) bone is referred to as “cortical” bone (Schwartz-Dabney & Dechow 2002; Humphries 2007). The thickness of the cortical bone reflects the mechanical loads exerted at a specific point on the mandible during mastication. The highest bite forces are found in subjects with a low mandibular angle, which appears to result in an adaptive increase in cortical bone thickness and density (Humphries 2007). Therefore, not only is the external shape of the mandible influenced by biomechanical factors but also the internal structure (Kohakura et al. 1997).

As the same biomechanical factors determining external morphology affect the internal morphology as well, various dimensions of the external shape of the mandible have been related to the cortical thickness at specific sites in the mandible; e.g. mandibular angle, mandibular length and height as well as width and height of the ramus (Xie & Ainamo, 2004). Biomechanical factors such as the orientation of the masticatory muscles and the forces that they generate differ amongst facial shape types; e.g. with prognathism between sexes, dentition groups and with age (Kohakura et al., 1997; Schwartz-Dabney & Dechow, 2002; Xie & Ainamo, 2004).

In the section to follow various determinants of cortical thickness will be outlined as well as the associated external mandibular morphological features.

2.4.3.1 External morphology

Continuous remodelling of the mandibular cortex exists that is influenced by dentition and therefore masticatory function. In addition, the bite force or masticatory function caused by the masticatory muscles also influences external mandibular shape and structure (Dutra et al. 2005). Kohakura et al. (1997), for instance, found that the size of the mandibular angle negatively correlated with the buccal cortical bone thickness of the second-premolar- and first-molar sections. The association between cortical bone thickness with masticatory function is demonstrated in the sharpness of the mandibular angle. The cortical bone thickness in the molar area is related to the proximity of the attachment of the masticatory muscles. There were also significant relationships between mandibular length and height of each section, and between the width and height of the ramus and the width of all sections.

Ogawa et al. (2012) provided more evidence that masticatory function influences both the internal structure and the size of mandibular body. These authors found a relationship between the mandibular angle and the buccal and lingual cortical bone thickness in the section at the second molar level. The mandibular angle was also related to the height of the symphysis and the height and width of the second molar section. The individuals used in the study had normal occlusion with minimal dental crowding. All subjects had mandibular third molars.

2.4.3.2 Aging

Senescence has a general effect on the skeleton and specifically on the morphology and cortical thickness of the mandible (Von Wowern & Stoltze 1979; Bras et al. 1982; Kribbs

1990; Hu et al. 2006). Cortical thickness increases up to 40 to 49 years of age and then may decrease in thickness after this period along with absolute bone mass and density, regardless of the state of the dentition (Henrikson et al. 1974; Von Wowern & Stoltze 1978; Kingsmill & Boyde 1998; Kingsmill 1999; Swasty et al. 2009). Researchers are not in agreement whether these aging effects are isolated from the change in dentition that often accompanies senescence, as Schwartz-Dabney and Dechow (2003) found no significant decline in density with age in dentate individuals. It was thought that cortical thickness was maintained by dentate mandibles, causing higher occlusal loads throughout later life. Contradictory to this finding, post-menopausal women of 60 years and older and individuals with tooth loss or chronic renal failure were more at risk for loss of cortical bone (Xie & Ainamo 2004; Dutra et al. 2005).

Remodelling of the mandibular cortex does not always entail a decrease in thickness with age as expected. Lestrel et al. (1980), for instance, found that although the cortical thickness of the inferior aspect of the mandibular symphysis decreased with age, the thickness of the inferior mandibular border increased slightly.

In summary it can be concluded that there is a continuous remodelling in the mandibular cortex with age and this is influenced by dental status, sex and chronic diseases.

2.4.3.3 Presence or absence of dentition and dentures

Differences in cortical thickness between edentulous and dentate mandibles vary regionally. In edentulous individuals alveolar bone is lost and throughout most of the mandible the cortical bone is thinner than in dentate mandibles. Conversely cortical bone thickness increases at the lingual aspect of the corpus, the angle and the condylar neck in edentate mandibles (Schwartz-Dabney & Dechow 2002; Katranji et al. 2007). The thickening might represent a secondary adaptation to relatively larger strains due to a reduction in alveolar height and corpus cross section, despite overall reduced muscular and biting loads (Schwartz-Dabney & Dechow 2002).

It was also found that the cortical thickness of the inferior mandibular border is significantly less in denture wearers than in those with dentition (Lestrel et al. 1980; Katranji et al. 2007). A slight increase in thickness of cortical thickness in the inferior aspect of the mandibular symphysis was noted with edentate individuals wearing dentures. The results suggest that bone remodelling can be expected at sites distant from the residual ridge in denture wearers (Atkinson & Woodhead 1968; Kingsmill & Boyde 1998).

Knezović-Zlatarić and Čelebić (2005) compared elderly individuals with removable partial dentures to those with complete dentures and found thicker cortical bone underlying the mucosa as well as underneath the remaining teeth in the first group with removable dentures. In the case of complete dentures, overload was demonstrated on the alveolar ridge, causing resorption of the ridge as opposed to removable dentures with some remaining teeth, where the forces of mastication was diverted to the remaining teeth promoting bone growth and cortical thickness. Stronger masseter contraction associated with greater chewing forces might thus be achieved with tooth and mucosa-borne dentures, which may stimulate bone growth at the mandibular cortex. In conclusion it seems that tooth and mucosa-borne removable partial dentures prevent alveolar bone overloading, thus allowing higher chewing forces and higher tensile forces of the masseter attachment to the lower border of the mandible preventing resorption of the residual ridge.

When an orthodontic force is placed upon a tooth, there is osteoclastic activity and bone resorption on the compression side and osteoblastic activity and bone deposition on the tension side. The functional loads are equal and opposite but the maxilla transfers stress to the cranium, whereas the mandible must sustain the entire load. The mandible is composed of thick cortical bone connected with coarse oriented trabeculae. It has been shown that bone remodelling in the alveolar bone is stimulated by the flexure produced by mechanical stimulation from mastication through the periodontal membrane and thus cortical bone thickness and density may increase as masticatory function develops (Richmond et al. 2005; Humphries 2007).

The changes that occur with loss of teeth are sometimes understood as disuse osteoporosis because of a reduction in mechanical stimulation. Disuse osteoporosis, however, is usually accompanied by endosteal resorption with little in the way of change in the external diameter of the bone. The resorption is self-limiting, ceasing when a new functional equilibrium has been established. In contrast, a resorbing alveolar ridge when teeth are lost shows bone apposition on the endosteal surface and a continuous overall decrease in size. In addition, studies of mandibular structural changes with age, no relation between cortical porosity and the presence or absence of teeth was found (Atkinson & Woodhead 1968; Knezović-Zlatarić & Čelebić 2005).

It seems that cortical thickness is preserved with aging in dentate individuals and even in elderly individuals with removable partial dentures as compared to those with complete dentures, because of preserved mechanical loading. Edentulousness is associated with a greater cortical thickness in the corpus, especially lingually, and lesser in the ramus except for the angle and the condylar neck. A slight increase in thickness of cortical thickness in the inferior aspect of the mandibular symphysis was further noted in individuals wearing dentures. This increase may be due to a secondary adaptation to relatively larger strains through a reduction in alveolar height and corpus cross section, despite overall reduced muscular and biting load.

2.4.3.4 Osteoporosis

It is expected that individuals with systemic osteoporosis would have less mandibular bone mass, lower bone density and a thinner cortex (Xie & Ainamo 2004). This relationship has not been confirmed by others; e.g. (Mohajery & Brooks 1992; Watson et al. 1995; Kingsmill 1999). It seems that in the mandible local functional factors are of paramount significance which may compensate for systemic osteoporosis (Knezović-Zlatarić & Čelebić 2005).

2.4.3.5 Regional variation of cortical thickness in the mandible

Cortical bone is thicker in the corpus than in the ramus, and thicker in the buccal than in the lingual corpus. Overall, the cortex is thickest at the lower border of the symphysis. Regionally, the symphysis, corpus, and ramus differ from each other. Many symphyseal sites share a unique set of features: they are thicker at the inferior border, less dense, less anisotropic, and less stiff in both axial loading and shear than many sites elsewhere. Overall, sites in the ramus are thinner, denser, and stiffer than sites in the corpus and at the symphysis. Many sites in the corpus have intermediate thickness values between those of the ramus and symphysis. This larger variation in cortical bone thickness reflects the functional heterogeneity of the mandible. The buccal side is thicker than the lingual, except in the region of the symphysis where the opposite was found (Schwartz-Dabney & Dechow 2003). The thickening of the lower lingual region noted at the symphysis could coincide with the midline lingual canal along which bone deposition was found (Oettlé et al. 2013).

It was further noted in subjects with complete dentition (with or without third molars) that the base of the mandible exhibited the greatest cortical plate thickness across all age groups (Swasty et al. 2009). In all regions these authors found that cortical thickness narrowed as the symphysis was approached. The one exception again was in the lower lingual region, which became twice as thick at the symphysis as it was in the molar regions. In both the upper buccal and lower buccal regions the thickest cortical plates were found at the molars (Pileicikiene & Surna 2004; Swasty et al. 2009). The upper lingual region had a pattern similar to the mandibular base where the greatest cortical thickness was seen in the area of the premolars and canines. In all cases, the changes in cortical thickness were symmetric for the right and left sides of the mandible. On coronal sections the mean cortical width of the buccal cortex is increased towards the ramus region while the lingual cortex is thinnest in the ramus region of the mandible (Kim et al. 1997). Cortical bone thickness further increases towards the apical regions of the alveolar process (Humphries 2007).

Variation in cortical thickness in regions of the mandible is thought to be related to uneven distribution of forces on the teeth despite simultaneous tooth contacts. Differential tooth loads are possible because of the flexibility of the dento-alveolar tissues and supporting mandibular bone when acted upon by the muscles of mastication (Kikuchi et al. 1997).

2.4.3.6 Sex differences in cortical thickness

Researchers are not in agreement whether there are sex-related differences in cortical thickness or not. Von Wowern and Stoltze (1978) found that there was no significant sex-related differences in the bone mass of the buccal and lingual cortices, trabecular coarseness or bone activity. Dutra et al. (2005) found that the relationship between cortical thickness and mandibular body height was greater in older males than in older females, which means that cortical thickness was relatively smaller than mandibular body height in females. It seems that females either have a smaller cortical thickness to start off with or lose their cortical bone more quickly (remodel quicker). This impression that cortical bone thickness is greater in males than in females was confirmed by Humphries (2007) but the difference was only statistically significant in the maxilla.

2.4.3.7 Ancestry group differences in cortical thickness

In general, mandibular cortical bone was found to be thicker in African-American individuals (Humphries, 2007). In addition, indicators of the protrusion of the upper and lower jaws have been positively correlated with the buccal cortical bone thickness of the second premolar section and the interincisal angle with basal cortical bone thickness of the second molar section (Kohakura et al. 1997). The correlation between facial shape and cortical thickness might also have implications for other population-specific features.

2.4.3.8 Summary

There are significant relationships between external morphological dimensions of the mandible and the cortical width of all sections of the mandible. Cortical bone is thicker in the corpus than in the ramus, and thicker in the buccal than in the lingual corpus. Overall, the cortex is thickest at the lower border of the symphysis. There is a continuous remodelling in the mandibular cortex with change in dental status. It is not clear whether aging without loss of teeth would have an effect on the cortical thickness. Regional slight increases in thickness of cortical thickness with loss of teeth, also in those wearing dentures, is thought to be due to a secondary adaptation to relatively larger strains through a reduction in alveolar height and corpus cross section, despite overall reduced muscular and biting load. It seems that in the mandible other factors that compensate for systemic osteoporosis are at play. There are no clear differences between sexes. Africans and individuals with prognathic faces generally present with a greater cortical thickness.

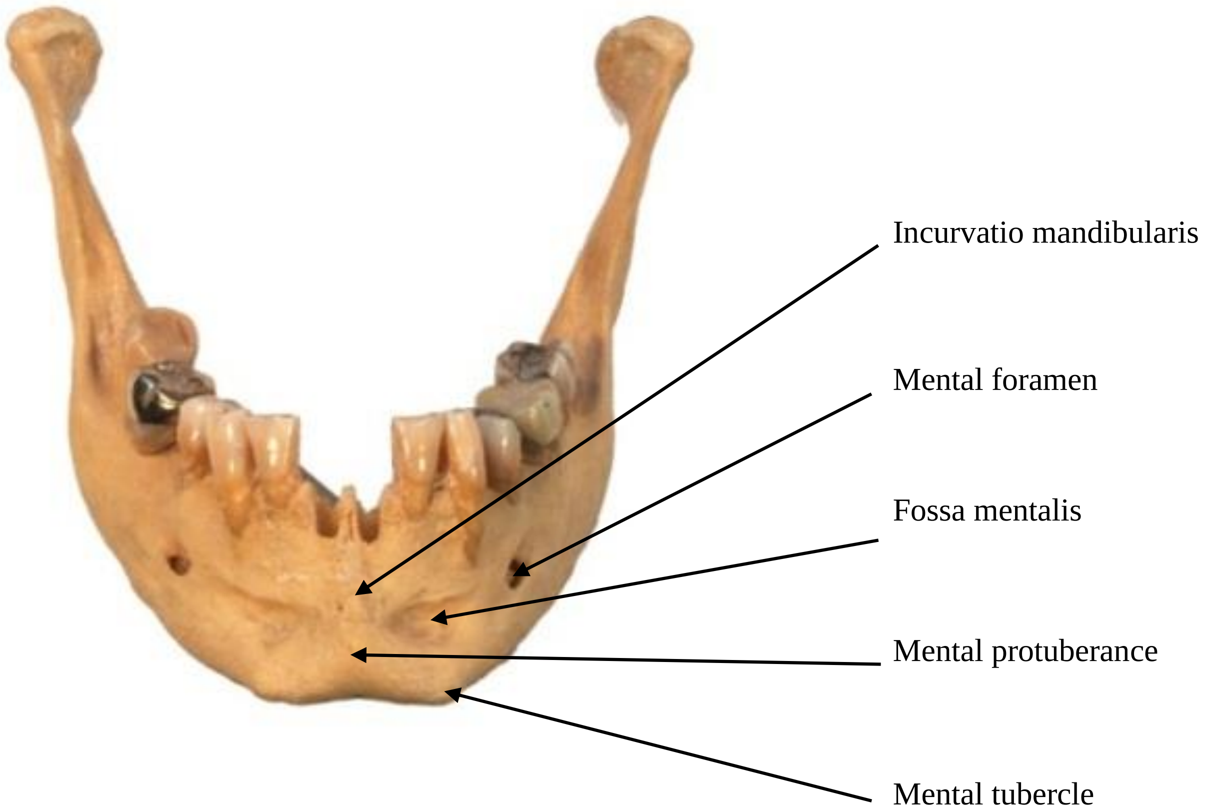


Fig. 2.1 Chin region of female SAE

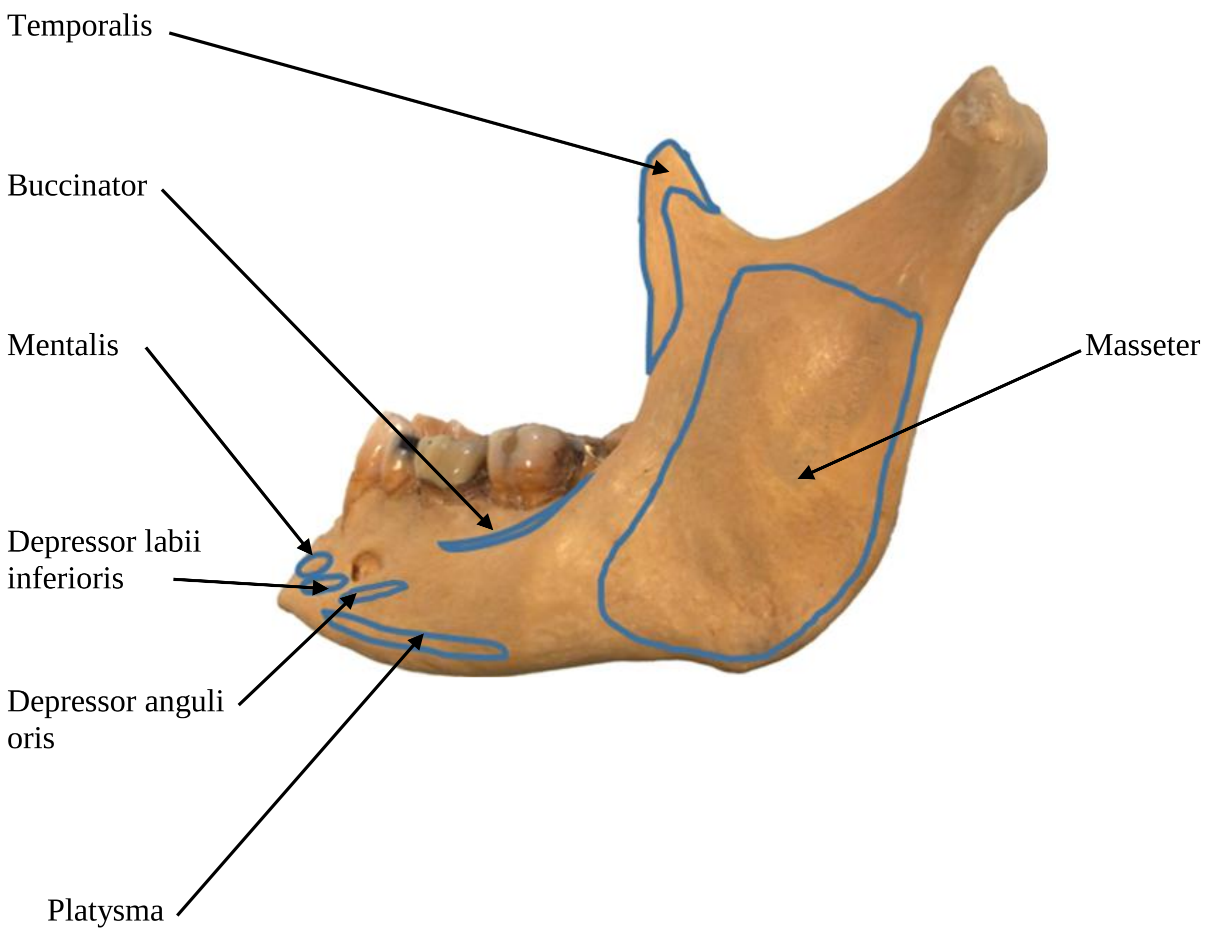


Fig. 2.2 Muscle attachments sites on the lateral aspect of the mandible

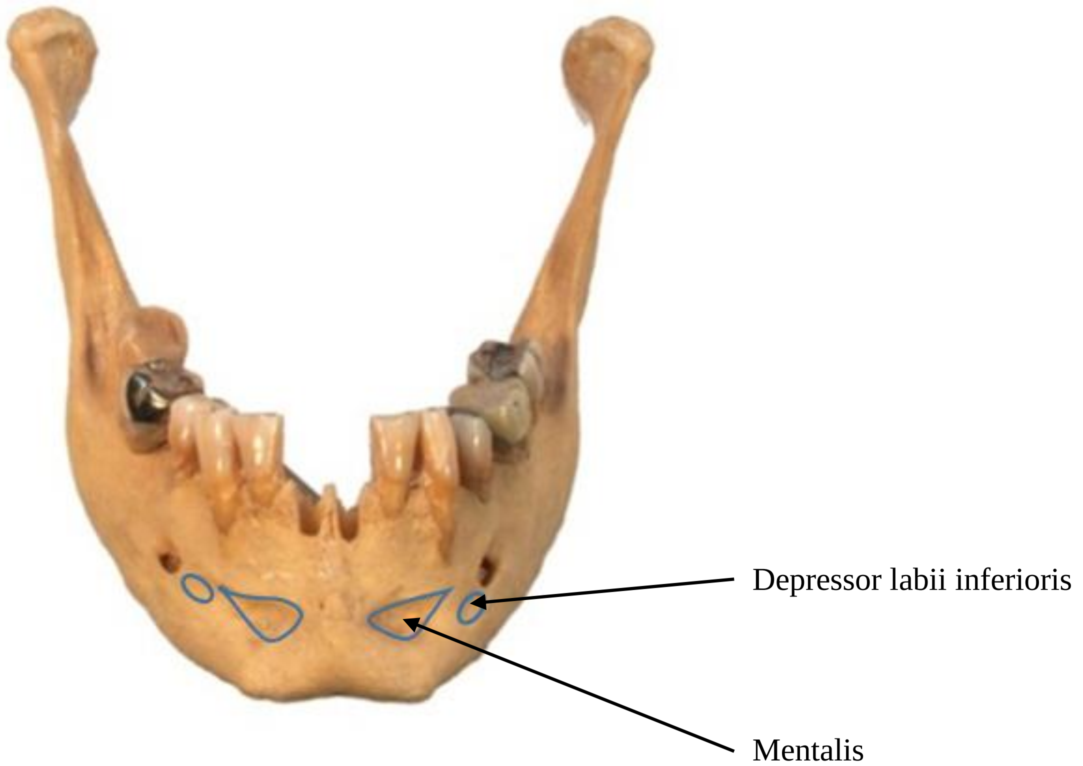


Fig. 2.3 Muscle attachments sites on the anterior aspect of the mandible

Chapter 3: INTRODUCTORY MATERIALS AND METHODS

3.1 Introduction

The purpose of this study was to investigate the manner in which dental loss and senescence influenced the morphology of the mandible within sex- and ancestry groups. Of particular note, was the impact of tooth loss and senescence on morphological features classically associated with sex- or ancestry group predictions in the investigation of unknown skeletal remains. These morphological features were evaluated in the sex and ancestry groups of this study, selected to comprise individuals with a spectrum of tooth loss patterns from the Pretoria Bone Collection (L'Abbé et al. 2005). The Pretoria Bone Collection is housed at the Department of Anatomy, University of Pretoria (Gauteng Province). Four sex-ancestry groups were considered, consisting of both sexes in SAA and SAE. Within each of these four sex-ancestry groups, three tooth loss (dentition) patterns associated with masticatory efficiency were identified (therefore producing 12 sex-ancestry-dentition groups in total).

Different methodologies ranging from simple measurements to advanced three-dimensional techniques were employed in an attempt to evaluate and visualise structural changes that occur with tooth loss. In this way a comprehensive understanding of the structural changes of the mandible with changes in dentition and senescence amongst the various sex-ancestry groups could be gained.

By applying various modalities specific characteristics used in the estimation of sex and to a lesser degree ancestry – for instance, gonial angle, gonial eversion, ramus flexure and chin shape in unknown skeletons – were not only viewed in isolation but also assessed as part of the overall shape changes in the mandible (De Villiers 1968; Acsádi et al. 1970; Tobias 1974; Novotny et al. 1993; Loth 1996; Ohm & Silness 1999; Loth & Henneberg 2000; Galdames et al. 2009).

The biomechanical forces associated with mastication affect the morphology of the mandible and form part of the differences noted with ancestry, sex, aging and tooth loss (Keen 1945; Enlow et al. 1976; Kohakura et al. 1997; Ohm & Silness 1999; Loth & Henneberg 2000; Hu et al. 2006). If a relationship exists between these mandibular shape features and senescence or tooth loss, it would need to be considered with regard to the determination of sex and ancestry in forensic anthropology.

3.2 Materials

This study was done on dried mandibles from the Pretoria Bone Collection. Adult mandibles including those with varying degrees of dental loss, but without obvious deformity or surgery, were randomly selected according to criteria explained for each part of the study, from the Pretoria Bone Collection, Department of Anatomy, University of Pretoria, Republic of South Africa (L'Abbé et al. 2005). Only mandibles from individuals with confirmed identities and known ages belonging to SAA and SAE ancestry were included. The ages of the individuals ranged from 18 to 98 years.

The skeletal material of the Pretoria Bone Collection originates mainly from individuals who died in the Tshwane metropolitan area. This does not necessarily mean that these individuals did not live elsewhere. Migrant labour, as is especially true for the South African male group of African origin, is an important reason for this discrepancy (L'Abbé et al. 2005). The individual skeletons in the Pretoria Bone Collection, representing the people of South Africa, a nation of over 52 million (census 2011), are broadly classified as Black, White, Coloured and Indian/Asian (L'Abbé et al. 2011). Membership of an ancestry group was previously a legal definition but is now based on self-perception and self-classification (Patterson et al. 2010).

Skeletons in the collection come from two sources – they are either donated bodies or unclaimed bodies from local hospitals. Both groups often represent individuals from lower socio-economic status. Individuals without a verifiable age or unassigned ancestral group or neither of European or African ancestry were excluded so that the study sample consisted of South African males and females of both African ancestry (known as black South Africans) and European ancestry (known as white South Africans). No Asians or coloured South Africans, were included, as numbers from these groups were insufficient for meaningful statistical analysis (Patterson et al. 2010).

The SAA group have long been the predominant people of South Africa and therefore they are the main ancestral group to consider in dealing with forensic cases in the country (L'Abbé et al. 2011). SAA as described by Tobias (1974), were previously considered as broadly alike in genetic constitution with similar cranial size and shape and significantly different from other African and American black ancestral groups. (De Villiers 1968; Tobias 1974; Loth & Henneberg 1996; Ribot 2004). Although the SAA group is composed of several different ethnic groups, osteological differences amongst these ethnic groups were previously not considered great enough to justify separation (Loth 1996). In contrast, more recently, Franklin et al. (2007) have shown that although the indigenous populations are closely related they show population-specific features. For the purpose of this study, however, the mandibles were regarded as a sample of a single group denoted by the term "SAA".

Representatives of European ancestry arrived from approximately 360 years ago as a direct result of European settlement in South Africa (Patterson et al. 2010). SAE have their origins from the Netherlands, but later also from France, Germany and Britain, as well as smaller additions from other countries (L'Abbé et al. 2011). However, as a result of temporal change, founder's effect, and admixture, SAE as a group have become osteologically distinguishable from both their European and North American counterparts (Steyn & İşcan 1997; Patriquin et al. 2002).

A total of 717 mandibles were assessed in the initial analysis (Table 3.1) to confirm whether the guidelines for the maximum tooth loss pattern associated with efficient mastication holds true as reflected in the size of the mandibular angle, contrary to situations where patterns do not meet this criteria. The mandibular angle varies from a sharp angle with strong masseter development associated with efficient mastication (Fig. 3.1) to an obtuse angle with reduced muscle activity associated with inefficient mastication (Fig. 3.2) (Kasai et al. 1996).

For subsequent analyses, involving more specialised techniques, subsets from the original sample were selected. Selection of a smaller sample was done so that comparable numbers of individuals could be obtained in all sex-ancestry groups representing individuals with varying degrees of masticatory efficiency. As many of the SAE in the collection are completely edentulous and many of the SAA have very limited antemortem tooth losses, these four subsequent samples or sex-ancestry groups are much smaller and range between 26 and 37 individuals, totalling at least 120. Although each sex-ancestry group was further divided into three smaller dentition subgroups of approximately 10 individuals, analyses for statistical significance were not interpreted between these sex-ancestry-dentition subgroups. Statistical comparisons for significance were made between the three dentition groups (approximately 40 individuals each); the two sex groups (approximately 60 individuals each); and lastly the two ancestry groups (approximately 60 individuals each). This selection will be explained in more detail in the relevant chapters.

The numbers for each of the 12 sex-ancestry-dentition groups were not consistent throughout this study and varied according to the suitability of the particular specimen for the analysis to be performed. For instance, a broken coronoid process excluded mandibles from linear measurements involving the coronoid process, but not from limited shape analysis or cortical thickness assessments. The clarity of some of the scans was influenced by the placement and number of dental fillings but it was still useful to do linear measurements on these mandibles.

3.3 Methods

Tooth loss patterns and their effect on mastication were firstly assessed on all 717 specimens by means of direct measurements of the mandibular angle. On the basis of published guidelines from the literature (Kasai et al. 1994; Kasai et al. 1996; Kohakura et al. 1997; Ceylan et al. 1998; Pileicikiene & Surna 2004; Knezović-Zlatarić & Čelebić 2005; Yanıkoğlu & Yılmaz 2008; Oettlé et al. 2009b), criteria were established to define three subgroups in each sex-ancestry group: individuals with no occlusions (completely inefficient mastication; Group 0); individuals with limited occlusions (inefficient mastication; Group 1); and enough occlusions to have efficient mastication (Group 2). It could so be confirmed whether the guidelines for the maximum tooth loss pattern associated with efficient mastication holds true as reflected in the size of the mandibular angle. This part of the study is outlined in detail in Chapter 4.

Eight osteometric distances on the specimens in each of the 12 sex-ancestry-dentition groups according to the criteria set out earlier were measured. This was done in order to assess changes in the linear dimensions of the mandible aging and tooth loss and is explained in more detail in Chapter 5.

In Chapter 6 shape changes with tooth loss were assessed using geometric morphometrics. A three-dimensional digitiser, Immersion's MicroScribe G2X portable digitiser, was used to evaluate variations in the overall mandibular shape amongst sex-ancestry-dentition groups. An analysis of shape variation was carried out to elucidate more specifically the influence of tooth loss on anthropological features classically associated with sex and ancestry group classifications. These features are mandibular ramus, gonial eversion, and chin shape. Detailed analyses of these specific features of the mandible were performed by incorporating CBCT-derived images. Application of detailed landmarks of specific mandibular features was made possible by using VG Studio MAX-2.1 software from Volume-Graphics, accompanying CBCT (Volume Graphics 2010). Three dimensional landmarks with x; y and z coordinates identified (digitised) with both modalities were entered on a Microsoft Excel worksheet. These landmarks were used for comparative analysis of shape using the free software package Morphologika.

Lastly, in Chapter 7, the cortical bone thickness and general appearance at specific sites were determined using CBCT images.

3.4 Repeatability and statistical analysis

The statistical analyses performed were similar for all dimensions determined (Fig. 3.3). Details of statistical analysis if not as outlined below, are considered in the relevant chapters.

Repeatability tests were executed for all measurements taken. Interrater reliability of the measurements taken by a second observer familiar with the technique was tested on a random sample of 30 specimens and measured by the Maximum Likelihood Estimate of the Intraclass Correlation Coefficient. Similarly, intrarater reliability of the measurements of the main investigator was tested when the measurements were repeated at a later stage.

The variation in the dimension measured (dependent variable) with age and tooth loss (independent variables) were graphically represented by scatter diagrams of Ordinary Least Square means regressions (or just regressions) for the entire sample. Thereafter Ordinary Least Square regressions were also presented for each sex-ancestral group (in the case of aging and tooth loss) and then for each dentition group (in the case of aging) to demonstrate the variation of the dimension with age and loss of teeth. The correlation coefficient (r) and coefficient of determination (r^2) were determined to measure the strength and direction of the linear relationship. A correlation coefficient (r) may range from -1 for a perfect negative relationship and +1 for a perfect positive relationship between variables. The percentage of variance r^2 refers to the proportion of variance explained by the linear relationship between the particular dimension and age. The main purpose of finding a relationship is that the knowledge of the relationship may enable events to be predicted to a specified degree (Namestnikova 2014).

Univariate analyses of the particular dimension within sex-ancestry-dentition groups were performed so as to determine the crude means and standard deviations. The Generalised Linear Model procedure was implemented to test for interaction between terms. Intersection terms were corrected for if any of the terms was found to be a significant variable. Least Square Means (adjusted means for cell imbalances) as well as 95% confidence intervals were calculated and reported. On the basis of the adjusted means, tests for statistical significance were performed and p-values determined between sex totals (males and females), ancestry-group totals (SAA and SAE) and between dentition-group totals (group 0, group 1 and group 2). More specific comparisons between sex-ancestry groups within dentition group, as well as between dentition group within sex-ancestry group, followed. Finally, the noted statistically significant differences were brought into context of the field of forensic anthropological identification of unknown individuals by discriminant analyses.

Table 3.1 Demographics of sample used

	Male	Female	Total
SAA	432	59	491
SAE	130	96	226
Total	562	155	717

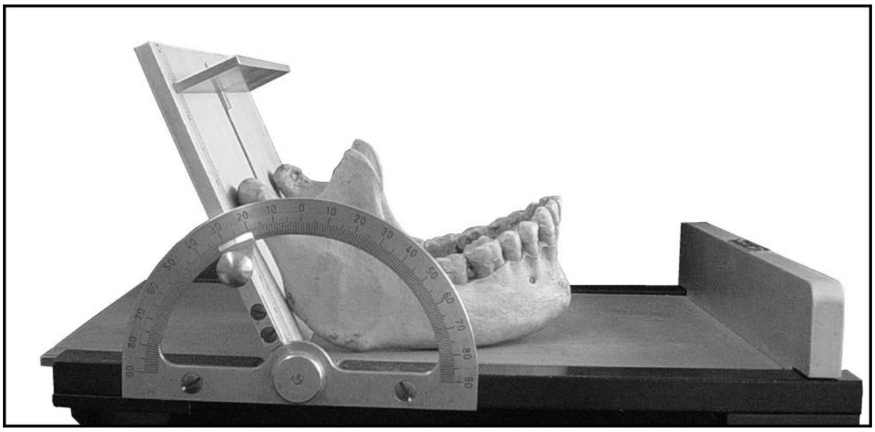


Fig. 3.1 Dentate subjects with small gonial angles

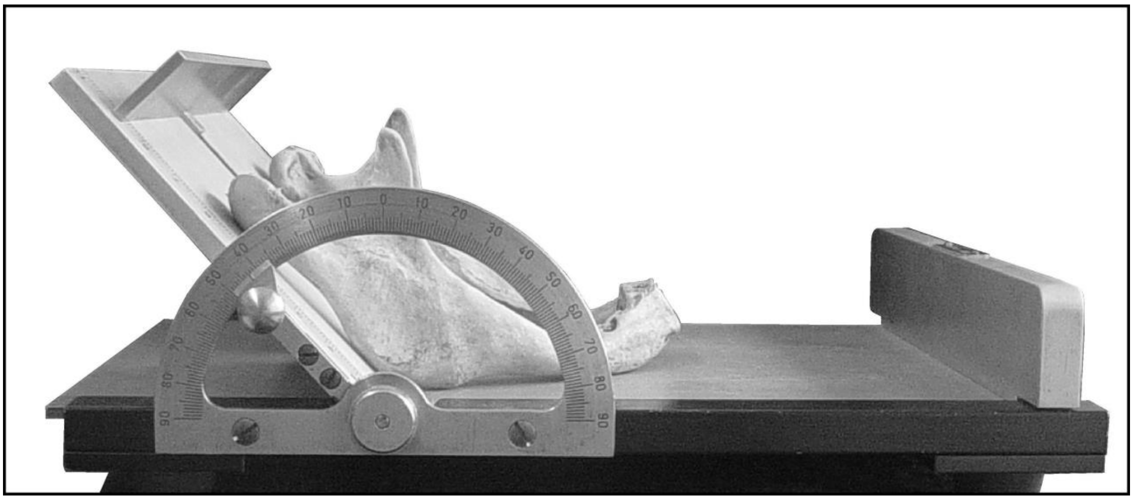


Fig. 3.2 Edentulous subjects with widening of the gonial angle

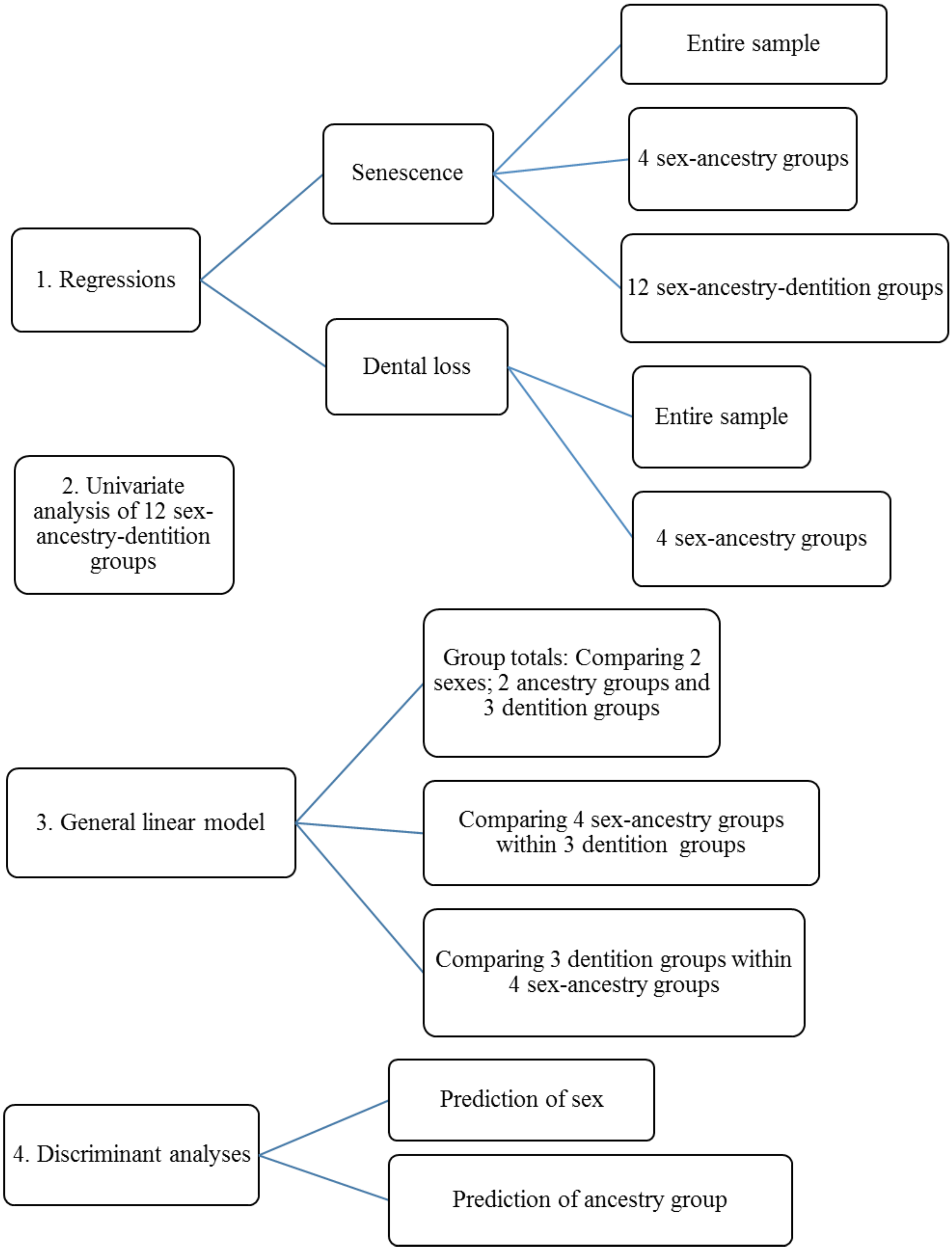


Fig. 3.3 Outline of statistical tests performed: The effect of dental loss and senescence on the variation of the dimensions determined and its implications for sex and ancestry identification

Chapter 4: MANDIBULAR ANGLE

4.1 Introduction

In this chapter, the size of the gonial or mandibular angle is investigated. This investigation entailed measuring the influence of tooth loss and senescence on the morphology of the mandible. The direct measurement of the mandibular angle was chosen as it is a well-known parameter with an established simple technique that represents the influence of biomechanical factors on the morphology of the mandible. The mandibular angle varies from being sharp with strong masseter development (Fig. 3.1) to obtuse with reduced muscle activity (Fig. 3.2) (Keen 1945; Kasai et al. 1996; Ohm & Silness 1999).

In physical anthropological assessments of human remains, the mandibular angle is often measured (Moore-Jansen et al. 1994) although less often used because there is some uncertainty as to what it exactly reflects. The size of the mandibular angle has been shown to display statistical differences between sexes and ancestral groups and, along with other linear measurements, may be used to discriminate sexes and populations (De Villiers 1968; Xie & Ainamo 2004; Parr 2005; Franklin et al. 2008a). For instance, the mandibular angle is considered less obtuse (under 125°) in male individuals and in SAA in general (Krogman & İşcan 1986; Parr 2005). In these assessments dental pattern is not always considered. It is thought that sex and ancestry, and specific mechanical forces involving the masticatory apparatus (e.g. whether cultural or dietary in origin) could directly influence the development of the muscles of the lower jaw and, by consequence, their underlying skeletal structures (Franklin et al. 2008a). It is therefore presumed that sex, ancestry, tooth loss and the process of aging by means of influencing masticatory function, might have an effect on the size of the mandibular angle.

The mandibular angle is considered to be formed by the ramus line (the tangent to the posterior border of the mandible) and the mandibular line (the relatively straight portion of the inferior border of the mandible that ends posterior to the gnathion – the most anterior midline point on the mandible) (Tobias 1974; Ohm & Silness 1999).

The mandibular angle is obtuse at birth. During childhood, as teeth are added and growth takes place, it becomes more angulated; i.e. the angle becomes smaller. At puberty, the influence of hormones accelerates these changes. The changes in the mandible are more pronounced and occur for a longer period of time in males (Walker & Kowalski 1972). For this reason, the male mandible is considered to be more angulated than is the case in females. Acsádi et al. (1970) scored the degree of development of any sexually differentiated characteristic into one of five categories, from the most feminine to the most masculine. According to this method, the most feminine category of the mandibular angle is rounded and with an angle of more than 125°. De Villiers (1968) found the mandibular angle in South African males of African ancestry to be on average 120.6° (range 103°–135°), which is significantly different from that of females of 125.0° (range 115°– 138°) (De Villiers 1968). With old age, the angle is said to regress to between 120° and 150° and becomes more similar to the infantile angle of 135° – 150° (Jensen & Palling 1954). The angle thus becomes more obtuse with advancing age.

However changes in the mandible are not clearly associated only with senescence and may be accounted for by tooth loss. Although a number of authors relate the number of teeth to the size of the mandibular angle (Keen 1945; Ohm & Silness 1999; Oettlé et al. 2009b), it is not confirmed by others (Israel 1973; Enlow et al. 1976). Oettlé et al. (2009b) remarked that, although the mandibular angle appeared to be more obtuse in females and in the SAE group, these observed differences in sex and ancestry were only noted in groups without molars. Significant differences were noted only among the sex-ancestry groups without molars. Oettlé et al. (2009b) suggested that this discrepancy in mandibular angle could be dependent on the sex-ancestry group differences in the time elapsed from loss of molars to time of death. With the course of time, the mandible would become moulded to a greater extent if molars were lost.

The purpose of this part of the study was to, first, note the number, placement and occlusions of the mandibular teeth with the corresponding maxillary teeth amongst the sex-ancestry groups on 717 mandibles belonging to the Pretoria Bone Collection. The mandibular angle was then determined and the association with tooth loss patterns and advancing age explored.

Partial dentition where sufficient remaining teeth are present in occlusion could contribute to a stable occlusal relationship and efficient mastication, contrary to situations where partial teeth are insufficient or not in occlusion with the teeth of the upper jaw (Kasai et al. 1994; Kohakura et al. 1997). According to Kasai et al. (1994), an arch is formed that transmits the forces of mastication on each side consisting of the occlusion of premolars and molars posteriorly and incisors and canines anteriorly. It was further taken into account that an uneven loss of molars between sides, even if not complete, has a considerable effect on the mandibular angle and, therefore, possibly on the efficiency of mastication (Oettlé et al. 2009b). To conclude: established determinants for the efficiency of mastication in the pattern of dentition from the literature include whether or not posterior and anterior teeth are in occlusion and whether they are evenly distributed between the left and the right (Kasai et al. 1994; Kasai et al. 1996; Kohakura et al. 1997; Ceylan et al. 1998; Pileicikiene & Surna 2004; Knezović-Zlatarić & Čelebić 2005; Yanıkoğlu & Yılmaz 2008; Oettlé et al. 2009b).

The mentioned determinants for efficacy of mastication were taken into consideration in the design of the study. Criteria were constructed to define three subgroups in each sex-ancestry group of the sample: group 0: a group with no occlusions; group 1: a group with fewer than two posterior teeth (molar and premolar teeth) and/or no front teeth (incisors and canine) in occlusion on each side (inefficient occlusion); and group 2: a group with two or more posterior teeth (molar and premolar teeth) and one or more front teeth (incisors and canine) in occlusion on each side (efficient occlusion). Therefore 12 sex-ancestry-dentition subgroups were defined.

The determination of the mandibular angle for the entire sample group of 717 was primarily performed to confirm whether the guidelines for the maximum tooth loss pattern associated with efficient mastication holds true as reflected in the size of the mandibular angle, contrary to situations where patterns do not meet this criteria. Apart from the association of the mandibular angle with tooth loss patterns, the correlation of mandibular angle and age was also investigated as well as its implications for sex- and ancestry identifications. The variation of the mandibular angle size amongst groups further rendered background information to masticatory function, the dental patterns and age distribution of the various sex-ancestry groups.

4.2 Materials

In order for the sample to be as representative as possible, all adult mandibles without obvious deformity or surgery, with varying degrees of dental loss and documented age, sex and ancestry group were included. A total of 717 mandibles from individuals between the ages of 18 to 98 years were selected from the Pretoria Bone Collection.

4.3 Methods

The number and location of the mandibular teeth as well as their occlusion with upper teeth, with identification numbers, were noted on a spread sheet. The identification number was used to look up the age, sex and ancestry group of the particular individual. Dental patterns were classified according to the described criteria into 0, 1 and 2.

The angle of the mandible was measured with a mandibulometer (GPM Gneupel, Switzerland) according to the standard method as described by Morant et al. (1936), Jensen and Palling (1954), De Villiers (1968b), and Srisopark (1975). Following De Villiers

(1968b), all measurements were taken with the mandibles placed on the horizontal surface with the teeth facing up. The mandible was adjusted so that the horizontal part of the board represented the standard horizontal plane, whereas the rameal (movable) wing of the board was in contact with the posterior surface of the left ramus at the condyle and inferiorly above the angle and with the right ramus at one or both of these regions. The mandible was therefore in such a position that three or more points made contact with the rameal plane of the mandibulometer when vertical pressure was applied to the left second molar tooth or its cavity (see Figs. 3.1 and 3.2). The left angle between the standard horizontal and standard rameal planes (the rameal wing of the board) was read on the protractor.

4.4 Statistical analysis

The variation in mandibular angle (dependent variable) with tooth loss and age (independent variables) were graphically represented by scatter diagrams of Ordinary Least Square Means Regressions (or just regressions) for the entire sample. Dentition groups, sexes and ancestry groups were distinguished by differential colouring of the scatter points. Thereafter Ordinary Least Square regressions were also presented for each sex-ancestral group (in the case of aging and tooth loss) and then for each dentition group (in the case of aging) to demonstrate the variation of the mandibular angle with age and loss of teeth. The correlation coefficients (r) and coefficients of determination (r^2) were determined to measure the strength and direction of the linear relationship.

Univariate analyses of the angle sizes within sex-ancestry-dentition groups were performed so as to determine the crude means and standard deviations. Distributions of the mandibular angle across sex-ancestry groups for each dentition group were used to visually compare the groups.

The Generalised Linear Model procedure was implemented to test for interaction between terms. Intersection terms or variables were corrected for if the terms were found to be significant variables. Least Square Means (adjusted means for cell imbalances) as well as 95% confidence intervals were calculated and reported. On the basis of the adjusted means, tests for statistical significance were performed and p-values determined. Comparisons for the entire sample between sex totals (males and females), ancestry-group totals (SAA and SAE) and between dentition-group totals (group 0, group 1 and group 2) were performed. More specific comparisons between sex-ancestry groups within dentition group, as well as between dentition group within sex-ancestry group, followed.

Finally, the noted statistically significant differences were brought into context of the field of forensic anthropological identification of unknown individuals by discriminant analyses.

4.5 Results

4.5.1 Occlusions

Firstly, the number of teeth, their locations and occlusions with the maxillary teeth were noted amongst sex-ancestry groups (Fig. 4.1). From Figure 4.1 it was noted that SAE presented with fewer teeth occlusions, with female SAE exhibiting the lowest percentage of molar-teeth occlusions. Third-molar occlusions were seldom present in SAE. SAA presented with higher percentages of teeth in all positions. Female SAA presented with the highest percentage of anterior occlusions and male SAA with the highest number of posterior occlusions. The posterior teeth occlusions in SAE were more often lost as compared to anterior teeth occlusions. The canine occlusions in all, and also sometimes the premolar occlusions in individuals of SAA achieved the highest percentages. In this sample, SAE therefore had considerably more ante-mortem tooth losses or absences than SAA.

The age distribution for each sex-ancestry-dentition groups in years can be found in Table 4.1. In this sample, the mean age of dentition group 0 was higher than that of dentition group 1 and dentition group 1 to dentition group 2 in all sex-ancestry groups. The difference in mean ages between dentition group in each sex-ancestry group were less than 14 years. The crude mean values of dentition groups of male SAE differed to a lesser degree as compared to the other sex-ancestry groups. The mean and maximum ages overlapped to a great extent between the sex- ancestry groups, although dentition group 2 had lower minimum values. Apart from male SAE, age distribution of the other three sex-ancestry groups represented individuals across the entire adult spectrum: female SAA (21 – 80 years), male SAA (18 – 98 years) and female SAE (21 – 97 years) respectively. Male SAE ages ranged from 36 – 91 years and a greater overlap of ages between dentition groups existed.

4.5.2 Mandibular angle amongst sex-ancestry-dentition groups

Various statistical comparisons of the size of the mandibular angle among sex-ancestry-dentition groups were performed as outlined in Fig. 4.2.

4.5.2.1 Regressions

Ordinary Least Square regressions were performed between the size of the mandibular angle and age or dentition group respectively.

4.5.2.1.1 Age regressions

To explore the influence of aging on the mandibular angle, Ordinary Least Square linear regressions were performed, displaying the normal distribution of size of mandibular angle vs. age in years over the entire sample (Fig. 4.3 – Fig. 4.8)

As suggested by the scatter plots (Fig. 4.3) and confirmed by the correlation coefficient (r) of only 0.15, a weak positive correlation between mandibular angle and age in the total sample (Dancey & Reidy 2007). The weak correlation between mandibular angle and age was also reflected in the coefficients of determination ($r^2 = 0.0237$). In other words only 2.4% of the variation in the mandibular angle in the total sample group could be explained with an advance in age (Fig. 4.3). In the first scatter plot dentition groups were differentiated. In the second scatter plot, scatter points were differentiated in sex groups and lastly ancestry groups were differentiated.

In the scatter plot differentiating between dentition groups, dentition group 0 as expected, predominated in the older age groups and often presented with greater mandibular angles. Dissimilarly, examples of dentition group 2 were more often seen in the younger age groups and less often in the older age groups. In the normal distribution differentiating between sexes, male scatter points predominated in the smaller-sized mandibular angle. In the scatter plot differentiating between ancestry groups, scatter points of SAE predominated in the higher-age group and somewhat in the greater-sized mandibular angle.

Although in the linear regressions of size of mandibular angle vs. age in years, the mandibular angle increased only minimally with age, other factors could have obscured this relationship. With reference to Figure 4.3, the differentially coloured scatter points with respect to dentition groups, sexes and ancestry groups displayed a pattern suggesting that these factors could have contributed to or interfered with the observed relationship between mandibular angle and age.

The loss of teeth as expressed by the distribution of dentition group 0, 1 and 2 scatter points were associated with greater mandibular angles and older age groups. Male scatter points predominated in the smaller-sized mandibular angles and SAE predominated in the higher age groups and greater-sized mandibular angle.

Overall within the four sex-ancestry groups, weak correlations between mandibular angle size vs. age existed (Table 4.2; Fig. 4.4). In females a weak negative correlation between mandibular angle and age existed. Seven percent of the decrease in angle size in female SAA was associated with aging and 1% in female SAE. In male SAA, the mandibular angle remained approximately the same size with aging (Table 4.2; Fig. 4.4). In male SAE a weak positive correlation between mandibular angle vs. age (Table 4.2, Fig. 4.4) was found. Aging in male SAA, contributed to 2% of the increase in mandibular angle size.

To isolate the changes with aging in the four sex-ancestry groups to a specific dentition group, the 12 sex-ancestry-dentition groups were further analysed by linear regressions of mandibular angle vs. age (Table 4.2 and Figs. 4.5 – 4.8). The decrease in mandibular angle size with age in females of both SAA and SAE were the most pronounced in dentition group 2 (female SAA: $r = -0.44$ and $r^2 = 0.19$) (Fig. 4.5) and female SAE: $r = -0.54$ and $r^2 = 0.30$) (Fig. 4.7). Dentition group 1 did not demonstrate the decrease in mandibular angle with age. Only weak to very weak associations existed between mandibular angle and age in males.

4.5.2.1.1 Dental loss regressions

Dentition group 0, as expected, predominated in the older age groups and often presented with greater mandibular angles and vice versa for dentition group 2. An inverse relationship between mandibular angle and dentition group existed. The higher the dentition number, the smaller the angle as expected. As tooth loss progressed (smaller dentition-group number), the greater the angle. This correlation between tooth loss and angle size in the complete sample was weak as tooth loss were only associated with 4% of the increase in mandibular angle noted (Fig. 4.9).

When considering all four sex-ancestry groups individually, the correlations were also weak as reflected in the low r and r^2 values (Fig. 4.10).The greatest effect of tooth loss was noted in male SAE, where tooth loss was associated with only 3% of the increase in angle size noted. The reason why male SAE exhibited the greatest correlation in tooth loss for mandibular angle, may be hidden in the fact that male SAE presented with a relatively narrower, older spectrum (36 - 91 years) as compared to the other sex-ancestry groups. The mandibular angle in this age spectrum might be more sensitive for tooth loss and therefore strengthening this correlation.

4.5.2.2 Univariate analysis

Basic descriptive statistics were performed by univariate analysis, producing crude mean values of the mandibular angle for the 12 sex-ancestry-dentition groups (Table 4.3, Fig. 4.11). In each dentition group, and overall, females of SAE presented with the greatest angle, followed by males of SAE, females of SAA and lastly males of SAA. Increases in the mandibular angle with loss of teeth (group 2 to group 1 and 0) were most noticeable in mandibles of SAE. Standard deviations were the greatest in males of SAA more so than SAE, as compared to females in general. Apart from females of SAE, standard deviations increased with loss of teeth.

4.5.2.3 General linear model

To explore further and confirm the relationship between mandibular angle across ancestry group, sex, dentition and age groups general linear models were applied. Analysis of variance (ANOVA) used in the general linear model is a statistical process for analysing the amount of variance that is contributed to a sample by different factors. ANOVA was designed for the case of balanced data (equal numbers of observations for each level of a factor). When data are unbalanced, as in this case, statistical significance testing is based on the Least Square Means, which are the adjusted means for a specific variable when other variables are kept constant; e.g. ancestral groups keeping sexes, dentition and ages constant. In Table 4.3 the least square means of the mandibular angle across ancestral group, sex and dentition groups are given corrected for age, a continuous variable.

In this instance ANOVA, Type III SS (sums of squares) showed that ancestral group totals and sex group totals were significantly different, both $p < 0.001$ (Table 4.4).The mandibular angle was therefore significantly greater in SAE and in females. In contrast age and dentition group totals were found not to be significant variables (age: $p = 0.753$ and dentition group: $p = 0.157$). No interactions between categorical variables: ancestral group and sex group totals were noted or between dentition group totals versus sex and dentition group totals versus ancestry totals. This meant that the statistical differences between sex and ancestral group totals could not have been confounded by differences in the dentition group of the various sexes or ancestry groups. Age, as a continuous variable, was corrected for in each case. Smaller levels of variance (more precise estimates) were evident from the narrow confidence intervals between sex, ancestry and dentition group totals. Although adjustments for age were made, sex-ancestry group differences in the period from tooth loss to death could not be regulated and could contribute to some of the differences noted between sex-ancestry groups.

Statistically significant differences were noted between male SAA and female and male SAE ($p < 0.001$ and $p = 0.001$ respectively) when sex-ancestry groups within dentition group 0 were compared (Table 4.5). Statistically significant differences were noted between male SAA and female SAE in dentition group 1 ($p < 0.0069$) and 2 ($p = 0.0029$). Greater levels of variance (less precise estimates) were evident from the larger confidence intervals in females and SAE as compared to male SAA.

When adjustments for age and cell imbalances (difference in group numbers) were made a steady increase in the mandibular angle were noted between dentition group 2 to 1 to 0 in female SAA. In male SAE, an increase in the mandibular angle was noted with the greatest increase between dentition group 1 and 0. In female SAE, the greatest increase in mandibular angle was noted between dentition group 2 and 1. Surprisingly the mandibular angle became sharper as teeth were lost further from dentition group 1 to 0. Male SAA presented with the smallest angle and showed little impact with loss of teeth. The mandibular angles of dentition group 0 and 2 were marginally smaller than that of dentition group 1.

The impression created in the adjusted means of the mandibular angles of female SAE and less so in male SAA was that the increase in mandibular angle was accentuated between dentition group 2 and 1 but improved as tooth loss progressed even further from dentition group 1 to 0, thus approximating the size of the mandibular angle of dentition group 0 and 2. Male SAA and female SAE presented with the widest and oldest distribution of individuals. It is interesting to note that the size of the mandibular angle in dentition group 1 was often the greatest for the particular sex-ancestry group. This would fit in with the proposal that unbalanced tooth loss between sides, would create an inefficient mastication process. Denture wearing could have confounded the results and will be considered in Chapter 8.

Greater levels of variance (less precise estimates) were evident from the larger confidence intervals in females as compared to males. This was most evident in group 0 female SAA and in group 1 female SAE. Confidence intervals and standard deviations of dentition groups overlapped each other within each sex-ancestry group. Greater levels of variance may indicate a process of change in the angle size and it could also have been the reason why an increase in angle size was not significant in most groups.

4.5.2.4 Discriminant function analyses

Discriminant function analyses were applied to determine whether the size of the mandibular angle was effective in predicting sex (Table 4.7) or ancestral group (Table 4.8). Discriminant analyses revealed percentages just above chance (60% or below) when predicting sex. The highest prediction percentages for sex were achieved in dentition-group 0 for both ancestry groups (62.7%) and in dentition group 1 SAA (64.4%). Sex prediction over the entire sample was 61%. Ancestral-group predictions fared marginally better with predictive percentages approaching 60%. Dentition-group 2 females fared the best with an ancestry group prediction percentage of 65.1%.

4.5.3 Summary

SAE, especially females, presented with greater tooth loss, older ages and larger crude and adjusted mean mandibular angles. A correlation between tooth loss and an increase in size of the mandibular angle as well as aging and an increase in size of the mandibular angle could not be confirmed by Ordinary Least Square regressions in the total sample. General Linear Models in the sex-, ancestry- and dentition-group totals confirmed that age and tooth loss were not significant variables for explaining variations in the mandibular angle.

When sex-ancestry groups were evaluated individually, some increase in size of the mandibular angle was noted with loss of teeth in all. Apart from female SAA, age was not a significant co-variate when dentition groups were compared within sex-ancestry group. A moderate negative correlation in the mandibular angle size, however, existed with aging in females in dentition group 2, but not in dentition group 1.

Tooth loss was accompanied by a significant increase in the mandibular angle in female SAA, counteracting the effect of aging. In female SAE and to a lesser extend in male SAA, the increase in mandibular angle was accentuated between dentition group 2 and 1. As tooth loss progressed even further from dentition group 1 and 0, the size of the mandibular angle remained unchanged. The findings that the mandibular angle did not decrease in dentition group 1 in females with age and also did not increase further with tooth loss from dentition group 1 to 0, could confirm that the dentition of group 1 was indeed inefficient.

Statistically significant differences were noted between male SAA and female and male SAE within dentition group 0 and between male SAA and female SAE in dentition groups 1 and 2. As female SAA were not significantly different from any other group and presented with overlapping values, discriminant analyses between sexes and ancestry groups fared poorly.

Table 4.1 Age distribution amongst sex-ancestry-dentition groups in years for the mandibular angle

Dentition groups ↓	Ancestry and sex			
	SAA		SAE	
	Female	Male	Female	Male
Group 0	11 [32 - 75] **56.36** (14.36)	103 [31 - 98] **63.97** (11.37)	70 [48 - 97] **75.10** (10.23)	87 [40 – 91] **72.74** (10.97)
Group 1	19 [26 - 80] **47.79** (16.84)	115 [24 - 80] **60.05** (11.99)	15 [56 – 88] **71.93** (10.95)	24 [38 – 89] **66.04** (13.00)
Group 2	32 [21 – 70] **45.16** (13.73)	213 [18 – 87] **50.68** (14.69)	11 [21 – 87] **64.73** (18.40)	17 [36 – 79] **64.53** (11.62)

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()

Table 4.2 Summary of correlations of the Ordinary Least Squares regressions between age and mandibular angle within each sex-ancestry-dentition group

Dentition groups ↓		Ancestry and sex			
		SAA		SAE	
		Female	Male	Female	Male
Group 0	r	**0.28**	**-0.21**	0.00	0.08
	r^2	**0.08**	**0.05**	0.00	0.01
Group 1	r	0.02	0.02	0.04	**0.26**
	r^2	0.00	0.00	0.00	**0.07**
Group 2	r	**-0.44**	**0.11**	**-0.54**	**-0.15**
	r^2	**0.19**	**0.01**	**0.30**	**0.02**
Sex-ancestry group totals	r	-0.27	0.05	-0.10	0.14
	r^2	0.07	0.00	0.01	0.02

Table 4.3 Univariate analysis of the mandibular angle for sex-ancestry-dentition groups

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	11 **123.00** (7.09)	103 **120.89** (8.03)	70 **127.90** (6.96)	87 **125.74** (7.12)	271 **124.34** (7.96)
Group 1	19 **124.63** (4.55)	115 **122.12** (8.16)	15 **127.60** (5.87)	24 **124.29** (8.74)	173 **123.17** (7.88)
Group 2	32 **122.34** (6.89)	213 **120.01** (6.85)	11 **126.64** (8.30)	17 **122.35** (5.93)	273 **120.70** (6.99)
Sex-ancestry group totals	62 **123.16** (6.29)	431 **120.79** (7.54)	96 **127.71** (6.91)	128 **125.02** (7.35)	Total 717

n the first value in every set
crude mean given in bold
standard deviation in parenthesis ()

Table 4.4 Least square means of the mandibular angle among sex-, ancestry- and dentition group totals adjusted for cell imbalances

Dentition group totals	Group 0 **124.01** (122.85; 125.16)	Group 1 **124.54** (122.97; 126.10)	Group 2 **122.86** (121.53; 124.18)
Ancestral group totals[1]	SAA **122.10** (121.03- 123.17)	SAE **125.50** (124.26- 126.74)	
Sex group totals[2]	Males **122.53** (121.70; 123.35)	Females **125.08** (123.82; 126.33)	

adjusted means are indicated in bold
95% confidence intervals are given in parentheses
[1]: $p < 0.0001$
[2]: $p = 0.0004$

Table 4.5 Least square means of the mandibular angle adjusted for age and cell imbalances when sex-ancestry groups are compared within dentition groups

Dentition groups ↓	Ancestry and sex			
	SAA		SAE	
	Female	Male	Female	Male
Group 0	**123.44**^{ab} (118.48; 128.40)	**121.06**^{a} (119.49; 122.62)	**127.55**^{b} (125.76; 129.34)	**125.50**^{b} (123.93; 127.07)
Group 1	**124.47**^{ab} (120.51; 128.43	**121.62**^{a} (120.32; 122.93)	**128.27**^{b} (123.65; 132.90)	**123.73**^{ab} (120.46; 127.00)
Group 2	**122.86**^{ab} (120.55; 125.16)	**120.30**^{a} (119.34; 121.25)	**125.69**^{b} (122.28; 129.09)	**123.17**^{ab} (119.96; 126.37)

adjusted means are indicated in bold
95% confidence intervals are given within parentheses
least square means with the same letter in the superscript do not differ significantly on the 5% level of significance

Table 4.6: Least square means of the mandibular angle adjusted for age and cell imbalances when **dentition groups** are compared within sex-ancestry groups

Dentition groups ↓	Ancestry and sex			
	SAA		SAE	
	Female	Male	Female	Male
Group 0	**126.65**[a] (122.86; 130.44)	**120.55** (118.99; 122.12)	**127.36** (125.67; 129.05)	**125.34** (123.91; 126.78)
Group 1	**124.71**[ab] (122.03; 127.39)	**121.59** (120.40; 122.78)	**128.17** (124.00; 132.34)	**123.96** (120.92; 127.00)
Group 2	**121.92**[b] (120.11; 123.72)	**120.29** (119.28; 121.30)	**125.35** (121.82; 128.89)	**123.60** (120.37; 126.84)
Dentition group totals	**123. 32**	**120.76**	**127.12**	**124.88**

adjusted means are indicated in bold.
95% confidence intervals are given within parentheses
least square means with the same letter in the superscript do not differ significantly on the 5% level of significance

Table 4.7: The percentage correct **prediction of sex** determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	57. 0	62.7	55.4
Group 1	64.4	59.0	56.4
Group 2	57.1	57.1	57.1
Complete sample	55.9	61.0	57.9

Table 4.8: The percentage correct **prediction of ancestral group** determined by discriminant function analyses

Dentition groups ↓	Male	Both sex groups	Female
Group 0	61.6	63.8	54.3
Group 1	61.8	60.7	61.8
Group 2	57.8	60.4	65.1
Complete sample	59.4	62.9	58.9

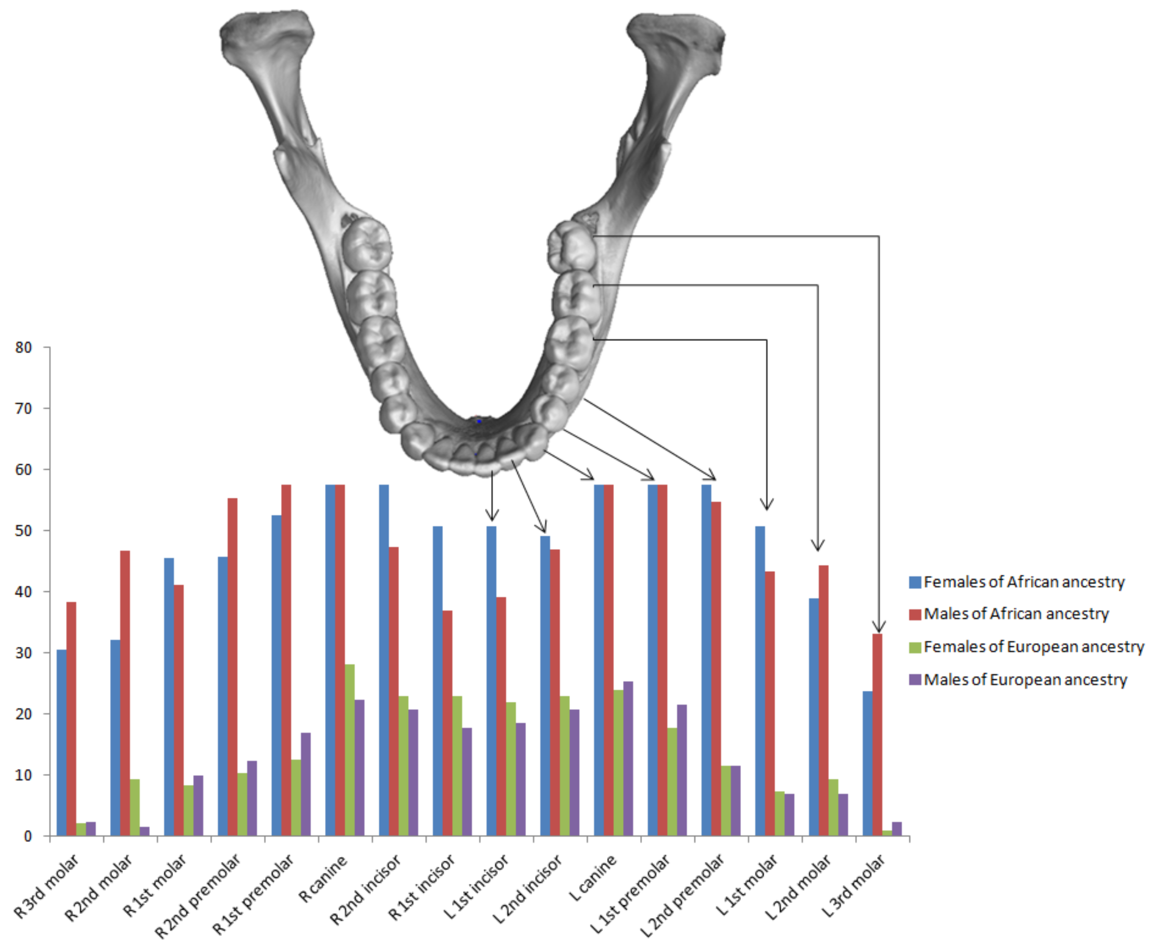


Fig. 4.1 Percentage of individuals presenting with occlusions at specific locations among the four sex-ancestry groups

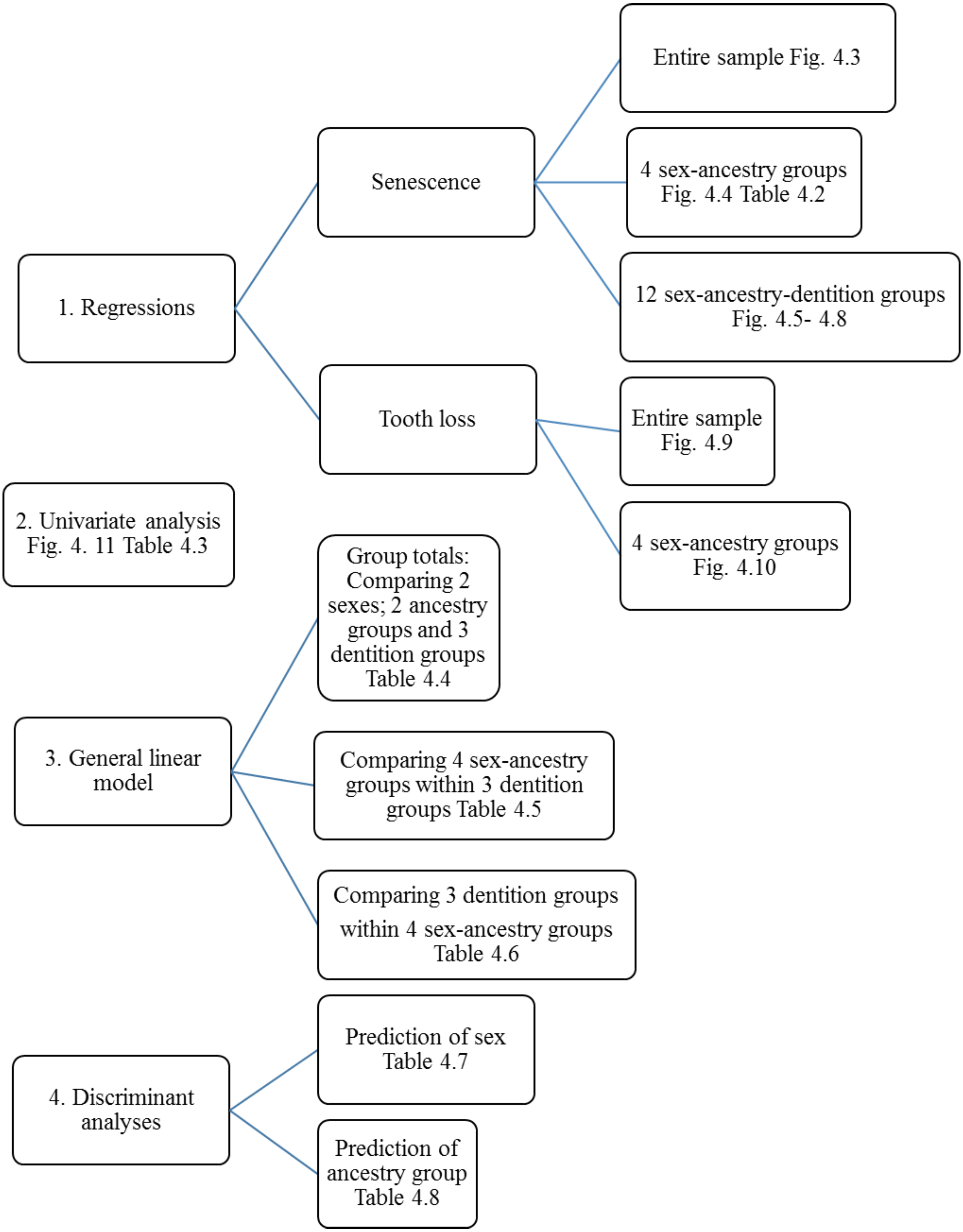
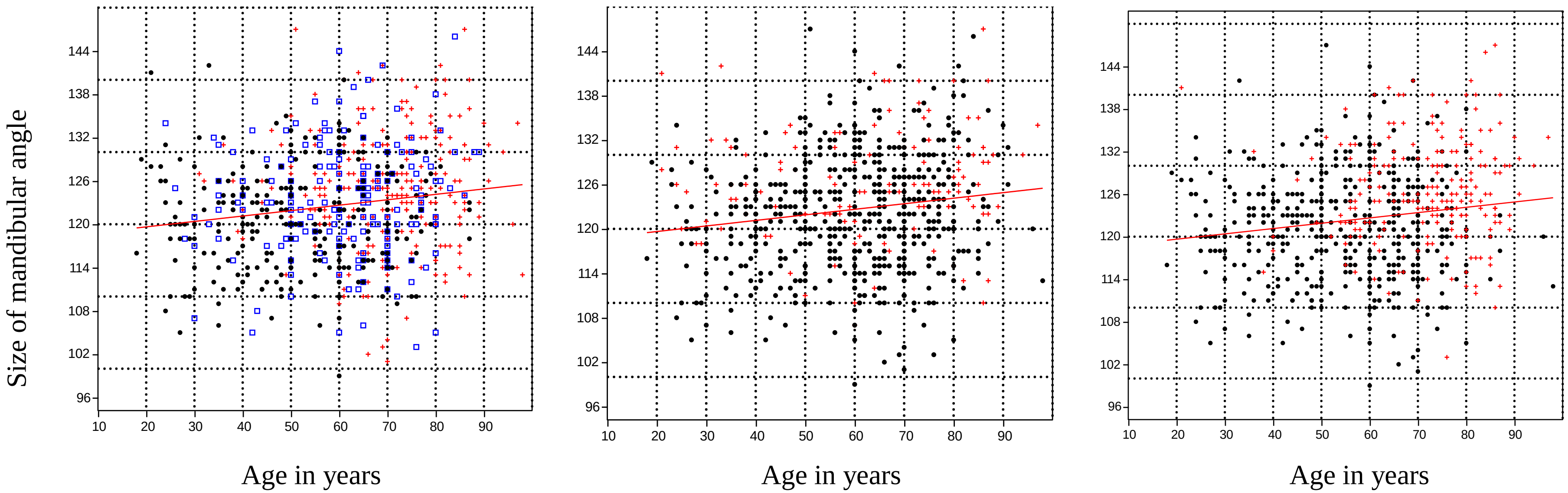


Fig.4.2 Summary of statistical tests done: The effect of tooth loss and aging on the size of the mandibular angle and its implications for sex and ancestry identification

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



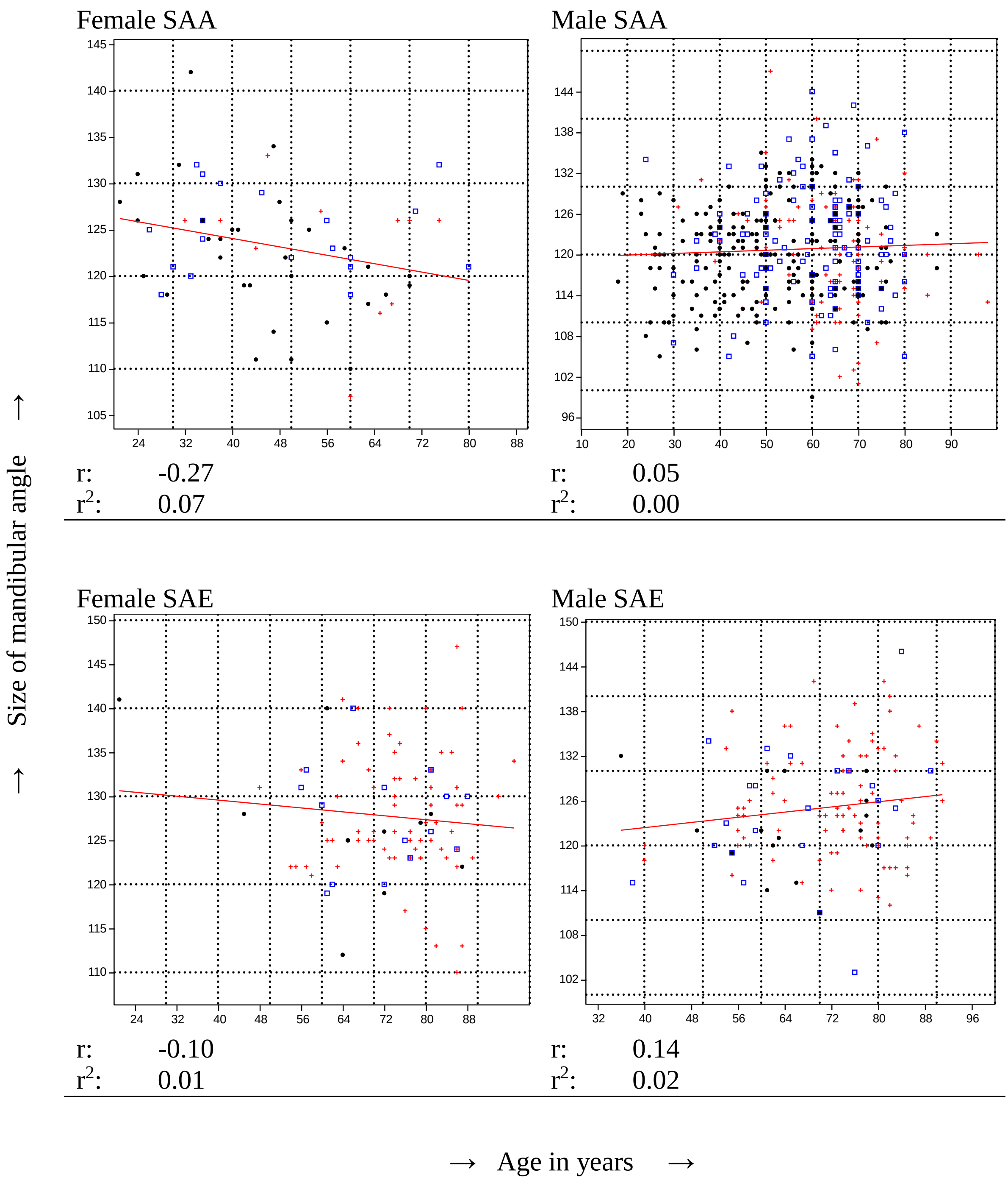
r: 0.15
r^2: 0.02

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Red: females
Black: males

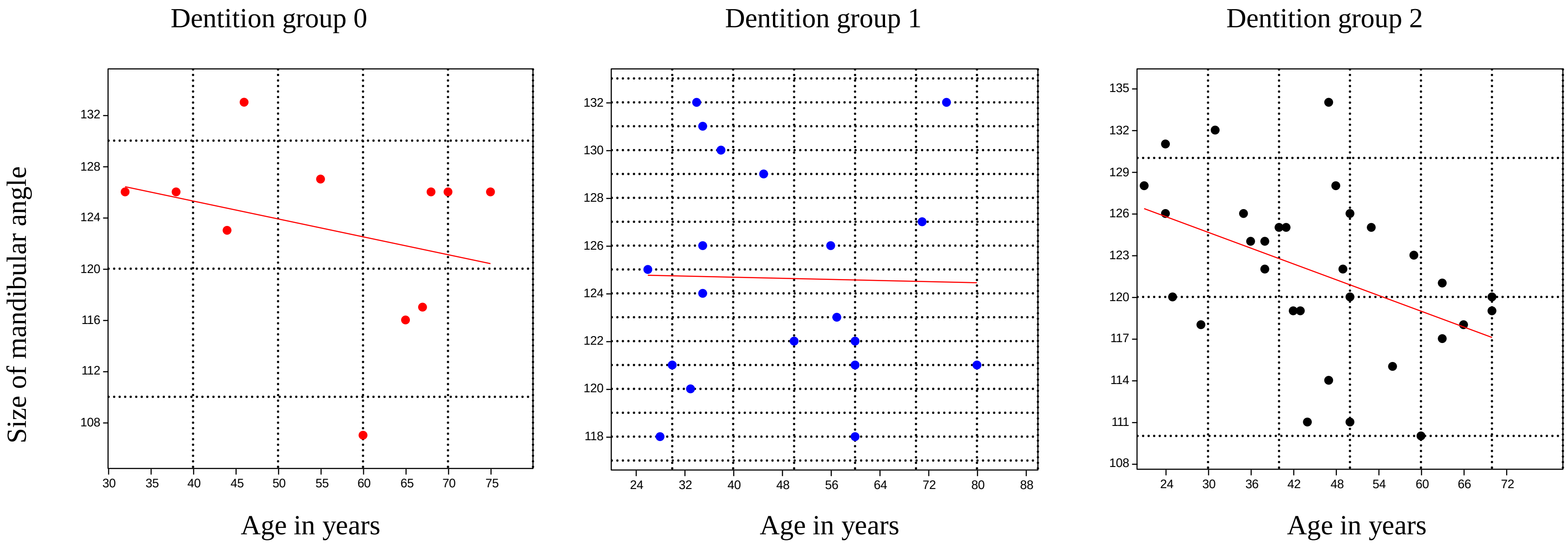
Black: SAA
Red: SAE

Fig.4.3 Linear regression of age in years vs. size of mandibular angle



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

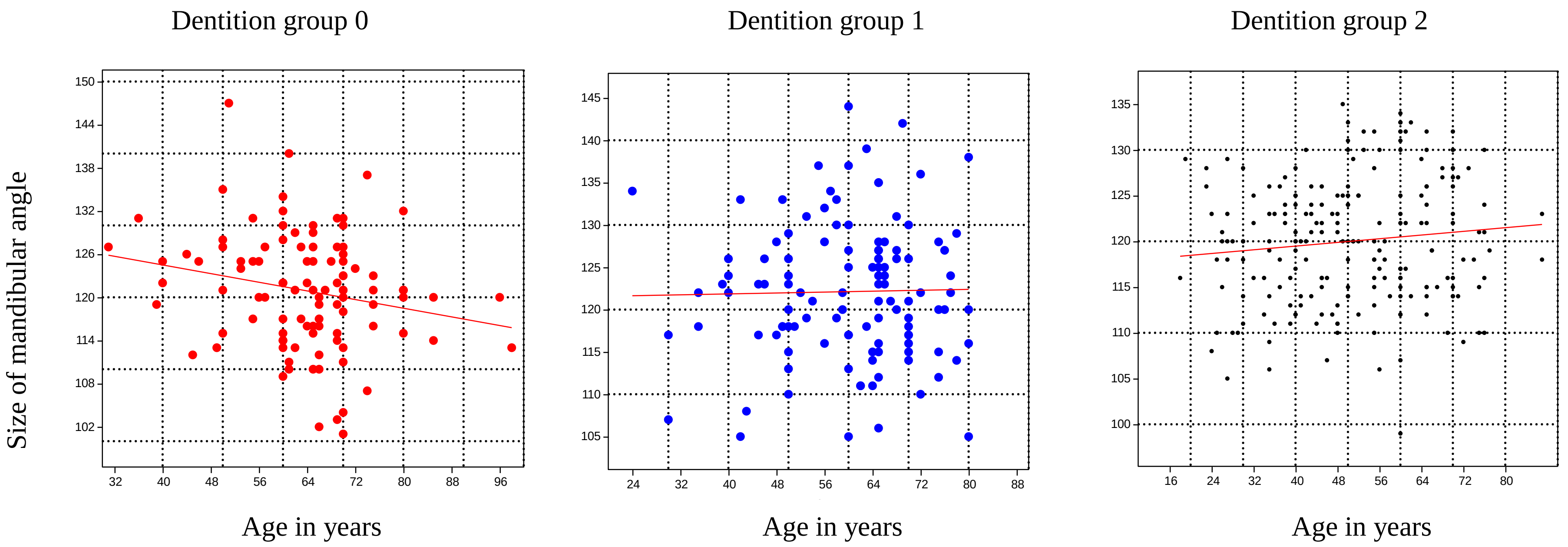
Fig.4.4 Linear regression of size of mandibular angle vs. age in years in sex-ancestry groups differentiating between dentition groups



r:	-0.28	r:	-0.02	r:	-0.44
r^2:	0.08	r^2:	0.00	r^2:	0.19

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

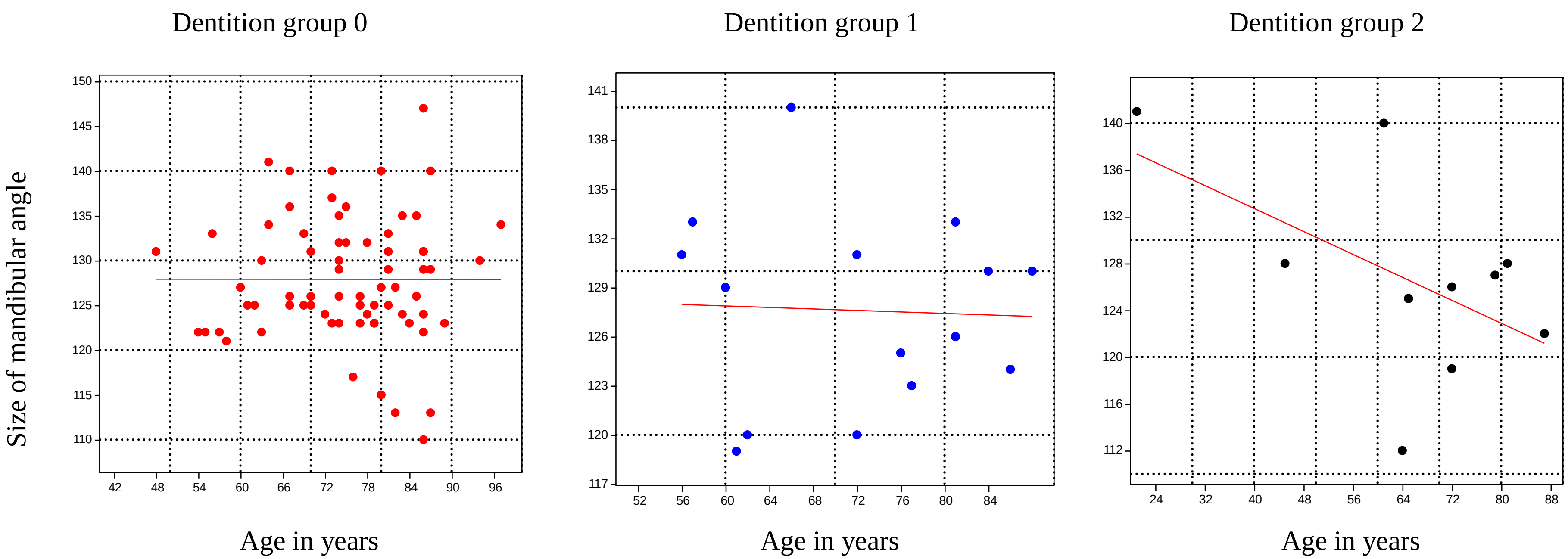
Fig.4.5 Linear regression of age in years vs. size of mandibular angle in female SAA



r:	-0.21	r:	0.02	r:	0.11
r^2:	0.05	r^2:	0.00	r^2:	0.01

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

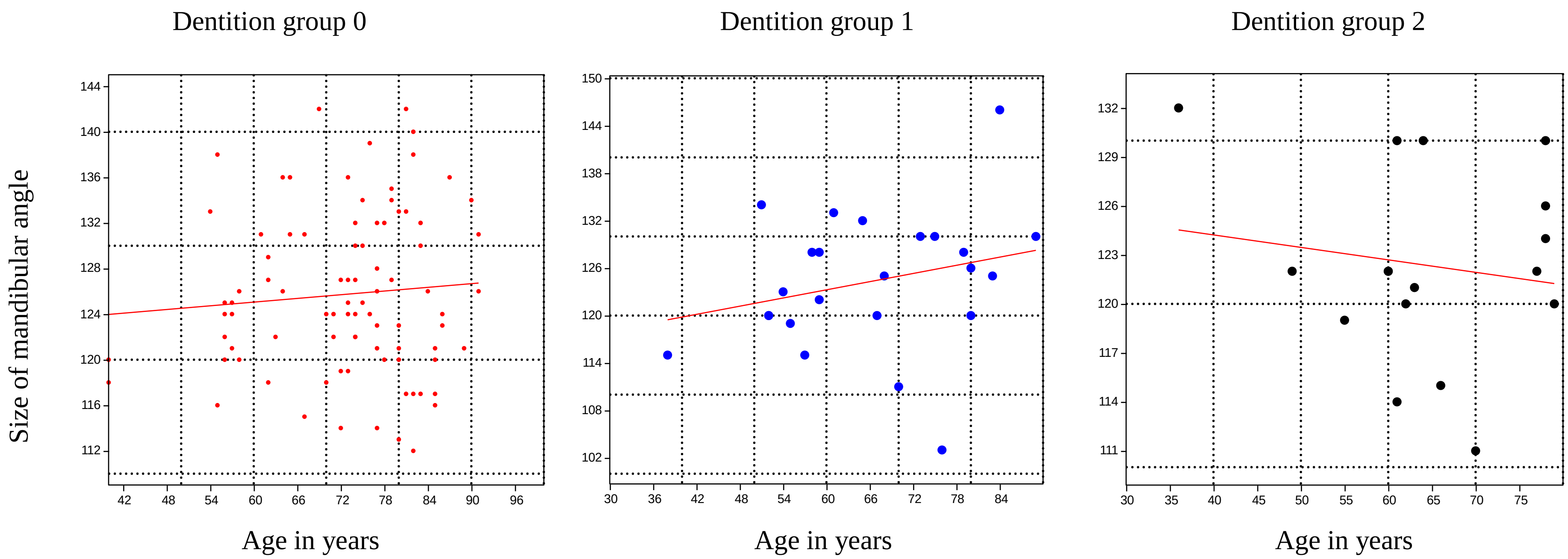
Fig.4.6 Linear regression of age in years vs. size of mandibular angle in male SAA



r:	-0.00	r:	-0.04	r:	-0.54
r^2:	0.00	r^2:	0.00	r^2:	0.30

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

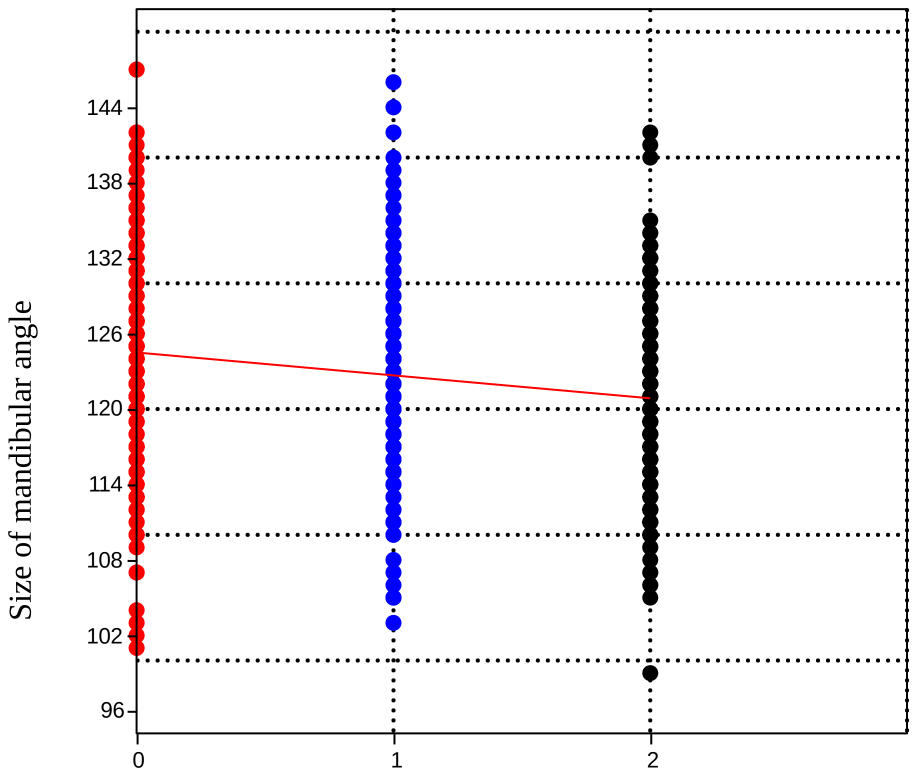
Fig.4.7 Linear regression of age in years vs. size of mandibular angle in female SAE



r:	0.08	r:	0.26	r:	-0.15
r^2:	0.01	r^2:	0.07	r^2:	0.02

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

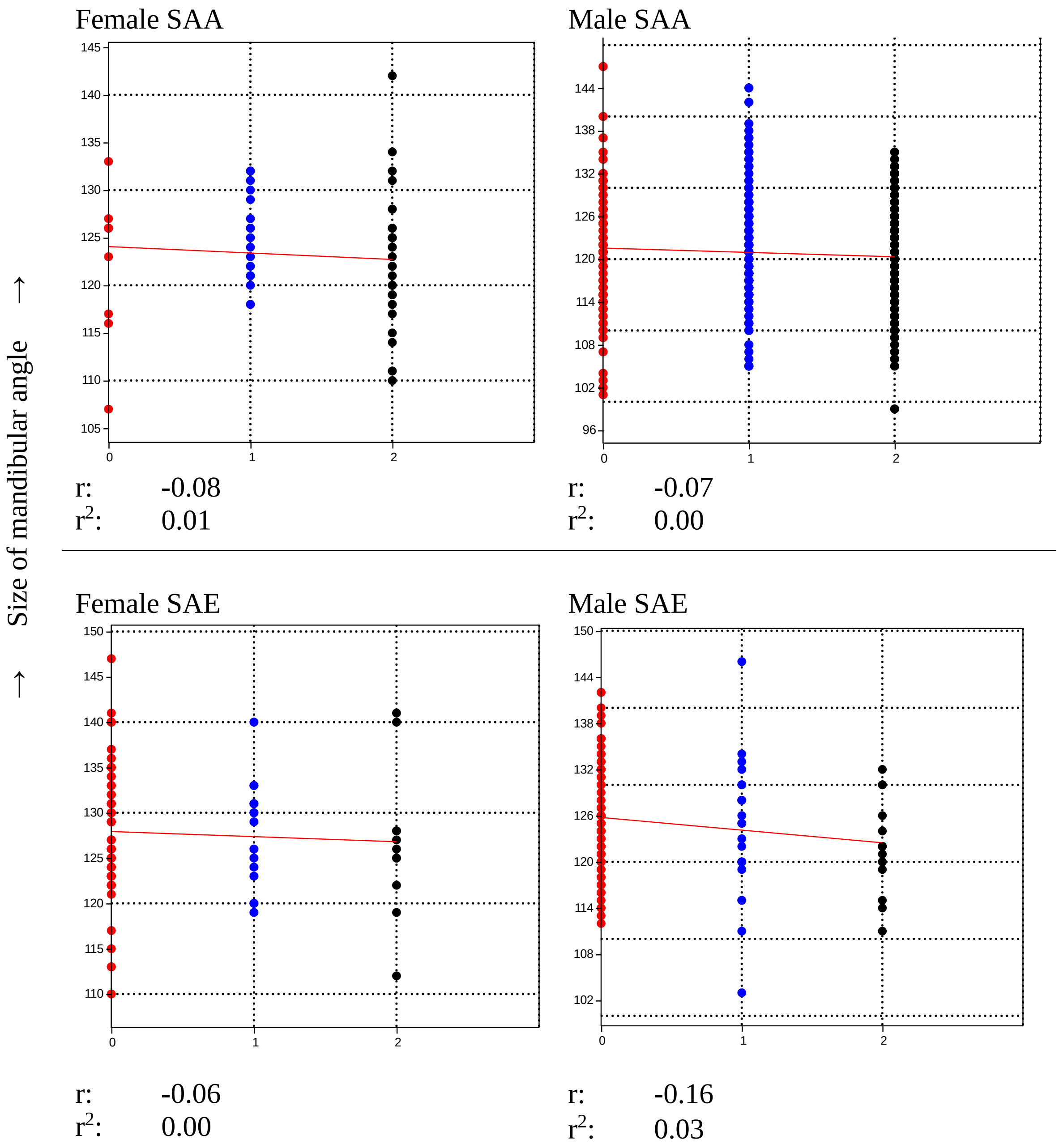
Fig.4.8 Linear regression of age in years vs. size of mandibular angle in male SAE



r: -0.21
r^2: 0.04

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig.4.9 Linear regression of dentition group vs. size of mandibular angle



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig.4.10 Linear regression of dentition group vs. size of mandibular angle

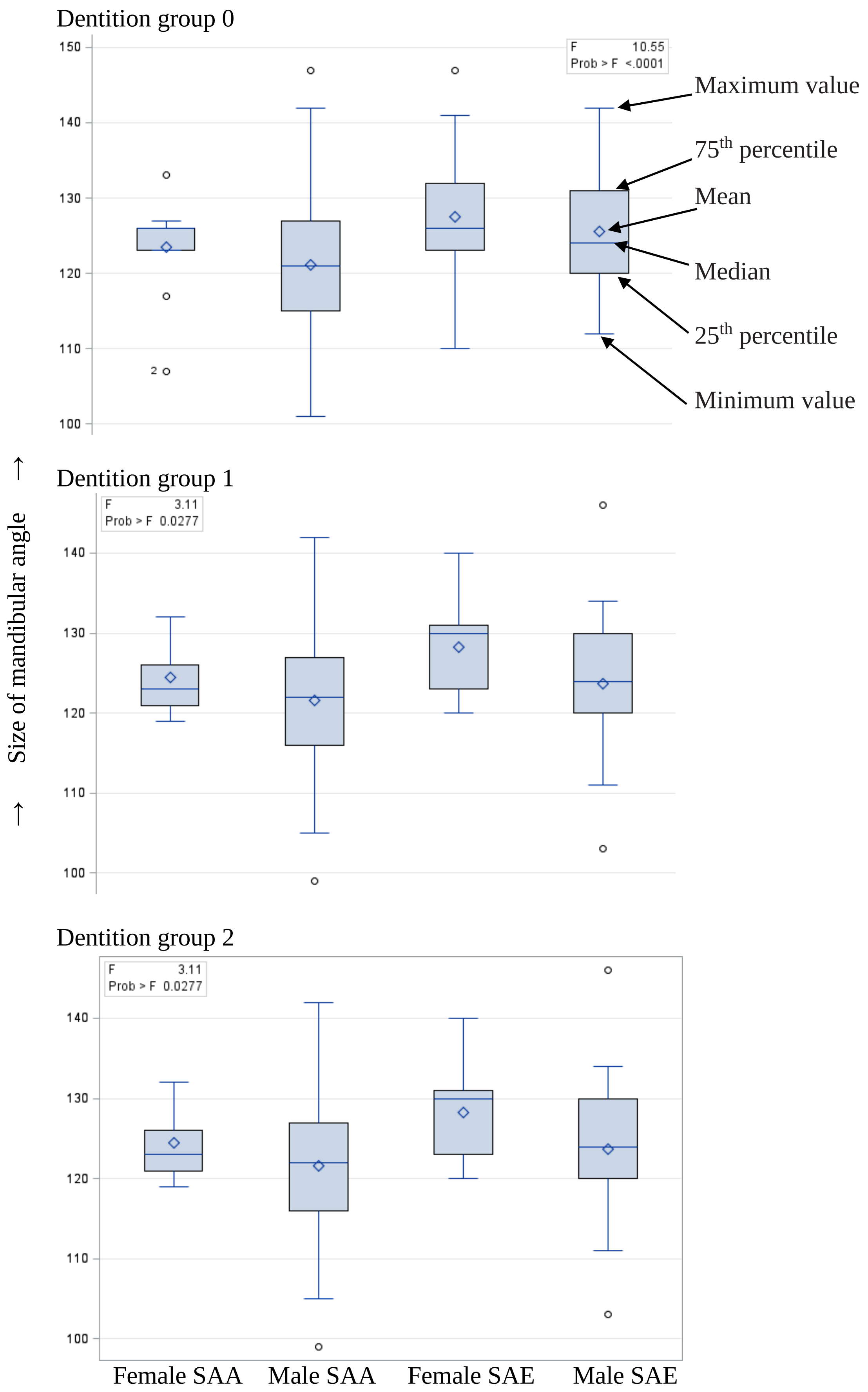


Fig.4.11 Distribution of mandibular angle across sex-ancestry groups in dentition group

Chapter 5: LINEAR MEASUREMENTS

5.1 Introduction

Traditional linear measurements are usually simple and repeatable and form the cornerstone of the identification of unknown individuals (Kimmerle et al. 2012). Significant effects of tooth loss and, to a lesser extent, aging on linear measurements have been described. Therefore tooth loss and aging need to be considered when linear measurements are applied in sex and ancestry estimations (Kasai et al. 1994; Kasai et al. 1996; Xie & Ainamo 2004). In this chapter the study on the effect of tooth loss and senescence on linear measurements of the mandible are reported on. The sample group was selected to comprise individuals with a spectrum of tooth-loss patterns associated with efficiency of mastication. The sex-ancestry-dentition subgroups defined in the previous chapter were employed in these measurements.

The findings regarding the mandibular angle in the previous chapter suggested that the size of the angle did generally increase with a progressive loss of teeth. On the basis of this observation, the effect of loss of teeth on the external morphology of the mandible was further researched on the linear measurements of the mandible. Variations according to age were investigated as well.

5.2 Materials

As mentioned before, three dentition subgroups were identified in each of the four sex-ancestry groups: group 0 – a group with no occlusions; group 1 – a group with fewer than two posterior teeth (molar and premolar teeth) and/or no front teeth (incisors and canines) in occlusion on each side (inefficient occlusion); and, lastly, group 2 – a group with two or more posterior teeth (molar and premolar teeth) and one or more front teeth (incisors and canine) in occlusion on each side (efficient occlusion).

A total of 12 groups were so defined (three dentition groups within each of the four sex-ancestry groups) and referred to as the sex-ancestry-dentition groups and used throughout the remainder of this study for metric and morphometric analyses. Mandibles representative of each of the 12 sex-ancestry-dental pattern groups, as described earlier, were selected for linear measurements. The numbers within each group used for linear measurements of each of the sex-ancestry-dentition groups are set out in Table 5.1.

5.3 Methods

The methods incorporated to evaluate the structural changes with aging and tooth loss amongst the four sex-ancestry groups involved linear measurements on the sample of 126 specimens. Eight osteometric distances were recorded on each mandible, in order to assess changes in the linear dimensions of the mandible with tooth loss and senescence.

Twelve landmarks were identified and marked (Fig. 5.1) and seven distances measured between them (Fig. 5.2), according to established techniques (De Villiers 1968; Kasai et al. 1996; Kohakura et al. 1997; Ubelaker 1997; Barthélémy et al. 1999; Haas et al. 2001; Moipolai et al. 2003; Ousley & Mckeown 2003; Xie & Ainamo 2004; Franklin et al. 2006; Franklin et al. 2007; Kimmerle et al. 2012).

In the mid-sagittal plane, the gnathion, the lowest point on the inferior margin of the mandibular body was marked as point 1. Point 2 was marked on the pogonion as the most forward-projecting point on the anterior surface of the chin, viewed from the side. The infradentale, point 3, was marked as the highest anterior point between the mandibular central incisors or, if edentulous, a point in the anterior midline on the superior border. Point 4 and 5 were marked respectively on the superior and inferior border of the mandible, (if teeth were present on the alveolus), perpendicularly superior and inferior to the mental foramen on the left.

The gonia landmarks 6 and 7 were defined by bissecting the angle formed by the tangents to the mandibular plane and the plane of the ramus. On the left, the condylion superior were identified as the most superior point, point 8, on the condylar process.

On either side, the condylion laterale was marked as the most lateral points, points 9 and 10, on the condylar processes. Bilaterally points 9 and 10 on the anterior and posterior border of the ramus respectively, corresponding to the narrowest distance across the mandibular ramus on the left were marked.

The following distances were measured between landmarks, using a digital sliding calliper (Fig. 5.2). All measurements were taken in mm to the nearest two decimal places. As described by De Villiers (1968) unilateral measurements were taken on the left side; however, if this side was defective they were taken on the right side.

The height of the mandibular body *(Hmb)* was measured as the direct distance between point 5 on the superior border of the mandible, (if teeth were present on the alveolus), perpendicularly above the mental foramen on the left to point 6 at the inferior border of the mandible perpendicular to the base at the level of the mental foramen on the left side. The bicondylar breadth (*Bicon*) was measured as the direct distance between the most lateral points (points 9 and 10) on the two condyles. The minimum ramus breadth *(Mrb)* was measured as the least breadth of the mandibular ramus measured approximately perpendicular to the height of the ramus between points 11 and 12 on the left side.

The projective length of the mandibular corpus *(M_corpus length)* was measured with the mandible in the first position on the mandibulometer: the mandible is adjusted so that the horizontal part of the board represents the standard horizontal plane, while the rameal wing of the board is in contact with the left ramus of the condyle and above the angle, and with the right ramus at one or both of these regions. The solid set square in this case is then brought into contact with the most advanced point in the chin region. The measurement is taken from the solid set square to the rameal wing of the mandible board (De Villiers 1968).

The maximum projective length of the mandible *(Max m_length)* was read on the horizontal scale on the mandibulometer in the second position with both condyles in contact with the vertical rameal wing. The set square is brought into contact with the most advanced point of the chin and the distance read between this point and the vertical rameal wing just touching the posterior extremity of the condyle (De Villiers 1968). This measurement is greater than the previous measurement.

The chin height was measured as the direct distance from the infradentale (point 3) or superior border if edentulous to gnathion (point 1). The bi-gonion breadth *(Bigon)* was measured as the direct distance between left (point 6) and right (point 7) gonion. Maximum ramus height *(Ram_ht)* was measured as the direct distance from the highest point on the mandibular condyle (point 9) to gonion (point 6) measured with a caliper. As this measurement forms part of a series measured between marked points by means of a caliper, the exact distance could be measured as opposed to the indirect means by a mandibulometer.

5.4 Statistical analyses

The eight osteometric distances were statistically analysed similarly to the mandibular angle in the previous chapter. The variation in the osteometric distances (dependent variable) with tooth loss and age (independent variables), were graphically represented by scatter diagrams of Ordinary Least Square Means regressions (or just regressions) on the entire sample. Dentition groups, sexes and ancestry groups were distinguished by differential colouring of the scatter points. Thereafter Ordinary Least Square regressions were also presented for each sex-ancestral group (in the case of aging and tooth loss) and then for each dentition group (in the case of aging) to demonstrate the change in size of the osteometric distances with age and loss of teeth.

Means and standard deviations of the recorded ages in years were determined by univariate analysis for each sex-ancestry-dentition group. Although the crude means and standard deviations were calculated for each of the twelve sex-ancestry-dentition subgroups, statistical analyses were based on the adjusted means of ancestry, sex and dentition group totals. As in the previous chapter, statistical comparisons between groups were done, correcting for age, if age was found to be a significant covariate or for other interactions amongst groups and imbalances in cell frequencies (differences between group numbers). The term correction for a variable implies that the mean value for statistical comparison is adjusted.

The ancestry groups consisted of 68 SAA and 58 SAE. The numbers representing the sexes were 63 females and 63 males. The dentition groups detailed before consisted of 39 individuals classified as dentition group 0; 41 as dentition group 1 and 46 as group 2 (Table 5.1).

The noted statistically significant differences between sexes and populations were brought into context by discriminant analyses.

5.5 Results

The age distribution amongst the sex-ancestry-dentition groups was statistically analysed and reflected upon. Thereafter the eight osteometric distances were statistically analysed within the various dentition, sex, and ancestry groups. Linear regressions, univariate analysis and least square means for statistical significance were calculated. Finally discriminant analysis was performed. Repeatability tests were executed for the linear measurements. Interrater reliability of the measurements taken by a second observer familiar with the technique was tested on a random sample of 30 specimens and measured by the maximum likelihood estimate of the intraclass correlation coefficient. Similarly intrarater reliability of the measurements of the main investigator was tested when the measurements were repeated at a later stage.

5.5.1 Age distributions

The means and standard deviations of age in years in each sex-ancestry-dentition group are given in Table 5.2. The greatest impact of age on the linear measurements between dentition groups was expected to be in male SAA followed by female SAE because of the wider age distribution. Female SAA presented with younger mean ages and female SAE with older mean ages.

5.5.2 Height of mandibular body (Hmb)

The *Hmb* was determined as described, at the level of the mental foramen on the left side. The Ordinary Least Square regression of *Hmb* vs. age demonstrated a weak negative correlation with a correlation coefficient (r) of -0.37 and coefficient of determination (r^2) of 0.13. The negative correlation meant that with aging the *Hmb* decreased. As illustrated by the differentially coloured scatter points in figure 5.3, dentition group 0, females and SAE presented with a lower *Hmb*. To explore these relationships further, linear regressions were performed for sex-ancestry groups separately (Fig. 5.4).

In all four sex-ancestry groups a weak to very weak negative correlation existed between height of mandibular body and age. With aging the *Hmb* decreased in size. Male SAA presented with the highest correlation ($r = -0.25$; $r^2 = 0.06$), followed by female SAE ($r = -0.29$; $r^2 = 0.08$), female SAA ($r = -0.19$; $r^2 = 0.03$) and male SAA $r = -0.08$; $r^2 = -0.08$). In all four sex-ancestry groups, but least so in female SAA, scatter points of dentition group 0 often had a lower *Hmb*. The correlation noted between *Hmb* and age might therefore be influenced by tooth loss and was analysed further.

A moderate positive correlation between *Hmb* and dentition group existed (Fig. 5.5) ($r = 0.54$; $r^2 = 0.29$). When analysing sex-ancestry groups separately, a moderate correlation was maintained in all four groups (Fig. 5.6). The greatest correlations were noted in female SAE and male SAA (female SAE: $r = 0.60$; $r^2 = 0.36$ and male SAA: $r = 0.57$; $r^2 = 0.32$). These positive correlations implied that as teeth were lost from dentition group 2 to 0, *Hmb* decreased in height. A weak positive correlation between *Hmb* and dentition group existed (32% of the decrease in Hmb was associated with tooth loss). The greatest decrease in *Hmb* occurred from dentition group 1 to dentition group 0, crude mean *Hmb* difference between dentition group 2 and 0 were 7.44 mm.

Therefore, both age (to a lesser extent) and loss of teeth (to a greater extent) were correlated to lowering of the *Hmb*. To differentiate further between these two interacting terms (age and loss of teeth) a general linear model was performed.

The crude means and standard deviations for *Hmb* are represented in Table 5.3. In general, as teeth were lost from dentition group 2 to 0, crude means of *Hmb* decreased in height in all sex-ancestry groups. Apart from female SAA, the greatest decrease in *Hmb* occurred from dentition group 1 to dentition group 0, From the difference in the crude means between dentition group 2 and 0, it can be noted that female SAE and male SAA lost more *Hmb* with loss of teeth (female SAE: 8.81 mm and male SAA: 7.66 mm) as compared to male SAE and female SAA (male SAE: 5.33 mm female SAA: 3.43 mm). Apart from male SAA dentition group 0, the crude means for males in each ancestry-dentition group were greater than in the female counterparts. As teeth were lost, male SAA lost much more height than their female counterparts. Greater numbers of occlusions were associated with higher mandibular bodies. The greatest standard deviations were noted in dentition group 0, especially female SAE (6.54).

Age was a confounding variable for *Hmb* ($p = 0.034$). There were no ancestry and sex group interactions ($p = 0.527$) or ancestry and dentition occlusion group interactions ($p = 0.706$) or sex and dentition occlusion group interactions ($p = 0.946$) (where a p-value ≤ 0.05 would have indicated a significant interaction).

Statistical significance based on the adjusted means for age revealed significant sex ($p = 0.0176$) and ancestry group ($p = 0.0076$) differences, with the *Hmb* in SAA and males being larger than the *Hmb* in SAE and females. Statistically significant differences existed between dentition groups (dentition group 0 compared to 1: $p = 0.0018$; dentition group 0 compared to 2: $p = 0.0000$).

Discriminant function analyses were applied to explore whether the significant differences in the size of *Hmb* had any discriminant value. Various combinations of group allocations were attempted in these analyses. The *Hmb* at the level of the mental foramen was in general not a good discriminator for sex or ancestry (Table 5.7 and 5.8). Ancestry prediction (72.2% overall) fared better than sex prediction (58.73% overall). However, when the dentition group was taken into consideration, accuracies increased for the prediction of sex in dentition group 0 (62.7%) and 1 (73.2%). Accuracies for sex determination often improved further if ancestry group was also taken into consideration. For instance, accuracies for sex determination from the *Hmb* increased in mandibles of SAA dentition group 1

(80.0%). Accuracy for ancestry group prediction also increased to 80.0%, when dentition group and sex were taken into consideration in females of dentition group 0,

Intraclass Correlation Coefficient and found as 0.943 for intraobserver repeatability and 0.985 for interobserver repeatability, denoting excellent agreement.

5.5.3 Bicondylar breadth (Bicon)

The Ordinary Least Square regression of *Bicon* vs. age demonstrated a weak positive correlation ($r = 0.11$ and $r^2 = 0.01$), indicating that *Bicon* increases negligibly with aging. As illustrated by the differentially coloured scatter points in Figure 5.7, dentition group 0 and SAE presented with a greater *Bicon*. Females presented with smaller *Bicon* distances. To explore these relationships further linear regressions were performed for sex-ancestry groups separately (Fig. 5.7).

A wide distribution of scatter points was noted in the regressions for *Bicon* vs. age in all four sex-ancestry goups (Fig. 5.8). The correlations were either weakly positive (male SAA and female SAE) or weakly negative (male SAE and female SAA).

No correlation between *Bicon* and dentition group existed (Fig. 5.9). When analysing sex-ancestry groups separately (Fig. 5.10), only female SAE displayed a weak negative correlation with dentition group (female SAE: $r = -0.27$; $r^2 = 0.07$). This negative correlation implied that as teeth were lost from dentition group 2 to 0, so did *Bicon* decrease in width. In the other sex-ancestry-dentition groups the correlations were non-existent to very weak.

The crude means and standard deviations for *Bicon* are presented in Table 5.6. SAE, males and dentition group 0 presented with the greatest values. The low correlations of *Bicon* vs. dentition group noted in the linear regressions were reflected in the minimal variation amongst dentition groups within sex-ancestry group. The greatest standard deviations were noted in female SAE group 0, Sex and dentition occlusion group interactions ($p = 0.031$) existed but no ancestry and sex group interactions ($p = 0.984$) or ancestry and dentition group interactions ($p = 0.508$), Age was not a confounding variable for *Bicon* ($p = 0.296$). There were no statistically significant differences in the adjusted means between ancestry or sex groups. Statistically significant differences between dentition groups 1 and 2 ($p = 0.0316$) as well as dentition group 0 and 2 ($p = 0.0440$) were revealed when adjusted for sex and dentition group interactions.

In the complete sample, 76.2% correct prediction of sex by *Bicon* were found, which improved when only dentition group 2 (80.6%) was considered and, to a lesser extent when only group 1 (78.1%) (Table 5.7) was considered. Dentition group 0 did not fare well, with only 59.0% correct prediction. Sex differences became less obvious with loss of teeth. Discriminant ability between sexes by *Bicon* did not improve when ancestry groups were considered separately (Table 5.8). *Bicon* fared poorly in the prediction of ancestry and in general did not improve much when dentition group or sex were taken into consideration.

The Intraclass Correlation Coefficient and found to be 0.994 for intraobserver repeatability and 0.974 for interobserver repeatability, denoting excellent agreement.

5.5.4 Minimum ramus breadth (Mrb)

The Ordinary Least Square regression of *Mrb* vs. age demonstrated a weak negative correlation to age ($r =- 0.29$ and $r^2 = 0.08$) (Fig. 5.11). This weak negative correlation means that with aging the *Mrb* decreased. As illustrated by the differentially coloured scatter points in Figure 5.11, a lower *Mrb*, like with *Hmb* was noted in the older ages. To explore these relationships further linear regressions were performed for sex-ancestry groups separately.

In the Ordinary Least Square regressions of sex-ancestry group individually (Fig. 5. 12), SAE were found to have a weak negative relationship of *Mrb* vs. age (females: $r = -0.16$ and $r^2 = 0.02$; males: $r = - 0.25$ and $r^2 = 0.06$). Therefore. in SAE the older individual the smaller the *Mrb*. In SAA the relationship between *Mrb* and age was negligible (females: r = 0.16 and r^2 = 0.03; males: r = 0.02 and r^2 = 0.00).

A weak positive correlation between dentition group and age existed (r = 0.21 and r^2 = 0.04) (Fig. 5.13). When the sex-ancestry groups were analysed separately. Female SAA also displayed a weak positive correlation with dentition group (r = 0.25; r^2 = 0.06) (Fig. 5.14). This implies that as teeth were lost from dentition group 2 to 0, so did the ramus decrease in width. The regressions of the other sex-ancestry groups were non-existent to very weak.

The crude means and standard deviations for *Mrb* are presented in Table 5.9. *Mrb* crude means were narrower in SAE and females and decreased with tooth loss in the complete sample and in female SAA and male SAE. *Mrb* crude means increased slightly in male SAA and female SAE.

No ancestry and sex group interactions (p = 0.442), or ancestry and dentition group interactions (p = 0.663) or sex and dentition group interactions (p = 0.923) were noted. Age was not a confounding variable for *Mrb* (p = 0.61). There were statistically significant differences between ancestry groups (p = 0.00) and the sexes (p = 0.01), but not between the dentition groups. SAA and males presented with a wider *Mrb*.

In the complete sample, 53.2% was correctly predicted for sex by *Mrb* and often improved when tooth loss was taken into consideration (69.2% in group 0 and 78.1% in dentition group 1) (Table 5.10). Sex predictions in dentition group 0 increased even further (78.6%) when only SAA were considered. Sex predictions were therefore partly obscured when ancestry or dentition group was not taken into account in the interpretation of minimum ramus breadth. *Mrb* fared poorly in the prediction of ancestry and in general did not improve much when dentition group or sex were taken into consideration (Table 5.11).

The Intraclass Correlation Coefficient was found to be 0.974 for intraobserver repeatability and 0.974 for interobserver repeatability, denoting excellent agreement.

5.5.5 Projective mandibular corpus length (M_corpus length)

The Ordinary Least Square regression of *M_corpus length* vs. age demonstrated a weak negative correlation (r = -0.11 and r^2 = 0.01). This means that with aging the *M_corpus length* decreased only minimally. As illustrated by the differentially coloured scatter points in Figure 5.15, dentition group 0, SAE and females as a group presented with smaller measurements. To explore these relationships further, linear regressions were performed for sex-ancestry groups separately.

In the Ordinary Least Square regressions of sex-ancestry groups individually, male SAA and female SAE were found to have a weak positive relationship of *M_corpus length* with age (male SAA: r = 0.26 and r^2 = 0.07; female SAE: r = 0.17 and r^2 = 0.03) (Fig. 5.16).

Therefore, in male SAA and female SAE the older the individual, the longer the *M_corpus length*. In SAA females and SAE males the opposite was true: the older the individual the shorter the *M_corpus length,* as a weak negative relationship existed between *M_corpus length* and age (SAA females: r = -0.07 and r^2 = 0.01; SAE males: r = -0.09 and r^2 = 0.01).

A weak positive correlation between *M_corpus length* and dentition group existed (r = 0.16; r^2 = 0.02) (Fig. 5.17). This implies that as teeth were lost, so *M_corpus length* decreased only minimally. When sex-ancestry groups were analysed separately (Fig. 5.18), female SAA and male SAE displayed a weak positive correlation with dentition group (female SAA: r = 0.33 and r^2 = 0.11 and male SAE: r = 0.11 and r^2 = 0.01). The positive correlations imply that as teeth were lost from dentition group 2 to 0, so did *M_corpus length* decrease in length. In male SAA and female SAE *M_corpus length* was not affected by age.

The crude means and standard deviations for the *M_corpus length* are represented in Table 5.12. Crude means were greater in males, SAA and dentition group 2. Apart from female SAA, which in general presented with smaller standard deviations, group 0 presented with the greatest standard deviations in sex-ancestry groups individually.

No ancestry and sex group interactions (p = 0.441), ancestry and dentition occlusion group interactions (p = 0.982), or sex and dentition occlusion group interactions (p = 0.310) were noted. Age was not a confounding variable for the *M_corpus length* (p = 0.771). Statistically significant differences were observed between ancestry groups (p = 0.0005) and sexes (p = 0.000), but not between the dentition groups. SAA and males presented with longer mandibular corpus length measurements.

Sex prediction percentage by *M_corpus length* in the complete sample (Table 5.13) was 50.8% and ancestry prediction, 53.2% (Table 5.14). Sex predictions improved when dentition groups were considered separately. For dentition group 1, 80.5% of sex groups were predicted correctly, and improved even more when considering only SAA (81.0%) and only SAE (87.5%), individually. Despite the low percentage of prediction of ancestry in dentition group 1 (58.5%), prediction percentage increased to 80.0%, when male dentition in group 1 was considered separately. Prediction of ancestry in dentition group 0 of 66.7% also increased to 73.7% when only males were considered. In considering SAA and SAE or males and females simultaneously, sex or ancestry differences respectively in *M_corpus length* were obscured.

Intraclass Correlation Coefficient was found to be 0.958 for intraobserver repeatability and 0.962 for interobserver repeatability, denoting excellent agreement.

<u>5.5.6 Maximum projective length of the mandible (Max m_length)</u>

To explore the influence of aging on the *Max m_length*, Ordinary Least Square linear regressions were performed, displaying the normal distribution of age in years vs. size of mandibular angle. In the first figure (Fig. 5.19) dentition groups were differentiated. Secondly scatter points were differentiated in sex groups and lastly ancestry groups were differentiated.

Females exhibited shorter *Max m_length* in general. A decrease in *Max m_length* was therefore not only influenced by old age, but also by tooth loss and sex.

In the Ordinary Least Square regressions of sex-ancestry groups individually (Fig. 5.20), males were found to have a weak positive relationship of *Max m_length* vs age (male SAA: $r = 0.26$; $r^2 = 0.07$ and male SAE: $r = -0.24$; $r^2 = 0.06$). Therefore. in males the older the individual the longer the *Max m_length*. In females the opposite was true: the older the individual the shorter the *Max m_length* as a weak negative relationship existed between *Max m_length* vs. age (females SAA: $r = -0.34$; r^2: = 0.11; females SAE: $r = -0.26$; r^2: = 0.07).

A negligible correlation between *Max m_length* and dentition group existed ($r = 0.06$; $r^2 = 0.00$) in the complete sample (Fig. 5.21) and in female SAE ($r = -0.03$ and $r^2 = 0.00$) (Fig. 5. 22), Female SAA displayed a weak positive correlation with dentition group ($r = 0.21$ and $r^2 = 0.05$). The weak positive correlation implied that as teeth were lost from dentition group 2 to 0, so did *Max m_length* decrease in width. In males a weak negative correlation between *Max m_length* and dentition group existed (male SAA: $r = -0.16$ and $r^2 = 0.03$, male SAE: $r = -0.08$ and $r^2 = 0.01$). These negative correlations implied as teeth were lost so *Max m_length* increased.

The means, minimum and maximum values as well as standard deviations for the *Max m_length* are presented in Table 5.15. The greatest crude mean values were found in dentition group 2 individuals, SAA and males in the complete sample. In males of both ancestry groups, mandibles without occlusions presented with a greater *Max m_length* as compared to dentition group 2. In male SAE the length of the *Max m_length* increased steadily with tooth loss from dentition group 2 through to 0, Females presented with smaller *Max m_length* and the greatest standard deviations. An initial shortening of *Max m_length* with tooth loss was noticed in females in dentition group 1, especially in female SAE. The initial shortening of the *Max m_length* with loss of teeth in dentition group 1 was followed by a lengthening of the *Max m_length* in dentition group 0 approaching values of dentition group 2.

Age was not a statistically significant confounding variable p = 0.4417 and no statistical interaction existed between the main factors (sex and ancestry: p = 0.3166; ancestry and dentition group: p = 0.8954 or sex and dentition group: p = 0.6014), There were statistically significant differences observed between males and females ($p < 0.0001$) but not between the dentition groups (p = 0.5969) or ancestry groups (0.5397). The initial shortening of the *Max m_length* and the recovering thereof in dentition group 0 were not statistically significant. Although mandibles of SAA had longer crude *Max m_length* means, the comparison between ancestry groups were not statistically significant.

Maximum mandibular length did not achieve high prediction percentages for sex (56.4%) (Table 5.16) or ancestry in the complete sample (49.2%) (Table 5.17). Sex predictions often improved when considering dentition group 0 and 1 individually. The best predictions for sex were achieved in SAA dentition group 0 in *Max m_length.*

Intraclass Correlation Coefficient was found to be 0.957 for intraobserver repeatability and 0.890 for interobserver repeatability, denoting excellent agreement.

<u>5.5.7 Chin height</u>

To explore the influence of aging on *Chin height*, Ordinary Least Square linear regressions were performed, which displayed the normal distribution of age in years vs. size of mandibular angle (Fig. 5.23). In the first figure dentition groups were differentiated. Secondly scatter points were differentiated in sex groups and lastly ancestry groups were differentiated. A moderate negative relationship existed between *Chin height* and aging in the complete sample ($r = -0.41$ and $r^2 = 0.16$). With aging *Chin height* decreased (Fig. 5.23). Differentially coloured scatter points indicated that lower *Chin heights* were noted in SAE, females and with tooth loss. A trend towards a more negative correlation between *Chin* *height* and age was observed in the Ordinary Least Square regressions of male SAE ($r = -0.04$; $r^2 = 0.00$) (Fig. 5. 24). This relationship became more noticeable in the other sex-ancestry groups (male SAA: $r = -0.25$ and r^2: 0.06; female SAA: $r = -0.27$ and $r^2 = 0.07$; female SAE: $r = -0.34$ and $r^2 = 0.12$).

A moderate positive correlation between *Chin height* and dentition group existed in the complete sample ($r = 0.48$; $r^2 = 0.23$) (Fig. 5.25). This implied that as teeth were lost so *Chin height* decreased. A positive correlation of *Chin height* vs. dentition group existed in all sex-ancestry groups (Fig. 5.26). In male SAE this correlation was weak ($r = 0.21$; $r^2 = 0.05$), but in the other three sex-ancestry groups a moderate positive relationship existed (female SAA: $r = 0.44$; $r^2 = 0.19$; male SAA: $r = 0.54$; $r^2 = 0.29$ and female SAE: $r= 0.57$; $r^2= 0.32$).

The crude means and standard deviations for *Chin height* are represented in Table 5.18. As expected, *Chin height* decreased with tooth loss and was lower in females and SAE. Standard deviations seemed to increase with tooth loss. There were no ancestry and sex group interactions ($p = 0.989$), or ancestry and dentition occlusion group interactions ($p = 0.536$) or sex and dentition occlusion group interactions ($p = 0.184$). Age was a confounding variable for the *Chin height* ($p = 0.008$). Despite adjusting means for age differences a statistically significant difference between the ancestry groups, sexes and dentition groups (at $p < 0.0001$) existed. SAA; males and individuals with more occlusions presented with greater chin measurements (Fig. 5.12).

Prediction by *Chin height* was more reliable for sex group (60.0%) (Table 5.19) than for ancestry (52.8%) (Table 5.20). Correct prediction percentage increased when dentition group, sex or ancestry group were taken into consideration. Sex predictions were improved when dentition group 1 was considered separately (85.4%) and also when only SAA (84.0%) and only SAE were considered (87.5%).

Intraclass Correlation Coefficient was found to be 0.983 for intraobserver repeatability and 0.990 for interobserver repeatability, denoting excellent agreement.

5.5.8 Bigonial breadth (Bigon)

To explore the influence of aging on the *Bigon*, Ordinary Least Square linear regressions were performed (Fig. 5. 27). With aging the *Bigon* increased, but this correlation was weak (r: 0.09 and r^2: 0.01). It seemed that dentition group did not have much influence on the *Bigon*. There was an obvious clustering of females with the smaller *Bigon* diameters. In the Ordinary Least Square regressions of sex-ancestry group individually (Fig. 5.28), the correlation between *Bigon* and age was weak to non-existent (female SAA = r: -0.07 and r^2: 0.00; male SAA: r: 0.10 and r^2: 0.01; female SAE = r: 0.10; r^2: 0.01; male SAE: r: 0.12; r^2: 0.02).

No correlation between *Bigon* and dentition group existed ($r = 0.04$; $r^2 = 0.00$) (Fig. 5.29). When the sex-ancestry groups were considered separately (Fig. 5.30), female SAA displayed a weak positive correlation with dentition group ($r = 0.35$; $r^2 = 0.12$). As teeth were lost *Bigon* decreased. The other three sex-ancestry groups exhibited a very weak negative correlation with dentition group (male SAA: $r = -0.18$; $r^2 = 0.04$; female SAE: $r = -0.02$; $r^2 = 0.00$ and male SAE: $r = -0.08$; $r^2 = 0.01$).

When testing for interactions, none were found between ancestry and sex group ($p = 0.796$) or ancestry and dentition group ($p = 0.267$) or sex and dentition group (p = 0,092). Age was not a confounding variable for *Bigon* ($p = 0.913$), indicating that *Bigon* was not affected by age per se and the significant differences between ancestry groups and sex were not confounded by interaction terms. The means and standard deviations for *Bigon* are represented in Table 5.21. There were statistically significant differences between sexes ($p = 0.0000$) but not between dentition groups ($p = 0.9190$). The differences between ancestry groups were significant. Males and SAE presented with greater *Bigon* dimensions than females and SAA.

Bigon in sex predictions (64.0%) (Table 5.22) were generally more accurate than ancestry group predictions (52.0%) (Table 5.23). Predictions of sex were the highest in dentition group 2 (73.9%) as well as for SAE when considering tooth loss pattern: dentition group 0 separately (83.3%); dentition group 1 separately (81.3%); and group 2 (82.4%). Ancestry predictions, although marginally better in females, did not fare well overall for *Bigon.*

Intraclass Correlation Coefficient was to be 0.996 for intraobserver repeatability and 0.988 for interobserver repeatability denoting excellent agreement.

5.5.9 Maximum ramus height (Ram_ht)

To explore the influence of aging on the *Ram_ht*, Ordinary Least Square linear regressions were performed displaying the normal distribution of *Ram_ht* vs. age in years (Fig. 5.31). In the first figure dentition groups were differentiated. Secondly scatter points were differentiated in sex groups and lastly ancestry groups were differentiated (Fig. 5.31). A weak positive correlation between *Ram_ht* and age existed ($r = 0.29$; r^2: 0.08). With aging the *Ram_ht*, increased and a lower *Ram_ht* was noted in females and SAA.

In the Ordinary Least Square regressions of sex-ancestry groups individually (Fig. 5.32), female SAA had a negligible or a very weak negative correlation between *Ram_ht* and age ($r = -0.04$; $r^2 = 0.00$). In the other three groups a weak positive correlation existed (SAA males: $r = 0.30$; $r^2 = 0.09$; SAE females: $r = 0.19$; $r^2 = 0.03$ and SAE males: $r = 0.06$; $r^2 = 0.00$).

No correlation between *Ram_ht* and dentition group existed ($r = 0.00$; $r^2 = 0.00$) (Fig. 5.33). When analysing sex-ancestry groups separately (Fig. 5.34), very weak positive correlations existed with female SAA ($r = 0.09$; $r^2 = 0.01$) and male SAE ($r = 0.11$; $r^2 = 0.01$).

Female SAE presented with the highest correlation ($r = 0.23$; $r^2 = 0.05$). This implies that as teeth were lost from dentition group 2 to 0, so did *Ram_ht* decrease. Male SAA presented with a small negative correlation ($r = -0.19$; $r^2 = 0.04$), meaning that with tooth loss *Ram_ht* increased.

The means, and standard deviations for maximum ramus height (*Ram_ht*) are represented in Table 5.24. The greatest crude mean values were noted in SAE and males. There were no ancestry and sex group interactions ($p = 0.245$); or ancestry and dentition occlusion group interactions ($p = 0.238$) or sex and dentition occlusion group interactions ($p = 0.112$). Age was not a confounding variable for ramus height (*Ram_ht*) ($p = 0.183$).It was therefore not surprising that statistically significantdifferences were observed between the ancestry groups and sexes ($p < 0.0001$) but not between the dentition groups.

Ram_ht was a better predictor of sex (60.0%) (Table 5.25) than ancestry group in the complete sample (52.8%) (Table 5.26). These percentages improved greatly when considering ancestry groups separately for sex predictions and to some extent when considering sexes separately for ancestry predictions. The prediction percentages for sex was the highest in dentition group 0, when only considering SAA (92.9%), followed by in SAE alone (76.0%) and in dentition group 0 overall (76.9%). Dentition group 2 overall and in SAA and SAE considered separately prediction percentages for sex were greater than 80.0%.

Intraclass Correlation Coefficient was found to be 0.987 for intraobserver repeatability and 0.975 for interobserver repeatability, denoting excellent agreement.

5.6 Summarised results

5.6.1 Integration of linear measurements for individual sex-ancestry groups

For clarity regarding variations with age and tooth loss within each sex-ancestry group, linear regressions within each were performed and are summarised below.

5.6.1.1 Female SAA

Female SAA presented with younger mean ages than the other sex-ancestry groups and lower minimum and maximum values within dentition groups. Age distributions amongst dentition groups exhibited a great deal of overlap and mean values were within a 10-year range.

Aging per se contributed to a small percentage of the decrease noted in *Hmb* (3%), *Bicon* (2%), *M_corpus length* (1%), *Max m_length* (11%) and *Chin height* dimensions (7%), as suggested by the weak negative correlation with age. Correlation with age and *Bigon* as well as *Ram_ht* were very weak or even non-existent. The older the individual the wider the *Mrb*, as a weak positive relationship existed between *Mrb* vs. age, contributing to 3% of the increase noted.

Tooth loss contributed to a small percentage of the decrease noted in *Hmb* (13%), *Bicon* (2%), *Mrb* (6%), *M_corpus length* (11%), *Max m_length* (5%), *Bigon* (12%) and *Ram_ht* (1%), as implied by the weak positive correlations noted. The initial shortening of the *Max m_length* with loss of teeth in dentition group 1 was followed by a lengthening of the *Max m_length*, approaching values of dentition group 2. A moderate positive correlation of *Chin height* vs. dentition group existed: 19% of the decrease in *Chin height* was correlated with tooth loss.

Apart from *Mrb*, which increased slightly with age, all other dimensions decreased with aging and loss of teeth in female SAA.

5.6.1.2 Male SAA

As the difference in mean values between dentition groups was greater than in the other sex-ancestry groups, the greatest impact of age on the linear measurements between dentition groups was expected.

Weak negative correlations noted in the linear regressions of *Hmb* and *Chin height* confirmed that aging contributed to 6% of the decrease noted in *Hmb* and *Chin height.* Aging was associated with 9% of the increase in *Ram_ht*, 7% of the decrease in *M_corpus length* and *Max m_length*, and 1% in the decrease in *Bicon* and *Bigon*. Aging was not associated with a change in *Mrb* dimensions.

Tooth loss correlated to 32% of the decrease noted in *Hmb*, 29% of *Chin height* and 4% of *Bigon.* Tooth loss had a negligible effect on *Bicon* and *Mrb* but was associated with an increase of dimensions of *Ram _height* (4 %), *Max m_length* (3%) and *M_corpus length* (2%).

Tooth loss had a greater correlation with the decrease noted in *Hmb*, *Chin height* and *Bigon* than aging. Tooth loss was associated with an increase of dimensions of *Ram_ht*, *Max m_length* and *M_corpus length*, while aging was associated with a decrease in *Ram_ht*, *Max m_length, M_corpus length* and *Bicon*. Tooth loss and aging did not affect *Mrb* dimensions.

5.6.1.3 Female SAE

Female SAE presented with the oldest crude mean age, which was found in dentition group 0, as compared to the other sex-ancestry groups. Therefore, the greatest impact of senescence was expected to be in this group.

Aging contributed to the decrease in size of 8% of *Hmb*, 12% of *Chin height*, 7% of *Max m_length* and 2% of *Mrb.* Aging contributed to the increase in size of 4% of *Bicon*, 3% of *M_corpus length*, 9% of *Bigon* and 3% *Ram_ht.*

Tooth loss contributed to an increase of 7% of *Bicon* and the decrease in size of 36% of *Hmb*, 32% of *Chin height and* 5% of *Ram_ht.* The greatest decrease in *Hmb* occurred from dentition group 1 to dentition group 0, No correlation between loss of teeth and *Mrb*, *M_corpus length*, *Max m_length* or *Bigon* existed. The correlation between loss of teeth and *Max m_length* could have been obscured by the initial shortening of *Max m_length* in dentition group 1, which was followed by a lengthening of the *Max m_length* in dentition group 0, approaching values of dentition group 2.

Tooth loss and aging to a lesser extent contributed to the decrease in size of *Hmb* and *Chin height.* Aging and tooth loss contributed to the increase in size of *Bicon.* Aging but not tooth loss was associated with the decrease in *Max m_length* and *Mrb* and the increase in *M_corpus length* and *Bigon.* Aging correlated with an increase in *Ram_ht* but a decrease with tooth loss.

5.6.1.4 Male SAE

The crude mean ages in all three dentition groups in male SAE were in the sixties and did not include individuals from the younger age groups. It was therefore expected that the effect of aging between groups would be limited and, overall, would involve age changes in later life and senescence.

Aging contributed to the decrease in size of 1% of *Hmb,* 2% of *Bicon*, 1% of *Mrb* and *M_corpus length*. Aging contributed to the increase in size of 6% *of Max m_length,* 2% of *Bigon* and 3% *Ram_ht.* No correlation between *Chin height* and aging was found.

A weak negative correlation was found between *Max m_length*, *Ram_ht* and *Bigon* vs. dentition group, contributing to 1% in the increase noted with tooth loss. Tooth loss contributed to the decrease in size of 20% of *Hmb*, 1% of *Mrb* and *M_corpus length* and 5% of *Chin height.* No correlation between loss of teeth and *Bicon* existed.

Tooth loss and to a lesser extent aging contributed to the decrease in size of *Hmb*, *Mrb* and *M_corpus length*. Aging and to a lesser extent tooth loss contributed to the increase in size of *Max m_length*, *Bigon* and *Ram_ht.* Tooth loss contributed to the loss of 5% *Chin height* but was not associated with aging. In contrast, aging contributed to 2% of the decrease noted in *Bicon*, but was not correlated with loss of teeth.

5.6.1.5 All 4 sex-ancestry groups

Apart from *Hmb* and *Chin height*, which indicated moderate correlations with tooth loss, all the other correlations between linear dimensions vs. aging and tooth loss were weak or even absent.

Tooth loss and to a lesser extent aging were associated with a decrease in *Hmb* in all groups. Tooth loss but not aging was associated with the decrease in *Chin height* in SAE males. In all other sex-ancestry groups *Chin height* decreased with aging and loss of teeth. The moderate correlations noted between aging vs. *Hmb* and *Chin height* were the greatest in male SAA and female SAE because of the greatest variation in age distribution.

Bicon decreased with aging and loss of teeth in SAA but decreased with aging only and not tooth loss in male SAE, while aging and tooth loss contributed to the increase in size of *Bicon* in female SAA. *Mrb* increased slightly with tooth loss and aging in female SAA and decreased slightly in male SAE. In male SAA tooth loss and aging did not affect *Mrb* dimensions. In female SAE, aging but not tooth loss was associated with the decrease in *Mrb. M_corpus length* decreased with aging and loss of teeth in female SAA and male SAE. Tooth loss was associated with the increase of dimensions of *M_corpus length* in male SAA and aging in female SAE. *Max m_length* decreased with aging and loss of teeth in female SAA, but increased in male SAE. Aging but not tooth loss was associated with the decrease in *Max m_length* in female SAE. Male SAA tooth loss was associated with the increase in *Max m_length*, while aging was associated with a decrease. In SAA and male SAE *Bigon* decreased to a greater degree with loss of teeth than with aging. In female SAE aging but not tooth loss was associated with the increase in *Bigon. Ram_ht* decreased with aging and loss of teeth in female SAA. With tooth loss *Ram_ht* increased in size in males. Aging correlated with an increase in *Ram_ht* in SAE – a decrease with tooth loss in female SAE and an increase in male SAE.

5.6.2 Integration of statistically significant findings

Statistically significant testing was performed between ancestry, sex and dentition groups on the eight osteometric distances outlined before, based on the adjusted means for imbalances between group numbers and age if found to be a confounding variable.

Significant sex and ancestry group differences existed in *Hmb, Mrb, M_corpus length, Chin height, Bigon and Ram_ht.* Significant sex- but not ancestry differences existed in *Max m_length,* males presented with greater dimensions than females. SAA presented with greater dimensions of *Hmb, Mrb, M_corpus length* and *Chin height* than SAE, while SAE presented with greater *Bigon* and *Ram_ht* than SAA. Significant dentition group differences were noted in *Hmb, Bicon and in Chin height.* Greater dimensions were related to a greater number of occlusions for *Hmb* and *Chin height*, while greater dimensions of *Bicon* were noted with tooth loss.

5.6.3 Discriminant qualities of linear measurements

Statistically significant differences between groups of the linear measurements did not necessarily imply discriminant qualities. Lack of discriminant qualities could have been caused by the high degree of overlap noted. In the complete sample the highest prediction for sex was noted in *Bicon* (76.2%) and the highest prediction for ancestry was *Hmb* (72.2%). The other dimensions achieved lower percentages and were not discriminant enough for either sex or ancestry in the complete sample.

Discriminant qualities often improved when dentition group, ancestry or sex group was taken into consideration. Some differences were obscured when sex, ancestry or dentition group was not taken into consideration. In this synopsis only the impact of dentition group is given. Higher discriminant qualities were more often noted for sex predictions than ancestry predictions in the linear measurements considered.

Sex predictions of approximately 60% based on *Bigon* and *Ram_ht* in the complete sample increased, when only dentition group 0 was taken into consideration, to 71.1% *(Bigon)* and 76.9% *(Ram_ht).* Sex predictions in dentition group 1 increased from 60% or lower on the complete sample to: 65.9% for *Bigon;* 73.2% for *Hmb;* 78.1% for *Mrb;* 80.5% for *M_corpus length* and 85.4% for *Chin height*. *Bicon* increased from 76.2% in the complete sample to 78.1% in dentition group 1. Sex predictions based on *Ram_ht, Bigon* and *Bicon* in the complete sample rose from 60.0%, 64.0% and 76.2% to 73.9%, 80.6% and 84.8% respectively when only dentition group 2 was considered.

When dentition group 2 was considered separately, ancestry prediction increased from 72.2% in the complete sample to 76.1% for *Hmb* and from 53.2% to 71.7% for *M_corpus length.*

Cumulative discriminant analysis on all linear measurements revealed 88.8% prediction of sex on the complete sample; dentition group 0: 94.9%; dentition group 1: 97.5% and dentition group 2: 87.0%.

Cumulative discriminant analysis on all linear measurements revealed 90.4 % correct classification of ancestry groups on the complete sample; dentition group 0: 89.7%; dentition group 1: 95.0% and dentition group 2: 95.7%.

The variance in the linear measurements amongst the groups would have implications for the external shape of the mandible and were considered in Chapter 6.

Table 5.1 Sample numbers used for linear measurements

Dentition groups ↓	Ancestry and sex				Total: dentition group
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7	7	13	12	39
Group 1	17	8	9	7	41
Group 2	10	19	7	10	46
Total: ancestry	68		58		
Total: sex		63	63		Total 126

Table 5.2 Mean ages amongst sex-ancestry-dentition groups (n is 126) in years

Dentition groups ↓	Ancestry and sex			
	SAA		SAE	
	Female	Male	Female	Male
Group 0	7 [32 - 68] **54.29** (13.89)	7 [53 - 86] **67.29** (10.78)	13 [48 - 87] **76.15** (10.40)	12 [40 – 83] **66.75** (15.49)
Group 1	17 [33 - 75] **52.82** (12.76)	8 [52 - 75] **63.25** (6.78)	9 [45 – 84] **65.67** (12.89)	7 [45 – 89] **61.57** (14.76)
Group 2	10 [31 – 70] **44.90** (13.81)	19 [23 – 76] **43.47** (13.34)	7 [21 – 87] **63.14** (21.12)	10 [55 – 79] **68.50** (8.15)

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()

Table 5.3: *Hmb* in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals[3]
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7 [18 – 33] **26.57** (5.19)	7 [17 – 32] **24.14** (5.27)	13 [9 – 29] **17.62** (6.54)	12 [12 – 31] **22.67** (5.77)	39 [9 – 33] **21.95[a]** (6.57)
Group 1	17 [20 - 32] **26.71** (3.18)	8 [29 - 36] **31.75** (3.01)	9 [18 - 31] **25.89** (3.98)	7 [21 – 34] **27.71** (4.96)	41 [18 – 36] **27.65[b]** (4.16)
Group 2	10 [26 – 33] **30.00** (2.36)	19 [25 - 38] **31.58** (2.91)	7 [22 - 31] **26.43** (2.94)	10 [23 – 37] **28.10** (3.78)	46 [22 – 38] **29.70[b]** (3.50)
Ancestry group totals[1]	68 [17 – 38] **28.87** (4.32)		58 [9 – 37] **24.03** (6.25)		
Sex group totals[2]		Males 63 [12 – 38] **28.10** (5.43)	Females 63 [9 – 33] **25.13** (5.86)		Total 126

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: p = 0.0076
[2]: p = 0.0176
[3]: p = 0.0001
[a,b]: least square means with the same alphabet letter in the superscript did not differ significantly on the 5% level of significance
Dentition group 0 compared to 1: p = 0.0018; dentition group 0 compared to 2: p = 0.0000

Table 5.4: The percentage correct **prediction of sex** by *Hmb* determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	57.1	62.7	72.0
Group 1	**80.0**	73.2	62.5
Group 2	69.0	54.4	64.7
Complete sample	66.2	58.7	56.1

Table 5.5: The percentage correct **prediction of ancestry group** by *Hmb* determined by discriminant function analyses

Dentition groups ↓	Male	Both sex groups	Female
Group 0	57.9	66.7	**80.0**
Group 1	53.3	63.4	65.4
Group 2	75.9	76.1	70.6
Complete sample	71.4	72.2	66.7

Table 5.6 *Bicon* in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals[1]
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7 [102 – 118] **111.71** (5.37)	7 [110 – 129] **116.86** (6.79)	13 [98 – 123] **114.38** (7.11)	12 [109 – 125] **119** (4.82)	39 [98 – 129] **115.77[a]** (6.46)
Group 1	17 [104 – 118] **110.18** (3.96)	8 [110 – 130] **118.125** (6.79)	9 [110 – 120] **113.44** (3.96)	7 [113- 130] **120.29** (6.26)	41 [104–113] **111.90[b]** (6.32)
Group 2	10 [110 – 118] **112.70** (2.16)	19 [97 – 123] **116.57** (6.12)	7 [102 – 117] **110.43** (5.09)	10 [111 – 124] **119.00** (4.64)	46 [97 – 124] **115.32[a]** (5.71)
Ancestry group totals	68 [97 – 130] **114.12** (5.94)		58 [98 – 130] **116.22** (6.17)		
Sex group totals		Males 63 [97 -130] **118.06** (5.77)	Females 63 [98 –123] **112.08** (9.59)		Total 126

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: p = 0.0317
[a.b]: least square means with the same letter in the superscript did not differ significantly on the 5% level of significance
Dentition group 1 compared to 2: p = 0.0316; dentition group 0 compared to 1: p = 0.0440

Table 5.7 The percentage correct **prediction of sex** by *Bicon* determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	50.0	59.0	60.0
Group 1	72.0	78.1	68.8
Group 2	75.9	**80.1**	76.5
Complete sample	69.1	76.2	65.5

Table 5.8 The percentage correct **prediction of ancestry group** by *Bicon* determined by discriminant function analyses

Dentition groups ↓	Male	Both sexes	Female
Group 0	68.4	64.0	55.0
Group 1	65.4	61.0	65.4
Group 2	48.3	52.2	64.7
Complete sample	61.9	62.7	58.7

Table 5.9 *Mrb* in mm

<table>
<tr><th rowspan="3">Dentition groups ↓</th><th colspan="4">Ancestry and sex</th><th rowspan="3">Dentition group totals</th></tr>
<tr><th colspan="2">SAA</th><th colspan="2">SAE</th></tr>
<tr><th>Female</th><th>Male</th><th>Female</th><th>Male</th></tr>
<tr><td>Group 0</td><td>7
[29 – 35]
32.14
(3.81)</td><td>7
[31 – 40]
36.43
(3 .21)</td><td>13
[23 – 34]
28.77
(3.19)</td><td>12
[26 – 37]
31.00
(3 .60)</td><td>39
[23 – 40]
31.44
(4.04)</td></tr>
<tr><td>Group 1</td><td>17
[26 – 40]
32.76
(3 .19)</td><td>8
[31 – 41]
35.00
(3.02)</td><td>9
[24 – 33]
28.89
(2 .67)</td><td>7
[28 – 36]
31.88
(2.79)</td><td>41
[24 – 41]
32.15
(3 .56)</td></tr>
<tr><td>Group 2</td><td>10
[28 – 40]
34.40
(4.22)</td><td>19
[30 – 45]
35.74
(3.66)</td><td>7
[23 – 32]
28.71
(2.87)</td><td>10
[26 – 36]
31.50
(3 .50)</td><td>46
[23 – 45]
33.46
(4.39)</td></tr>
<tr><td>Ancestry group totals[1]</td><td colspan="2">68
[26 – 45]
34.41
(3.58)</td><td colspan="2">58
[23 – 37]
30.09
(3.32)</td><td></td></tr>
<tr><td>Sex group totals[2]</td><td></td><td>Males
63
[26 - 45]
33.71
(3.96)</td><td>Females
63
[23 – 40]
31.08
(3.80)</td><td></td><td>Total
126</td></tr>
</table>

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: p = 0.0000
[2]: p = 0.0076

Table 5.10 The percentage correct **prediction of sex** by *Mrb* determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	78.6	69.2	64.0
Group 1	61.9	78.1	68.4
Group 2	55.2	60.9	64.7
Complete sample	51.5	53.2	67.2

Table 5.11 The percentage correct **prediction of ancestry group** by *Mrb* determined by discriminant function analyses

Dentition groups ↓	Male	Both sex group	Female
Group 0	68.4	64.0	55.0
Group 1	73.3	73.2	65.4
Group 2	48.3	52.2	64.7
Complete sample	47.6	49.2	58.9

Table 5.12 *M_corpus length* in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7 [72 – 81] **76.71** (3.25)	7 [69 – 100] **84.86** (9.79)	13 [65 – 100] **73.84** (8.91)	12 [66 – 97] **77.25** (9.96)	39 [65 – 100] **77.38** (9.23)
Group 1	17 [68 – 87] **75.88** (4.48)	8 [77 – 91] **84.88** (4.58)	9 [66 – 79] **70.67** (4.00)	7 [75 – 87] **79.86** (4.18)	41 [66 – 91] **77.05** (6.43)
Group 2	10 [74 – 85] **80.40** (3.81)	19 [75 – 94] **82.84** (4.74)	7 [67 – 81] **73.57** (5.34)	10 [69 – 88] **79.00** (6.48)	46 [67 – 94] **80.07** (5.85)
Ancestry group totals[1]	68 [68 – 100] **80.56** (6.10)		58 [65 – 100] **75.64** (7.71)		
Sex group totals[2]		Males 63 [66 – 100] **81.32** (7.18)	Females 63 [65 – 100] **75.16** (6..7)		Total 126

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: p = 0.0005
[2]: p = 0.0000

Table 5.13 The percentage correct **prediction of sex** by *M_corpus length* as determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	78.6	64.1	60.0
Group 1	**81.1**	**80.5**	**87.5**
Group 2	65.5	63.0	64.7
Complete sample	57.4	50.8	56.1

Table 5.14 The percentage correct **prediction of ancestry group** by *M_corpus length* as determined by discriminant function analyses

Dentition groups ↓	Male	Both sex groups	Female
Group 0	73.7	66.7	65.0
Group 1	**80.0**	58.5	**84.6**
Group 2	69.0	71.7	70.6
Complete sample	57.1	53.2	58.9

Table 5.15 Crude means of Maximum projective length of the mandible *(Max m_length)* in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7 [99 – 115] **105.29** (5.06)	7 [100 – 123] **112.57** (8.38)	13 [93 – 114] **105.08** (6.30)	12 [102 – 120] **110.08** (5.62)	39 [93 – 123] **108.00** (6.81)
Group 1	17 [91 – 113] **103.94** (5.48)	8 [106 – 117] **112.25** (4.23)	9 [79 – 111] **102.33** (9.26)	7 [101 – 120] **109.57** (7.18)	41 [79 – 120] **106.08** (7.48)
Group 2	10 [101 – 116] **107.90** (4.12)	19 [105 – 117] **110.63** (4.22)	7 [12 – 38] **106.00** (8.02)	10 [97 – 123] **108.90** (7.67)	46 [92 – 123] **108.83** (5.87)
Ancestry group totals	68 [91 – 123] **108.40** (5.98)		58 [79 – 123] **106.90** (7.48)		
Sex group totals[1]		Males 63 [97 – 123] **110.56** (5.88)	Females 63 [79 – 116] **104.77** (6.36)		Total 126

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1:] $p < 0.0001$

Table 5.16 The percentage correct **prediction of sex** by *Max m_length* as determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	78.6	61.5	60.0
Group 1	63.7	63.4	56.3
Group 2	62.1	58.7	64.7
Complete sample	55.8	56.4	63.8

Table 5.17 The percentage correct **prediction of ancestry group** by *Max m_length* as determined by discriminant function analyses

Dentition groups ↓	Male	Both sexes	Female
Group 0	57.9	48.7	45.0
Group 1	46.7	56.1	42.3
Group 2	51.7	54.4	64.7
Complete sample	50.8	49.2	49.2

Table 5.18 *Chin height* in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals[1]
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7 [22 – 34] **27.71** (4.39)	7 [23 – 36] **29.14** (4.38)	13 [10 – 29] **18.92** (6.66)	12 [13 – 37] **26.25** (7.15)	39 [10 – 37] **24.59^{a}** (7.24)
Group 1	17 [22 – 39] **30.69** (4.14)	8 [29 – 40] **33.88** (4.02)	9 [13 – 33] **26.33** (5.61)	7 [26 – 38] **32.43** (4.35)	41 [13 – 40] **30.65^{b}** (5.09)
Group 2	10 [28 – 42] **33.30** (4.32)	19 [19 – 28] **35.74** (3.87)	7 [24 – 33] **27.86** (3.18)	10 [17 – 36] **29.00** (4.85)	46 [17 – 42] **32.54^{b}** (5.14)
Ancestry group totals[1]	68 [22 – 42] **32.44** (4.85)		58 [10 – 38] **26.03** (7.00)		
Sex group totals[2]		Males 63 [13 – 42 **31.52** (5.97)	Females 63 [10 – 42] **27.35** (6.84)		Total 126

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: $p = 0.0000$
[2]: $p = 0.0001$
[a.b]: least square means with the same letter in the superscript did not differ significantly on the 5% level of significance
Dentition group 0 compared to 1: $p < 0.001$; dentition group 0 compared to 2: p = < 0.001

Table 5.19 The percentage correct **prediction of sex** by *Chin height* as determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry group	SAE
Group 0	57.1	61.5	64.0
Group 1	**84.0**	**85.4**	**87.5**
Group 2	69.0	58.7	70.6
Complete sample	55.9	60.0	64.9

Table 5.20 The percentage correct **prediction of ancestry group** by *Chin height* as determined by discriminant function analyses

Dentition groups ↓	Male	Both sex groups	Female
Group 0	57.9	55.3	68.4
Group 1	46.7	61.0	53.9
Group 2	55.7	56.5	47.1
Complete sample	50.8	52.8	53.2

Table 5.21 *Bigon* in mm

Dentition groups ↓	Ancestry and sex: SAA Female	SAA Male	SAE Female	SAE Male	Dentition group totals
Group 0	9 [80 – 96] **88.00** (5.00)	7 [95 – 105] **99.43** (3.99)	13 [84 – 96] **90.46** (3.64)	12 [94 – 105] **98.50** (4.03)	39 [80 – 105] **94.10** (6.17)
Group 1	17 [81 – 96] **89.06** (4.36)	8 [87 – 110] **95.13** (8.04)	9 [88 – 98] **92.78** (3.27)	7 [91 – 110] **99.29** (7.20)	41 [81 – 110] **92.90** (6.59)
Group 2	10 [83 – 101] **92.50** (4.97)	19 [82 – 104] **95.89** (6.01)	7 [82 – 100] **89.71** (5.91)	10 [89 – 106] **97.50** (4.90)	46 [82 – 106] **94.57** (6.01)
Ancestry group totals[1]	SAA: 68 [80 – 110] **93.21** (6.47)		SAE: 58 [82 – 110] **94.67** (5.92)		
Sex group totals[2]		Males 63 [82 – 110] **97.32** (5.76)	Females 63 [80 – 101] **90.40** (4.58)		Total 126

n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: p = 0.0499
[2]: p = 0.0000

Table 5.22 The percentage correct **prediction of sex** by *Bigon* as determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	71.4	71.1	**83.3**
Group 1	56.0	65.9	**81.3**
Group 2	69.0	73.9	**82.4**
Complete sample	55.9	64.0	64.9

Table 5.23 The percentage correct **prediction of ancestry group** by *Bigon* as determined by discriminant function analyses

Dentition groups ↓	Male	Both sex groups	Female
Group 0	47.4	48.9	60.0
Group 1	53.3	62.9	68.0
Group 2	51.7	50.0	58.8
Complete sample	54.0	52.0	54.8

Table 5.24 *Ram_ht* in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	7 [50 – 54] **51.71** (1.70)	7 [53 – 71] **60.71** (5.85)	13 [49 – 64] **55.92** (4.57)	12 [50 – 75] **63.67** (6.92)	39 [49 – 75] **58.41** (6.81)
Group 1	17 [44 – 55] **50.06** (3.28)	8 [53 – 63] **59.13** (3.76)	9 [52 – 61] **57.22** (2.44)	7 [58 – 72] **65.14** (4.49)	41 [44 – 72] **56.13** (6.54)
Group 2	10 [48 – 57] **52.10** (2.69)	19 [46 – 67] **58.21** (5.54)	7 [55 – 62] **57.86** (2.67)	10 [54 – 73] **65.10** (5.19)	46 [46 – 73] **58.33** (6.23)
Ancestry group totals[1]	68 [12 – 38] **55.78** (6.62)		58 [12 – 38] **60.95** (6.14)		
Sex group totals[1]		Males 63 [46 – 75] **61.51** (6.07)	Females 63 [44 – 64] **53.73** (4.34)		Total 126

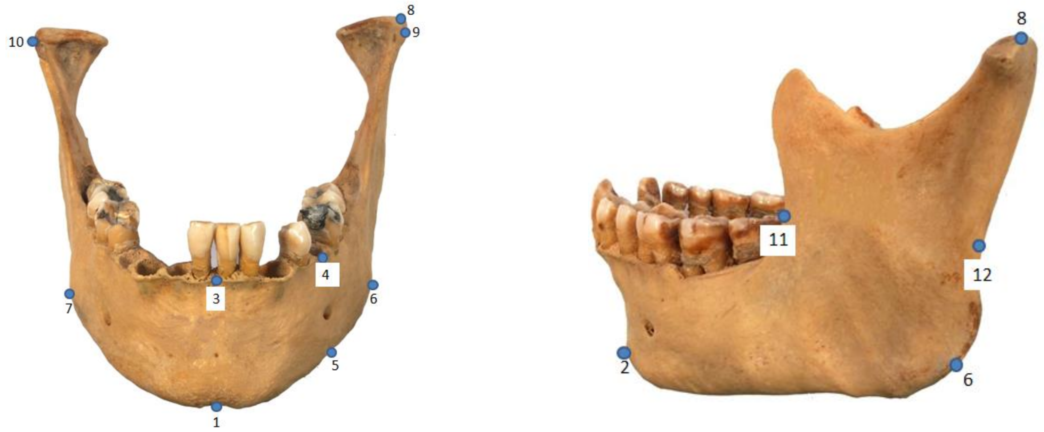
n the first value in every set
minimum and maximum values in square brackets []
mean given in bold
standard deviation in parenthesis ()
[1]: p = 0.0000

Table 5.25 The percentage correct **prediction of sex** by *Ram_ht* as determined by discriminant function analyses

Dentition groups ↓	SAA	Both ancestry groups	SAE
Group 0	**92.9**	76.9	76.0
Group 1	68.8	58.5	68.0
Group 2	**82.8**	**84.8**	**88.2**
Complete sample	61.8	60.0	57.9

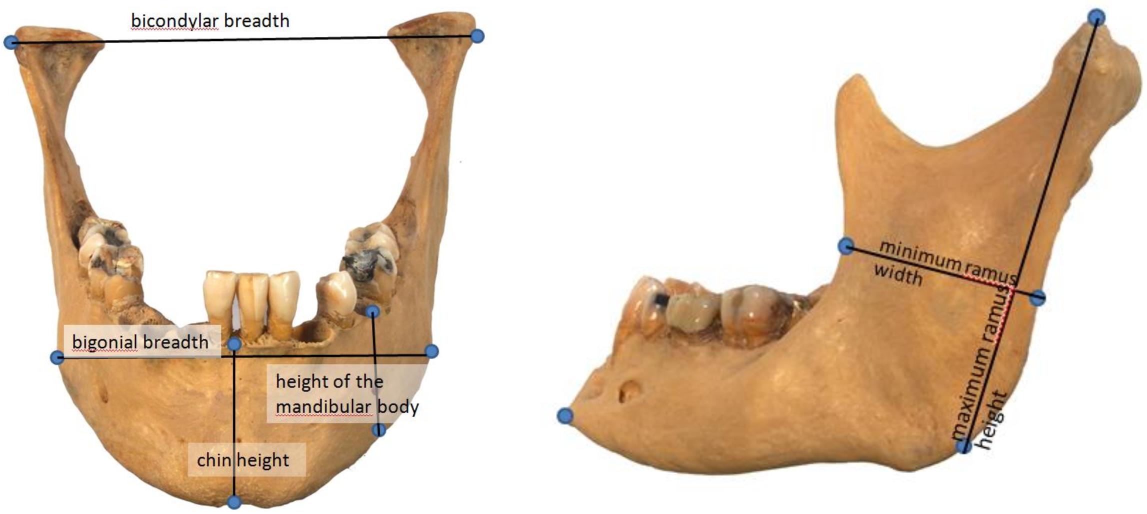
Table 5.26 The percentage correct prediction of ancestry group *Ram_ht* as determined by discriminant function analyses

Dentition groups ↓	Male	Both sex groups	Female
Group 0	52.6	55.3	57. 9
Group 1	60.0	53.7	53.9
Group 2	51.7	48.9	58.8
Complete sample	49.2	52.8	58.1



Anterior view   Lateral view

Fig. 5.1 Landmarks identified on dried mandibles. The descriptions of the specific landmarks can be found in the text



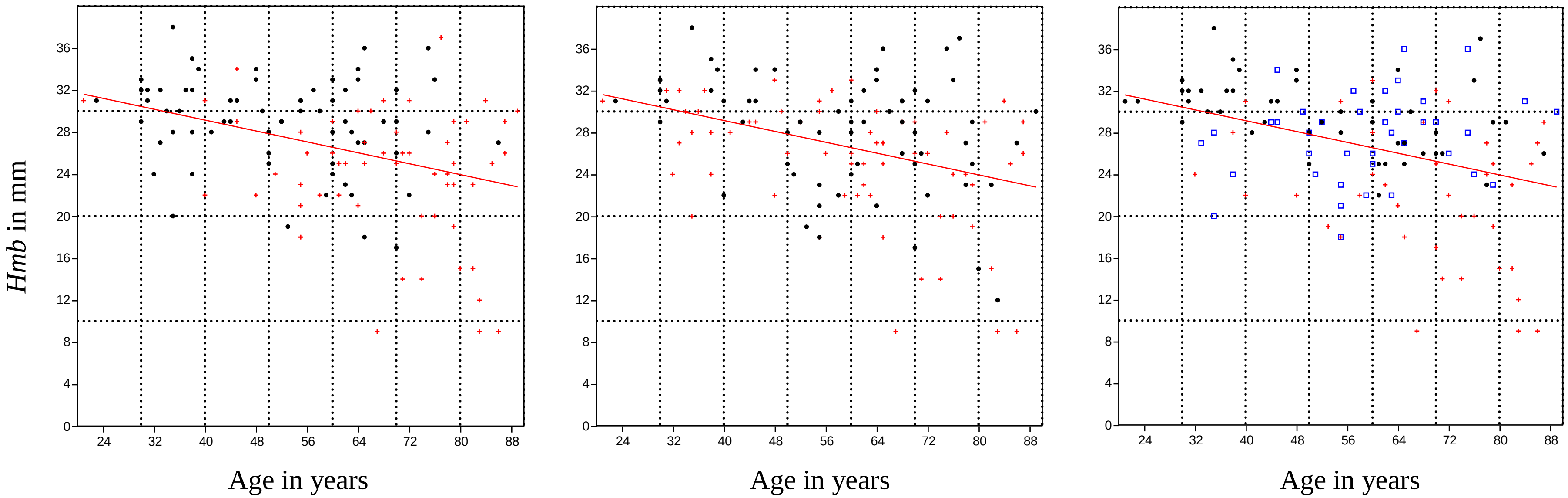
Anterior view   Lateral view

Fig. 5.2 Distances measured on dried mandibles

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



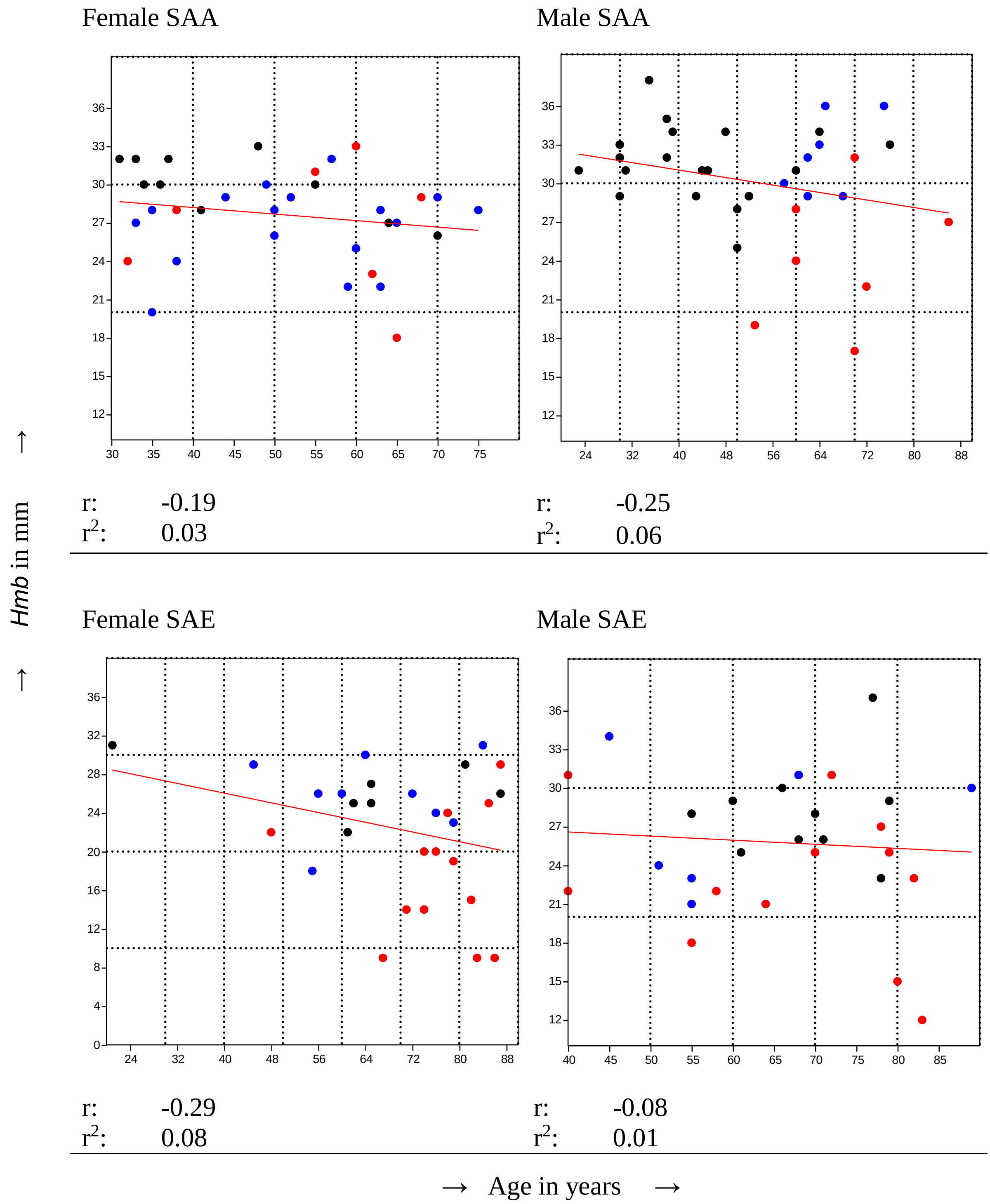
r:	-0.37
r^2:	0.13

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

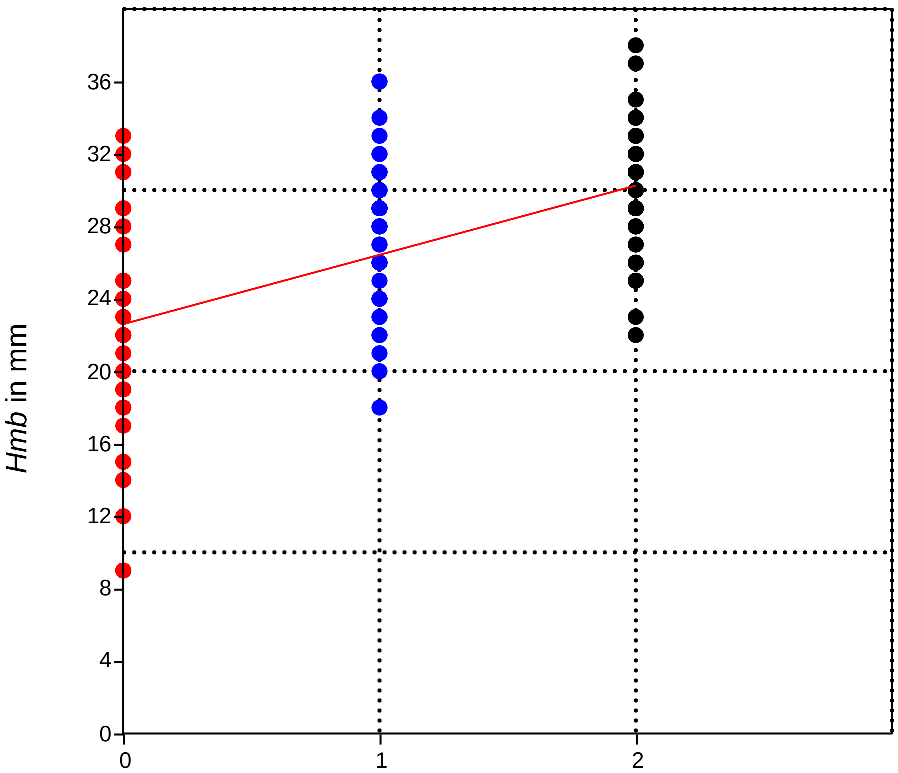
Red: SAE
Black: SAA

Fig. 5.3 Linear regression of age in years vs. *Hmb*



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

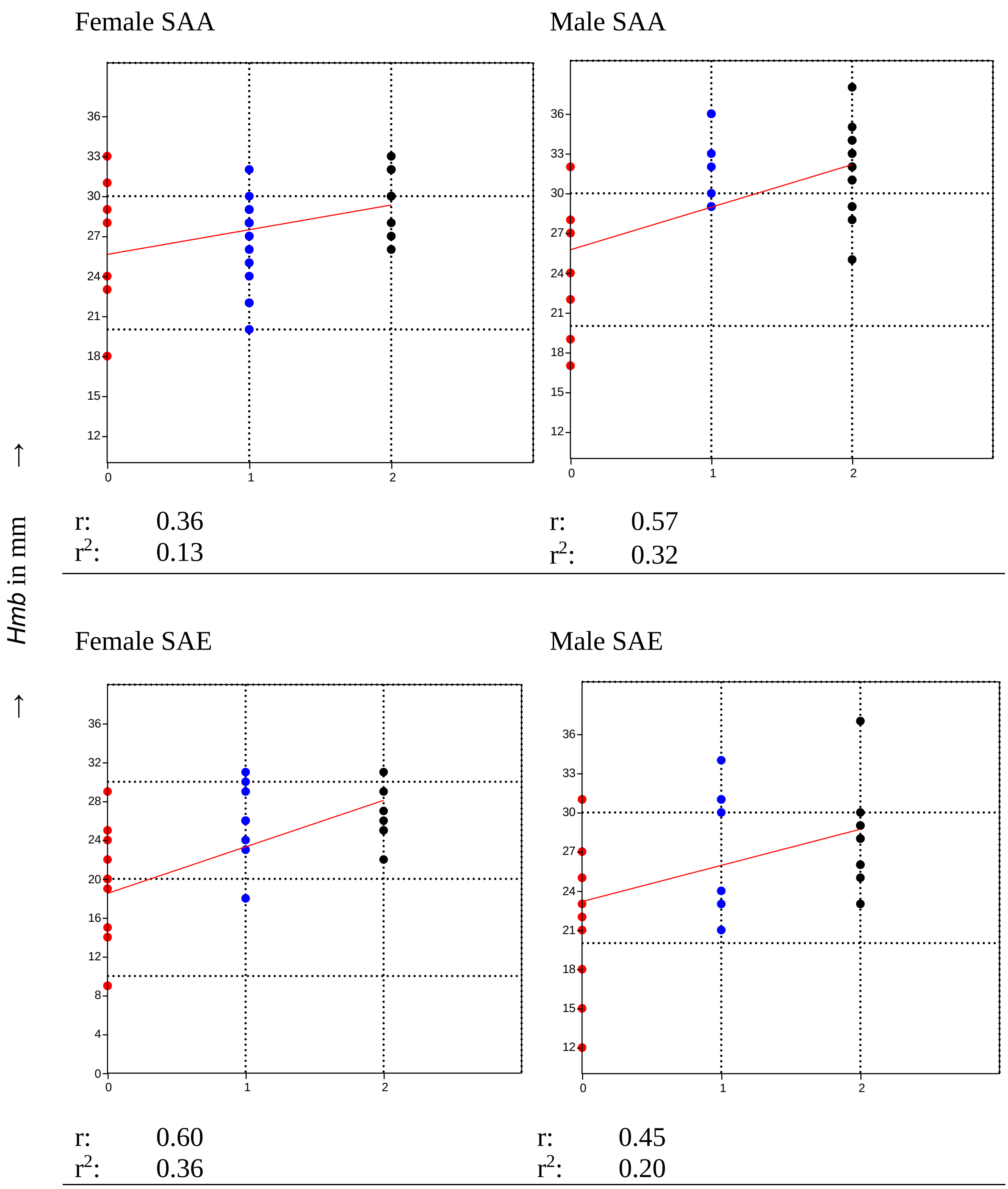
Fig. 5.4 Linear regression of *Hmb* vs. age in years in sex-ancestry groups differentiating between dentition groups



r:	0.54
r^2:	0.29

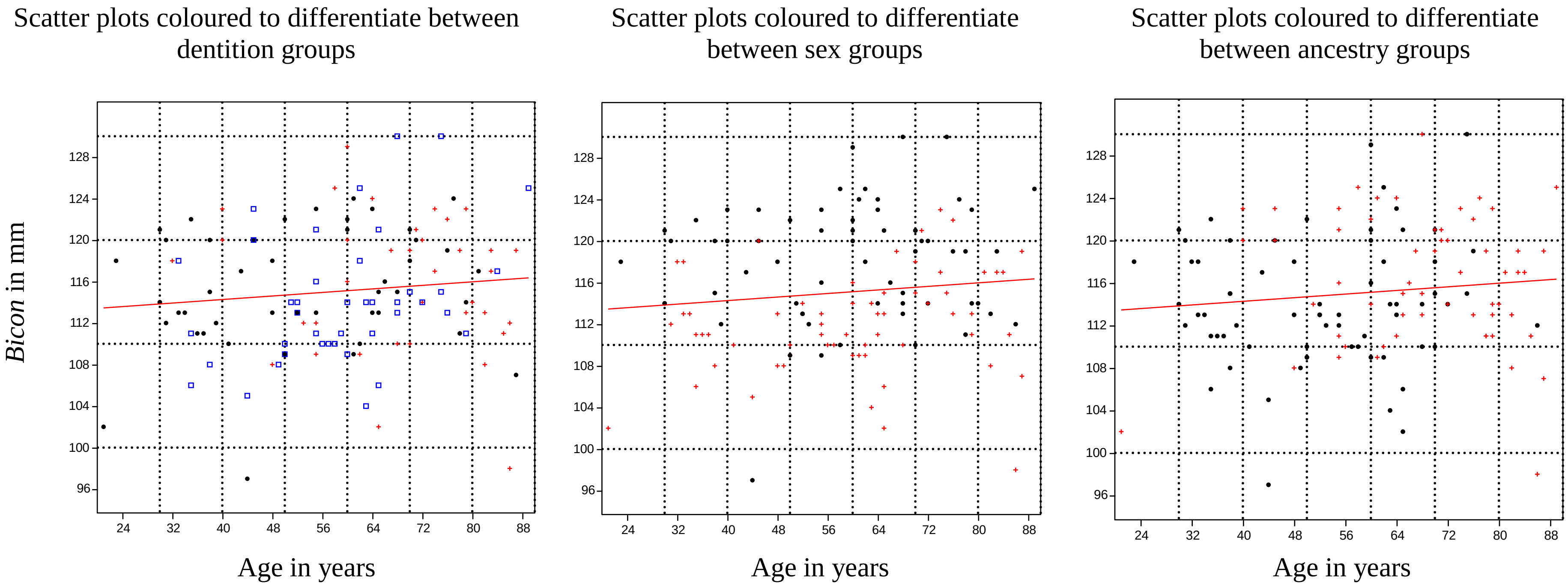
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.5 Linear regression of *Hmb* vs. dentition group differentiating



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.6 Linear regression of *Hmb* vs. dentition group in sex-ancestry groups



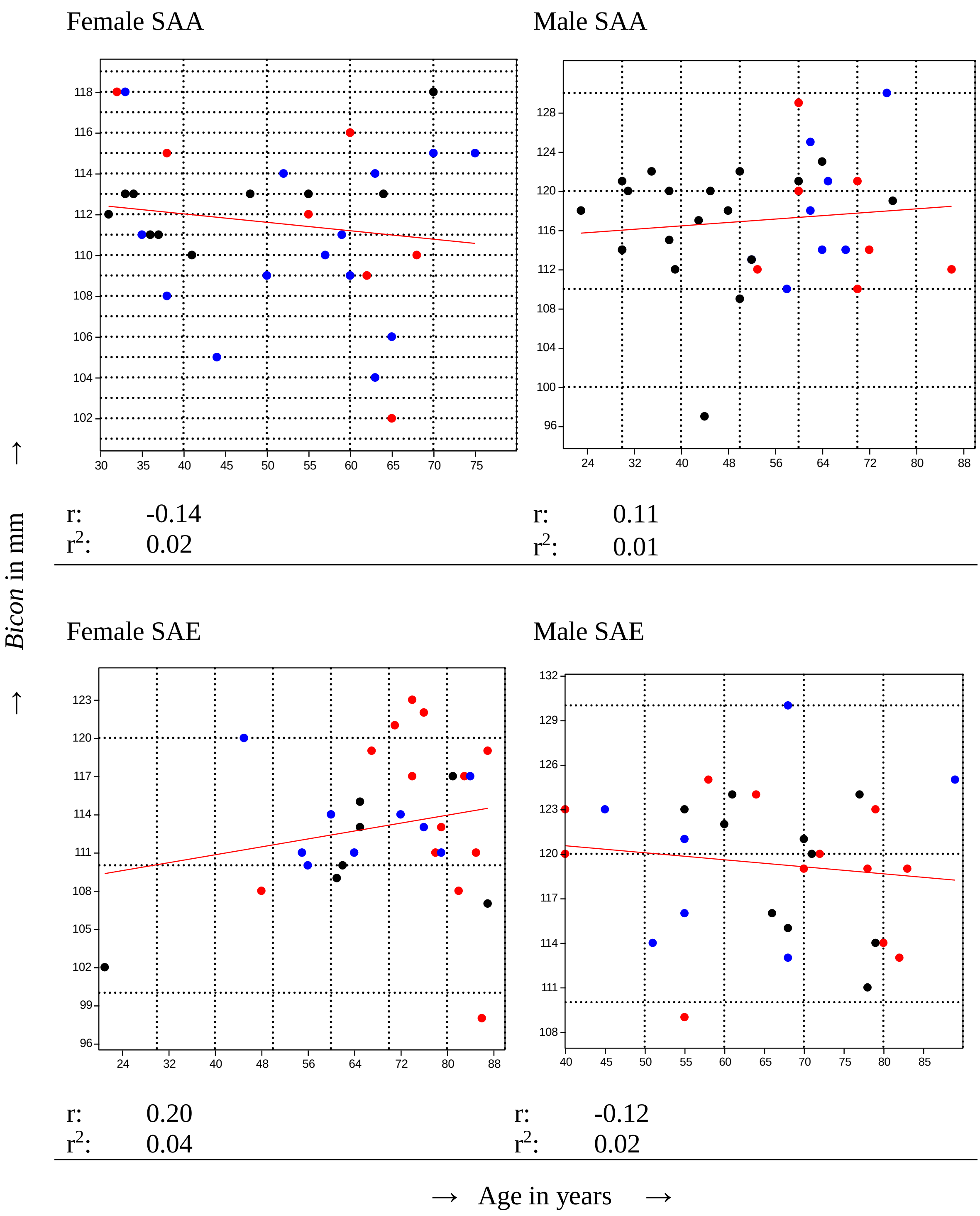
r:	0.11
r^2:	0.01

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

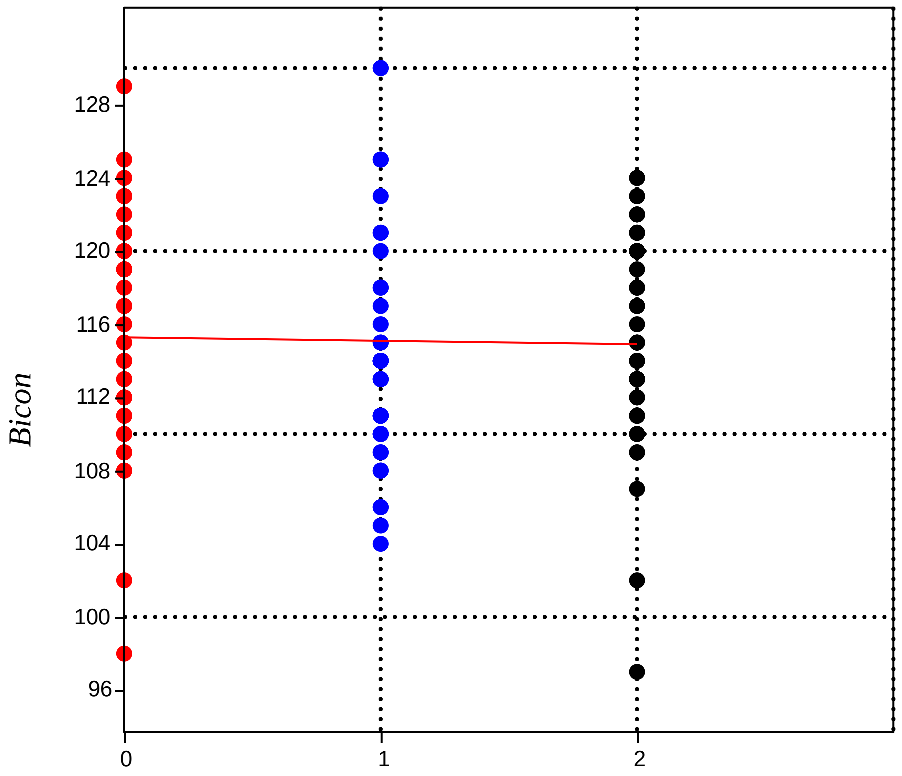
Red: SAE
Black: SAA

Fig. 5.7 Linear regression of age in years vs. *Bicon* in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

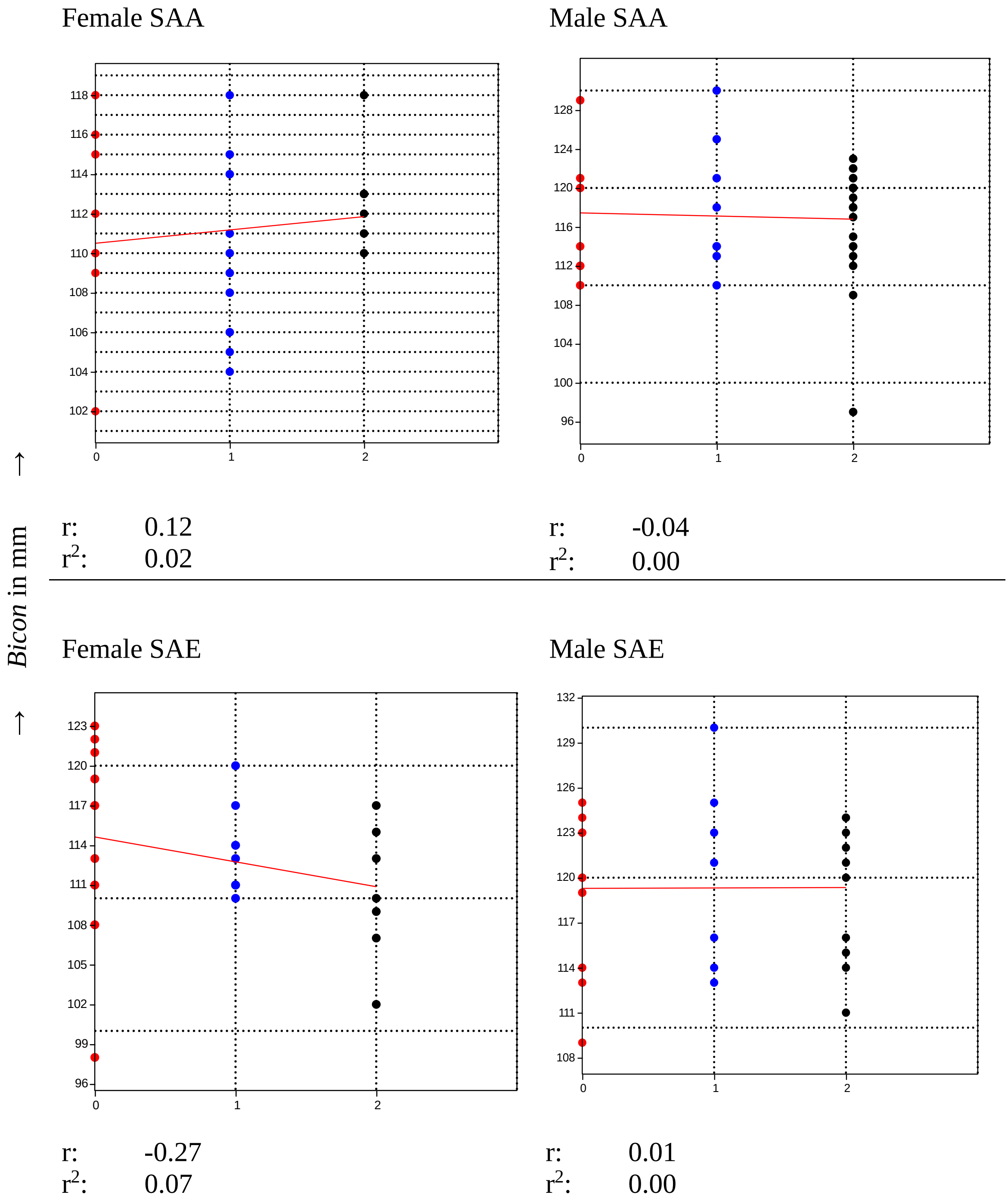
Fig. 5.8 Linear regression of *Bicon* vs. age in years in sex-ancestry groups differentiating between dentition groups



r: -0.02
r^2: 0.00

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.9 Linear regression of *Bicon* vs. dentition group in years differentiating between dentition groups



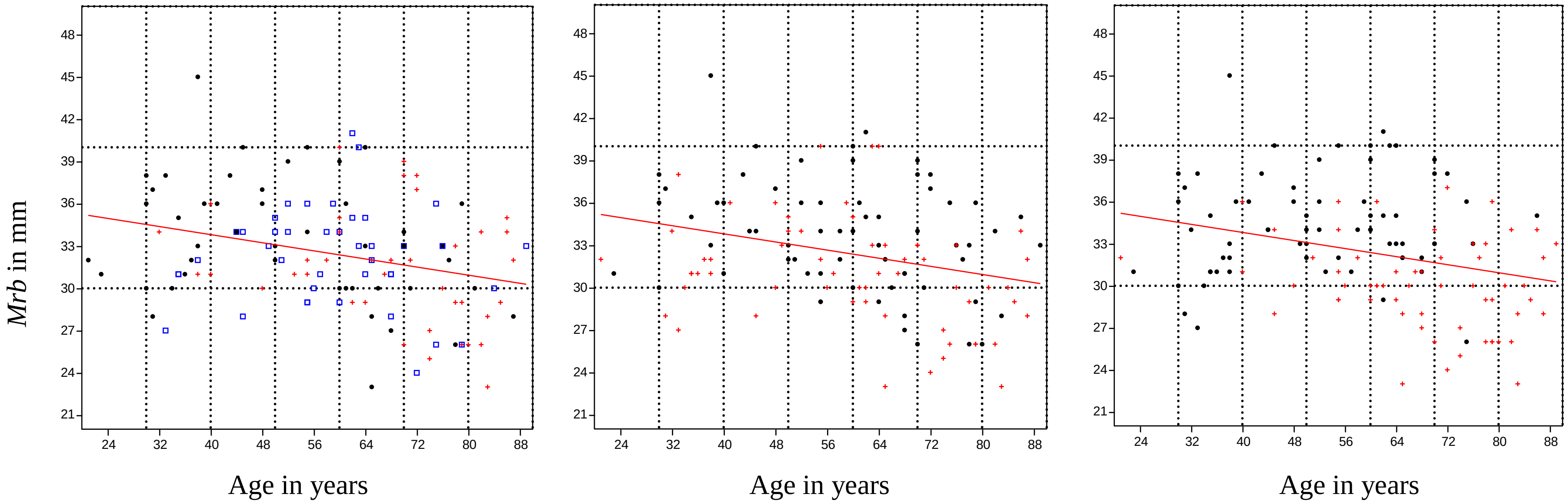
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.10 Linear regression of *Bicon* vs. dentition group in sex-ancestry groups differentiating between dentition groups

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



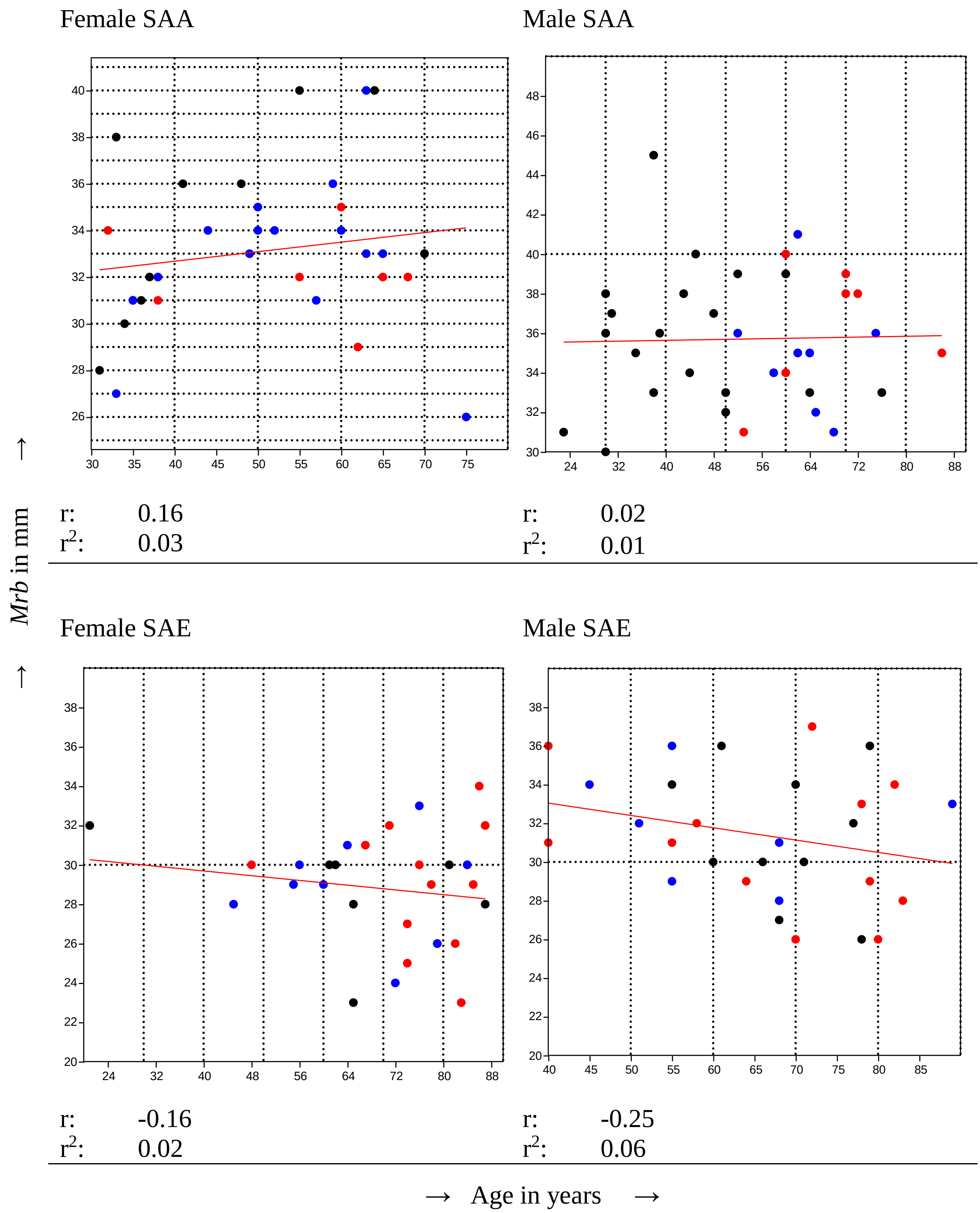
r:	-0.29
r^2:	0.08

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

Red: SAE
Black: SAA

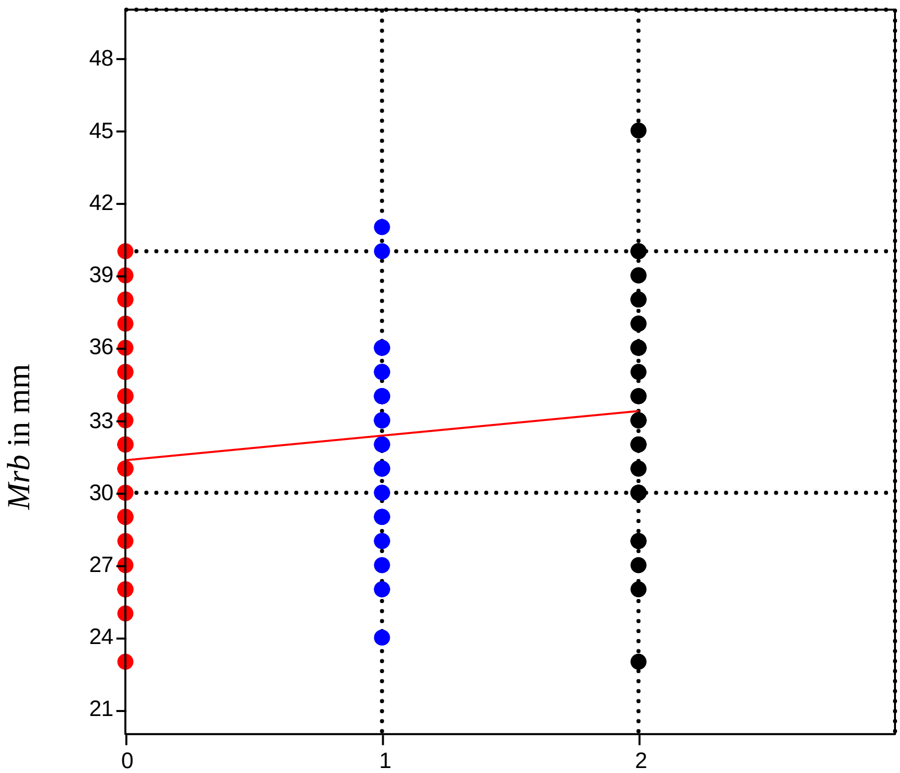
Fig. 5.11 Linear regression of age in years vs. *Mrb* in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.12 Linear regression of *Mrb* vs. age in years in sex-ancestry groups differentiating between dentition groups

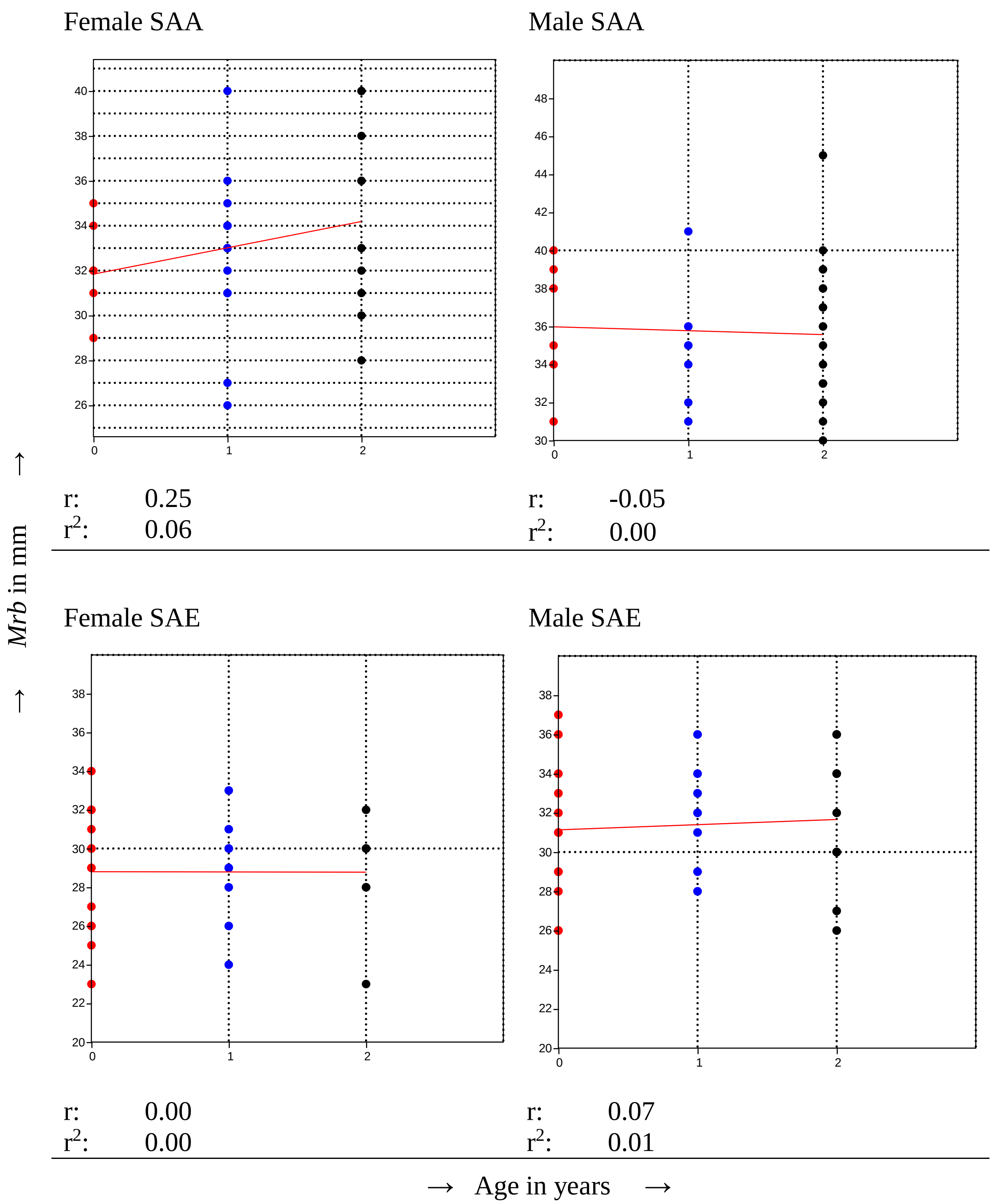
.



r: 0.21
r^2: 0.04

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.13 Linear regression of *Mrb* vs. age in years differentiating between dentition groups



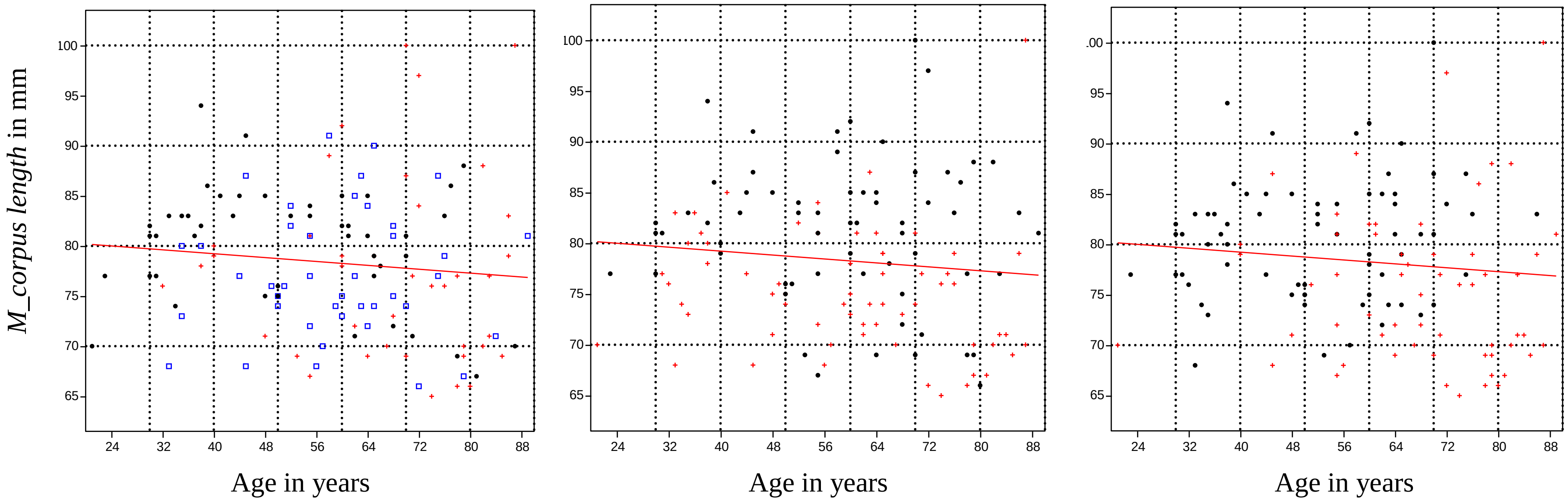
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.14 Linear regression of *Mrb* vs. age in years in sex-ancestry groups differentiating between dentition groups

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



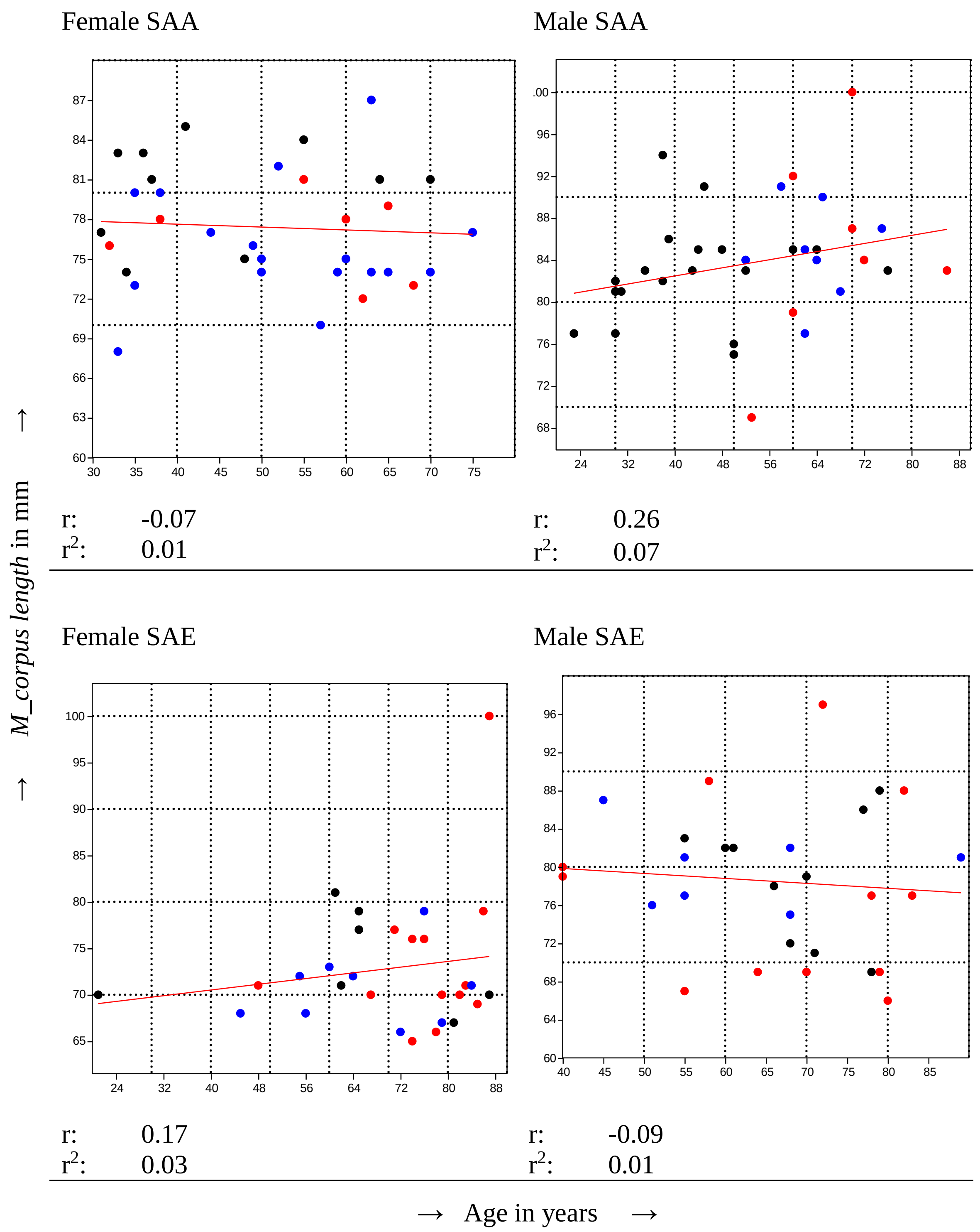
r:	-0.11
r^2:	0.01

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

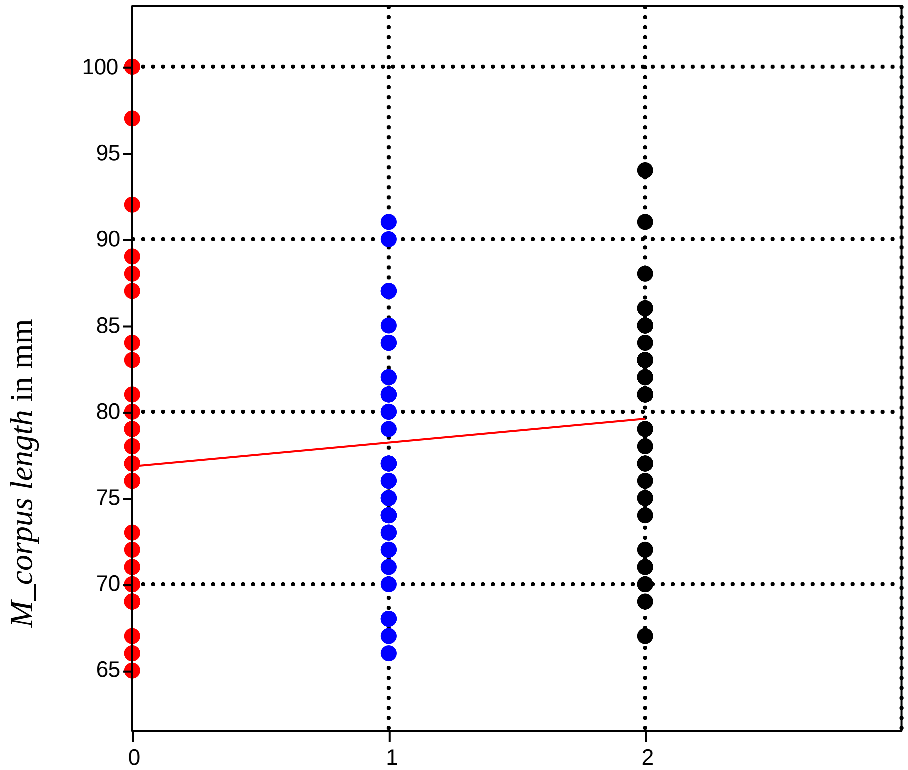
Red: SAA
Black: SAE

Fig. 5.15 Linear regression of age in years vs. *M_corpus length* in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.16 Linear regression of *M_corpus length* vs. age in years in sex-ancestry groups differentiating between dentition groups

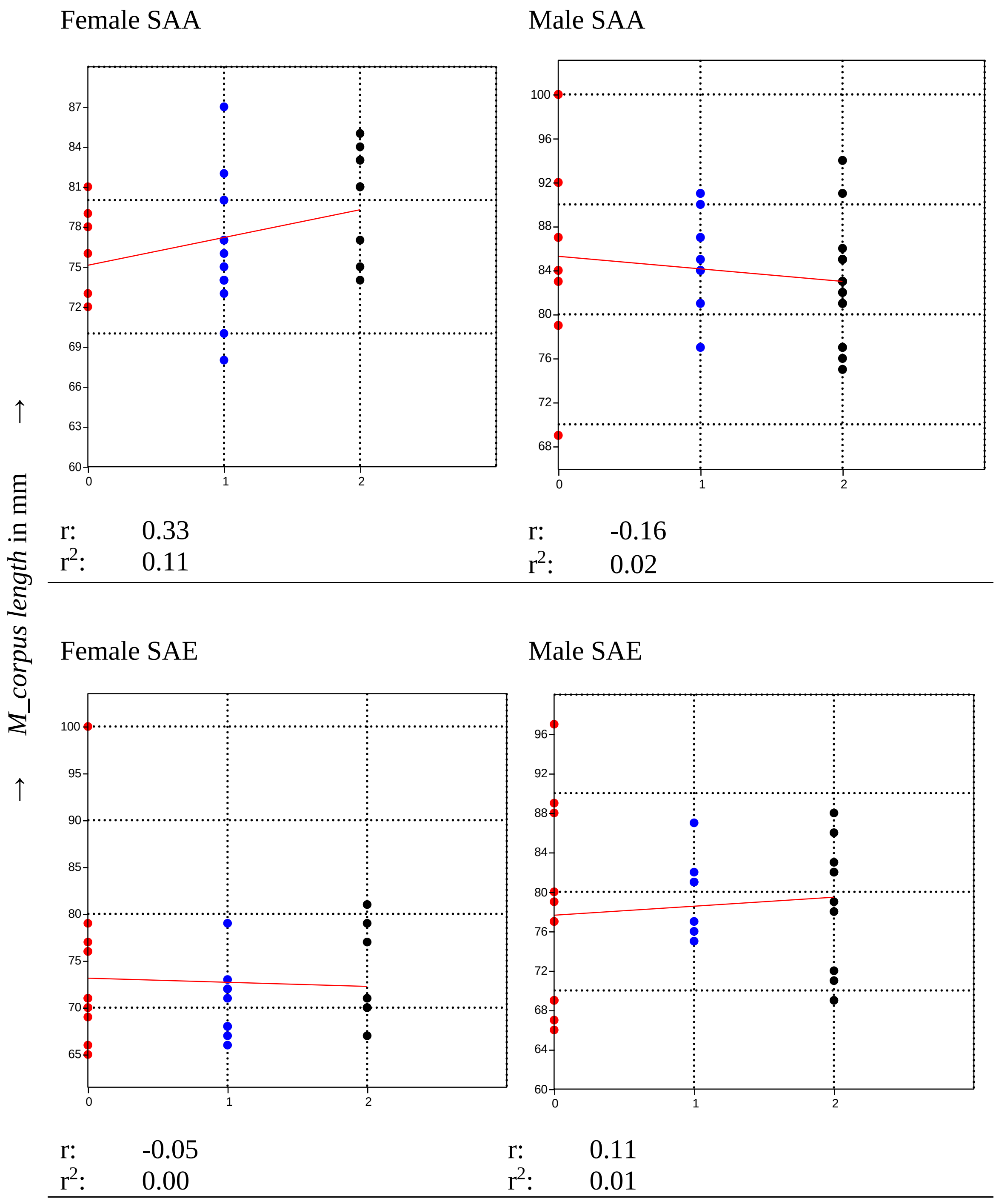


r: 0.16

r^2: 0.02

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Fig. 5.17 Linear regression of *M_corpus length* vs. dentition group in years differentiating between dentition groups



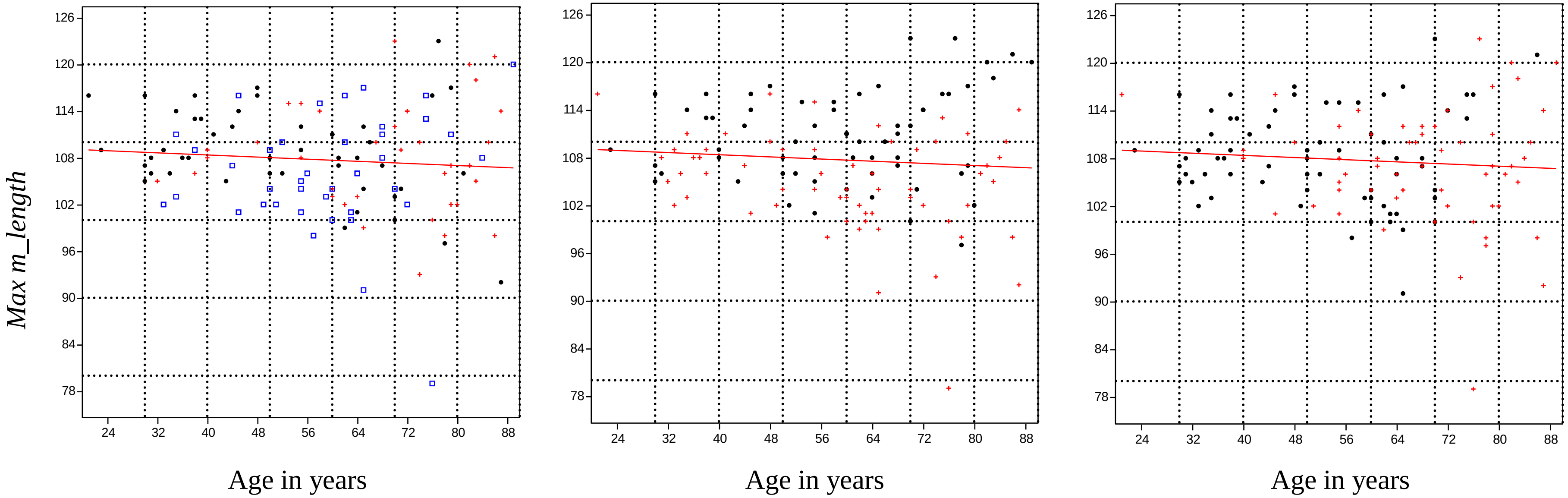
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.18 Linear regression of *M_corpus length* vs. dentition group in sex-ancestry groups

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



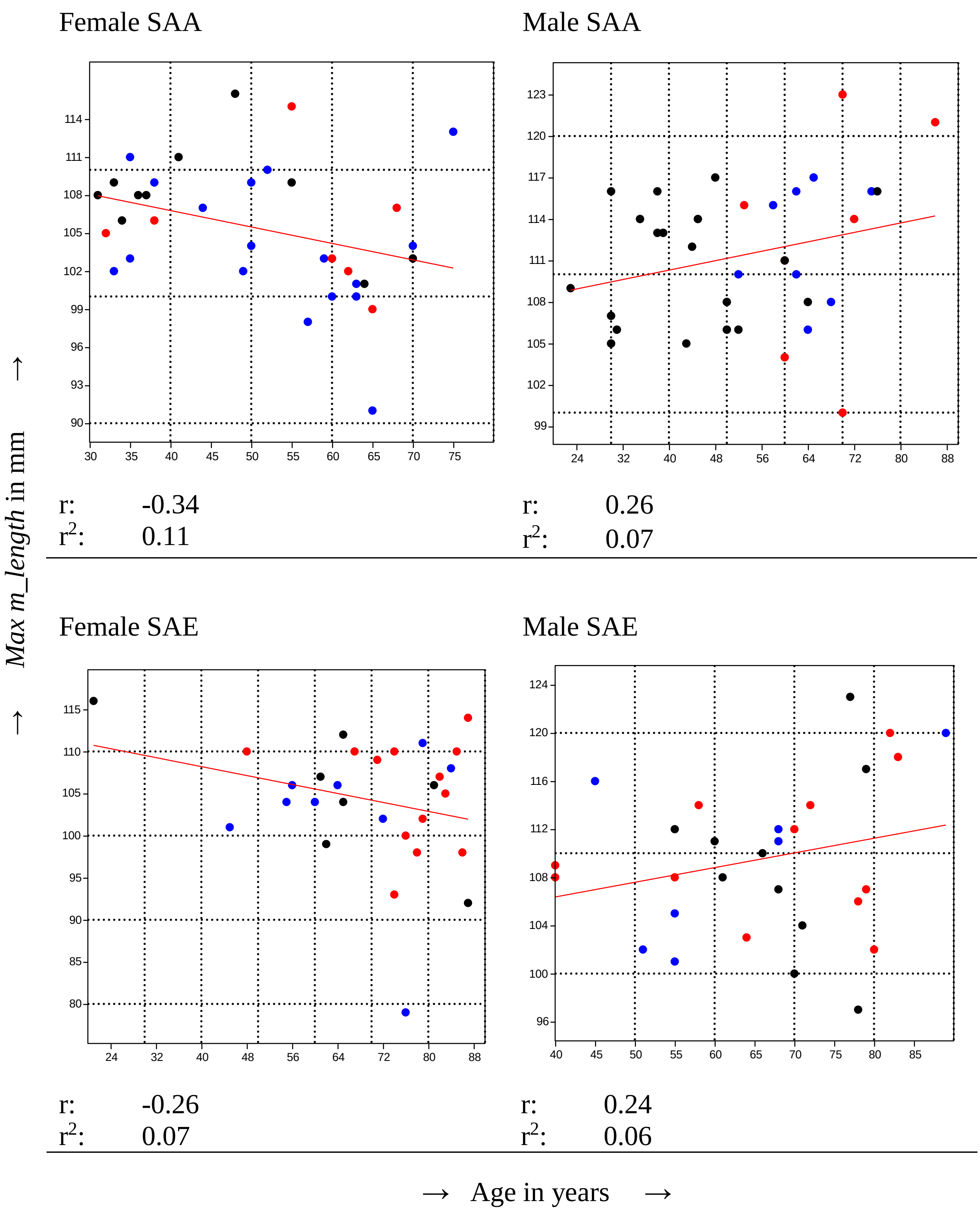
r:	-0.09
r^2:	0.01

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

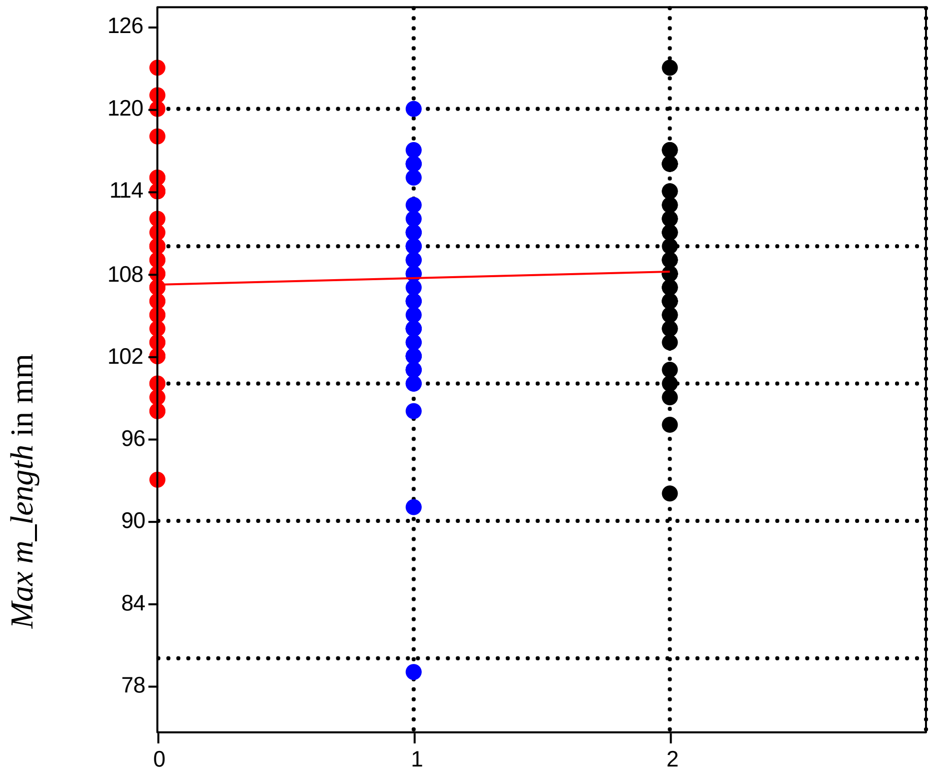
Red: SAE
Black: SAA

Fig. 5.19 Linear regression of age in years vs. *Max m_length* in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.20 Linear regression of *Max m_length* vs. age in years in sex-ancestry groups differentiating between dentition groups

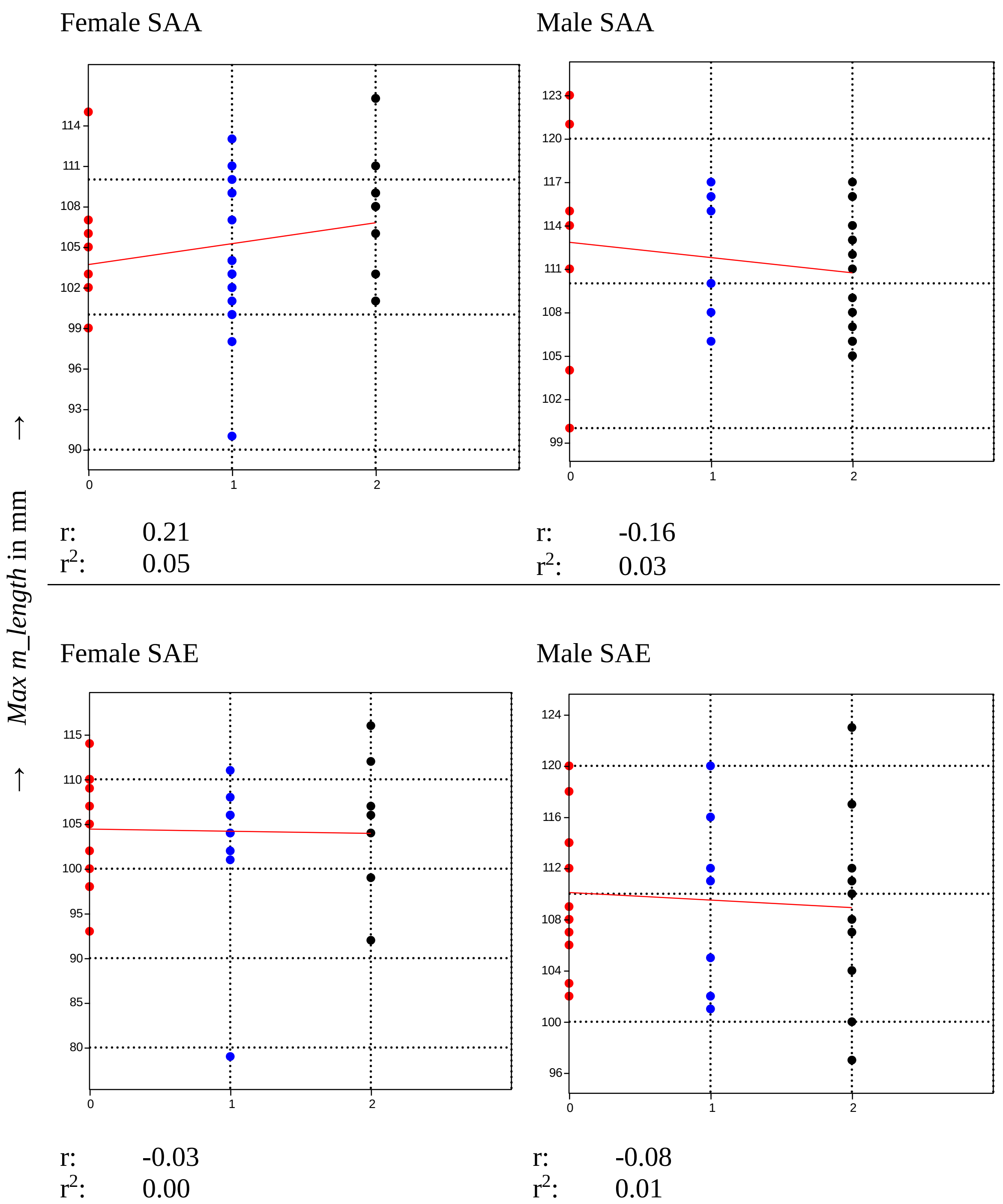


r: 0.06

r^2: 0.00

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.21 Linear regression of *Max m_length* vs. dentition group



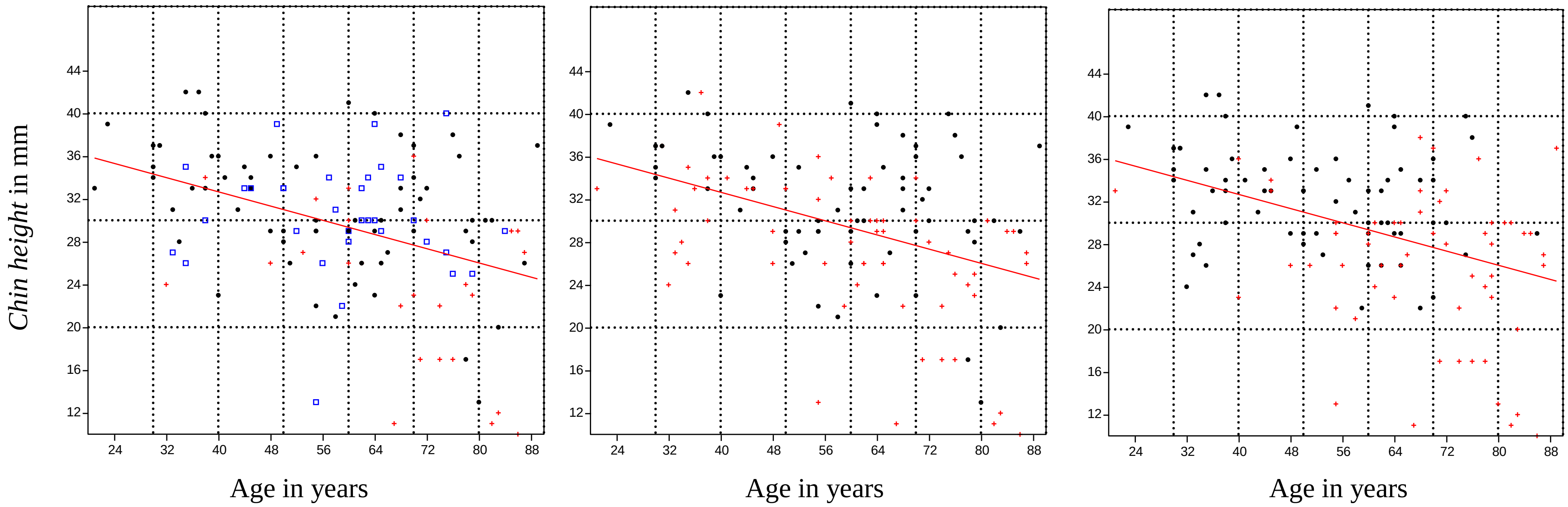
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.22 Linear regression of *Max m_length* vs. dentition in years in sex-ancestry groups differentiating between dentition groups

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



r: -0.41

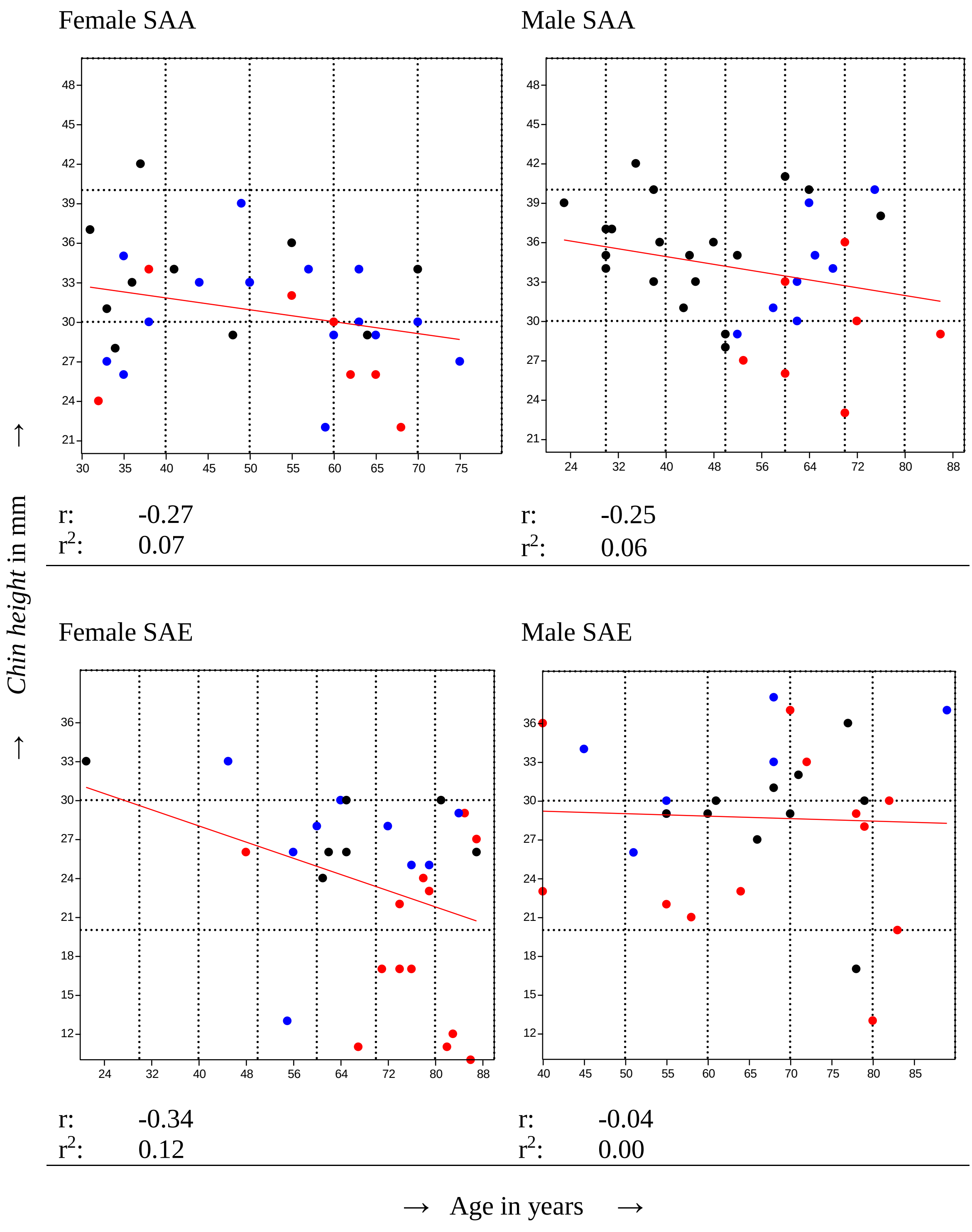
r^2: 0.16

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

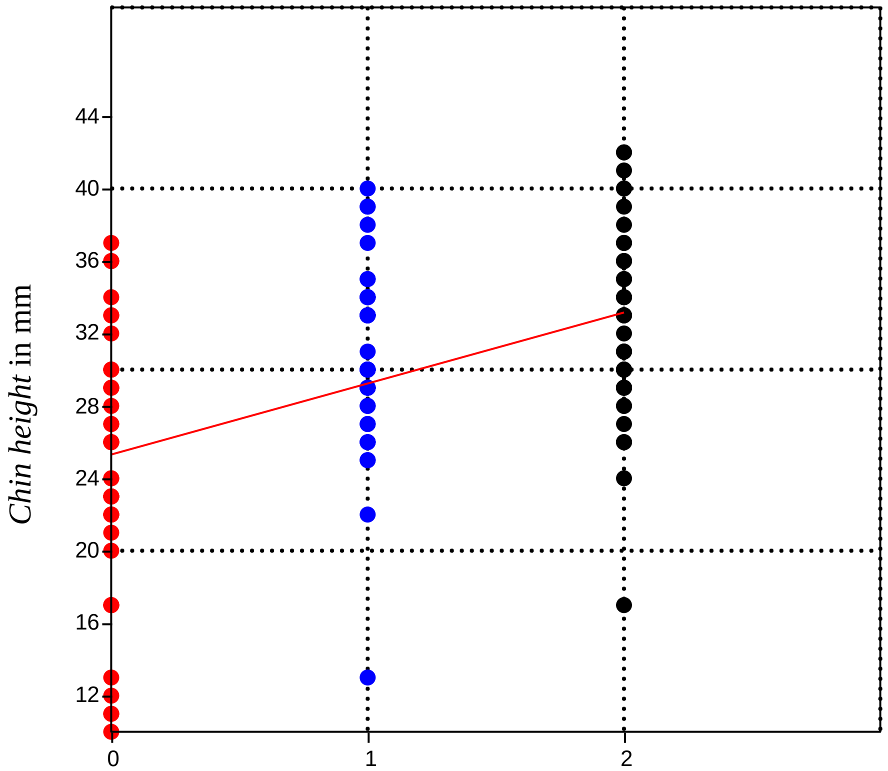
Red: SAE
Black: SAA

Fig. 5.23 Linear regression of age in years vs. *Chin height* in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

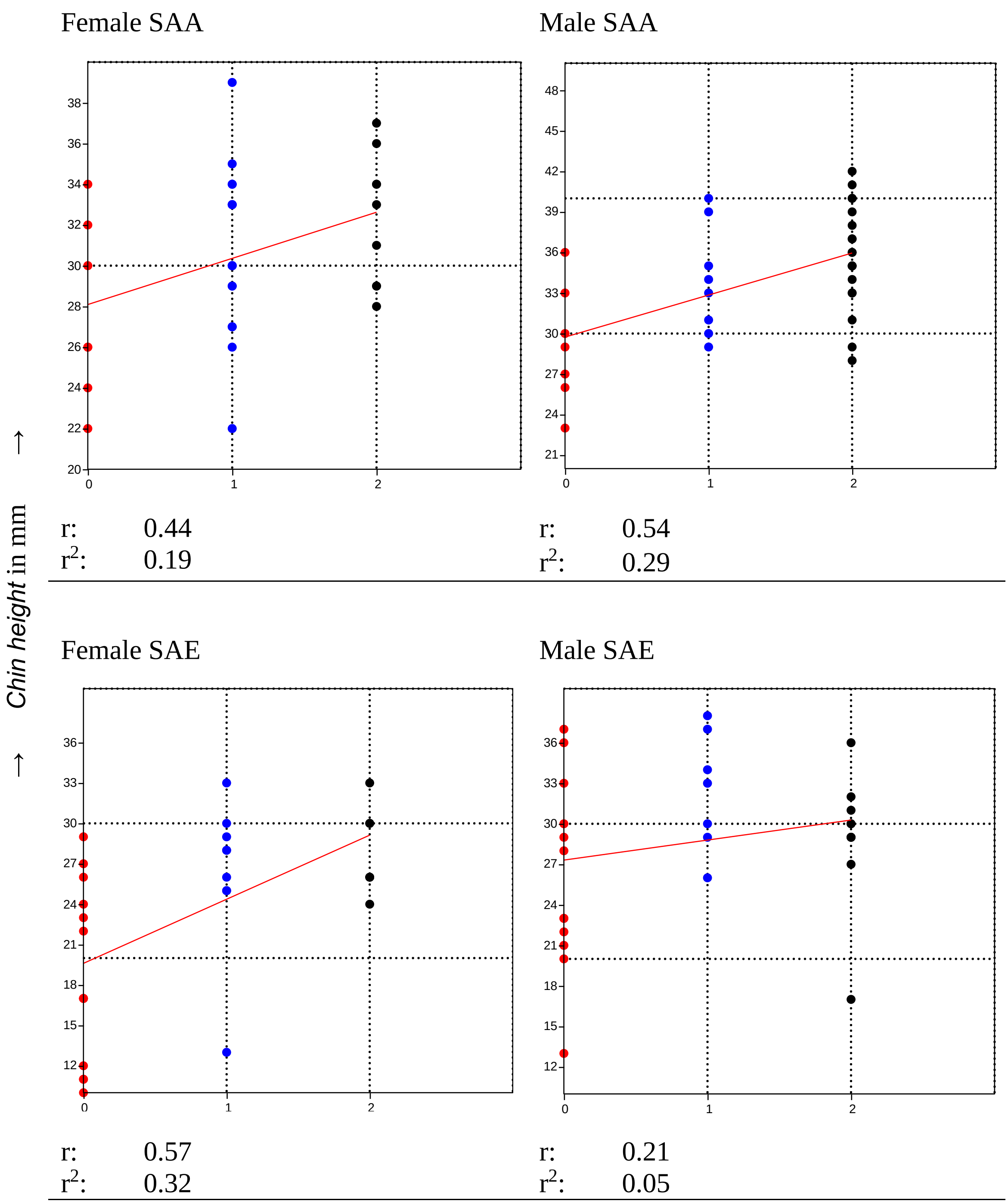
Fig. 5.24 Linear regression of *Chin height* vs. age in years in sex-ancestry groups differentiating between dentition groups



r: 0.48
r^2: 0.23

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.25 Linear regression of *Chin height* vs. dentition group



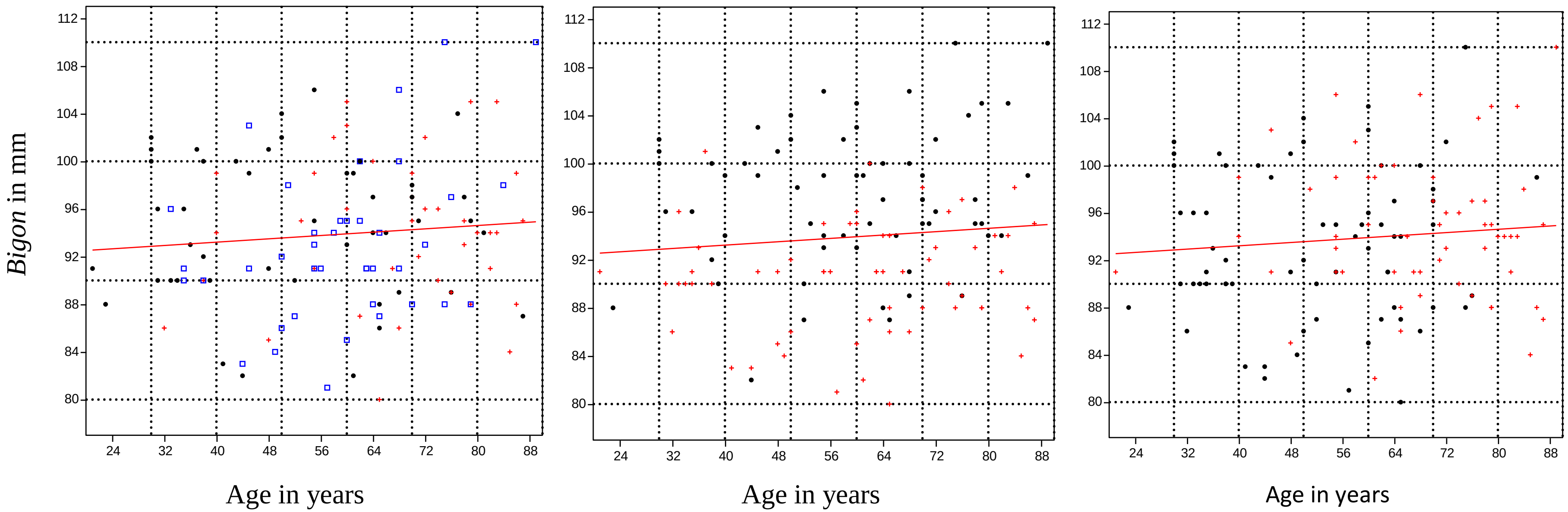
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.26 Linear regression of *Chin height* vs. dentition in years in sex-ancestry groups differentiating between dentition groups

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



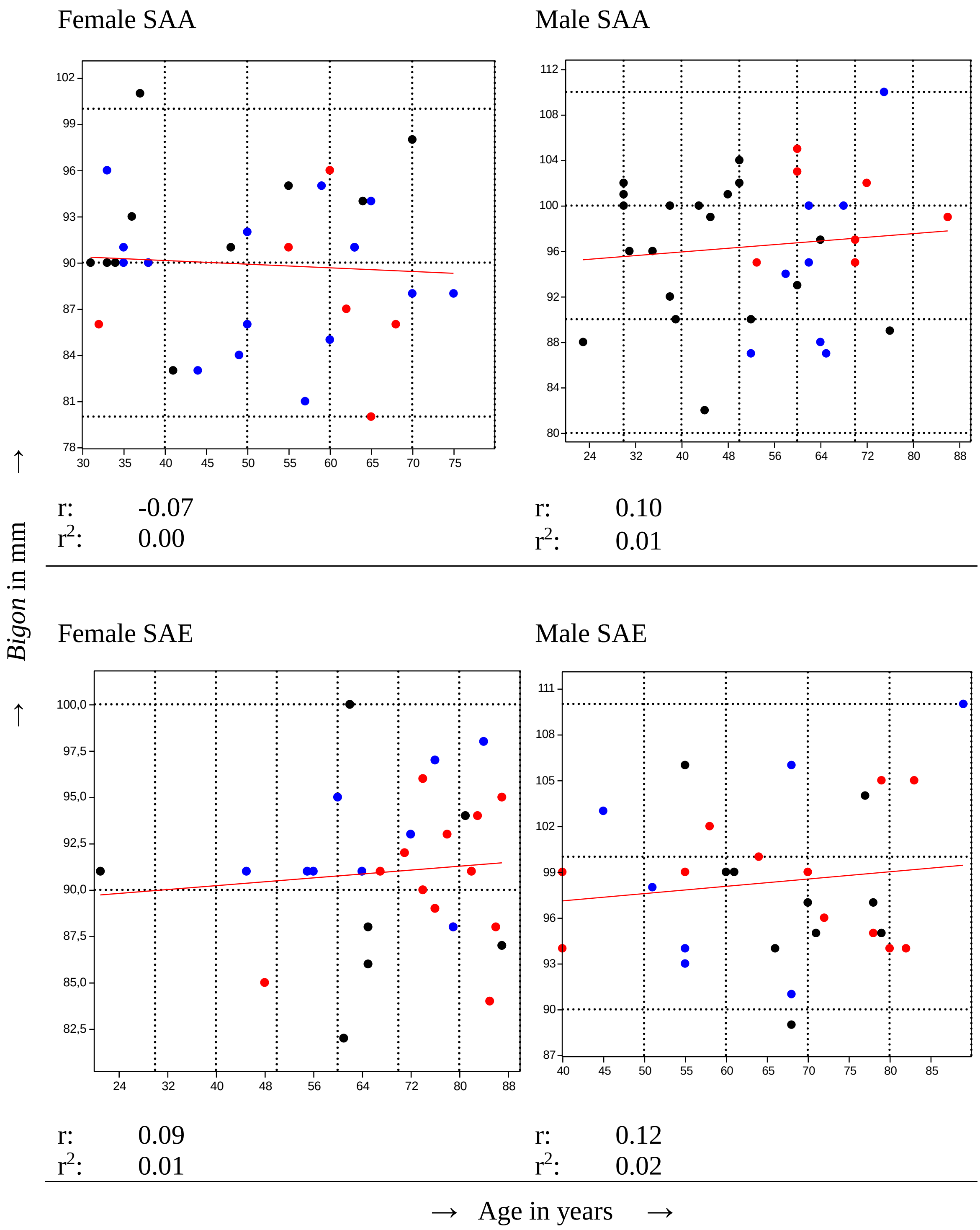
r:	0.09
r^2:	0.01

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

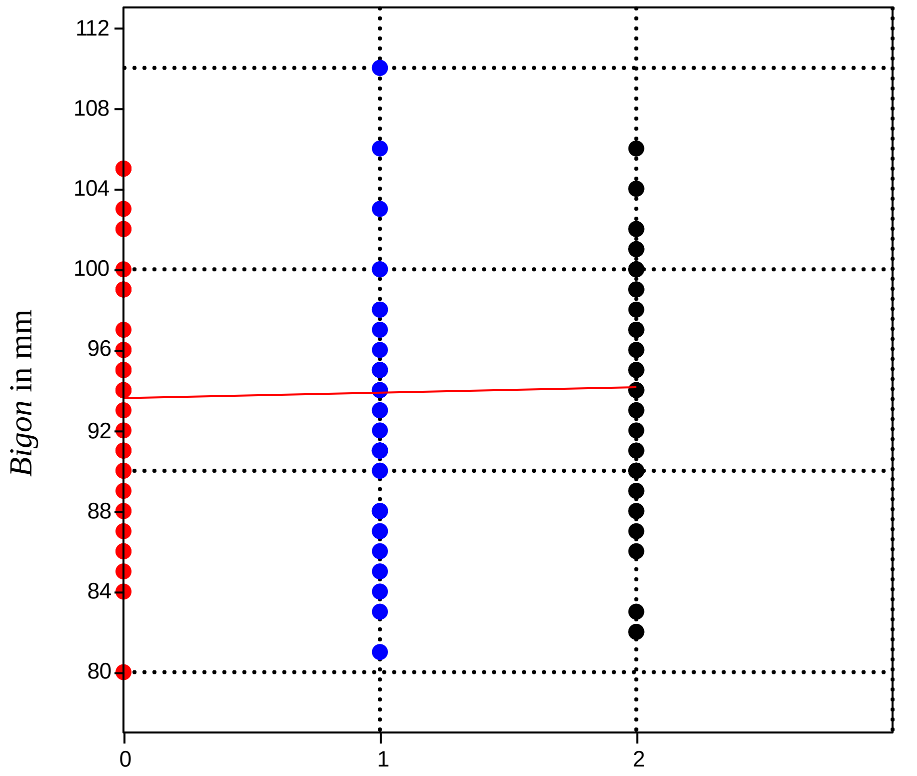
Red: SAE
Black: SAA

Fig. 5.27 Linear regression of age in years vs. Bigon in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

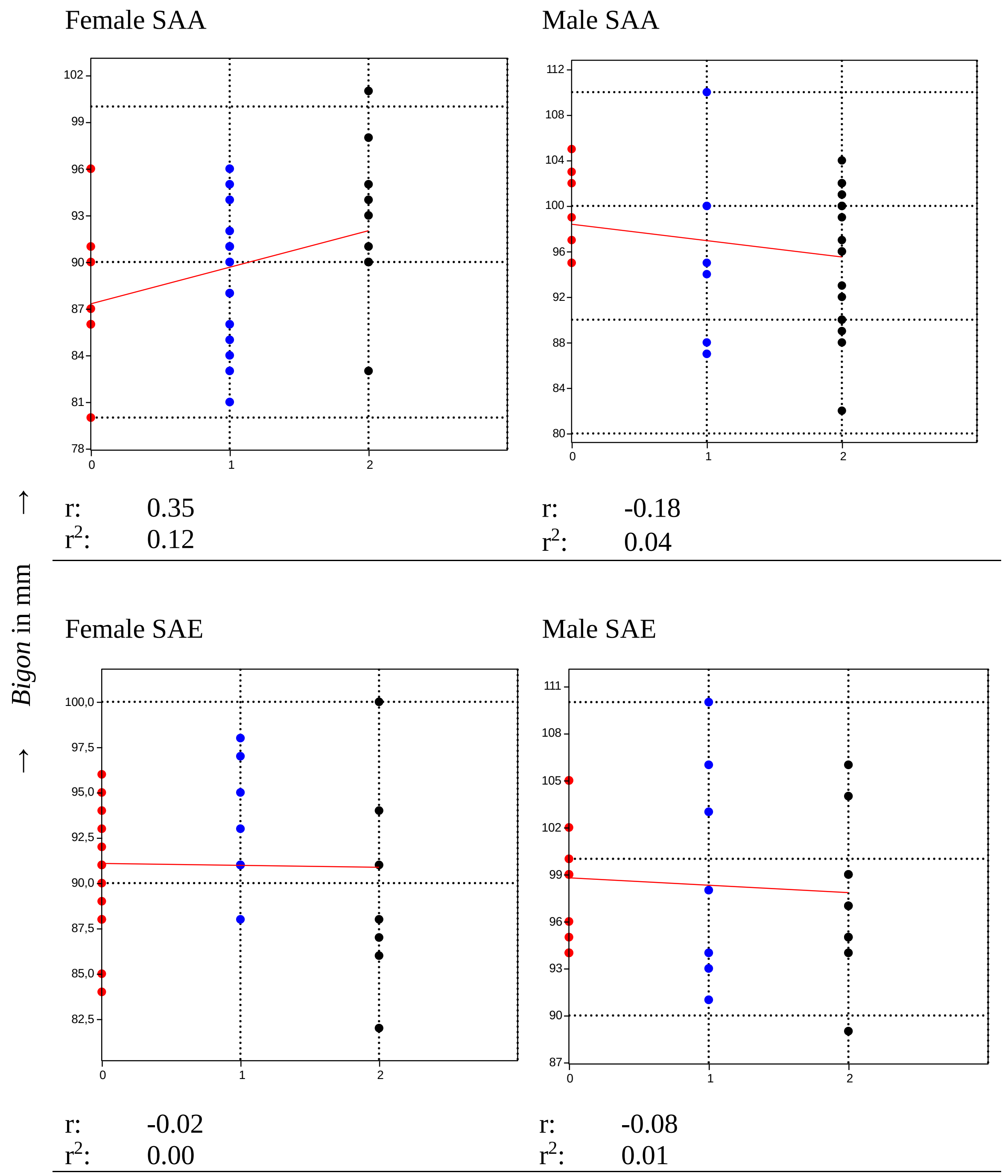
Fig. 5.28 Linear regression of *Bigon* vs. age in years in sex-ancestry groups differentiating between dentition groups



r: 0.04
r^2: 0.00

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.29 Linear regression of *Bigon* vs. dentition group



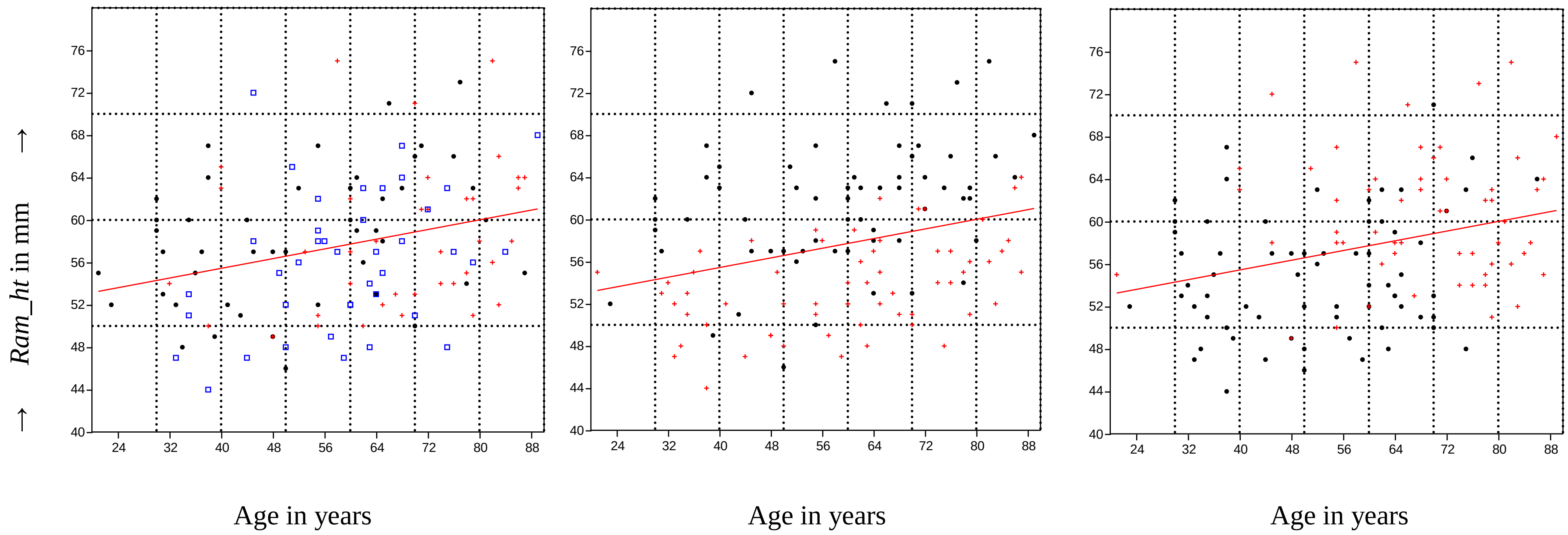
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.30 Linear regression of *Bigon* vs. dentition groups

Scatter plots coloured to differentiate between dentition groups

Scatter plots coloured to differentiate between sex groups

Scatter plots coloured to differentiate between ancestry groups



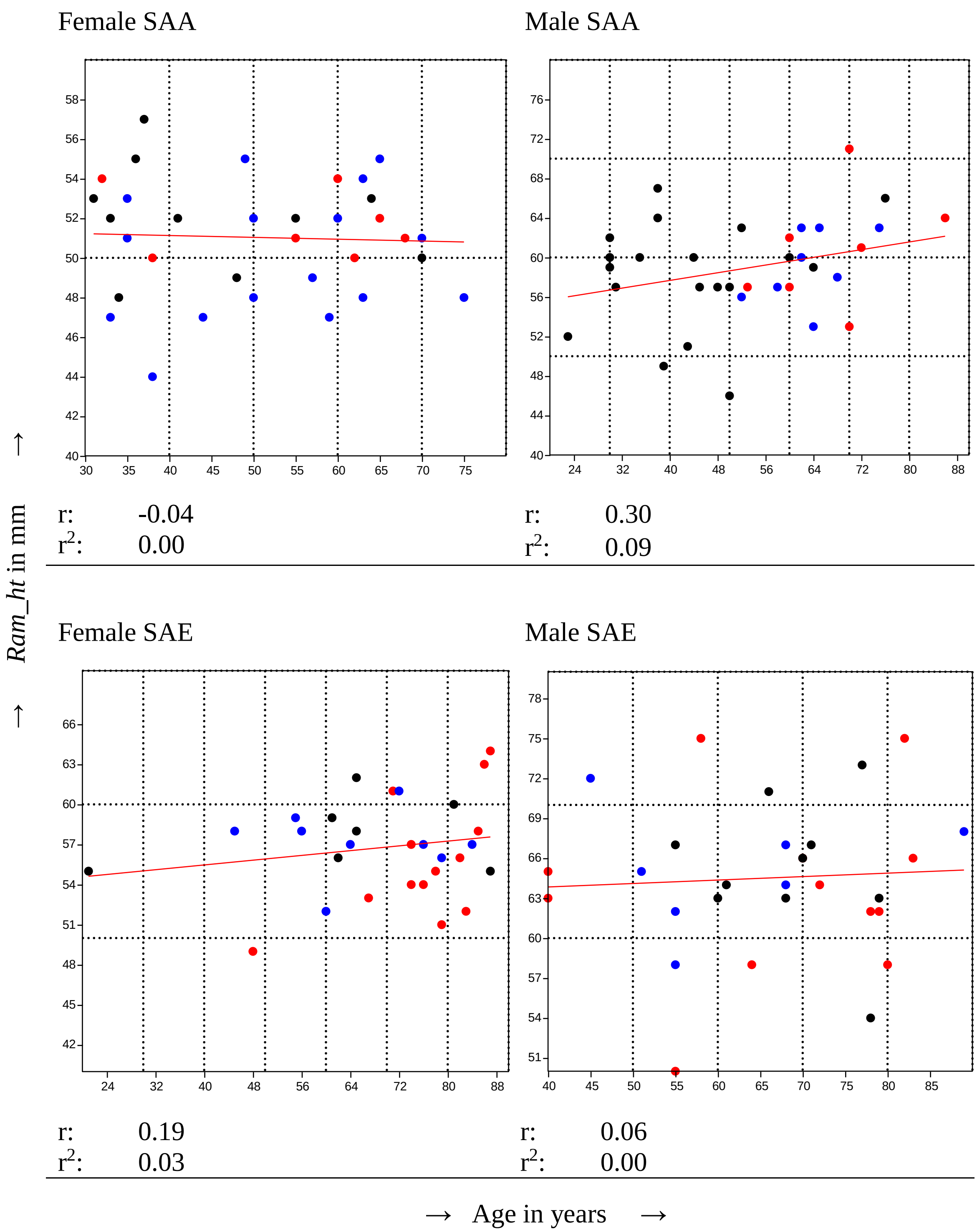
r: 0.29
r^2: 0.08

Red: dentition group 0
Blue: dentition group 1
Black: dentition group 2

Red: females
Black: males

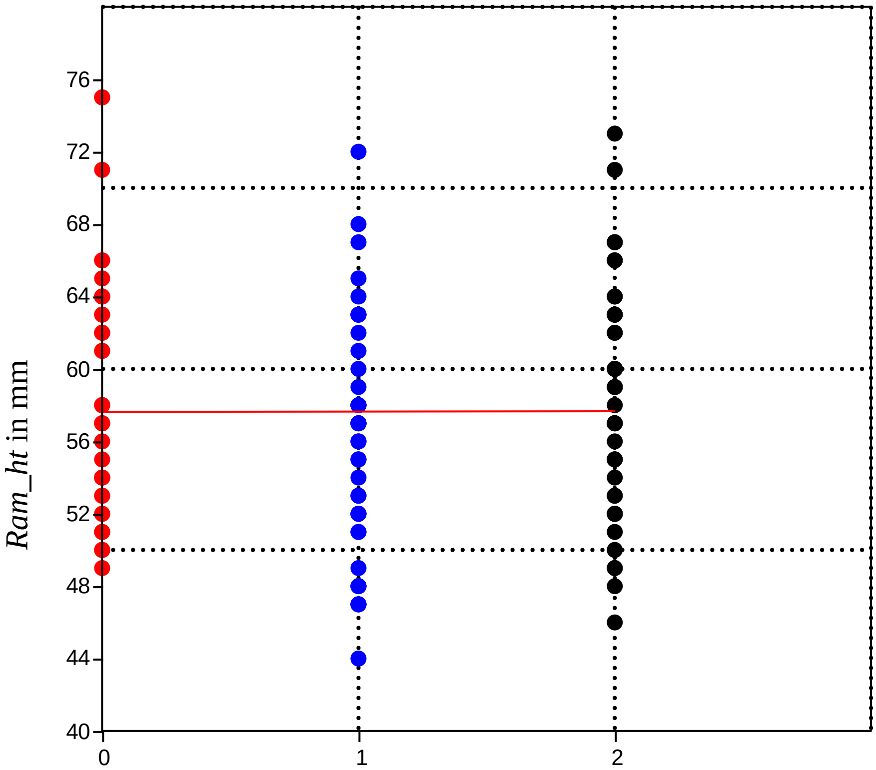
Red: SAE
Black: SAA

Fig. 5.31 Linear regression of age in years vs. *Ram_ht* in mm



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

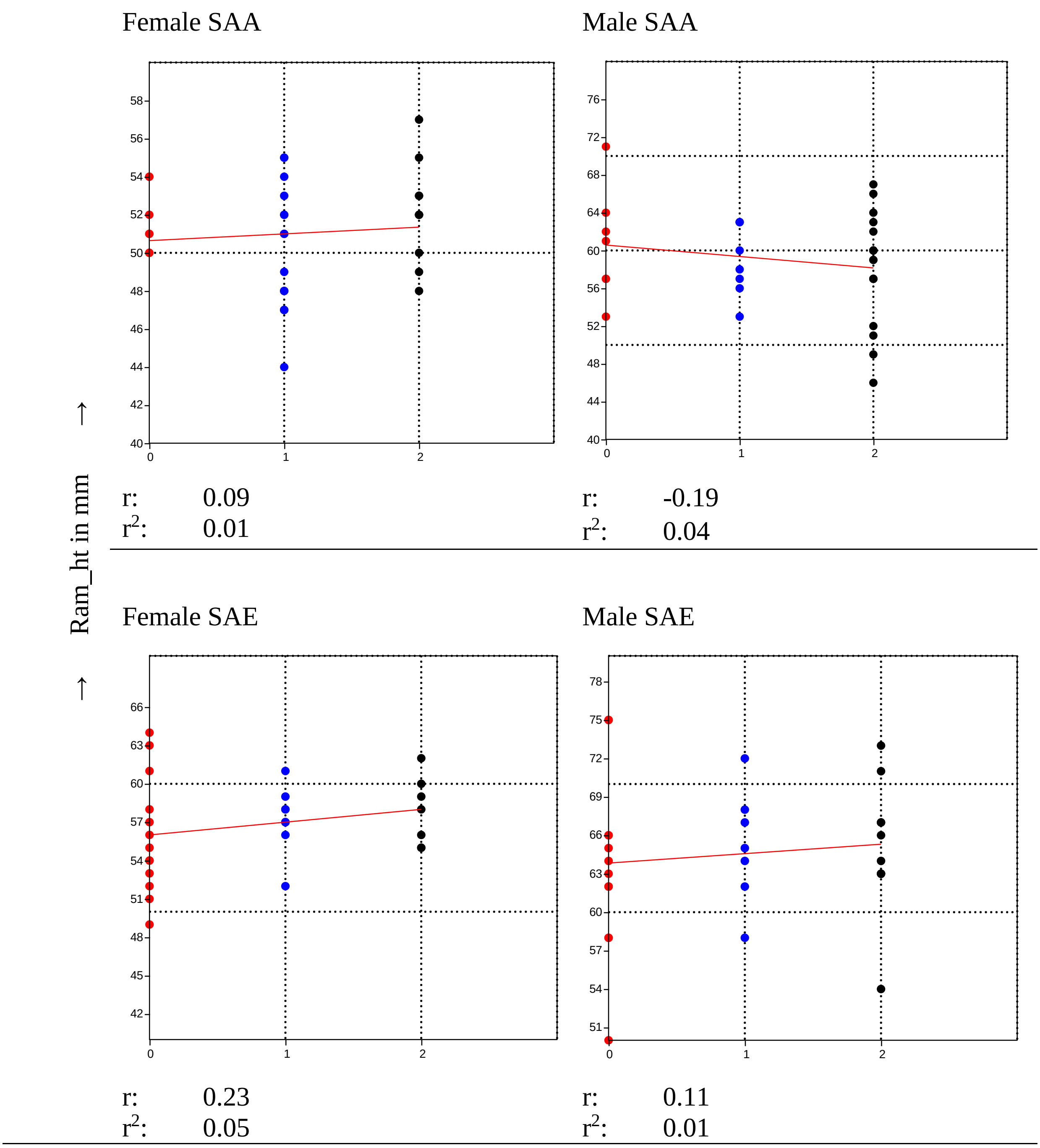
Fig. 5.32 Linear regression of *Ram_ht* vs. age in years in sex-ancestry groups differentiating between dentition groups



r: 0.00
r^2: 0.00

Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.33 Linear regression of *Ram_ht of the mandible* vs. dentition group



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 5.34 Linear regression of *Ram_ht* vs. dentition groups

Chapter 6: SHAPE ANALYSIS

6.1 Introduction

Ancestry group and sex specific shape features of the mandible have been routinely described (e.g. Antón 1996; Loth & Henneberg 2000; Viðarsdóttir et al. 2002). These ancestry group and sex specific features may not be fixed, as diet and dental care may influence postnatal development of the mandible (Oettlé et al. 2009b). For instance, fluctuating changes in diet and dental care with time within a group could have an effect on dental patterns, which in turn could influence the mandibular characteristics that are used to estimate sex and ancestry. If a relationship exists between these mandibular shape features and dental loss or senescence, this relationship would need to be considered with regard to the estimation of sex and ancestry in forensic anthropology.

Ramus flexure, (Loth & Henneberg 1996) and gonial eversion (Fig. 6.1) (Acsádi et al. 1970; Ferembach et al. 1980; Novotny et al. 1993) are two mandibular shape features situated around the posterior aspect of the mandible that have been used extensively in sex estimation. The shapes of the chin area and ramus have been linked to aging, sex and ancestry group affiliation (Jensen & Palling 1954; De Villiers 1968; Acsádi et al. 1970; Tobias 1974; Novotny et al. 1993; Loth 1996; Loth & Henneberg 1996; Doual et al. 1997; Ohm & Silness 1999; Galdames et al. 2009). As repeatability testing and interpretation of morphological traits are often difficult, geometric morphometrics were used to quantify the shape of the mandible overall as well as of specific features.

6.2 Materials

Representatives of each of the 12 sex-ancestry-dentition groups as described earlier were selected for this part of the study. The numbers of individuals within each of the sex-ancestry-dentition groups used in the overall shape analysis of the mandible overall are set out in Table 6.1. The detailed analyses of specific features are in Table 6.2. These differed slightly because of the suitability of the particular specimen for the analysis to be performed. For instance, a broken coronoid process excluded mandibles from the mandibular shape analysis, but not from limited shape analysis of specific features. In order to compensate for these individuals and to ensure a distributed sample across ancestry, sex and dentition groups, other individuals were incorporated.

6.3 Methods

Advanced assessments of shape involving geometric morphometrics were employed to identify homologous points or landmarks. Landmarks over the surface of the mandible, representing its overall shape, were identified using of MicroScribe G2. More detailed analyses of specific features were achieved by incorporating cone beam computer tomography (CBCT) generated images.

6.3.1 Microscribe

To evaluate variations in the overall mandibular shape amongst sex-ancestry-dentition groups, x, y and z co-ordinates from homologous landmarks were obtained by a three dimensional (3D) digitiser, Immersion's MicroScribe G2 digitiser.

The 3DXL MicroScribe® Digitizer, a registered trademark of the Immersion Corporation, provides spatial information in the form of landmarks about a three dimensional object to a computer system for a three dimensional (3D) representation of that object to be manipulated as digital data. In this study the digitizer: Immersion's 3DXL MicroScribe® Digitizer was used to analyse the external morphological features of the mandible.

The 3DXL MicroScribe® Digitizer has an articulated arm which consists of mechanic linkages that allows the user six degrees of motion in a 3D space ending in a stylus with the other end connected to a base fixed to a stationary surface (Jackson et al. 1998; Nagasaka S 2003). The tip of the stylus is used as a probe device to trace over the surface of the 3D object. Sensors are included in the joints of the linkage chain to sense the relative orientation of linkages and, therefore, where the stylus is located with respect to the base. The angle data read by the sensors can be converted into coordinate data by the microprocessor. The sensors of the probe apparatus are zeroed by placing the probe apparatus in the only possible home position. In this way, 3D repetitive landmarks of an object are recorded by the 3DXL MicroScribe® Digitizer with a click of the hand switch. The X, Y and Z coordinates of each 3D landmark appear on a Microsoft excel chart of a linked computer, which can later, for instance, be used with the free software programme: Morphologika for shape analysis (Jackson et al. 1998; Nagasaka S 2003; Von Cramon-Taubadel et al. 2007).

The following landmarks that reflect the overall external features of the mandible were identified and digitised (Fig. 6.2) (De Villiers 1968; Ousley & Mckeown 2001; Franklin et al. 2006). In the midline two points were marked: the pogonion (landmark 1) and the infradentale (landmark 2). The pogonion is the most forward projecting point on the anterior surface of the chin, as viewed from the side. Infradentale is the highest anterior point between the mandibular central incisors or, if edentulous, a point in the anterior midline on the superior border.

Bilaterally points on the superior border of the mandible or the alveolus, perpendicularly above the mental foramen were marked (landmark 3). Landmark 3 was previously named “HMF (height at mental foramen) superior point”. “HMF superior point” refers to the point perpendicular to the mental foramen on the alveolus used to determine the height of the mandibular body (Ousley & Mckeown 2001). As landmark 3 was not used in the determination of mandibular body height for this part of the study, but for shape analysis, this term could not be applied here. Similarly, bilateral landmarks on the inferior border of the mandible perpendicularly below the mental foramen were identified. It was originally named “HMF inferior point” (landmark 4). Landmark 4 “HMF” inferior point refers to the point perpendicular to the mental foramen on the inferior border of the mandible used to determine the height of the mandibular body (Ousley & Mckeown 2001). As this landmark again was not used in the determination of mandibular body height for this part of the study, but for shape analysis, this term could not be applied here.

Gonion (landmark 5) was bilaterally defined by bisecting the angle formed by the tangents to the mandibular plane and the plane of the ramus. Point 5 is defined by De Villiers (1968) as the point nearest to the zero axis of the mandibulometer (mandible board). The term “tangent” is a well-known geometrical term that refers to a line positioned to just touch a curved shape ("Tangent" 2014). The point of contact of the tangent and the shape is called the “tangent point”. The mandible is adjusted so that the horizontal part of the board represents the standard horizontal plane, while the rameal wing of the board is in contact with the left ramus of the condyle and above the angle, with the right ramus at one or both of these regions). Other definitions include: the most lateral external point of the lower jaw at the junction of the horizontal and ascending rami (Franklin et al. 2006). The most lateral external point might not be at the junction of the horizontal level of the inferior border of the mandible and the ascending rami and may thus create results that are not repeatable throughout. These definitions had to be adapted for use with cone beam derived images, as the use of a mandibulometer in these situations is not feasible. Tangents as described before were drawn by the soft ware VG studio and used to identify the gonia as the nearest point from where the tangents intersect.

On either side, the most superior points on the coronoid (landmark 6) and condylar processes (landmark 7) were marked. Bilaterally points on the anterior (landmark 8) and posterior border of the ramus (landmark 9) corresponding to the narrowest distance across the mandibular ramus on the left and right were marked.

6.3.2 Cone beam computer tomography

Further analysis of shape variation was carried out to more specifically elucidate the influence of tooth loss on anthropological features classically associated with sex and ancestry group classifications. These features are mandibular ramus, gonial eversion, gonial angle and chin shape. Detailed analyses of these specific features of the mandible were performed by incorporating CBCT generated images.

CBCT is well suited for imaging the craniofacial area and is the preferred choice (Ozan et al. 2013). It provides clear images of highly contrasted structures and is extremely useful for evaluating bone (Scarfe et al. 2006). CBCT images provide generally more precise identification of traditional cephalometric landmarks; e.g. condylion and gonion in cephalometric landmark identification (Ludlow et al. 2009). Measurements of cortical bone thickness are performed by CBCT (Humphries 2007; Loubele et al. 2007; Baumgaertel & Hans 2009). Razavi et al. (2010) warn that measurements done on CBCT systems producing images with voxel size of 0.3 mm^3 or greater might not be very accurate.

Although CBCT is considered an emerging imaging technology, development of this technology dates back to the mid-1970s and was introduced in the 1990s for dental purposes (Quereshy et al. 2008). CBCT provides an innovative means of image scanning and volumetric reconstruction of CT data (Humphries 2007).

The principal differences that distinguish CBCT from traditional CT (computed tomography) are the type of imaging source detector complex and the method of data acquisition (Table. 6.3). The X-ray source for CT is a high output rotating anode generator while that for CBCT can be a low energy fixed anode tube. Cone beam scanners incorporate a cone shaped X‒ray beam rather than a conventional linear fan beam by CT. CBCT uses a single 360° imaging rotation around the object to obtain the radiographic data needed (Danforth et al. 2003). The motion centre is placed in the area of interest, with the X-ray detector on the opposite side of the circle. Conventional CT scanners utilise a single row or a series (4, 8, 12, 32 and now 64) of solid state detectors paired with a fan shaped beam whereas CBCT scanners utilise a square two dimensional (2D) array of detectors to capture the cone shaped beam, thus providing a volume of data, instead of a set of consecutive slices provided by conventional CT scanners (Mueller 1998).

This data is then transferred to a computer, reconstructed and displayed as either consecutive tomographic layers in all three planes – i.e. coronal, sagittal and axial – or as a 3D rotatable model. The spatial resolution is measured in voxels (mm^3) as opposed to CT, which is measured pixels (mm^2) (Mueller 1998). The size of these voxels determines the resolution of the image (Scarfe et al. 2006).

The tomography system used in this study is housed at Necsa, Pelindaba and was designed specifically for the beam geometry at the South African Neutron Radiography (SANRAD) facility, located on the beam port floor of the SAFARI 1 nuclear research reactor (De Beer 2005). The VGStudio MAX-2.1 software (Volume Graphics 2010) was used for the 3D rendering, segmentation and visualisation of the reconstructed volume data. Landmarks were applied on the 3D reconstructed CBCT images (Fig. 6.3). VG Studio MAX 2.1 allowed midpoints between standard landmarks to be marked as well as prompt revision and correction of marked points if deemed necessary. These landmarks were used to create 3D models for shape analysis and comparison between groups.

Before marking any points on the 3D models, two tangents were drawn: one touching the inferior border of the body of the mandible and the other touching the posterior border of the mandible. The tangent on the posterior border of the mandible touched the mandible at two points on either side of the ramus flexure: the inferior tangent point and the superior tangent point.

On either side, as part of the gonial area the following four landmarks were marked: the inferior tangent point on the posterior border of the mandible (G1); the most posterior point on the tangent drawn on the inferior border of the body of the mandible (G2); the point of maximum curvature between the previous two points or gonion (G3); the most prominent lateral point on the gonial eversion (G4). As part of the reference of the gonial area the superior tangent point to the posterior surface of the mandible (PSTP) was also recorded (Fig. 6.3).

On either side, as part of the ramus flexure assessment the following three landmarks were marked: the deepest point on the posterior mandibular border as measured from the tangent drawn on the posterior border of the mandible (RF1); the point midway on the posterior mandibular border between the previous point and the superior tangent point (RF2); the point midway on the posterior mandibular border between the deepest point previously described and the inferior tangent point (RF3) (Fig. 6.3).

The first point marked on the chin area was the point in the midline where a depression is formed, coinciding with the commencement of the dental roots or the alveolar process or the most superior point in the midline of an edentulous mandible (inferior alveolar). As the edentulous mandible loses its alveolar process, it was presumed for the purposes of this analysis, that these points would be equivalent. The following four points were marked on the chin: bilateral points on the mental tubercle prominences; pogonion and gnathion (Fig. 6.3) (Thayer & Dobson 2010). In some mandibles the mental tubercles were less prominent and were identified at the apex of the most prominent raised areas bilaterally. Rotation of the image so that it was viewed from inferior facilitated this process.

3D landmarks with X, Y and Z coordinates identified (digitised) with both modalities were entered on a Microsoft excel worksheet. These landmarks were used for comparative analysis of shape using the free software package Morphologika. Morphologika is a set of integrated tools for examining size and shape variation among objects described by sets of landmark coordinates. This program was developed by Paul O'Higgins and Nicholas Jones to enable geometric morphometric analyses of 2 and 3D landmark configurations, allowing for the visualisation of shape variation (O'Higgins & Jones 1998; Franklin et al. 2007).

A full generalised procrustes shape analysis was performed by Morphologika to eliminate the nonshape variation in the sample so that shape differences may be appreciated (Franklin et al. 2007). A potential drawback of procrustes superimposition is that the orientation of biologically relevant axes is not respected during rotation. This is inconvenient if differences in shape are to be described in terms of landmark locations relative to the axis of symmetry (Webster & Sheets 2010). For this reason shape analyses of the mandible were performed first on the overall shape, which included both sides of the mandible, and then on specific features unilaterally. The gonial area was considered in isolation and then repeated by including the gnathion so that eversion from the mid axis could be appreciated.

The procrustes analysis was followed by a principal component analysis. A full tangent space projection was performed by Morphologika. A series of principal component analyses was used to explore the relationships between sex-ancestry-dentition groups in various combinations. The first principal component of shape variation was plotted against the second. Further comparisons of other principal components were considered but did not contribute substantially to the understanding of the shape variations detected. The distribution of the variation in shape amongst individuals could be visualised on the principal components analyses plots, wireframes, and thin plate spline grid deformations.

6.4 Statistical analysis

Multivariate statistical analyses were performed on the principal components of shape variation of each mandibular feature (Franklin et al. 2007). Statistical significance of these variations could so be assessed amongst sex, ancestry or dentition group or combinations of these groups in the sample. Differences amongst sexes and ancestry groups were first ascertained and, if significant, sexes and/or ancestry groups were considered separately for variation in shape with tooth loss. Finally shape variations amongst tooth loss groups were considered individually for each sex, ancestry or sex ancestry group as necessary.

In order to control for inter- and intraobserver error, a total of at least 30 randomly selected mandibles were digitised again at a later occasion by the principal investigator and another observer familiar with the method. Statistical differences between the sample groups were assessed in a principal component environment. If significant differences existed amongst the groups, individual landmarks were considered to isolate the particular landmark where variations contributed to the noted statistical difference.

PAleontological STatistics (PAST) v1.92 free software, was used to test for statistically significant differences between groups and for repeatability studies. The two group permutation option of multivariate analysis was applied in these analyses (Harper & Ryan 2001). The input information for the multivariate analyses consisted of principal component scores accessed from the output file created by Morphologika after general procrustes analysis, followed by principal component analysis (Franklin et al. 2007). In situations where landmark positions were compared, landmark X, Y and Z coordinates were accessed from the output files created by Morphologika after general procrustes analyses were performed.

Linear regression of centroid size vs. dentition group and age were performed followed by discriminant analysis of individual shapes as well as collectively combining chin shape and gonial area with gnathion.

6.5 Results

In this section, results of the shape analyses of each mandibular feature demarcated by the digitization of a set of landmarks are represented on XY graphs in a principal component environment. Principal component analyses, which followed on the procrustes analyses, were depicted/portrayed as XY graphs where principal component 1 (contributing to the greatest shape difference) represents the X axes, versus principal component 2 (contributing to the second greatest shape difference) representing the Y axes. The specific percentage each principal component contributes to the shape variation noted in the specific morphological feature being examined was indicated on the axes. The distribution of the variation in shape amongst individuals could be visualised on the graph. Sex-ancestry-dentition group scatter points were differentiated by specific colours in the comparison of principal components (Table 6.4).

Wire frames (landmark connecting diagrams) were inserted (Fig. 6.4) at specific locations on the graph to indicate the variations of the particular feature at that point, along with the accompanying thin plate spline grid deformations and their axes. Connecting lines or convex hulls of the extremes of each group were indicated by either a solid line or, where distinction between ancestry or sex groups was desired, a dash connector was used for SAE or females and a solid connector for SAA or males (see Figs. 6.5, 8, 10, 12, 15, 16, 18 and 24). The convex hull, therefore, contains or envelops all the points belonging to the specific group of interest within the hull forming the perimeter or outline of the group ("Convexhull" 2014). In cases where differences between dentition group were noted, a dashed line represented the lower dentition group number (see Figs. 6.6, 7, 13, 17, 19 and 20). In situations where all three dentition groups were represented a shorter dash connector represented group 0 dentition (Fig. 6.25). The analysis of variance was described along the arrow inserted to indicate the direction of shape variation change on the XY graph if perceived amongst the groups considered.

<u>6.5.1 Overall mandibular shape</u>

The thin plate splines accompanying the wireframes that illustrated the mandible from superior were in the XY plane, the wire frames from lateral were accompanied by the XZ plane thin plate splines and the wire frames from anterior was accompanied by YZ plane thin plate splines.

Multivariate analyses by two group permutation tests revealed statistically significant differences in the overall mandibular shape between ancestry and dentition groups in the complete sample. Interancestry group variability yielded a p value of 0.0010 and dentition group 0 combined with 1 as compared to 2 yielded a p value of 0.0065 and dentition group 0 as compared to 1 combined with 2 yielded a p value of 0.0095. When SAA was considered separately, dental pattern 0 as compared to 1 and 2 combined was not significant, (p = 0.6165). Dental pattern 0 and 1 combined as compared to 2, although not significant, approached significance with p = 0.0675. In SAE the dental pattern 0 as compared to 1, 2, combined approached significance with p = 0.0740. In SAE dental pattern 0 and 1 combined as compared to 2 was not significant (p = 0.15).The shape variations noted between ancestry groups and dentition groups when plotting principal component 1 vs. 2 are represented in Figures 6.5 to 6.7. The overall mandibular shape did not vary significantly between sexes (p = 0.657) in the sample as a whole.

In the comparison of principal components 1 (contributing 25.8%) and 2 (contributing 11.6%) of the shape variations observed (Fig. 6.5), differences between ancestry groups were demonstrated by the separation of the convex hulls, enveloping all the points belonging to the specific group of interest. Although overlap existed, extreme scatter points in the right quadrants were usually attributed to representatives of SAA and extreme scatter points in the left quadrants were usually attributed to representatives of SAE. The direction of interancestry group variation differences was indicated by an arrow from the right lower quadrant to the left upper quadrant. The morphological variations were represented by wireframes and thin plate splines in the extremes of each quadrant and described along the direction of the indicated arrow.

In SAE the mandibular body height was relatively low as compared to the ramal height. The ramus was longer and slimmer and accompanied by a less upright observed gonial angle. The dental arch or superior border of the mandible was relatively smaller than the inferior border, which presented with a more prominent pogonion. The coronoid process was relatively high compared to the condylar process. The overall appearance of the mandible was relatively widened and flattened in SAE compared to SAA.

The comparison of principal components 1 (contributing 20.7% of the shape variation) and 2 (contributing 14.1% of the shape variation) revealed a great deal of overlap between dentition groups (Fig. 6.6). Representatives of dentition group 2 were found in the extreme right half of the XY graph while representatives of dentition group 0 and 1 were found in the extreme left half of the XY graph. In the left half of the graph loss of alveolar bone is displayed in a relatively lower mandibular body and smaller dental arch or superior border of the mandible compared to the inferior border. A prominent pogonion as well as a coronoid process higher than condylar process were evident in those with fewer occlusions. In addition the rami were longer and and less upright. Some individuals belonging to group 2 in the right lower quadrant presented with narrower rami, lower mandibular bodies and narrower arches while those in the right upper quadrant had high mandibular bodies, widened rami with coronoid and condylar processes at approximately the same level.

From the comparison of principal components 1 (contributing 20.6% of the shape variation noted) and 2 (contributing 14.3% of the shape variation), a great deal of overlap was once again noted amongst the dentition groups in SAA (Fig. 6.7). Mandibles with group 0 dentition, though, represent the extremes in the left lower quadrant and the wireframes and the accompanying thin plate splines display similar shape variations with tooth occlusion loss as seen in SAE.

When dentition groups were considered separately – i.e. the statistical differences between sexes and ancestry groups in group 0, 1 and 2 separately – only group 2 dentition group displayed variance in shape amongst the ancestry groups ($p = 0.0194$). None of the other comparisons were significant: intersex variation for group 2: $p = 0.2195$; interancestry groups variation for group 1: $p = 0.8855$; intersex variation for group 1: $p = 0.2195$; inter ancestry group variation for group 0: $p = 0.109$ and intersex variation for group 0: $p = 0.118$.

Landmarks on the right side of the mandible were not taken into consideration in the repeatability tests. The total number of landmarks for repeatability tests were therefore reduced to nine to facilitate statistical testing. The intrarater variability was excellent at $p = 0.9995$. The interrater variability was significant ($p < 0.005$) and involved mainly the choice of the location of the narrowest distance across the mandibular ramus affecting the position of the point on the anterior border of the ramus and the point on the posterior border of the ramus.

Linear regression of overall mandibular shape vs. dentition group in the complete sample exhibited a weak but significant correlation ($r = 0.2141$; $r^2 = 0.0458$; $p = 0.0179$). Linear regression of overall mandibular shape vs. age in the complete sample exhibited a weak and insignificant correlation ($r = 0.0875$; $r^2 = 0.0077$; $p = 0.3377$). Linear regressions of overall mandibular shape vs. dentition group and aging in the sex-ancestry groups individually were weak and insignificant.

Statistical comparison of 3D landmarks after procrustes analysis between the two observers indicated that the following points did not differ significantly: infradentale ($p = 0.23$); pogonion ($p = 0.0645$); gonion ($p = 0.0685$); condylion superior ($p = 0.0965$); condylion laterale ($p = 0.205$); the point on the superior border of the mandible perpendicularly above the mental foramen ($p = 0.138$) and the point on the inferior border of mandible perpendicularly below the mental foramen ($p = 0.1495$).

However, the interobserver variation for the identification of the pogonion and gonion landmarks approached significance. The location of the point on the anterior border of the ramus and the point on the posterior border of the ramus differed significantly between observers in both cases. In Figure 6.8, the scatter points of these 3D landmarks are portrayed to illustrate the variation between observers. It should be noted, however, that this 3D shape cannot be fully displayed on a 2D diagram.

6.5.2 Gonial area

On either side as part of the gonial area the following five landmarks were marked (Fig. 6.9): RF3; G1; G2; G3 and G4 previously defined. The thin plate splines accompanying the wireframes in this section were in the XZ plane and inserted on the graphs to illustrate the shape variations observed at the specific locality by deformation of the grid.

Statistically significant differences were found when plotting principal component 1 (accountable for 53.6% of the shape variation noted) and principal component 2 (accountable for 24.3% of the shape variation noted) in the shape variation between sexes ($p = 0.011$) (Fig. 6.10) and approaching significance between ancestry groups ($p = 0.062$) (Fig. 6.11). No statistical differences were found between dentition group 0 versus 1 and 2 combined or between 0 and 1 combined as compared to 2 in the sample group as a whole.

Although a great deal of overlap exists between the sexes especially in the left lower quadrant and at the centre, the extremes on the right half of the XY graph were points belonging to female SAA(Fig. 6.10). The extremes in the left upper quadrant were points belonging to male SAA. The shape variations observed from the right half of the graph (females) towards the left upper quadrant (males) involved the increase in the angulation of the line connecting RF3 (the inferior tangent point to the posterior surface of the mandible) and G1 (the most posterior point on the inferior border of the body of the mandible). The most prominent lateral point on the gonial eversion was situated inferior to the gonion on the right half of the XY graph (females). The most prominent lateral point on the gonial eversion was situated more superior and anterior, closer to the axes. In the left upper quadrant (males), the most prominent point on the gonial eversion was situated more superior and posterior to the gonion. The shape of the gonial area was often relatively elongated between G1 (the most posterior point on the inferior border of the body of the mandible) and the gonion.

In the comparison between the sexes, a great deal of overlap exists (Fig. 6.11), In general SAE often presented more towards the centre of the XY graph. At this location the posterior curvature of the gonial area was confined to the more inferior portion of the gonial area. The gonial eversion was also more often directed inferiorly and anteriorly in females and SAE in general as opposed to superiorly in relation to the gonion in males and SAA in general. Greater variability in the shape of the gonial area existed when comparing SAA to SAE.

The differences noted between the sexes in SAA in the gonial area, although not significant ($p = 0.097$), did approach significance and principal components 1 (accountable for 58.4% of the shape variation noted) vs. 2 (accountable for 20.8% of the shape variation noted) are plotted on the XY graph to illustrate these differences (Fig. 6.12). Males in general exhibited greater variation in shape compared to females. When the extremes belonging to males on the right half of the XY graph were compared with the female extremes on the left half of the graph, the gonial area was notably more convex in males. Differences between group 0 versus 1 and 2 combined or between 0 and 1 combined versus 2 were not significant at $p = 0.135$ and $p = 0.2765$ respectively.

In SAE, differences between sexes were not significant ($p = 0.473$). Significant differences were noted between dentition group 0 versus 1 and 2 combined ($p < 0.0388$) but not between dentition group 0 and 1 combined versus 2 ($p = 0.094$). Principal component 1 contributed to 58.6% and principal component 2 to 20.9% of the shape differences noted

(Fig. 6.13). Points belonging to dentition group 2 were scattered across the centre into the right half of the XY graph presenting with a more convex gonial area and inferiorly placed gonial eversion as opposed to those of group 0. Individuals with group 1 dentition displayed the greatest variation while group 0 was more represented in the centre and towards the left.

When considering dentition groups separately – i.e. the statistical differences between sexes and ancestry groups in groups 0, 1 and 2 separately – no comparisons were statistically significant: interancestry group variation for group 2: $p = 0.343$; intersex variation for group 2: $p = 0.3965$; interancestry group variation for group 1: $p = 0.6855$; intersex variation for group 1: $p = 0.935$; interancestry group variation for group 0: $p = 0.16$ and the intersex variation for group 0: $p = 0.6935$.

The gonial area in the complete sample had a very small or negligible and insignificant correlation with dentition group ($r = -0.0553$; $r^{2\,=}$ 0.0031). Dentition group remained weakly correlated ($r^2 < 0.16$) with the gonial area when sex-ancestry groups were analysed individually. The gonial area in female SAE presented with the greatest correlation with tooth loss, although weak and statistically insignificant ($r = -0.3242$; $r^2 = 0.1051$; $p = 0.0862$), followed by female SAA ($r = 0.2113$; $r^2 = 0.0446$); male SAA ($r = 0.1004$; $r^2 = 0.0101$) and male SAE: ($r = 0.0302$; $r^2 = 0.0009$). In the gonial area shape correlations with age in SAA were very weak (female SAA: $r = 0.0508$; $r^2 = 0.0026$ and male SAA: $r = -0.0703$; $r^2 = 0.0049$), but moderate in SAE (female SAE: $r = 0.4336$; r^2 squared = 0.188 and male SAE: $r = -0.4435$; $r^2 = 0.1967$).

Discriminant analysis of the gonial area without the gnathion revealed a 63.7% accuracy for sex and a 58.7% accuracy for ancestry estimations. Ancestry accuracies improved to a minimal degree for dentition group 0 (63.9%), but not for for dentition group 1 (40.5%) and for dentition group 2 (47.5%). Prediction of sex group increased to a minimal degree for dentition group 1 (73.0%) and for dentition group 2 (64.6%), but not for dentition group 0 (61.1%).

6.5.3 Gonial area with gnathion

In addition to the landmarks identified as explained in the previous section, the gnathion was incorporated as well for this analyses (Fig. 6.14). This was done to evaluate the degree of eversion or deflection from the mid axis.

Significant differences were found between the sexes ($p = 0.0075$) (Fig. 6.15) and the ancestry groups ($p < 0.01$) (Fig. 6.16). In the comparison between dentition group 0 versus 1 and 2 combined in the entire sample no significant difference was found ($p = 0.5181$), nor was the comparison between dentition group 0 and 1 combined versus 2 ($p = 0.204$). Principal component 1 contributed to 42.7 % and principal component 2 to 21.8% of the shape differences noted.

Females as compared to males demonstrated a relatively elongated gonial area with a more obtuse angle and a less obvious gonial eversion. The elongated gonial area seen in females represents a relatively higher point at which the posterior tangent will touch the posterior border. The posterior convexity is therefore smoother and reaches its maximum curvature at a higher point.

SAE as compared to SAA demonstrated a relatively elongated gonial area with a more obtuse angle and a less obvious gonial eversion. A wider range of shape variation was seen in individuals of SAA compared to SAE, in an evaluation of the gonial area with gnathion in SAA ($p = 0.37$) or when comparing those with a dental pattern associated with inefficient mastication (group 1) as opposed to an efficient mastication (group 2) ($p = 0.395$).

A statistically significant difference ($p = 0.0345$) was found in the comparison between dentition group 0 versus 1 and 2 combined in SAA. In individuals with no occlusions compared to those with occlusions (dentition group 1 and 2), the gonial area was more obtuse, the eversion slight and the posterior curvature more pronounced and concentrated lower down (Fig. 6.17). Principal component 1 contributed to 44.2% and principal component 2 to 26.0% of the shape differences noted.

A statistically significant difference ($p = 0.0035$) was noted between the sexes amongst SAE. Although great overlap existed, females displayed greater variability in shape often in a relatively shortened gonial area (Fig. 6.18). When comparing the gonial area with gnathion in SAE no significance was found between group 0 versus 1 and 2 combined ($p = 0.678$) and between group 0 and 1 combined as compared to 2 ($p = 0.538$).

When comparing the gonial area with gnathion by principal component 1 vs. 2 amongst dentition groups in female SAE, significant differences were found ($p = 0.0055$) between group 0 versus 1 and 2 combined but none between group 0 and 1 combined as compared to 2 ($p = 0.4055$). A greater variation in shape was noted amongst members of group 0.The main difference seemed to be a relatively shortened and curved gonial area as compared to the mandibular length (Fig. 6.19). Principal component 1 contributed to 47.9 % and principal component 2 to 19.6% of the shape differences noted.

When comparing the gonial area with gnathion by principal component 1 vs. 2 amongst dentition groups in male SAE, significant differences were found ($p = 0.0195$) between group 0 versus 1 and 2 combined but none between group 0 and 1 combined as compared to 2 ($p = 0.4425$). The main differences seemed to be a more variable shape in dentition group 0 as compared to dentition group 1 and 2 combined (Fig. 6.20), which were scattered closer to the axes.

In dentition group 1 no significant difference could be demonstrated amongst ancestry groups ($p = 0.1625$) or sexes ($p = 0.0995$). This was the case for dentition group 2 as well (amongst ancestry groups, $p = 0.315$ or sexes, $p = 0.316$). No significant difference could be demonstrated between sexes ($p = 0.5585$) in those with no occlusions (group 0). A significant difference did exist between ancestry groups with dentition groups pooled ($p = 0.002$) (Fig. 6.21). SAA with no occlusions presented with a relatively shorter gonial area and more upright angle as compared to SAE. Principal component 1 contributed to 45.8% and principal component 2 to 20.3% of the shape differences noted.

Female SAA presented with a statistically significant ($p = 0.040594$), though weak correlation ($r = 0.3428$; $r^2 = 0.11751$) in the linear regression of gonial area with gnathion vs. dentition group. The correlations with dentition group in all other sex-ancestry groups were insignificant and weak. The correlation of shape of the gonial area with gnathion vs. age was the greatest in male SAE as 4.5% of the changes noted could be attributed to aging.

The discriminant analysis of the gonial area with gnathion revealed a 59.7% accuracy for ancestry and a 75.8% accuracy for sex estimation. The discriminant qualities of the gonial area with gnathion improved to 74.4% for ancestry when considering dentition group 0 in isolation, 54.1% for dentition group 1 and 70.8% for dentition group 2. The discriminant qualities of the gonial area with gnathion were less accurate for sex prediction when dentition groups were considered in isolation: dentition group 0 (69.2%), 67.6% for dentition group 1 and 75.0% for dentition group 2.

6.5.4 Ramus flexure area

For the ramus flexure region the superior tangent point to the posterior surface of the mandible (PSTP) was marked in addition to the following three landmarks: the deepest point as measured from the tangent to the posterior mandibular border (RF1); the point midway on the posterior mandibular border between the previous point and the superior tangent point (RF2); the point midway on the posterior mandibular border between the deepest point previously described and the inferior tangent point (RF3) (Fig. 6.22).

As with the gonial area, the first principal component of shape variation was plotted against the second. The distribution of the variation in shape amongst individuals can be visualised on the graph. No significant differences could be found in the shape of the ramus flexure region amongst the sexes (p = 0.634); amongst the ancestry groups (p = 0.5745) or amongst the dentition groups (between dentition group 0 versus 1 and 2 combined: p = 0.881 or between group 0 and 1 combined versus 2: p = 0.174) when the entire group was considered.

When considering ancestry groups separately. no significant difference could be found amongst the sexes in SAA (p = 0.3595) or SAE (p = 0.97). No statistically significant differences were found amongst dentition groups when considering sex ancestry groups separately either.

The interobserver variation for all posterior mandibular landmarks – which included the gonial area, gonial area with gnathion and ramus flexure on 30 individuals – showed no significant difference amongst groups (p = 0.221). Neither was the intraobserver variation for posterior mandibular landmarks significant (p = 0.9405), which denotes excellent repeatability.

6.5.5 Chin

The following five points were marked on the chin: gnathion (the lowest point on the anterior margin in the midsaggital plane), pogonion (most anterior point in the midline on the mental protuberance), left and right mental tubercle (rounded projections forming the inferior angles at the base of the triangular mental protuberance), as well as the deepest point in the midline corresponding to the lower margin of the alveolar process or the highest point in the anterior midline in edentulous mandibles, the infradentale (Fig. 6.23). The point was named the infradentale, based on the presumption that the alveolar process is the only aspect that will be lost with loss of teeth. This concept will be further explored in Chapter 8.

The differences between sexes overall (p = 0,251), sexes within ancestry groups (p = 0.1965 for SAA, p = 0.315 for SAE) and sexes within tooth loss groups (p = 0.564 group 0; p

= 0.7825 group 1 and p = 0.117 for group 2) were not significant. Principal component 1 contributed to 55.3% and principal component 2 to 19.8% of the shape differences noted.

Significant differences existed between ancestry groups overall (p = 0.018) (Fig. 6.24) and between ancestry groups with dentition that is functioning efficiently (p = 0.034), as well as approaching significance between ancestry groups for dentition group 0 (p = 0.0595). Interancestry group variation for dentition group 1, however, was not significant (p = 0.317). The mental tubercles in SAE seemed to be relatively wider apart than in SAA and protruding further anteriorly whilst the pogonion seemed relatively lower. In some individuals the mental tubercles were more prominent than the pogonion.

Significant chin shape changes could be demonstrated with loss of teeth in individuals of SAE but not in SAA. The p value between individuals of SAE without occlusions and those with occlusions was 0.0005 (group 0 versus 1 and 2) and between those with efficient occlusions and those without (groups 0 and 1 versus 2) the p value was 0.0005 (Fig. 6.25).

Principal component 1 contributed to 59.0% and principal component 2 to 18.2% of the shape differences noted. The most obvious difference was the relative decrease in the distance between the pogonion and the lower margin of the alveolar process in those with teeth or the highest point in the anterior midline in edentulous mandibles, with loss of teeth. Shape changes with tooth loss did not correspond in all individuals: some of those with tooth loss displayed a shorter distance between mental tubercles or a shortened distance between the deepest point and pogonion. Clearly there was more variability with tooth loss in SAE, which could account for individuals living a longer period after tooth loss, as supported by a higher age in SAE when compared to SAA.

The correlation of chin shape vs. dentition group in the complete sample was weak (r = 0.3160; r^2 = 0.0999) but significant (p = 0.0004). In the individual sex-ancestry groups: female SAA (r = 0.1258; r^2 = 0.0158; p = 0.4855); male SAA (r = 0.1888; r^2 = 0.0357; p =

0.366); female SAE (r = 0.4456; r^2 = 0.1986; p = 0.0136); male SAE (r = 0.2479; r^2 = 0.0614; p = 0.1714).

In chin shape, correlations with age in all sex-ancestry groups were weak (female SAA: r = 0.0801; r^2 = 0.0064; male SAA: r = -0.1108; r^2 = 0.0123; female SAE: r = 0.3871; r^2 = 0.1499 and male SAE: r = 0.1329; r^2 = 0.0177).

Discriminant qualities for ancestry in chin shape were 61.2% overall, 71.1 % in dentition group 0 in isolation, 51.3% in dentition group 1 and 52.3% in dentition group 2. The percentage correct prediction for sex overall was 58.0%; 65.8% for dentition group 0; 33.3% for dentition group 1 and 68.2% for dentition group 2.

6.5.6 Cumulative discriminant analysis

The percent sex group correctly classified in the complete sample when considering the shape of two features: gonial area with gnathion as well as the chin area, was 63.3%. The percent sex group correctly classified increased to 75.4% when only considering SAE, but remained low in SAA: 64.3%. When isolated dentition groups and ancestry groups were considered, the prediction percentage for sex increased: SAA dentition group 0, 83.3%; SAA dentition group 1, 79%; dentition group 2, 80%; SAE dentition group 0, 69.2%; SAE dentition group 1, 94.4%; SAE dentition group 2, 82.4%.

The percent ancestry group correctly classified in the complete sample for gonial area with gnathion as well as the chin area was 59%. When the sex-ancestry groups were considered separately, it did not improve much. The highest prediction for ancestry group was found in dentition group 2, when females and males were considered separately (73.7% and 72% respectively).

Repeatability studies for chin shape were not significant: intraobserver (p = 0.9815) and interobserver variation (p = 0.1505). As these differences were not statistically significant, a high degree of repeatability was implied.

6.6 Summary

6.6.1 Overall mandibular shape

In this section results are summarised and related to photographic images of typical examples of each individual sex ancestry group (Figs. 6.26 and 6.27). Significant differences were demonstrated between ancestry groups (Fig. 6.5) and dentition groups when all principal components were considered, but not between sexes in the complete sample. Variations between dentition group combinations were not significant but approached significance when the ancestry groups were considered separately (Figs. 6.6 and 6.7)

The overall mandibular shape exhibited a great deal of overlap across ancestry and dentition groups when considering principal component 1 versus 2, which represented less than 38% of the total shape variation. The direction of variation or change with tooth loss could be illustrated in the extremes and mirrored the variation between the ancestry groups. The variation between SAA as opposed to SAE and the changes with tooth loss from dentition group 2 to 0 in the overall group and in ancestry groups individually were similar.

The changes with tooth loss (comparing dentition group 0 to dentition group 2) and in SAE (comparing SAE to SAA) included (Figs. 6.26 and 6.27) lowering of mandibular body height as compared to the ramal height and less upright, longer and slimmer rami. The dental arch or superior border of the mandible was relatively smaller than the inferior border, which presented with a more prominent pogonion. The coronoid process was relatively higher compared to the condylar process. The overall appearance of the mandible was relatively widened and flattened. It should be kept in mind, though, that these variations were not restricted to SAE and individuals with a greater tooth loss (dentition group 0) as a great deal of overlap existed with SAA or dentition group 2.

When considering dentition groups separately, only dentition group 2 displayed variance in shape amongst the ancestry groups. Variations between the sexes were still not significant.

6.6.2 Gonial area

Statistically significant differences were found when all the principal components were considered in the shape variation of the gonial region between sexes (Fig. 6. 10) and approaching significance between ancestry groups (Fig. 6.11). No statistical differences were found between dentition group combinations in the sample group as a whole.

Principal component 1 and principal component 2 accounted for 77.9% of the shape variations. Although a great deal of overlap in the shape of the gonial area was present, the shape variations between the sexes as evident in the extremes involved the greater posterior convexity of this area, which manifested as a greater angulation between the most superior and inferior points of the gonial area considered in males (Fig. 6.28). The most prominent lateral point on the gonial eversion was situated more superior and posterior to the gonion in males.

SAE, in general, exhibited less shape variation in the gonial area with confinement of the posterior curvature of the gonial area to the more inferior portion of the gonial area. The gonial eversion was also more often directed inferiorly and anteriorly

The differences noted between the sexes in SAA in isolation approached significance. Males in general exhibited greater variation in shape compared to females. The gonial area was more convex in an infero posterior direction. Differences between dentition group combinations were not significant (Fig. 6.12).

In SAE differences between sexes were not significant. Differences between dentition group combinations were significant or approached significance. Dentition group 2 presented with a more convex gonial area and inferiorly placed gonial eversion. The dentition of group

1 displayed the greatest shape variation, which might be a reflection of changes in the biomechanical forces determined by loss of occlusions (Fig. 6.13).

When considering dentition groups separately, no comparisons were statistically significant. This may indicate that the gonial area could be very sensitive to the functional changes caused by loss of dental occlusions and when corrected for this, other variations between groups were not significant. The sex differences noted, therefore, could be confounded by mechanical processes involved in dentition group 0 SAE females, affecting significance testing amongst sex and ancestry groups, and will be considered in greater detail in the discussion section.

Discriminant analysis for the gonial area approximated 60% for ancestry and sex prediction and improved to some extent for sex prediction in dentition group 1 (73.0%).

6.6.3 Gonial area with gnathion

Significant differences were found between the sexes and the ancestry groups when considering all principal components (Figs. 6.15 and 6.16). No statistically significant differences were noted between dentition group combinations in the complete sample.

Principal component 1 and 2 accounted for 64.5% of the variation present. Females as compared to males and SAE as compared to SAA demonstrated a relatively elongated gonial area with a more obtuse angle on observation and a less obvious gonial eversion (Fig. 6.30). The elongated gonial area seen in females and SAE represents a relatively higher point at which the posterior tangent will touch the posterior border. The posterior convexity is therefore smoother and reaches maximum curvature at a higher point. A wider range of shape variation was seen in SAA compared to SAE.

SAA, when considered separately, demonstrated no significant differences when comparing the sexes. Significant differences were found between those with no occlusions (dentition group 0) compared to those with occlusions (dentition groups 1 and 2). In SAA dentition group 0, the ramus was less upright, the eversion slight and the posterior curvature more pronounced inferiorly (Fig. 6.17).

A statistically significant difference was noted between the sexes in SAE (Fig. 6.18). Females displayed greater variability in shape, often in a relatively shortened gonial area. The sex differences noted in the whole sample could have been confounded by the impact of the extent of variations seen in female SAE. The inclination of the ramus and the gonial eversion, however, were often similar in appearance.

Females (Fig. 6.19) and males of SAE (Fig. 6.20), when considered separately, exhibited significant differences between those without occlusions (dentition group 0) and those with occlusions (dentition groups 1 and 2). The main differences seemed to be a relatively shortened gonial area as compared to the mandibular length and smaller gonial eversion in dentition group 0.

When dentition groups were considered separately, the only significant difference noted was between ancestry groups in those individuals with no occlusions (dentition group 0) (Fig. 6.21). The ancestry group differences noted in the group without occlusions (dentition group 0) could account for the variations noted between ancestry groups in the complete sample.

The discriminant ability of the gonial area with gnathion for ancestry prediction increased from 59.7% overall to 74.4% when dentition group 0 was considered in isolation. In contrast, 75.8% accuracy for sex determination overall could not be improved by taking dentition group into account.

6.6.4 Ramus flexure area

No significant differences could be found amongst the sexes, ancestry groups or dentition groups when the entire group was considered or amongst the sexes or dentition groups when ancestry groups were considered separately.

6.6.5 Chin

The differences between sexes overall, sexes within ancestry groups and sexes within tooth loss groups were not significant. Significant differences existed between ancestry groups overall and between ancestry groups in dentition group 2 and approaching significance in group 0. Principal components 1 and 2 contributed to 75.1% of the shape differences noted. The mental tubercles in SAE seemed to be relatively wider apart and protruding further anteriorly whilst the pogonion seemed relatively lower. In some individuals the mental tubercles were more prominent than the pogonion (Fig. 6.29).

Significant chin shape changes with tooth loss, could be demonstrated with loss of teeth in SAE but not in SAA. Principal components 1 and 2 contributed to 77.1% of the shape differences noted. The expected relative lowering of the height of the chin between the pogonion and the most superior point were noted and represented the loss of alveolar bone with loss of occlusions. This was however not noted in all individuals.

Discriminant qualities for ancestry in chin shape were 61.2% and 58.0% for sex prediction. Accuracies increased when taking specific dentition groups into account: in dentition group 0: accuracies increased to 71.1% for ancestry and 65.8% for sex. In dentition group 2 accuracies for sex determination improved to 68.2%.

6.7 Conclusion

The variations in the overall mandibular shape demonstrated in Figures 6.5 to 6.7 represented less than 38% of the total shape variation. Shape variations in the gonial area without gnathion presented with 77.9% of the variations (Figs. 6.10 to 6.13) and with gnathion: 64.5% of the variations (Figs. 6.15 to 6.21) present. The variations noted in the chin contributed to 75.1% of the shape differences noted in the entire sample group (Fig. 6.24) and 77.1% of the shape differences noted in SAE (Fig. 6.25). The statistically significant findings noted in the gonial area and chin represented the greatest variation when plotting principal components 1 and 2.

In conclusion, the overall mandibular shape differed significantly between ancestry groups in the entire group and in those with dentition group 2. Interancestry group differences were lost in dentition group 0 and 1. Significant differences were noted between dentition groups but not between sexes. The gonial area with or without the gnathion exhibited significant differences or approached significant differences between sexes and ancestry groups. Discriminant analysis of the gonial area for ancestry and sex prediction, as well as the gonial area with gnathion for ancestry prediction, approximated 60%. Most intersex and interancestry group variations were lost when dentition groups were regarded separately, apart from the interancestry group differences in the gonial area with gnathion noted in group 0. This significant interancestry group difference noted in group 0 was also reflected in the discriminant analysis of 74.4%. Discrimination by gonial area with gnathion improved to some extent for sex prediction in dentition group 1 (73.0%).The discriminant ability for sex by the gonial area with gnathion were 75.8%.

The chin shape did not exhibit sex differences and dentition group differences were noted only in SAE. However, significant differences existed between ancestry groups overall and in dentition group 2 and approaching significance in group 0. Discriminant analysis of chin shape for ancestry and sex prediction once again approximated 60%. Accuracies increased for sex and ancestry estimations when dentition group 0 was considered in isolation, but only for sex estimation in dentition group 2.

Therefore, in general, when dental occlusions were lost, the interancestry group variations in the shape of the gonial area without gnathion (appraising the gonial eversion) and chin often became less pronounced. However, the interancestry group difference of the gonial area with gnathion noted in group 0 was significant, with a 74.4%.accuracy.

The discriminant ability for sex by the gonial area with gnathion were 75.8% accurate, but approximated 60% for gonial area without gnathion and chin shape. The intersex variations of the gonial area with or without the gnathion (appraising the gonial eversion) and the chin shape, could have been confounded by the loss of dental occlusions.

Table 6.1. Sample group used for overall mandibular shape analysis by a 3D digitiser

Dental pattern → Sex ancestry group ↓	Group 0	Group 1	Group 2	Total
Male SAA	10	10	10	30
Females SAA	8	10	14	32
Males SAE	10	8	10	28
Females SAE	10	13	10	33
All	38	41	44	123

Table 6.2. Sample group used for detailed shape analysis by CBCT generated images

Dental pattern → Sex ancestry group ↓	Group 0	Group 1	Group 2	Total
Male SAA	6	5	20	31
Females SAA	7	15	12	34
Males SAE	14	9	9	32
Females SAE	13	10	8	31
All	40	39	49	128

Table 6.3. A comparison of CT and CBCT modalities

	Computed Tomography	Cone beam computed tomography
X− ray beam	Linear fan shaped X-ray beam	Cone shaped
Detectors	single row or a series (4, 8, 12, 32 and now 64) of solid state detectors	Square 2 dimensional (2D) array of detectors
Number of projections	3 (coronal, transverse and sagittal) in 360º	376 in 360˚
Spatial resolution	0,6 mm^2	0,080 mm^3
Measurement of spatial resolution	pixels (mm^2)	voxels (mm^3)

Table 6.4. Sex-ancestry-dentition group colouring symbolisation

Symbol	Sex/ancestry/dentition group
	Females SAA dentition group 0
	Females SAA dentition group 1
	Females SAA dentition group 2
	Females SAE dentition group 0
	Females SAE dentition group 1
	Females SAE dentition group 2
	Males SAA dentition group 0
	Males SAA dentition group 1
	Males SAA dentition group 2
	Males SAE dentition group 0
	Males SAE dentition group 1
	Males SAE dentition group 2

Gonial eversion variations as seen from posterior

Mandibular ramus flexure variations as seen from lateral

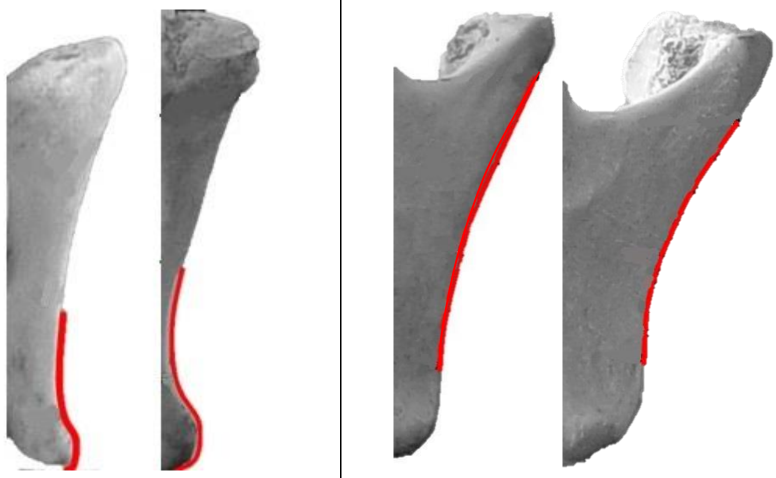


Fig. 6.1 Shape features of the posterior aspect of the mandible

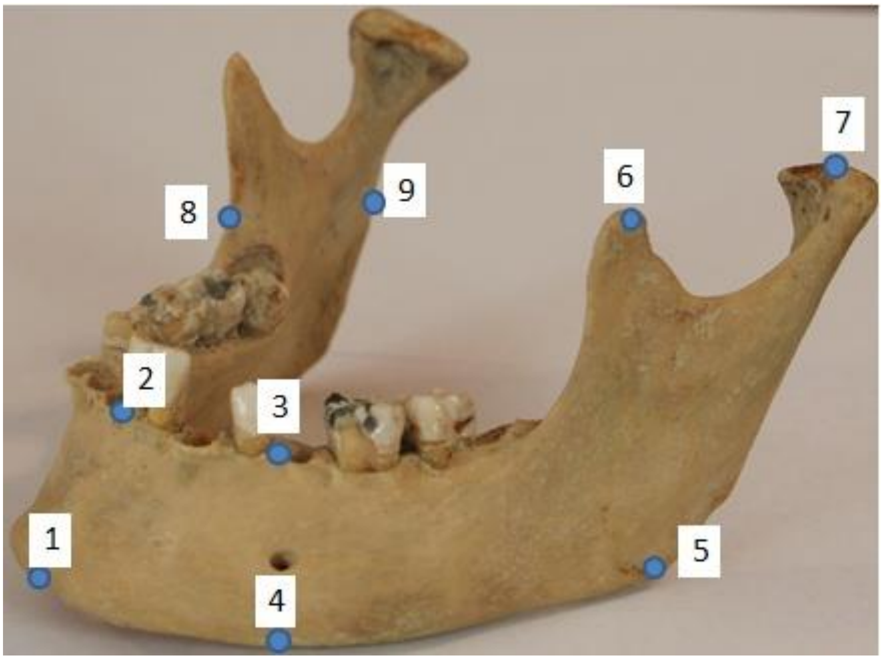
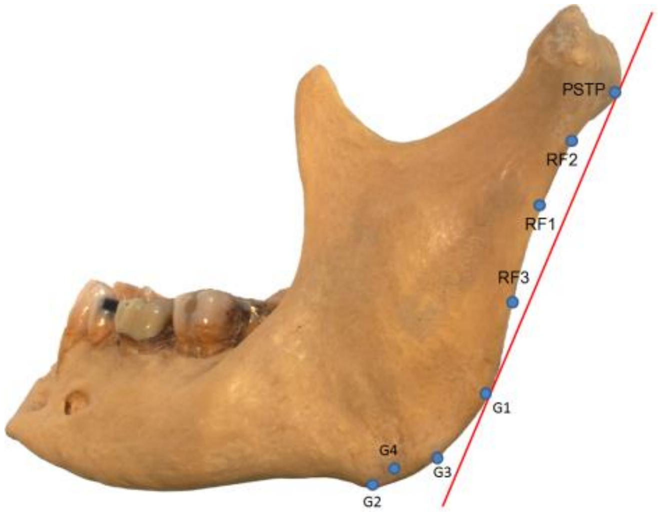
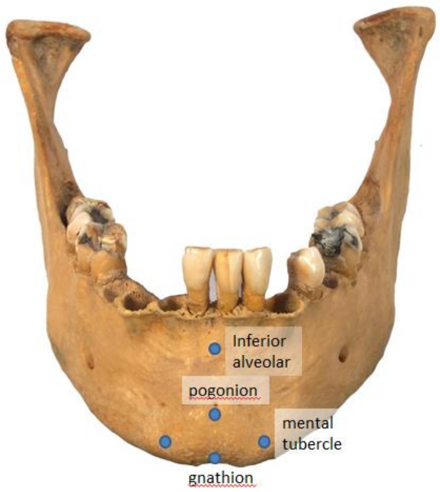


Fig. 6.2 Landmarks used for overall mandibular shape analysis by a 3D digitiser. The descriptions of the specific landmarks can be found in the text.



Lateral view

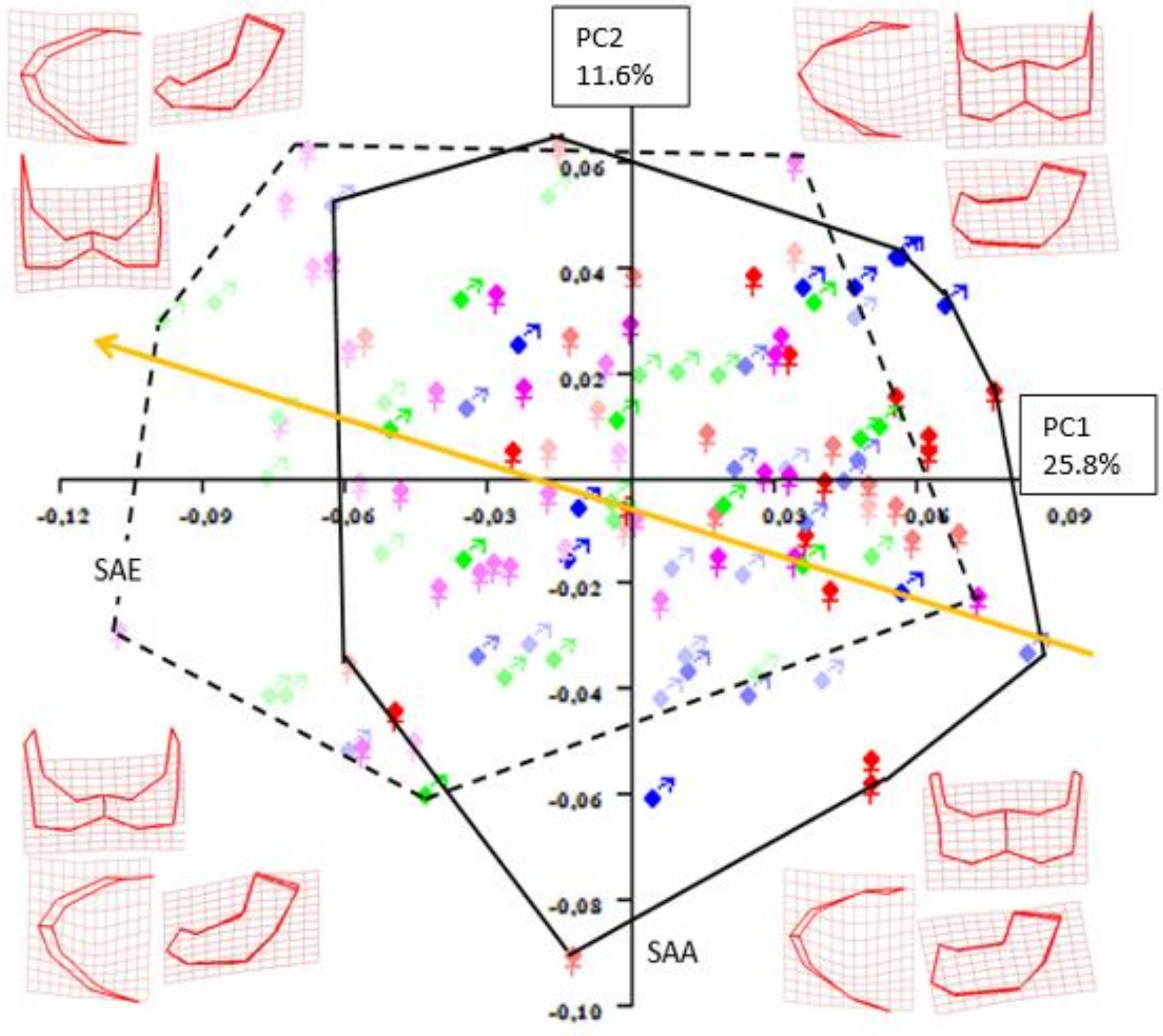


Anterior view

Fig. 6.3 Landmarks identified on CBCT images for shape analysis. The descriptions of the specific landmarks can be found in the text.

Superior Anterior Lateral

Fig. 6.4 Overall mandibular shape reflected in wireframes



Key:

SAE:

SAA:

General direction of change:

Colouring of scatter points is explained in Table 6.4.

Fig. 6.5 Principal component 1 vs. 2 in the comparison of ancestry groups in the complete sample for the overall mandibular shape

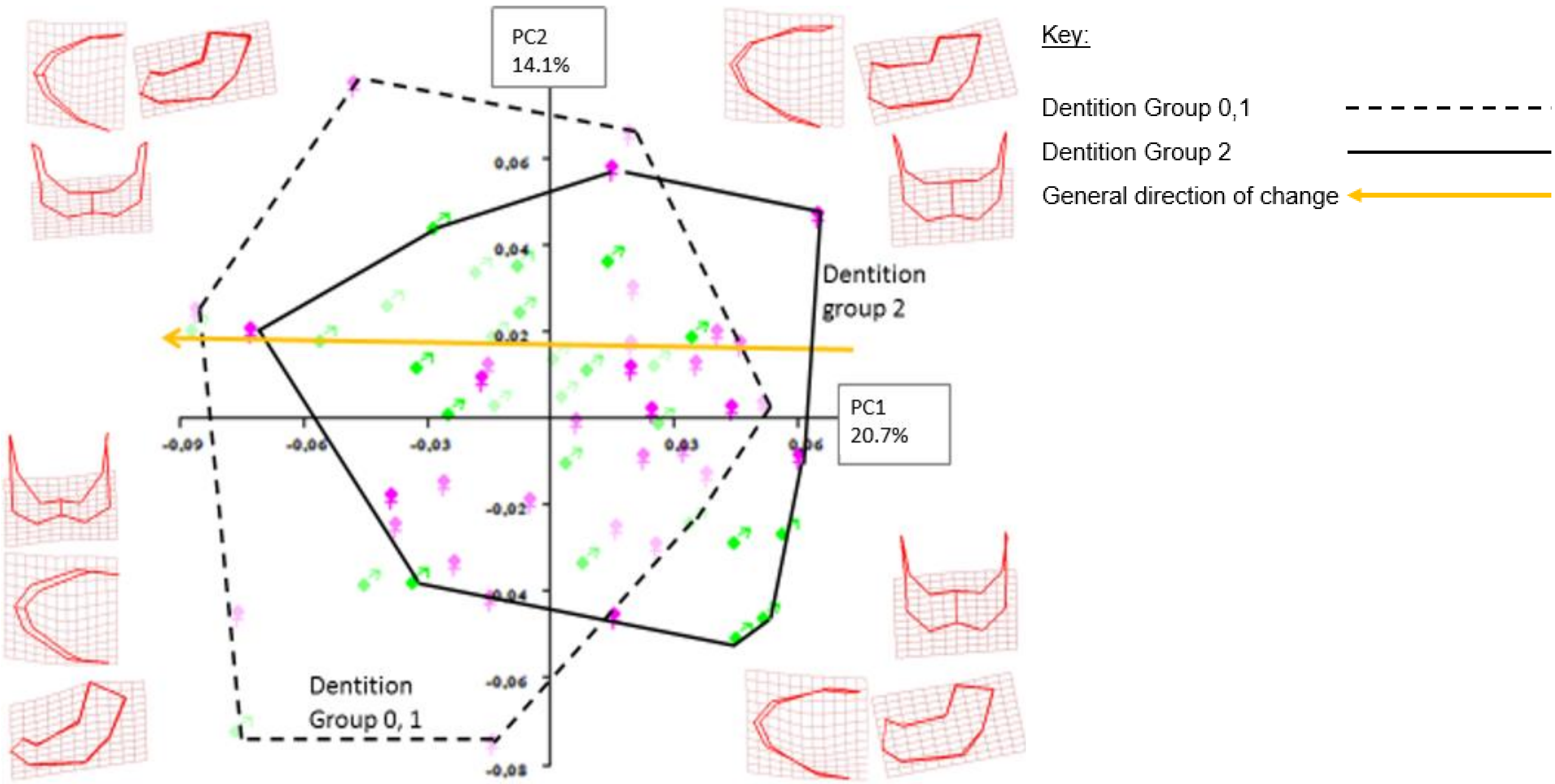


Fig. 6.6 Principal component 1 vs. 2 in the comparison of dentition groups 0 and 1 combined compared to 2 in SAE for the overall mandibular shape

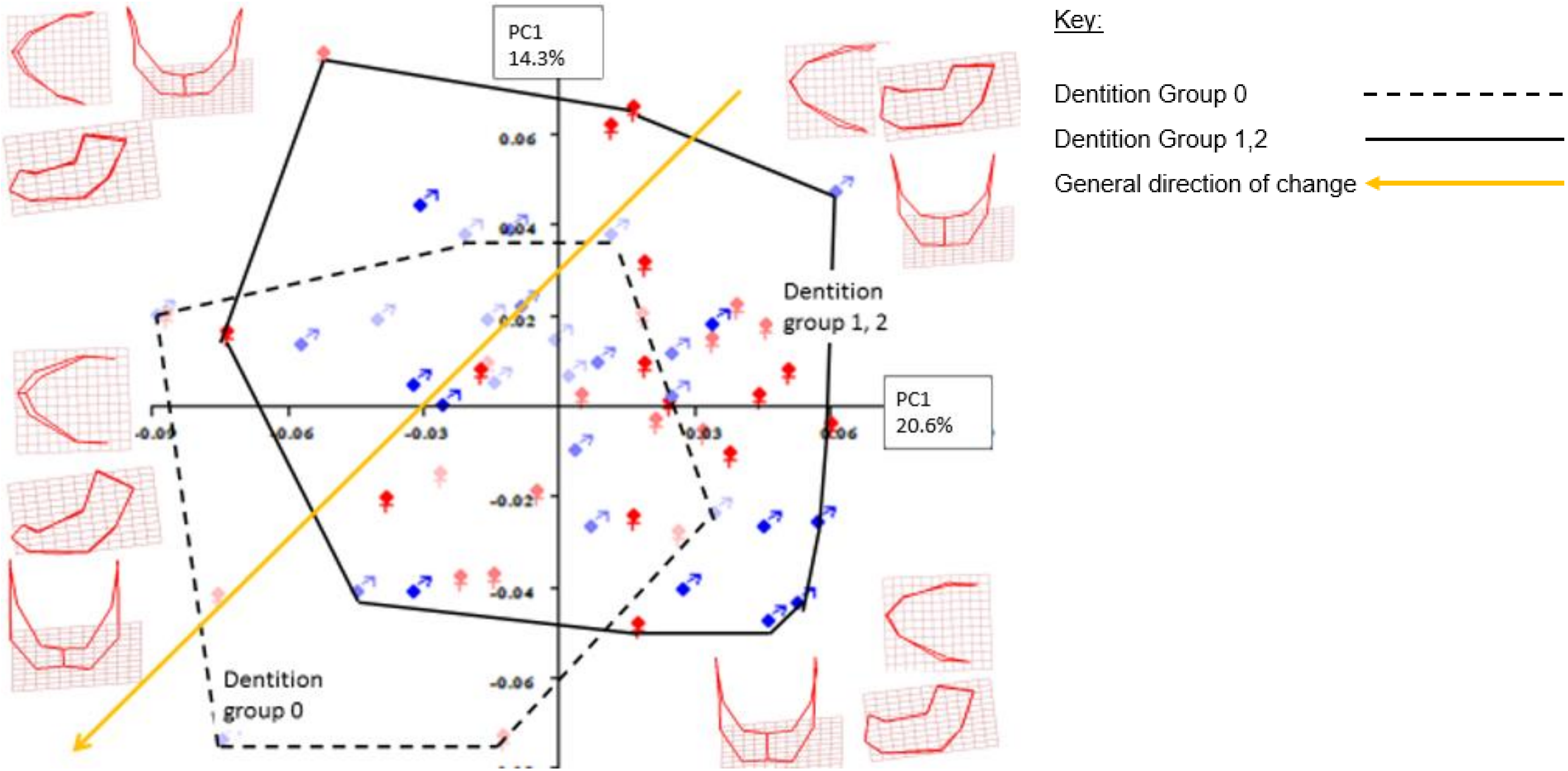
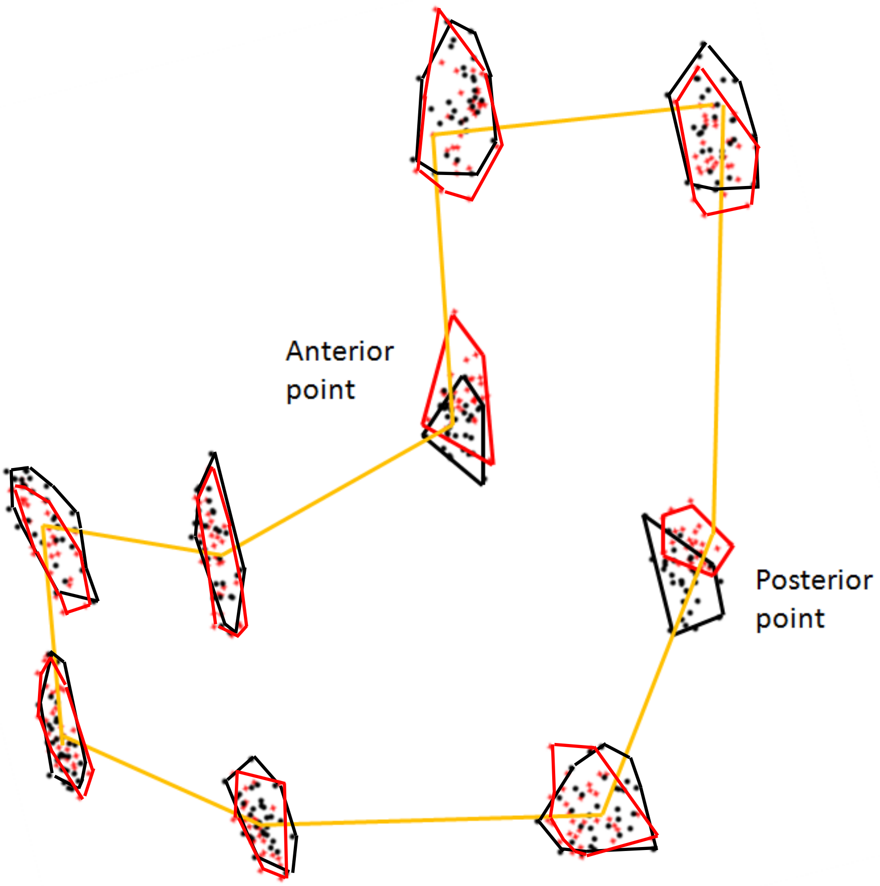


Fig. 6.7 Principal component 1 vs. 2 in the comparison of dentition group 0 compared to 1 and 2 combined in SAA for the overall mandibular shape



Yellow wireframe connecting points are for illustrative purposes only
Red and black hulls illustrate variations between two observers at these landmarks

Fig. 6.8 Interobserver 3D landmark scatter points of overall mandibular shape by two observers

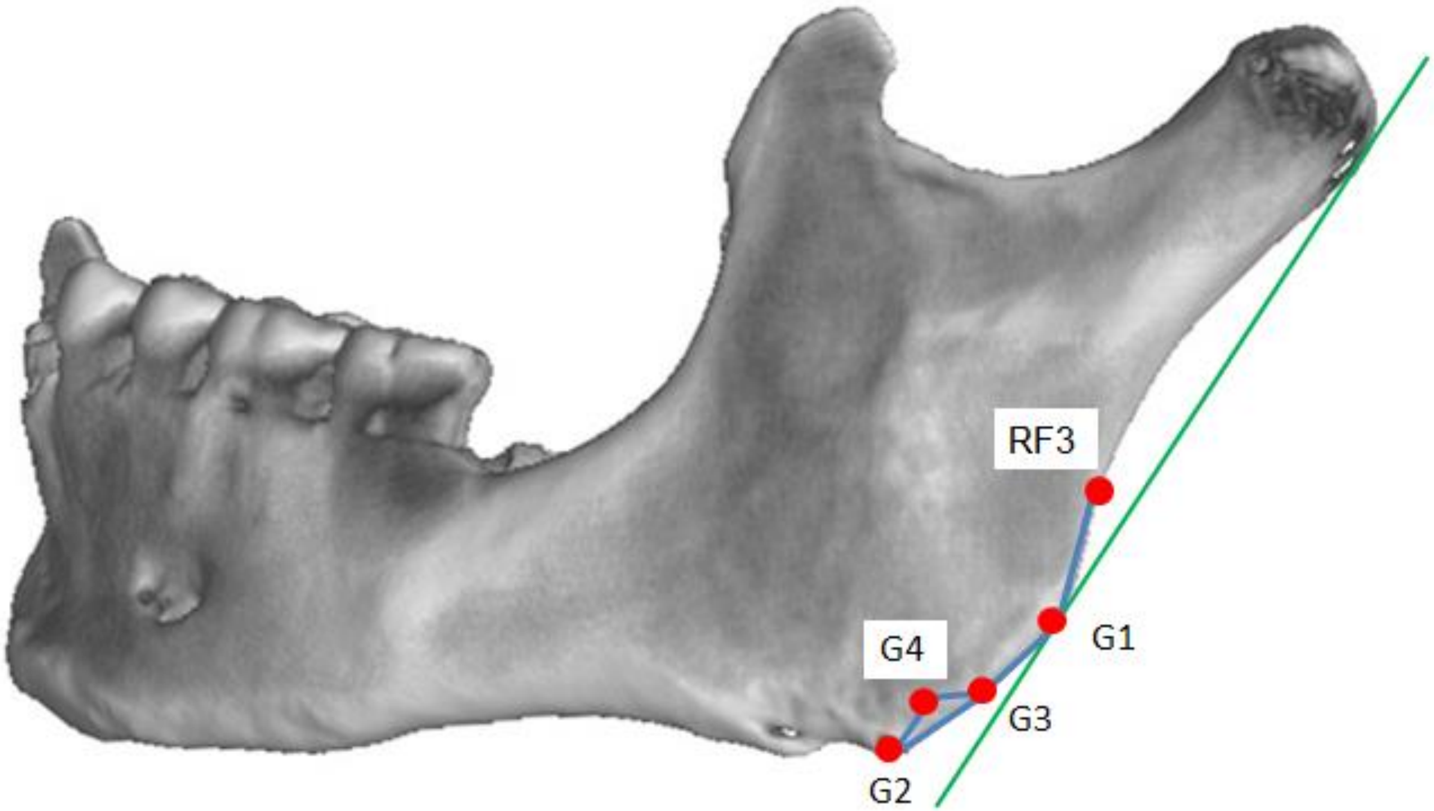


Fig. 6.9 Cone beam derived image of the mandible with applied landmarks and wire frame of the gonial area without the gnathion

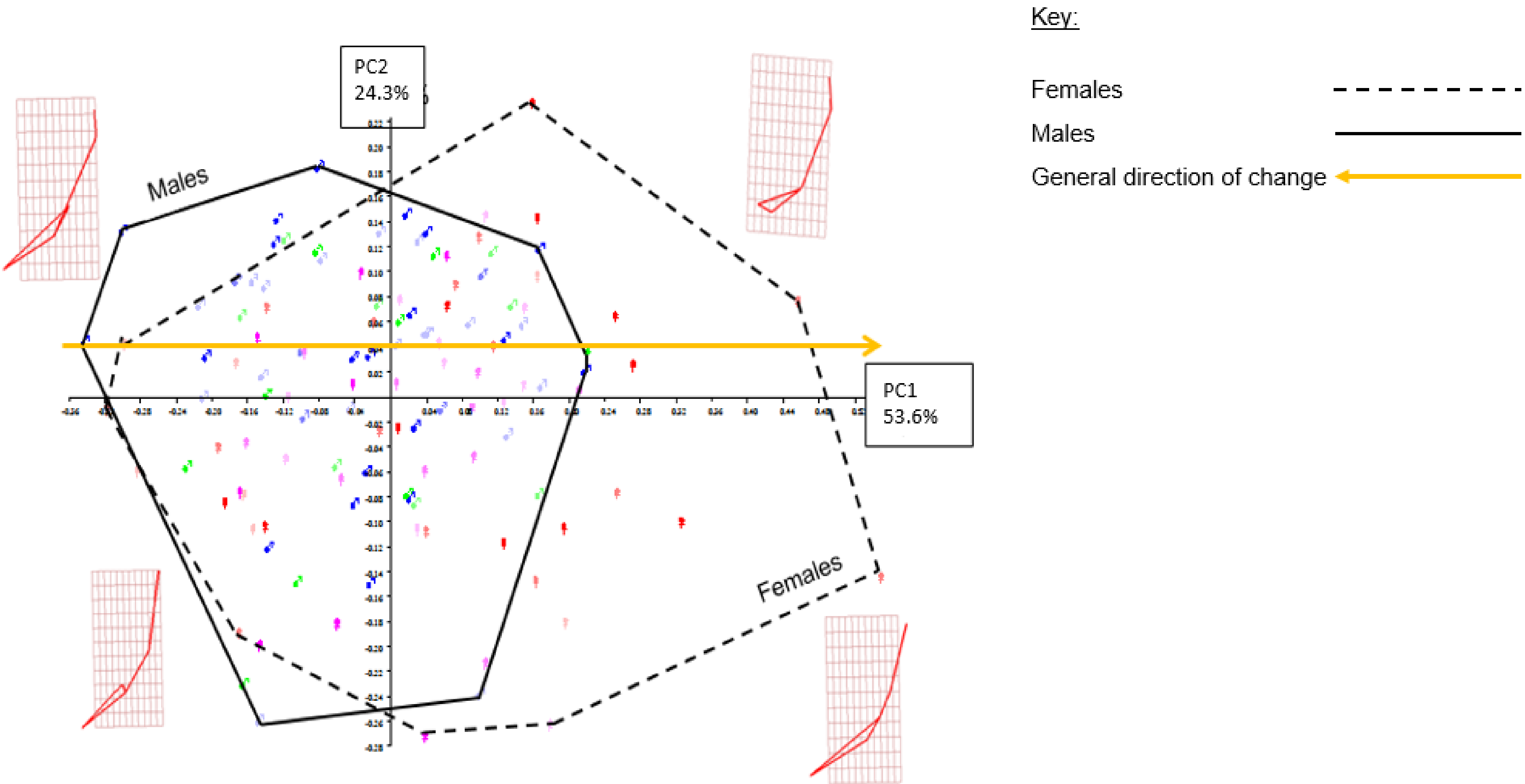


Fig. 6.10 Principal component 1 vs. 2 in the comparison of the sexes in both ancestry groups and all dentition groups for the gonial area

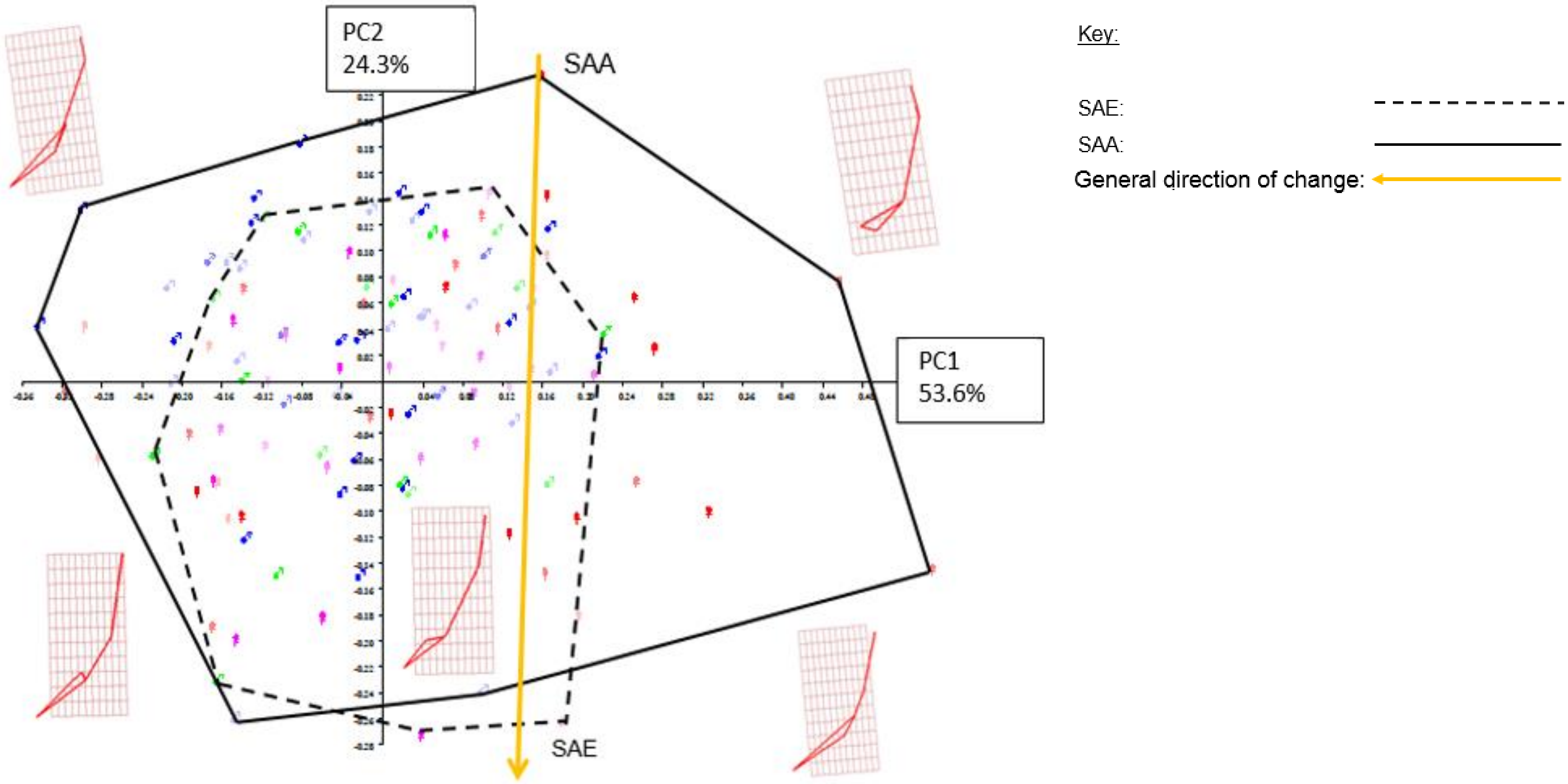


Fig. 6.11 Principal component 1 vs. 2 in the comparison of the ancestry groups in all dentition and both sexes for the gonial area

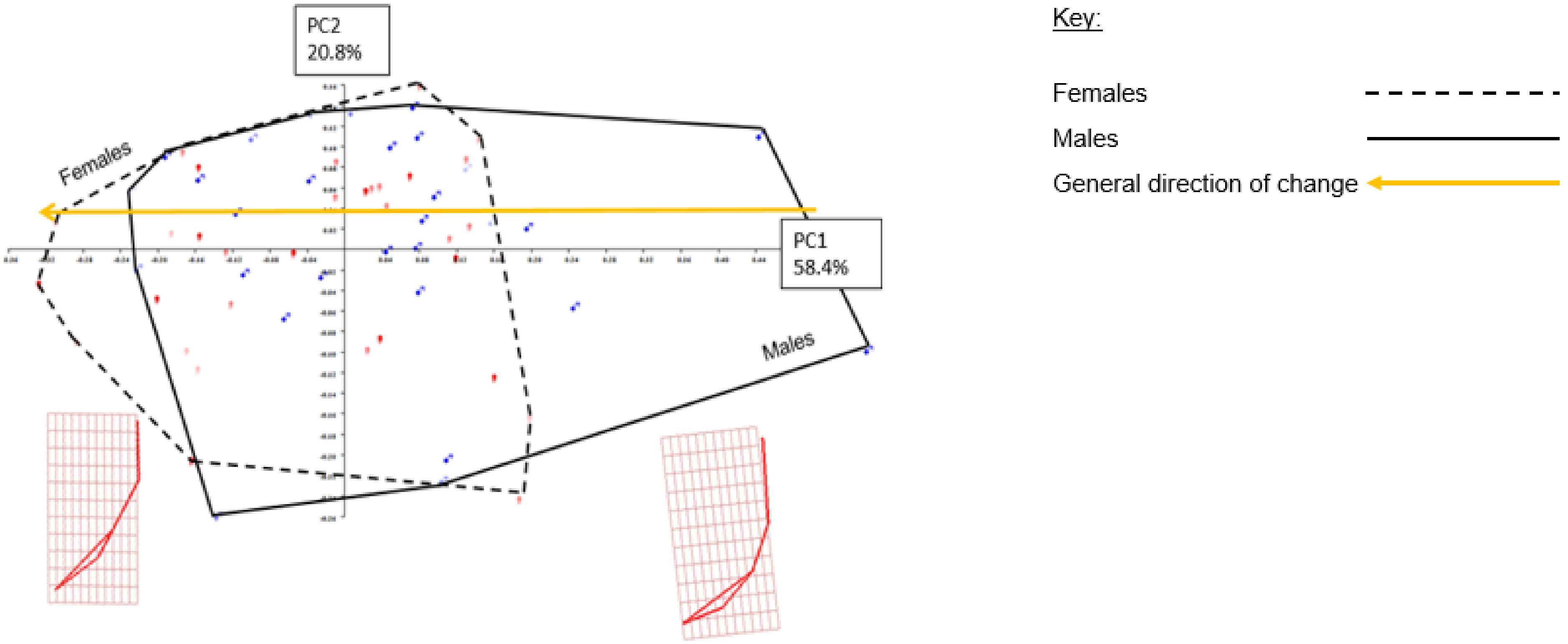


Fig. 6.12 Principal component 1 vs. 2 in the comparison of sexes in SAA for the gonial area

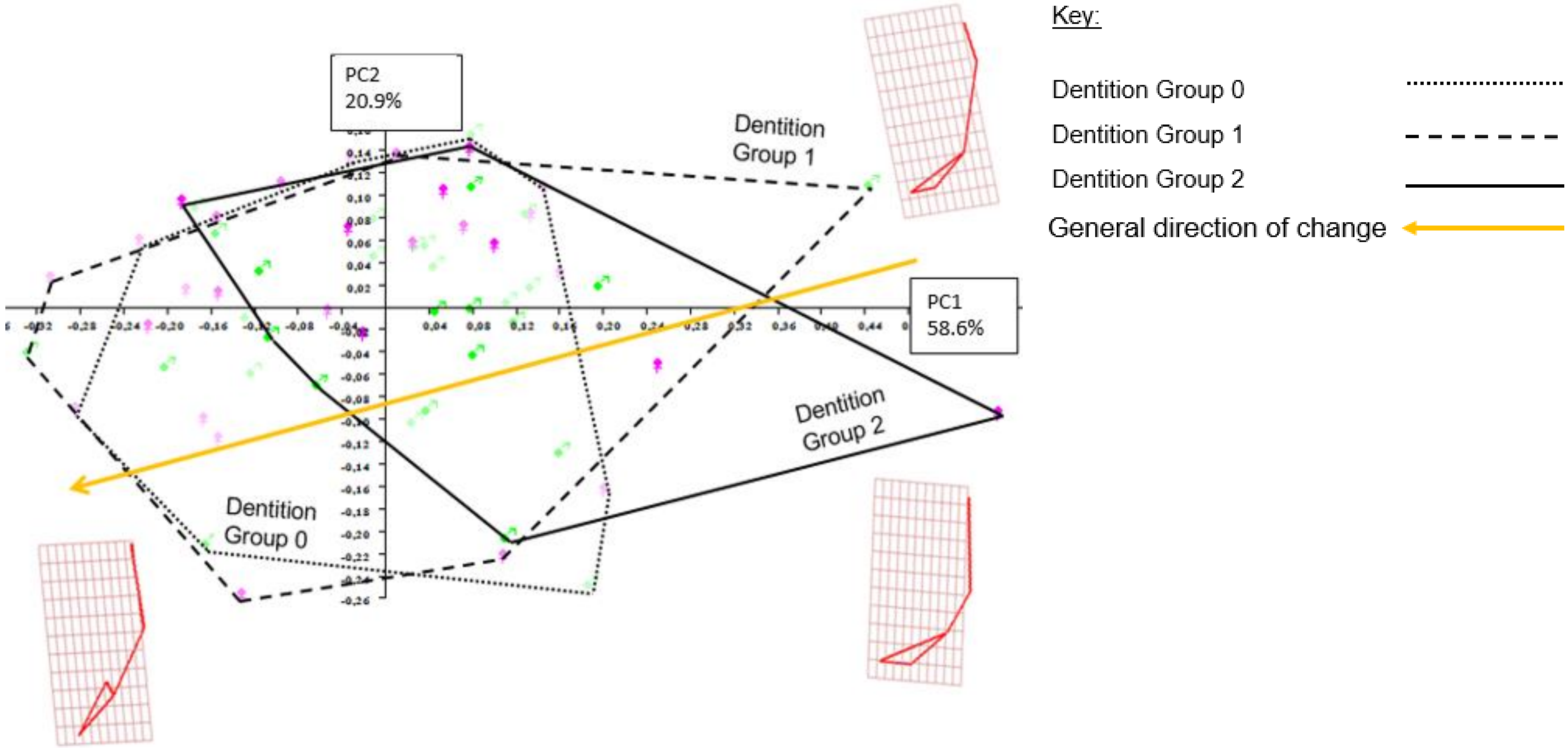


Fig. 6.13 Principal component 1 vs. 2 in the comparison of dentition groups in SAE for the gonial area

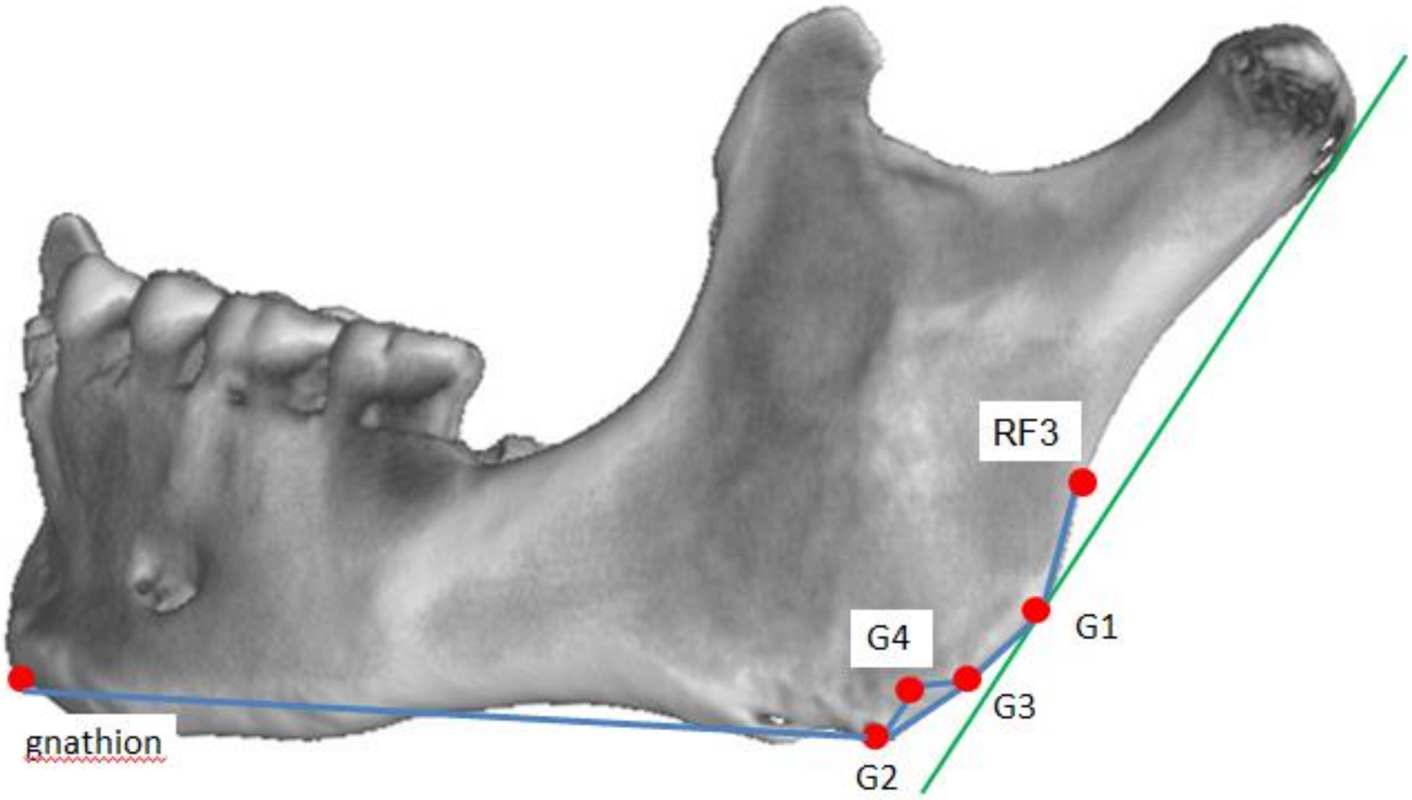


Fig. 6.14 Cone beam derived image of the mandible with applied landmarks and wire frame of the gonial area with the gnathion

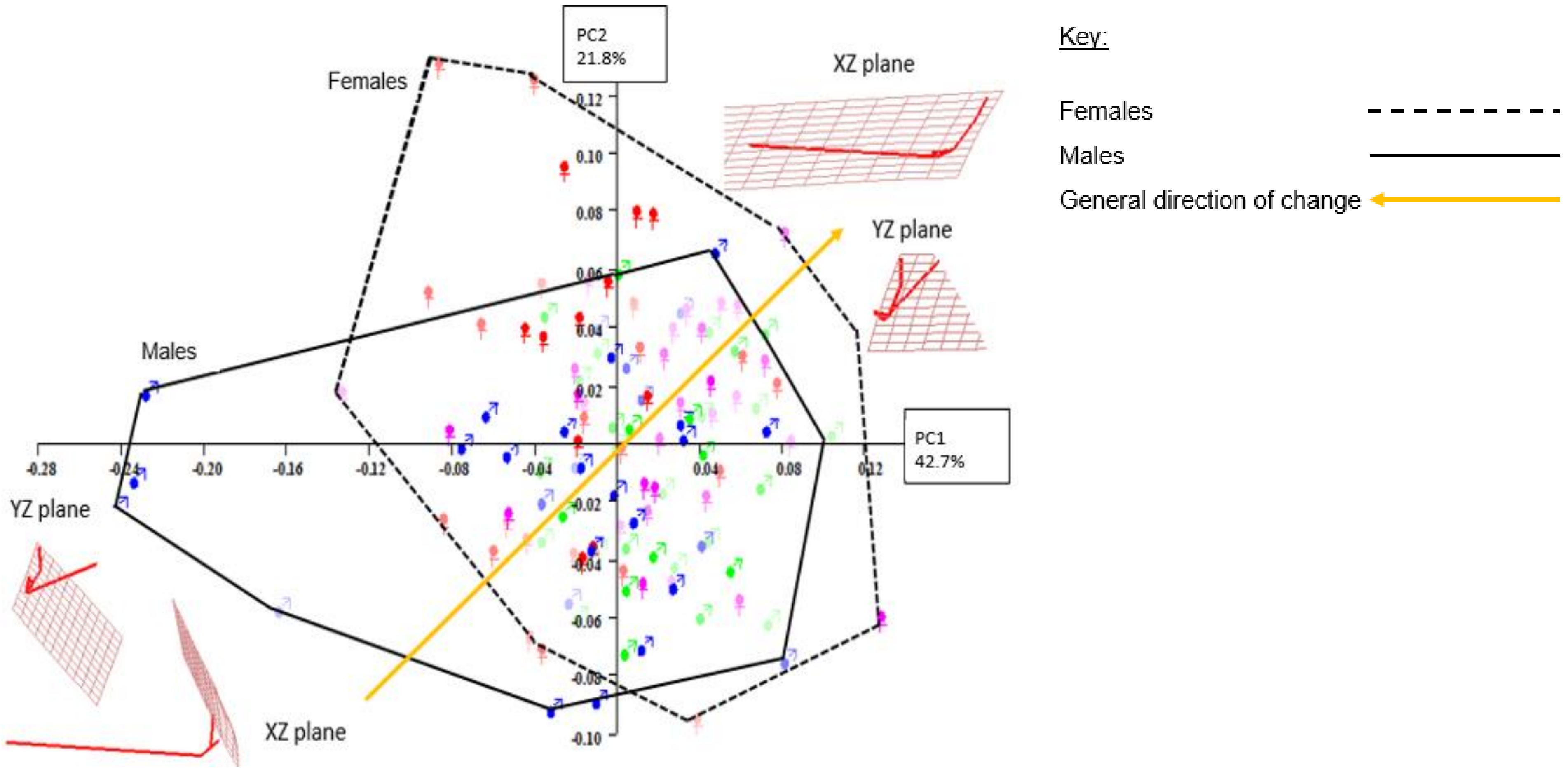


Fig. 6.15 Principal component 1 vs. 2 in the comparison of the sexes in both ancestry groups and all dentition groups for the gonial area with gnathion

0

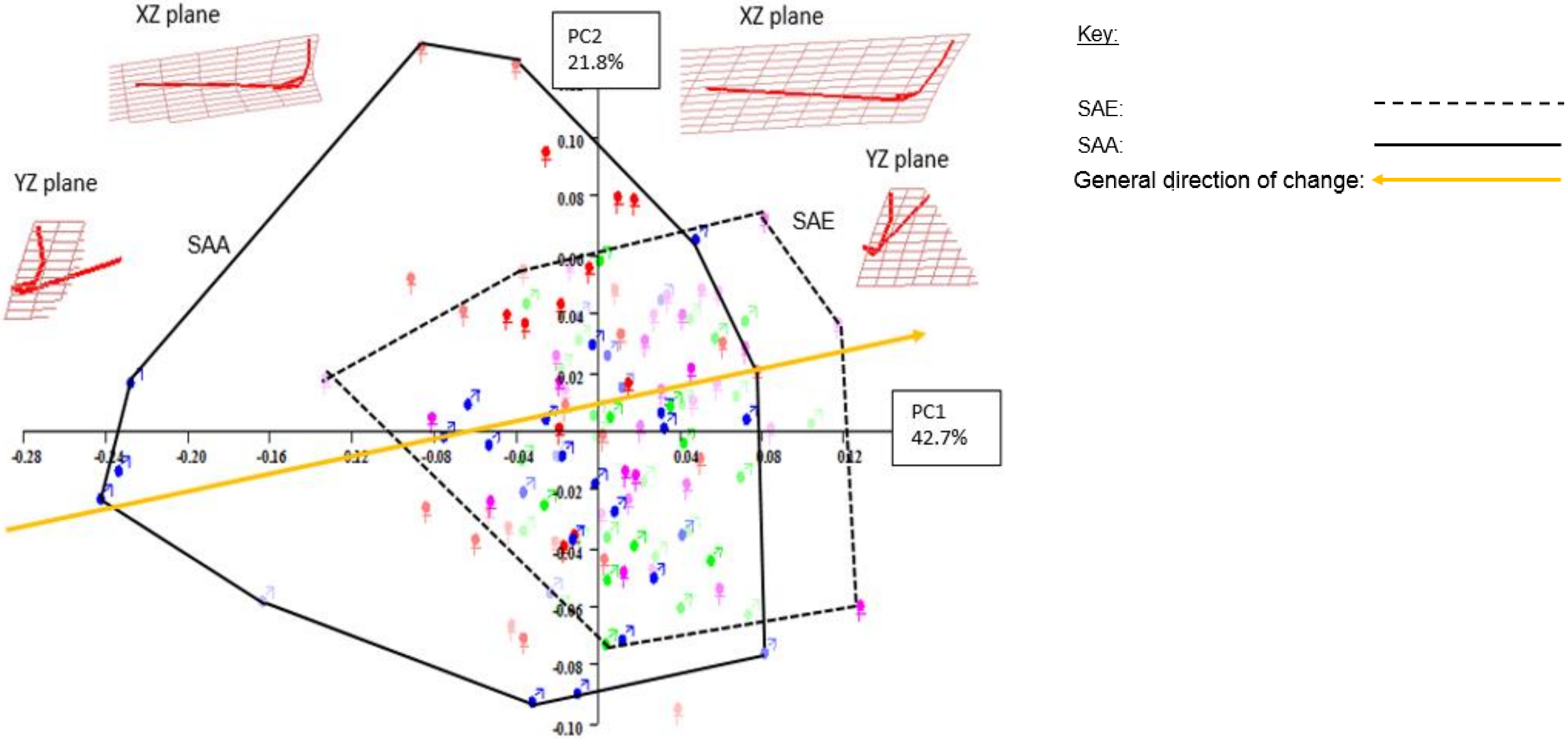


Fig. 6.16 Principal component 1 vs. 2 in the comparison of the ancestry groups in both sexes and all dentition groups for the gonial area with gnathion

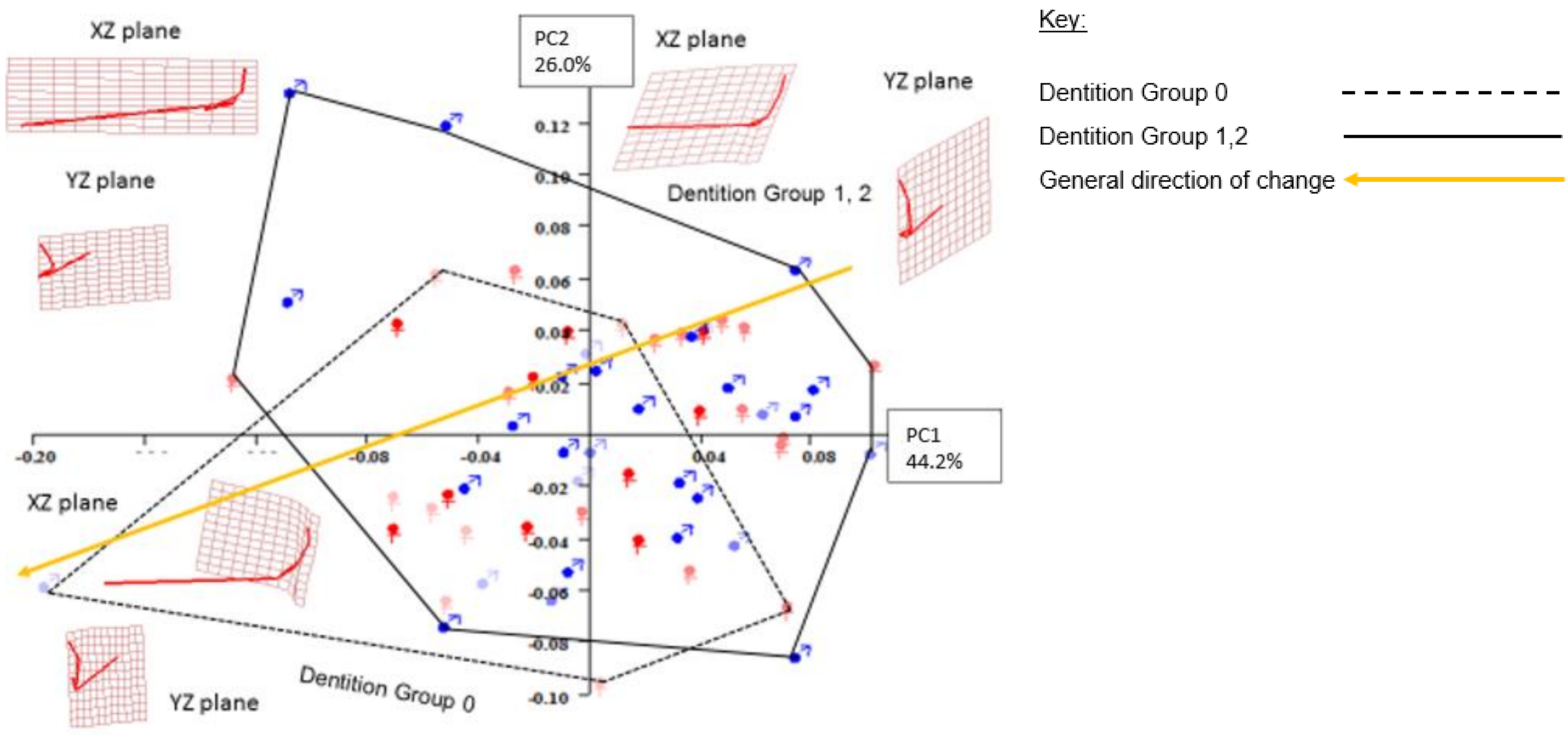


Fig. 6.17 Principal component 1 vs. 2 in the comparison of dentition group 0 as compared to 1 and 2 combined in both sexes in SAA for the gonial area with gnathion

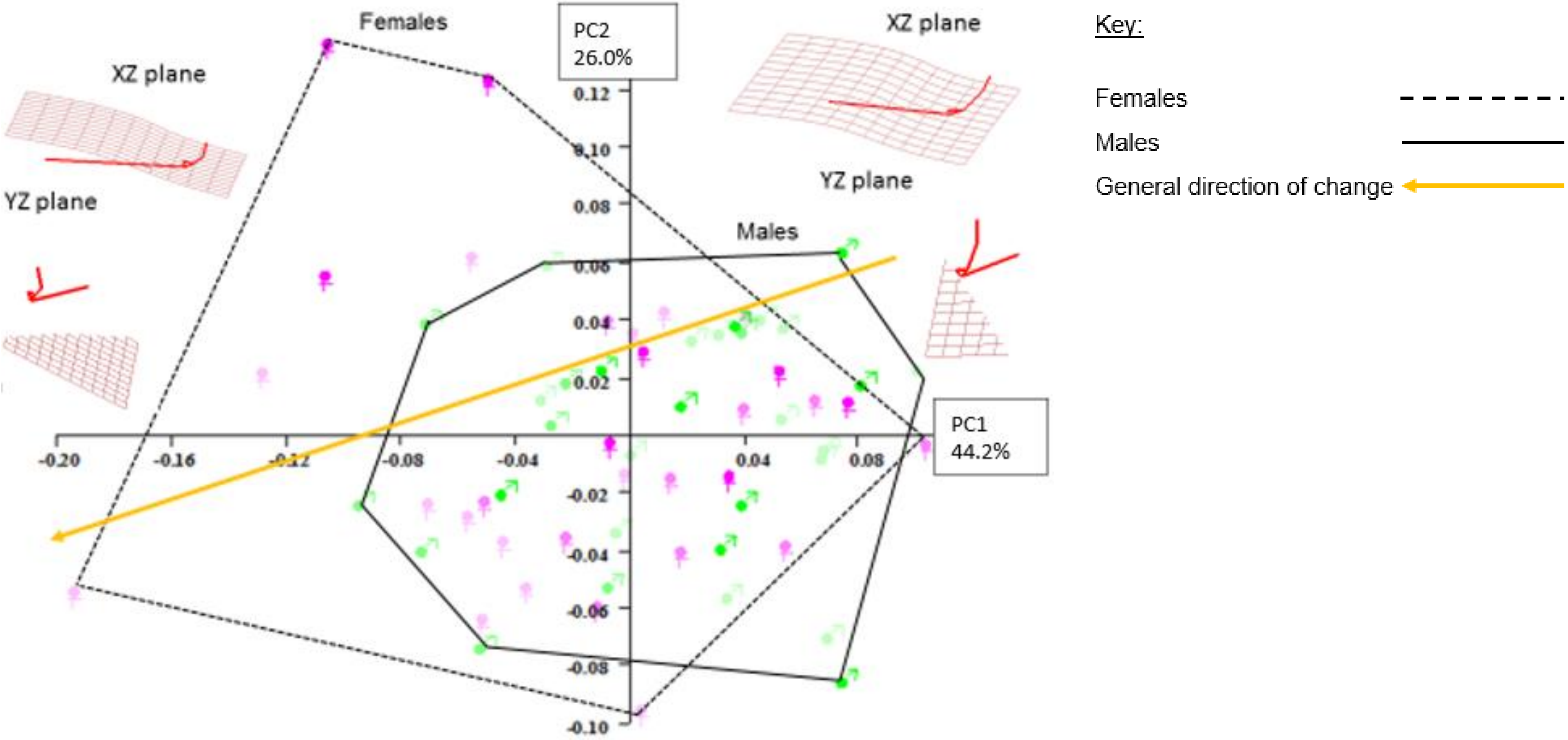


Fig. 6.18 Principal component 1 vs. 2 in the comparison of the sexes in al dentition groups in SAE for the gonial area with gnathion

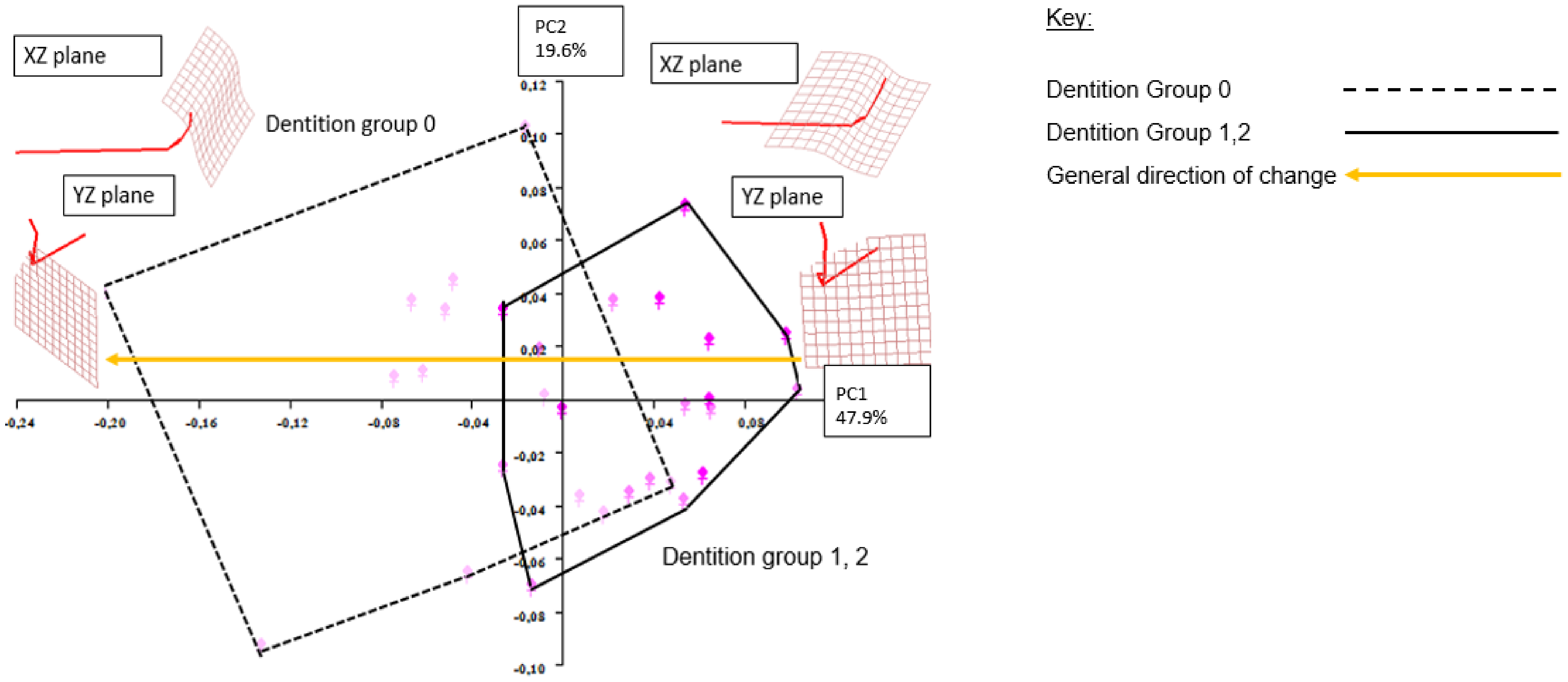


Fig. 6.19 Principal component 1 vs. 2 in the comparison of dentition groups in female SAE for the gonial area with gnathion

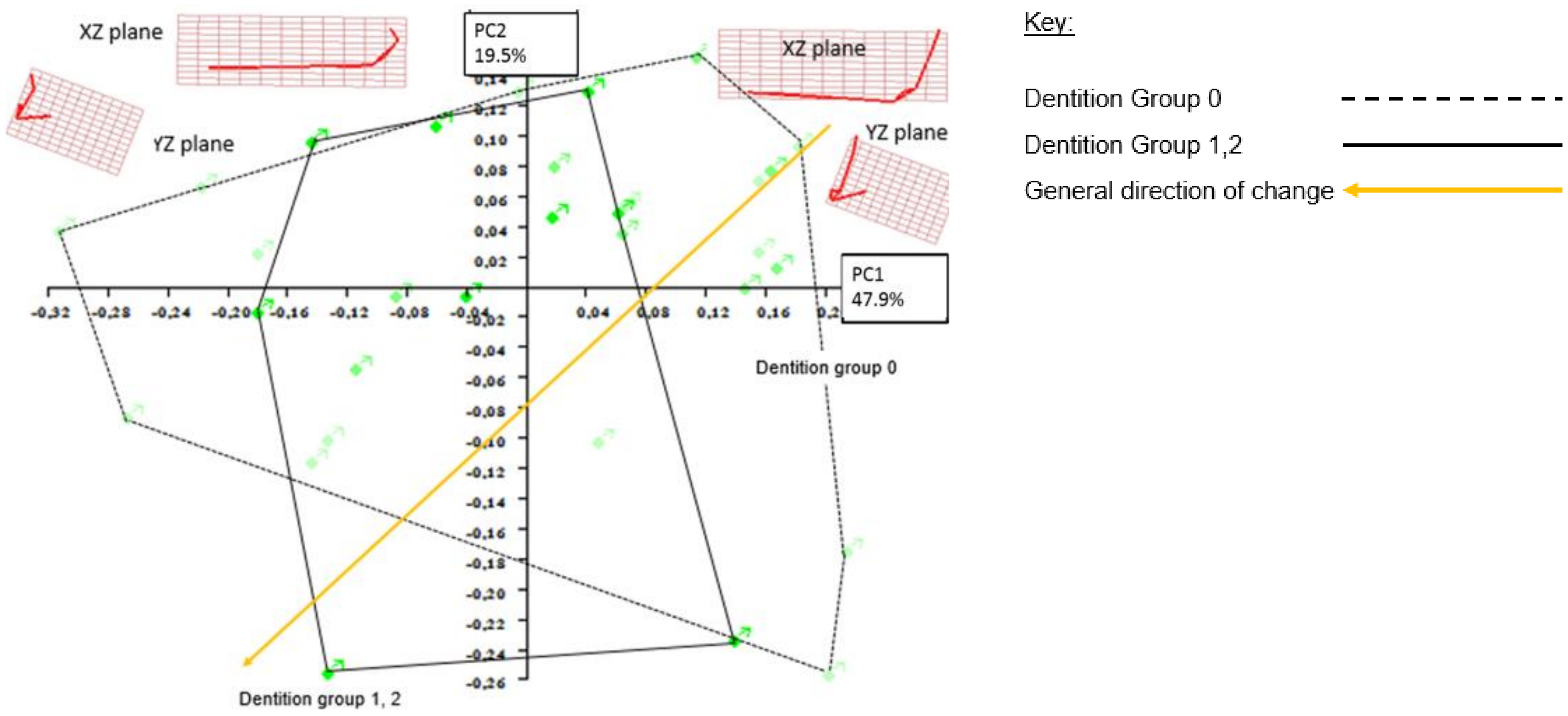


Fig. 6.20 Principal component 1 vs. 2 in the comparison of the dentition groups in male SAE for the gonial area with gnathion

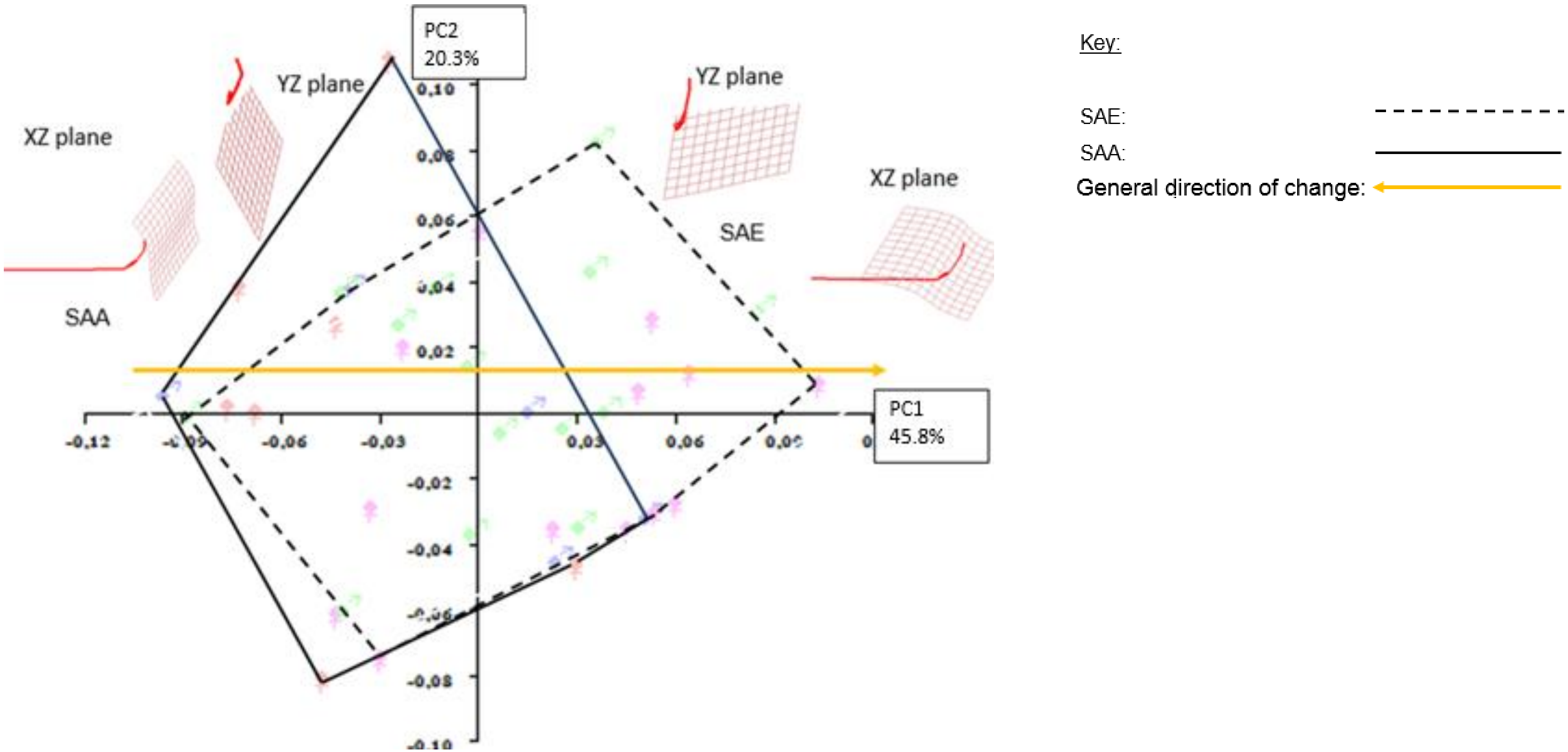


Fig. 6.21 Principal component 1 vs. 2 in the comparison of the ancestry groups in dentition group 0 in all sex ancestry group groups for the gonial area with gnathion

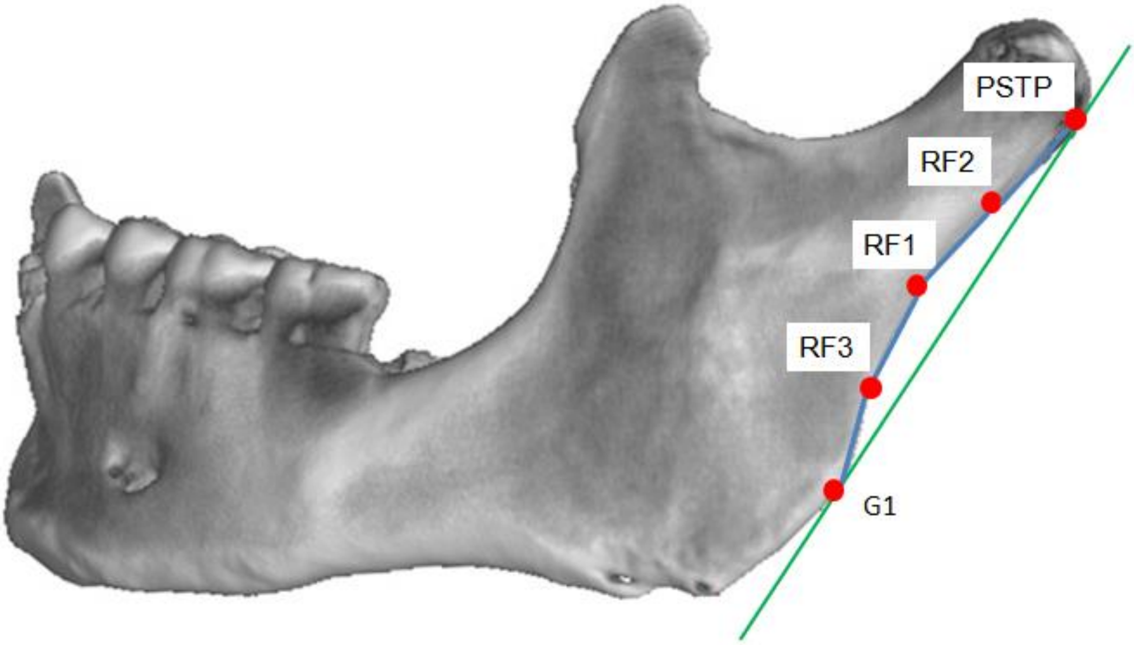


Fig. 6.22 Cone beam derived image of the mandible with applied landmarks and wire frame of the ramus flexure area

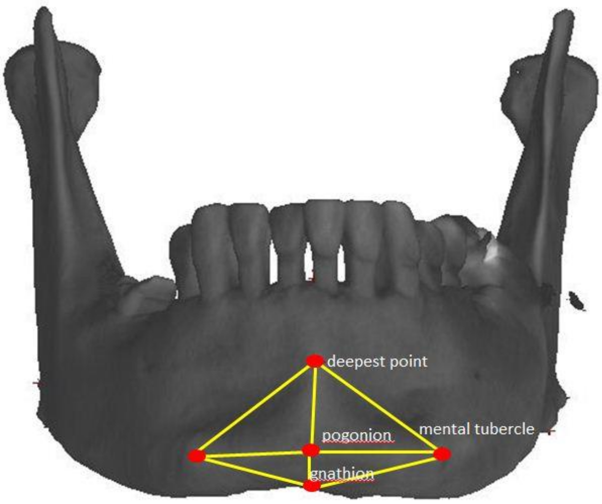


Fig. 6.23 Cone beam derived image of the mandible with applied landmarks and wire frame of the chin area

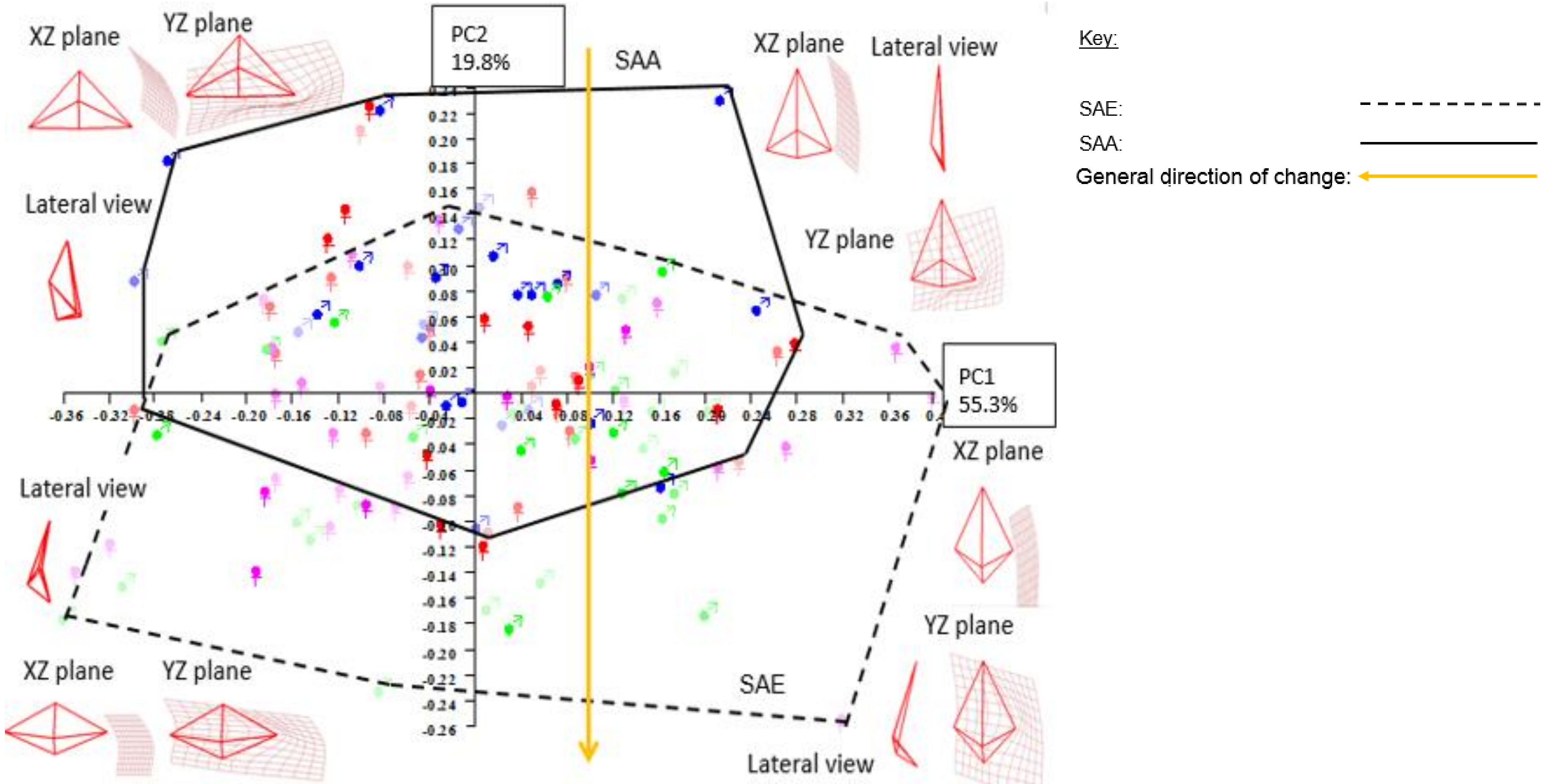


Fig. 6.24 Principal component 1 versus 2 in the comparison of chin shape amongst the ancestry groups in all dentition groups

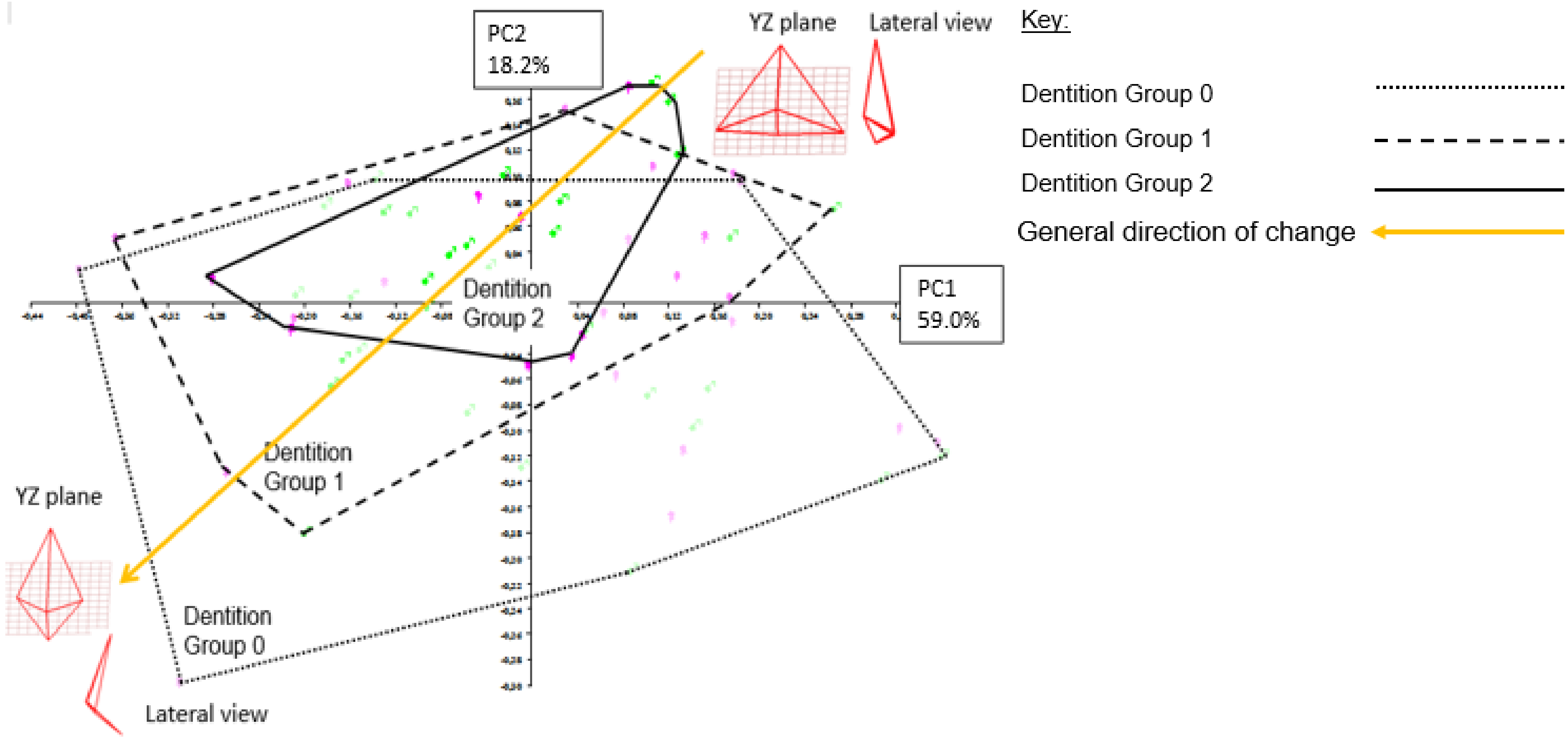


Fig. 6.25 Principal component 1 versus 2 in the comparison between chin shape amongst dentition groups in SAE

SAA

SAE compared to SAA: lowering of mandibular body height; more obtuse gonial angle; superior border of the mandible smaller than inferior border; more prominent pogonion

Group 2 dentition

Lateral | Superior | Lateral | Superior

Group 0 dentition as compared to Group 2: lowering of mandibular body; longer and slimmer rami; less upright gonial angles; mandible widened and flattened; SAE example: coronoid process higher compared to the condylar process

Lateral | Superior | Lateral | Superior

Fig. 6.26 Overall mandibular shape comparisons between ancestry and dentition groups in males

SAA

SAE compared to SAA: lowering of mandibular body; longer and slimmer rami; more obtuse gonial angle superior border of the mandible smaller than inferior border; more prominent pogonion

Group 2 dentition

Lateral Superior Lateral Superior

Group 0 dentition as compared to Group 2: lowering of mandibular body; longer and slimmer rami; less upright gonial angles; superior border of the mandible smaller than inferior border; more prominent pogonion; coronoid process higher compared to the condylar process; mandible widened and flattened

Lateral Superior Lateral Superior

Fig. 6.27 Overall mandibular shape comparisons between ancestry and dentition groups in females

SAA	SAE
More pronounced posterior convexity in the gonial area and gonial eversion more prominent	Elongated ramus and smoother posterior margin; angle more obtuse and posterior curvature limited to the more inferior portion.

Males

Lateral | Posterior | Lateral | Posterior

Females

Compared to males: elongated ramus and smoother posterior margin; more obtuse angle; posterior curvature limited to the more inferior portion

Lateral | Posterior | Lateral | Posterior

Fig. 6.28 Gonial area comparisons between sexes and ancestry groups

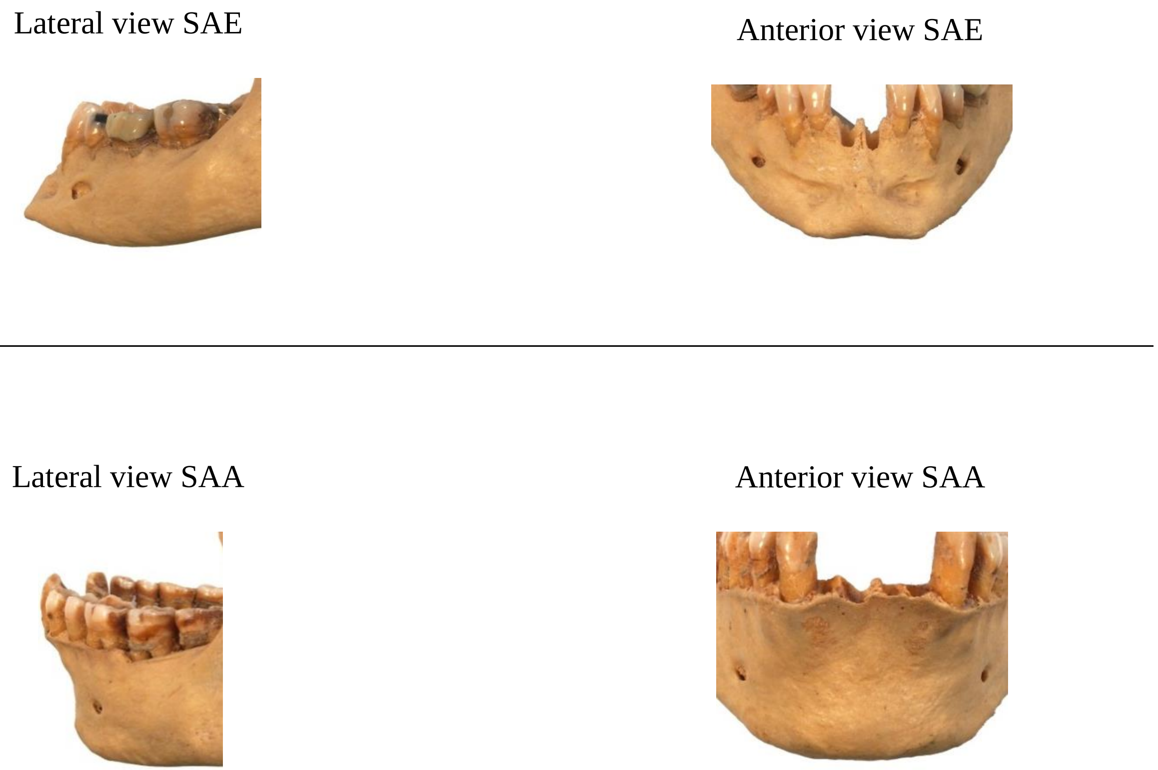


Fig. 6.29 Chin shape variation amongst the ancestry groups

Chapter 7: CORTICAL BONE THICKNESS

7.1 Introduction

Cortical bone is the outer dense compact bone which can be differentiated from the spongy interior. Various dimensions of the external shape of the mandible have been related to the thickness of the cortical bone at specific sites in the mandible, as the same biomechanical factors determining external morphology affect the internal morphology as well (Kohakura et al. 1997; Xie & Ainamo 2004).

Biomechanical factors such as the orientation of the masticatory muscles and the forces that they generate differ amongst facial shape types, and the degree of prognathism (Patriquin 2013). Protrusion of the upper and lower jaws are positively correlated with the buccal cortical bone thickness at certain sites (Kohakura et al. 1997). It is therefore anticipated that cortical bone thickness associated with protrusion of the jaws such as in prognathic individuals, might be extrapolated to differences amongst ancestry groups associated with differences in the extent of protrusion of the jaws.

Differences between sexes, dentition groups and changes with age can also play a role (Kohakura et al. 1997; Schwartz-Dabney & Dechow 2003; Xie & Ainamo 2004). Xie and Ainamo (2004) remark that on average men have a greater masticatory force than women, and these authors used this to explain their findings that dentate women had greater gonial angles than dentate men in both young and elderly groups. In contrast to what is expected, Schwartz-Dabney and Dechow (2002) proposed that edentulous subjects may present with thicker cortical bone at specific regions than dentate mandibles. The thickening of the cortical bone was thought to represent a secondary adaptation to relatively larger strains due to a reduction in alveolar height and corpus cross section, despite overall reduced muscular and biting loads (Schwartz-Dabney & Dechow 2002). This proposition will be explored further in this chapter to see whether it holds true or not.

The cortical thickness and appearance at specific sites on CBCT generated images of the specimens for each of the 12 sex-ancestry-dentition groups were assessed to find associations with cortical bone thicknesses at specific sites. The effect of aging was investigated as well. The overall purpose of this part of the study was to relate masticatory function with cortical thickness amongst various sex-ancestry-dentition groups and in a later chapter to compare these findings to the metric and shape variations discovered amongst groups. The regional variation of cortical bone thickness further contributes to the understanding of the biomechanical forces of mastication with tooth loss determining the external morphology of the mandible.

7.2 Materials

CBCT images derived from 130 dried mandibles were selected as representatives of the 3 dentition subgroups within each sex ancestry group as defined before and are represented in Table 7.1. The means and standard deviations of the ages per cell group (sex-ancestry-dentition group) are indicated in Table 7.2. There were significant differences in age between ancestry and dentition groups, with the youngest group being female SAA and the oldest group female SAE. The youngest subgroup were male SAA dentition group 2. Male SAE had very similar ages across the dentition groups.

7.3 Methods

A general account of the appearance of the sections derived from 3D reconstructed images is given. This was done to explain the placement of the caliper tool (VG studio max software) in taking the measurements across the shortest distance of the compact cortical bone. Cortical thickness distances were measured by integrating the information provided by the 3D reconstructed CBCT image together with the axial, sagittal and frontal views which showed the XY, YZ and XZ slices respectively.

The cortical thickness at various areas was measured in each specimen by means of VG Studio MAX 2.1 software studio. Sections were made on the CBCT derived images at five homologous locations that had the possibility to be repeated in all specimens regardless of dentition group. These sections were therefore also possible on edentulous mandibles.

Firstly, a section was made at a line joining the most posterior point on the inferior border of the mandibular body to the coronoid process for the cortical thickness in the gonial area on either side (Fig. 7.1). Secondly a section was made perpendicular to the long axis of the mandibular body through the mental foramen for measuring the cortical thickness inferiorly (from the most inferior point) and lingually (from a point opposite the mental foramen) (Fig. 7.2). Lastly a midline sagittal section was made to measure the anterior, inferior and posterior shortest cortical thickness (Fig. 7.3). All measurements were taken as the shortest perpendicular distances from the each surface.

Inter- and intraobserver errors were tested by remeasuring a total of 30 randomly selected mandibles at a later occasion by the principal investigator and another observer familiar with the method.

7.4 Statistical analysis

Linear regressions of the cortical thicknesses with dental loss and age at the six sites described were performed. The means and standard deviations of the cortical thickness at the various sites were calculated for each of the four sex ancestry dentition subgroups. Statistical analyses were performed amongst ancestry, sexes and dentition groups. The ancestry groups comprised 68 SAA and 62 SAE. The numbers representing the sexes were 67 females and 63 males. The dentition groups detailed before consisted of 49 as group 2; 41 as dentition group 1 and 40 individuals classified as dentition group 0 (Table 7.1). Statistical comparisons between groups were made using analysis of covariance (ANCOVA), correcting for age if it was found to be a significant covariate. Interactions amongst sex, ancestry and dentition groups were also investigated. Lastly discriminant analysis on individual cortical thicknesses as well as cumulative thicknesses were performed.

Interrater reliability of the measurements by a second observer familiar with the technique was tested on a random sample of 30 specimens and measured by the maximum likelihood estimate of the intraclass correlation coefficient. Similarly, intrarater reliability of the measurements of the main investigator was tested when the measurements were repeated at a later stage.

7.5 Results

7.5.1 Cortical bone appearance

The appearance of the cortical bone structure on the CBCT derived images is illustrated in Table 7.3. The first row of images (Table 7.3 a) presents examples of thick dense cortical bone usually found in dentulous individuals. The individuals in the second and third row were also dentate (Table 7.3 b, c). A few translucencies from the medullary side were evident in the second row of examples, which became more obvious in the third row. Some of the individuals in the fourth row were edentulous and the cortical bone presented as dense cortical bone around the edges (a double rim), with more translucent bone on the inside. The double rim appearance is presumed to be a consequence of coalescence of the translucencies (Table 7.3 d). Only the outer rim was regarded as cortical bone in this study when measurements were taken.

7.5.2 Gonial cortical thickness (Gon)

Cortical thickness in the gonial region in both female SAA and male SAE presented with weak positive correlations with age associated with 2.3% and 0.1% respectively of the increase in *Gon* (Fig. 7.4). In contrast *Gon* in male SAA and female SAE, with wider age ranges, demonstrated a weak negative relationship. It may therefore be assumed that a decrease in *Gon* may only be evident when extremes of ages were present.

In the linear regression of *Gon* with dental loss (Fig.7.5), the cortical thickness approached a moderate relationship in female SAE. This was not entirely unexpected as female SAE group consisted of the oldest individuals. A longer time period with fewer occlusions could therefore render a greater thinning effect on the inferior cortical thicknesses.

Comparisons between sex-ancestry-dentition groups of the *Gon* cortical thickness can be found in Table 7.4. As age was not a significant covariate (p = 0.8472) for the entire sample, no adjustments were made for age. In the adjusted mean values for dentition group interactions (p = 0.028), statistically significantly greater cortical thicknesses were encountered in SAE. Even though the cortical thickness diminished with loss of occlusions in SAE, the *Gon* thickness was still greater than the dimensions of SAA. The differences between sexes were not significant.

The repeatability of the measurements was assessed by means of intraclass correlation coefficients (ICC), which was 0.963 (maximum 1) for intraobserver correlations, denoting excellent agreement. ICC for interobserver correlations was 0.787. The discrepancy between intra- and interobserver correlations for cortical thicknesses at this site and, in general, will be considered later in this chapter and more fully in Chapter 8.

<u>7.5.3 Inferior cortical thicknesses at the left mental foramen level (Inf MF)</u>

Of particular note in the correlations of *Inf MF* with dental loss and age was that all sex-ancestry groups presented with negative correlations (Figs. 7.6 and 7.7), but female SAE presented with the highest correlations. The moderate relationship with thinning of the cortical thickness in the inferior border of the mandible in female SAE was not entirely unexpected as this group consisted of the oldest individuals. A longer time period with fewer occlusions could have rendered a greater thinning effect on the inferior cortical thicknesses.

In the comparisons between sex-, ancestry- and dentition groups of the *Inf MF* thickness no differences were significant (Table 7.5). Age was not a significant covariate for the inferior cortical thickness at the left mental foramen level ($p = 0.196$) and no other group interactions existed in the complete sample.

The repeatability of the measurements was assessed by means of intraclass correlation coefficient (ICC), which was 0.963 (maximum 1) for intraobserver correlations, denoting excellent agreement. ICC for interobserver correlations was 0.907.

7.5.4 Lingual cortical thicknesses at the left mental foramen level (Ling MF)

A weak positive correlation between age and the *Ling MF* existed in female SAE ($r = 0.20798$ and $r^2 = 0.043255$) (Fig. 7.8). A slight increase in *Ling MF* with age was therefore noted in female SAE. It could be presumed that during old age in female SAE some stimulus caused a slight increase in the *Ling MF* and will be explored in Chapter 8. Cortical thickness decreased to some extent with tooth loss in male SAA, but increased in female SAA. Negligible changes with tooth loss were noted in SAE (Fig. 7.9). These variations in correlations will be further explored in Chapter 8.

Comparisons between sex-, ancestry- and dentition groups of the *Ling MF* cortical thickness can be found in Table 7.6. No significant differences were found between the sexes, ancestry or dentition groups. No group interactions were present and age was not a significant covariate ($p = 0.123$); therefore, no adjustments for age were made. For this reason, *Ling MF* did not change significantly with aging, or loss of occlusions, and was similar amongst sexes and ancestries in the complete sample.

The repeatability of the measurements was assessed by means of intraclass correlation coefficient (ICCs), which was 0.797 (maximum 1) for intraobserver correlations, denoting reasonable agreement. ICC for interobserver correlations was 0.612.

7.5.5 Anterior cortical thicknesses in the anterior midline (Ant Mid)

Although a general decrease in the *Ant mid* with age existed, it was most noticeable in male SAA, where the negative correlation between cortical thickness and age was of a moderate extent ($r = -0.38683$; r^2: 0.14964; and $p = 0.031573$) (Fig. 7.10). In general the cortical thickness decreased with tooth loss at the various sites examined (Fig. 7.11). This correlation was mostly very weak in females, but approached a moderate relationship in males. The moderate relationship noted in the decrease in midline cortical thicknesses with tooth loss in males was an interesting finding. Both male groups started off with thicker cortical thicknesses at these sites, which decreased to a greater extent than females with tooth loss.

Comparisons between sex-, ancestry- and dentition groups of the *Ant Mid* cortical thickness in the complete sample can be found in Table 7.7. As age was a significant covariate for the anterior cortical thicknesses in the anterior midline ($p = 0.0018$), adjustments for age were made for statistical analyses between sex-, ancestry- and dentition groups. Variations between dentition groups were not significant when adjustments for age were made and results were further confounded by the fact that there were sex and dentition group interactions ($p = 0.0499$). Therefore, some of these differences observed between dentition groups might be attributed to sex or aging. Dentition group 0 had the smallest values, followed by group 1 with the greatest values in group 2. Females and older individuals had thinner cortical distances anteriorly in the midsagittal plane. No significant differences between sexes or ancestry groups were noted.

The repeatability of the measurements was assessed by means of intraclass correlation coefficient (ICCs), which was 0.831 (maximum 1) for intraobserver correlations denoting excellent agreement. ICC for interobserver correlations was 0,582.

7.5.6 Inferior cortical thicknesses in the anterior midline (Inf Mid)

In general *Inf Mid* decreased with age (Fig. 7.12) and tooth loss (Fig. 7.13). This correlation was most often weak, but approached a moderate relationship in male SAA for aging as well as tooth loss and in male SAE for tooth loss only. The moderate relationship noted in the decrease in midline cortical thicknesses with tooth loss in males was an interesting finding. Both male groups started with thicker cortical thicknesses at these sites, which decreased to a greater extent with tooth loss. A very weak or negligible positive correlation between age and the anterior inferior cortical thickness existed in male SAE ($r = 0.02544$ and $r^2 = 0.00064721$).

Comparisons between the sex-, ancestry- and dentition groups of the *Inf Mid* cortical thickness can be found in Table 7.8. As age was a significant covariate for the inferior cortical thicknesses in the anterior midline ($p = 0.0033$), adjustments for age were made in the statistical comparisons between sex-, ancestry- and dentition groups. After adjustments for age were made, no statistically significant differences between sex-, ancestry- and dentition groups could be demonstrated.

The repeatability of the measurements was assessed by means of intraclass correlation coefficient (ICC), which was 0.786 (maximum 1) for intraobserver correlations, denoting reasonable agreement. ICC for interobserver correlations was 0.502.

7.5.7 Posterior cortical thicknesses in the anterior midline (Post Mid)

The posterior cortical thicknesses in the anterior midline generally decreased with aging and tooth loss (Figs. 7.14 and 7.15). The greatest correlations of *Post Mid* with age and tooth loss were noted in males. The comparisons between sex-, ancestry- and dentition groups of the *Post Mid* cortical thickness can be found in Table 7.9. As age was not a significant covariate for the posterior cortical thicknesses in the anterior midline ($p = 0.091$)

in the complete sample, no adjustments were made. There were no statistically significant differences found between sexes, ancestry and dentition groups.

The repeatability of the measurements was assessed by means of intraclass correlation coefficient (ICC), which was 0.957 (maximum 1) for intraobserver correlations denoting excellent agreement. ICC for interobserver correlations was 0.795.

7.6 Discriminant analysis

Using discriminant analysis, 75.4% of individuals were correctly assigned for ancestry, based on the combination of cortical thicknesses at the various sites examined. The ancestry group percentage identified was in the complete sample, taking into account all thicknesses. When the cortical thicknesses were individually considered, the gonial thickness delivered the highest discriminant ability of 68.5%. The cortical thicknesses at the other sites presented with lower percentages. When sexes were considered separately, the percentage ancestry group correctly predicted rose to 79.4% for males, but decreased to 71.6% for females. The discriminant ability of *Ant Mid* cortical thickness in males also rose to 68.3%.

Ancestry group prediction percentage in dentition group 0 was only 67.5% but rose to 68.3% in dentition group 1 and 83.7% for dentition group 2 when all cortical thicknesses were considered. The most reliable predictors when considered separately in dentition group 2 remained *Gon* (77.6%) and, to some extent, *Ant Mid* (61.2%) and *Post Mid* (65.3%) cortical thicknesses.

In the complete sample, 60.0% of individuals were correctly assigned for sex, taking into account all thicknesses. When the cortical thickness at varying sites was individually considered, the *Ling MF* thickness delivered the highest discriminant ability for sexes at 61.8%. The cortical thicknesses at the other sites presented with lower percentages. For SAA the percentage sex group correctly identified when all cortical thicknesses were considered was 64.7% and for SAE, 56.5%.

Sex was correctly estimated by taking dentition group into account in 72.5% for dentition group 0, 73.2% for dentition group 1 and 67.4% for dentition group 2.

7.7 Summary

In general a weak negative correlation existed with aging and tooth loss in the cortical thicknesses at most of the sites examined. A few exceptions, though, were noted. In males the negative correlations with tooth loss for the cortical thicknesses at the mandibular symphysis (*Ant Mid; Inf Mid* and *Post Mid*) were stronger in males than for females. In male SAA the negative correlations with aging were also greater at the symphysis than the other groups.

Female SAE had stronger negative correlations with tooth loss at the inferior cortical thicknesses: *Gon* and *Inf MF* as well as with aging at *Inf MF*. The negative correlations with aging at the gonial region were only noted when extremes of ages were present as in male SAA and female SAE.

The *Ling MF* cortical thickness was the only dimension not affected by aging or loss of occlusions and was similar amongst sexes and ancestry when the complete sample were analysed and should be noted. The possibility of concealed variations exist; e.g. the fact that this dimension does not show the expected change with loss of occlusions and/or aging could mean that there is a process maintaining the cortical thickness at that site. The slight increase in *Ling MF* with age and tooth loss noted in female SAE could further strengthen this proposal and will be discussed in greater detail in Chapter 8.

The lack of statistically significant variations between sex- and ancestry groups in the cortical thicknesses at all sites apart from *Gon*, could be related to the variations with aging and tooth loss. The discriminant ability of the cortical thicknesses for ancestry and sex estimations improved when all cortical thicknesses were considered simultaneously at all sites (75.4% and 68.5% respectively). Percentages further increased when dentition group 2 was considered for ancestry group prediction (83.7%). The percentage of sex group correctly estimated was also improved by taking dentition group into account: dentition group 0: 72.5%; dentition group 1: 73.2% and dentition group 2: 67.4%.

Table 7.1: Sample group used in the measurement of cortical bone thickness

Dental pattern→	Group 0	Group 1	Group 2	Total
Sex ancestry group↓				
Male SAA	6	5	20	31
Female SAA	8	17	12	37
Male SAE	14	9	9	32
Female SAE	12	10	8	30
All	40	41	49	130

Table 7.2: Age distribution in years

Dental pattern groups ↓	Ancestry and sex				Dentition group totals[1]
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	8 **52.75** (13.57)	6 **68.5** (11.27)	12 **76.92** (10.47)	14 **68.64** (15.17)	40 **67.93** (15.14)
Group 1	17 **53.29** (12.56)	5 **66** (6.44)	10 **67.7** (13.75)	9 **66.11** (15.67)	41 **61.17** (14.30)
Group 2	12 **45.91** (13.52)	20 **43.35** (13.00)	8 **62.88** (19.57)	9 **67.56** (8.05)	49 **51.73** (16.80)
Ancestry group totals[1]	68 **51.36** (14.66)		62 **68.82** (14.16)		
Sex group totals		Males 67 **59.64** (16.96)	Females 63 **59.87** (16.82)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()
[1]$p < 0.001$

Table 7.3 Cortical bone features

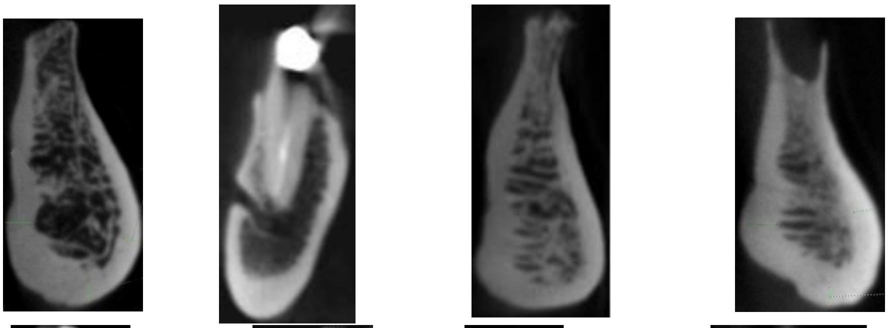
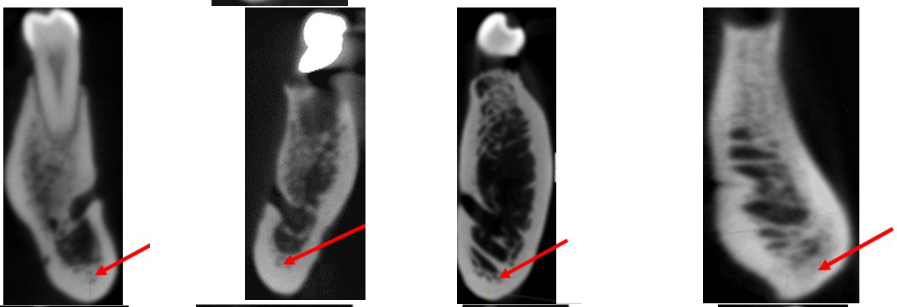
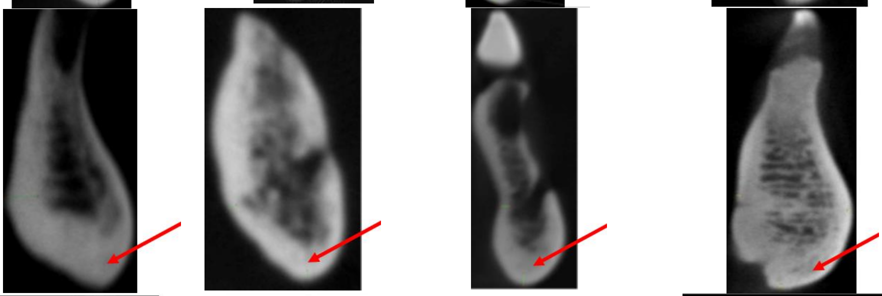
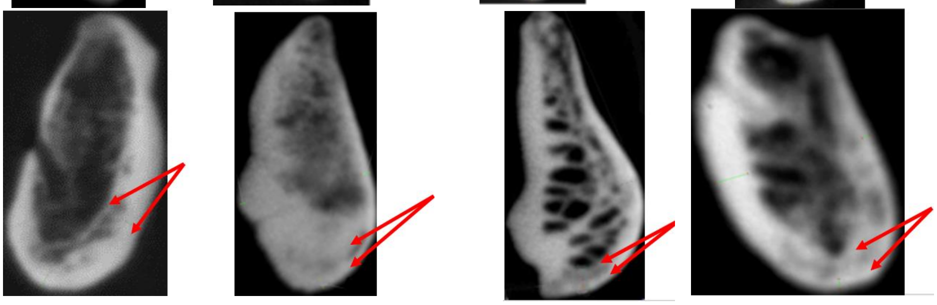
a. Dense cortical bone	
b. Translucencies forming from medullary side	
c. Translucencies closer to edge	
d. Translucencies coalesce so that only a double rim of cortical bone remains	

Table 7.4 Gonial cortical thickness (*Gon*) in mm

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	8 **1.006** (0.217)	6 **1.015** (0.412)	12 **1.116** (0.412)	14 **1.276** (0.363)	40 **1.135** (0.367)
Group 1	17 **0.969** (0.303)	5 **0.952** (0.232)	10 **1.146** (0.301)	9 **1.093** (0.319)	41 **1.038** (0.299)
Group 2	12 **0.893** (0.124)	20 **1.017** (0.273)	8 **1.492** (0.546)	9 **1.500** (0.530)	49 **1.153** (0.436)
Ancestry group totals[1]	68 **0.977** (0.261)		62 **1.258** (0.427)		
Sex group totals		Males 67 **1.090** (0.395)	Females 63 **1.152** (0. 383)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()
[1] $p < 0.001$

Table 7.5 Inferior cortical thicknesses at the left mental foramen area (*Inf MF*) in mm amongst groups

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	8 **0.979** (0.209)	6 **1.063** (0.296)	12 **1.033** (0.253)	14 **1.323** (0.480)	40 **1.697** (1.035)
Group 1	17 **1.019** (0.283)	5 **0.922** (0.342)	10 **1.244** (0.415)	9 **1.223** (0.264)	41 **2.043** (1.073)
Group 2	12 **0.890** (0.204)	20 **1.053** (0.329)	8 **1.546** (0.698)	9 **1.221** (0.439)	49 **2.108** (1.033)
Ancestry group totals	68 **1.845** (1.019)		62 **2.088** (1.084)		
Sex group totals		Males 63 **2.15** (1.113)	Females 67 **1.783** (0.969)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()

Table 7.6 Lingual cortical thicknesses at the left mental foramen area (*Ling MF*) in mm amongst groups

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	8 **1.349** (0.546)	6 **0.998** (0.304)	12 **1.168** (0.424)	14 **1.254** (0.556)	40 **1.209** (0.481)
Group 1	17 **1.311** (0.522)	5 **1.720** (0.677)	10 **1.550** (0.598)	9 **1.229** (0.404)	41 **1.401** (0.544)
Group 2	12 **1.078** (0.282)	20 **1.356** (0.515)	8 **1.146** (0.199)	9 **1.260** (0.294)	49 **1.236** (0.396)
Ancestry group totals	68 **1.290** (0.500)		62 **1.268** (0.453)		
Sex group totals		Males 63 **1.300** (0.491)	Females 67 **1.264** (0.466)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()

Table 7.7 Anterior cortical thicknesses in the anterior midline (*Ant Mid*) in mm amongst groups

Dentition groups ↓	Ancestry and sex				Dentition group totals
	SAA Female	Male	SAE Female	Male	
Group 0	8 **1.349** (0.546)	6 **0.998** (0.304)	12 **1.168** (0.424)	14 **1.254** (0.556)	40 **0.973** (0.371)
Group 1	17 **1.311** (0.522)	5 **1.720** (0.677)	10 **1.550** (0.598)	9 **1.229** (0.404)	41 **1.031** (0.496)
Group 2	12 **1.078** (0.282)	20 **1.356** (0.515)	8 **1.146** (0.199)	9 **1.260** (0.294)	49 **1.292** (0.490)
Ancestry group totals	68 **1.221** (0.525)		62 **0.992** (0.388)		
Sex group totals		Males 63 **1.156** (0.553)	Females 67 **1.070** (0.393)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()

Table 7.8 Inferior cortical thicknesses in the anterior midline *(Inf Mid)* in mm amongst groups

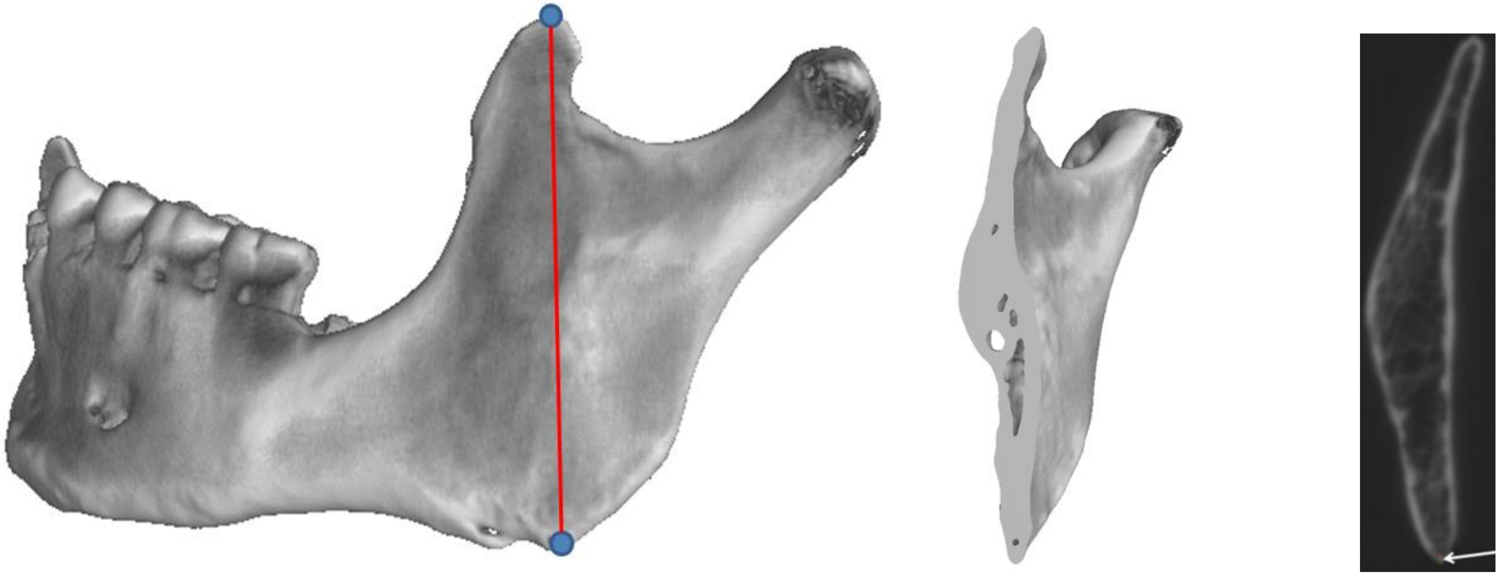
Dentition groups ↓	Ancestry and sex				Dentition group Totals
	SAA		SAE		
	Female	Male	Female	Male	
Group 0	8 **1.211** (0.452)	6 **0.930** (0.433)	12 **1.126** (0.433)	14 **0.989** (0.429)	40 **1.066** (0.430)
Group 1	17 **1.215** (0.457)	5 **1.266** (0.635)	10 **1.363** (0.565)	9 **1.153** (0.319)	41 **1.244** (0.471)
Group 2	12 **1.149** (0.376)	20 **1.620** (0.762)	8 **1.442** (0.488)	9 **1.450** (0.572)	49 **1.444** (0.622)
Ancestry group totals	68 **1.300** (0.589)		62 **1.225** (0.486)		
Sex group totals		Males 63 **1.295** (0.455)	Females 67 **1.236** (0.623)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()

Table 7.9 Posterior cortical thicknesses in the anterior midline *(Post Mid)* in mm amongst groups

Dentition groups ↓	Ancestry and sex				Dentition group Totals
	SAA Female	Male	SAE Female	Male	
Group 0	8 **2.225** (1.101)	6 **2.040** (0.782)	12 **2.176** (1.030)	14 **2.272** (0.882)	40 **2.199** (0.928)
Group 1	17 **2.115** (0.919)	5 **2.136** (1.101)	10 **2.605** (1.482)	9 **2.830** (0.584)	41 **2.394** (1.056)
Group 2	12 **1.991** (1.120)	20 **2.313** (0.821)	8 **2.661** (0.898)	9 **2.657** (0.935)	49 **2.354** (0.940)
Ancestry group totals	68 **2.159** (0.926)		62 **2.494** (0.995)		
Sex group totals		Males 63 **2.387** (0.845)	Females 67 **2.255** (1.078)		Total 130

n the first value in every set
mean given in bold
standard deviation in parenthesis ()

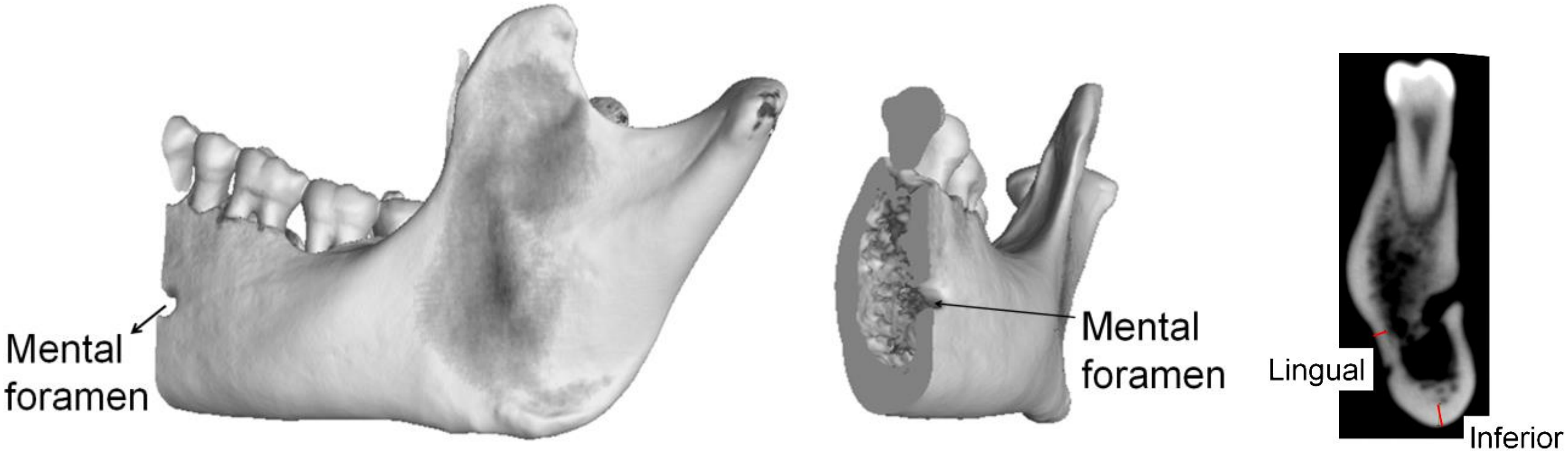


Line joining the most posterior point on the inferior border of the mandibular body to the coronoid process

Anterior view of section

Cortical thickness measured

Fig. 7.1 Coronal section through gonial area

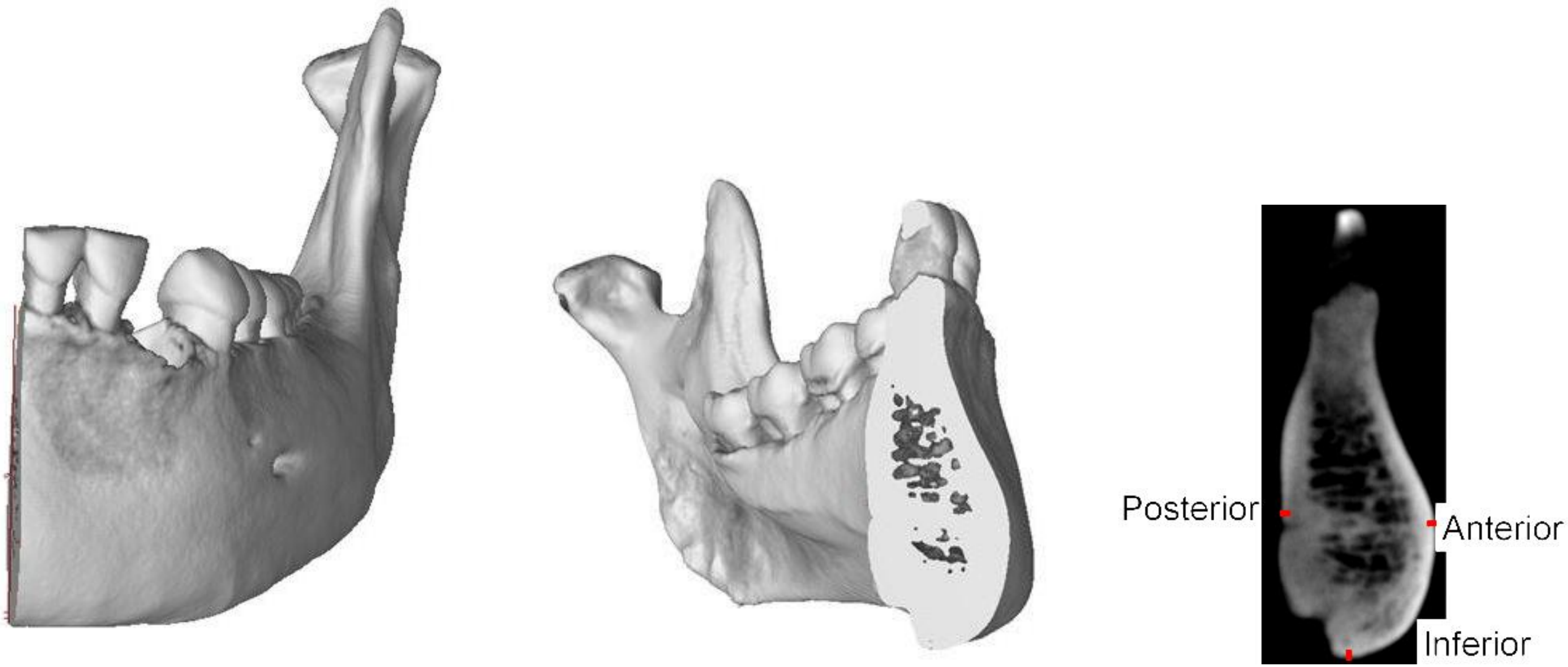


Lateral view

Anterior view

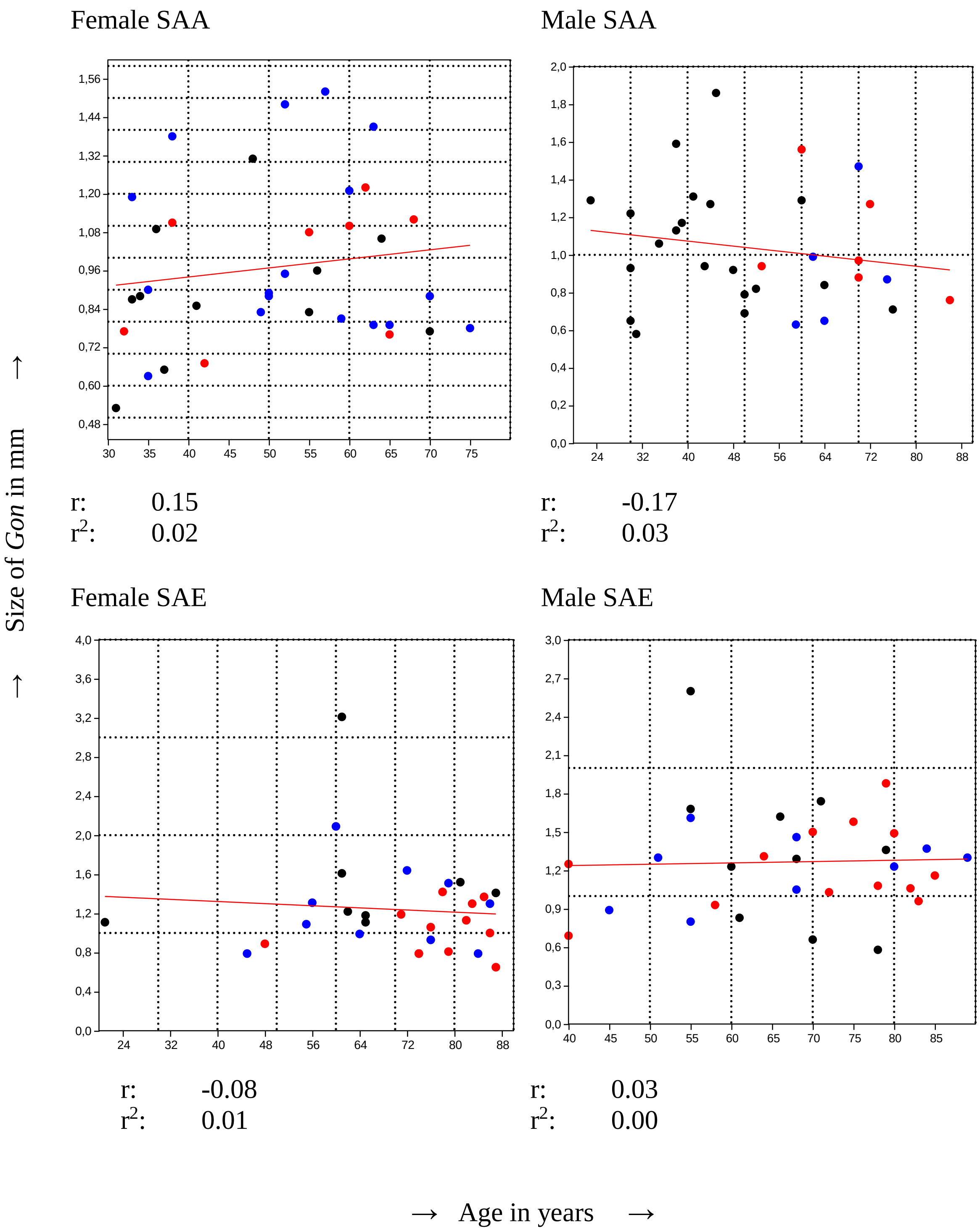
Cortical thicknesses measured

Fig. 7.2 Section through the mental foramen



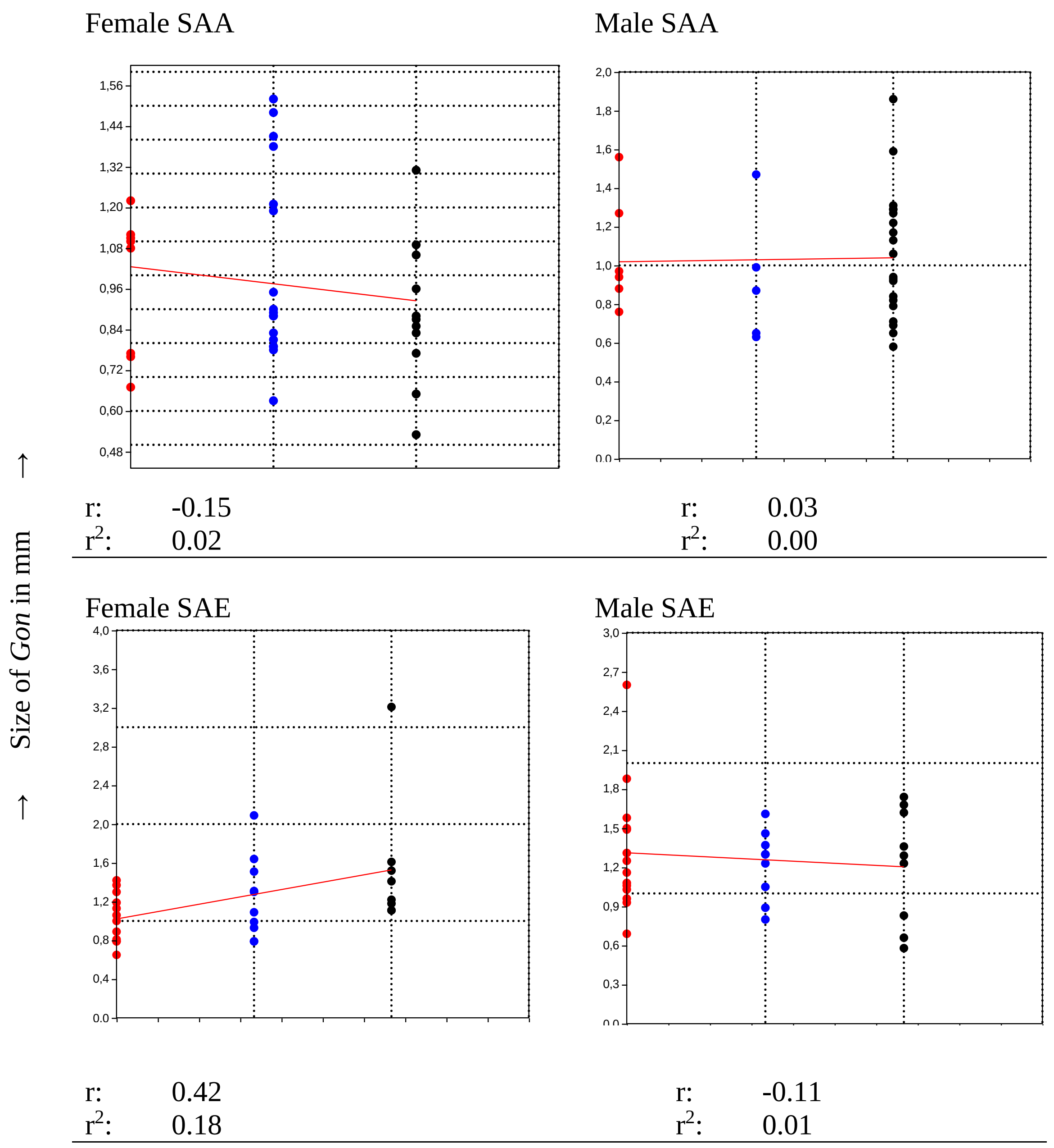
Section Lateral view of section Cortical thicknesses measured

Fig. 7.3 Anterior midline sagittal section



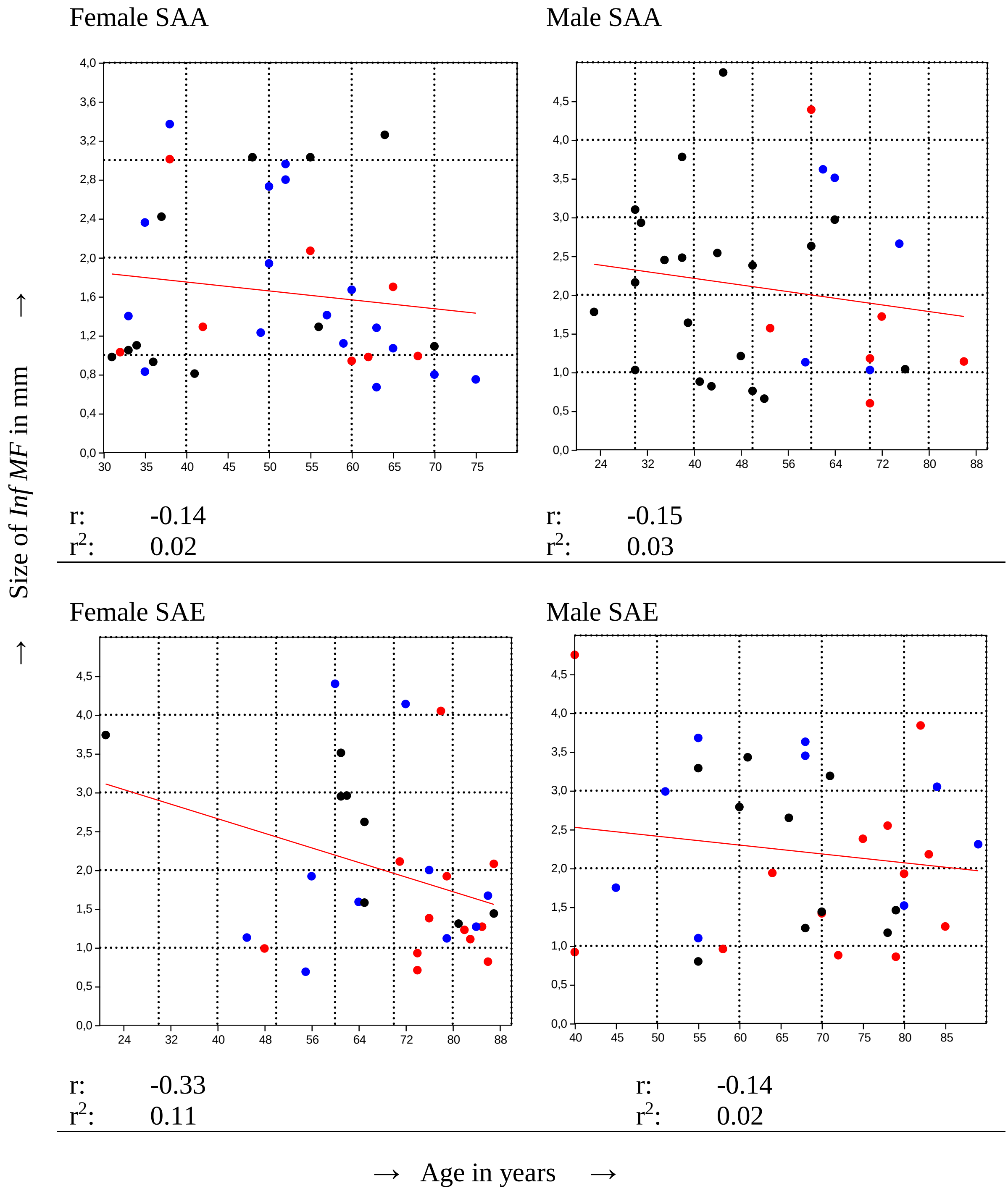
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.4 Linear regression of *Gon* vs. age in years in sex-ancestry groups differentiating between dentition groups



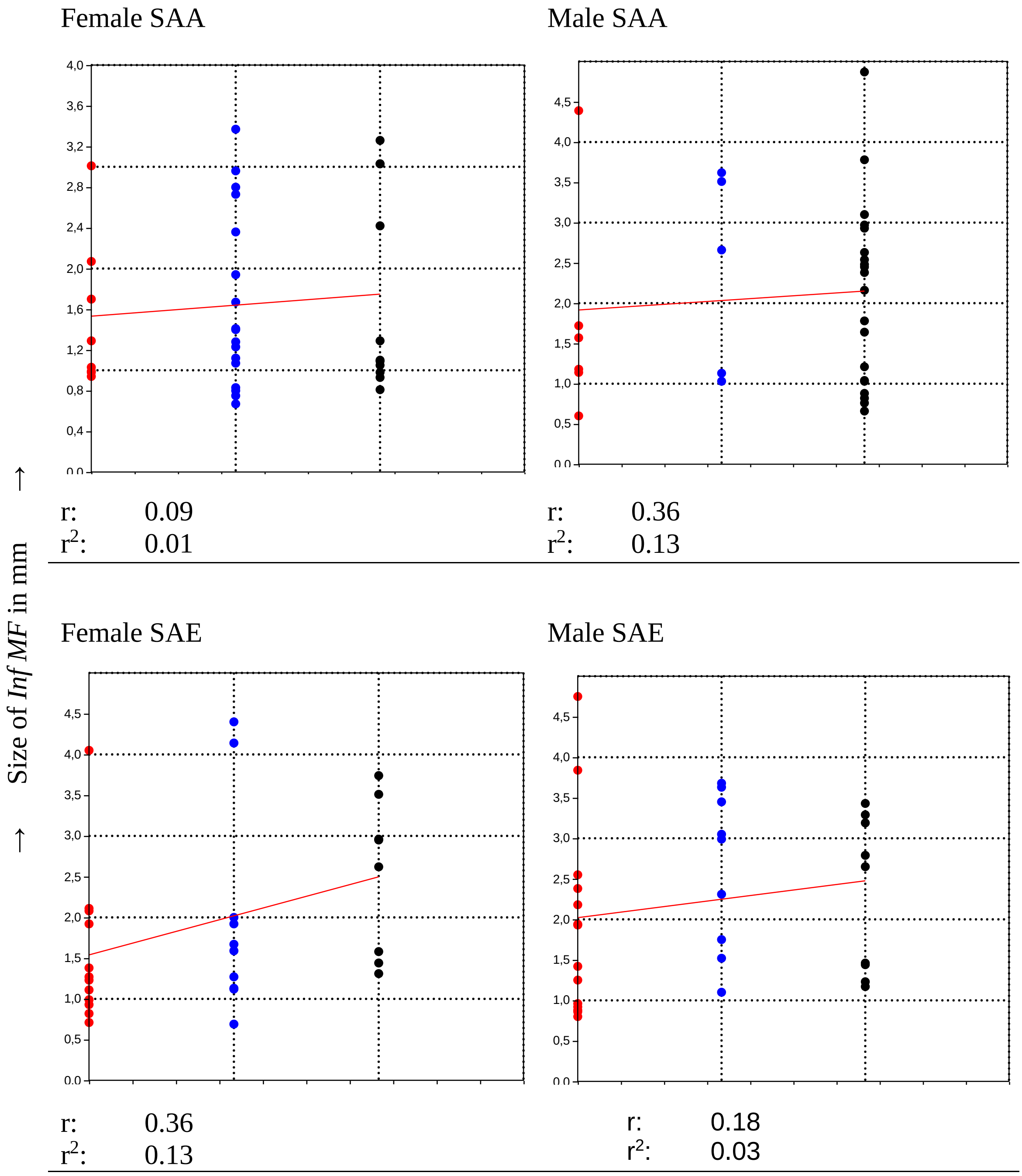
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.5 Linear regression of *Gon* vs. dentition group in sex-ancestry groups differentiating between dentition groups



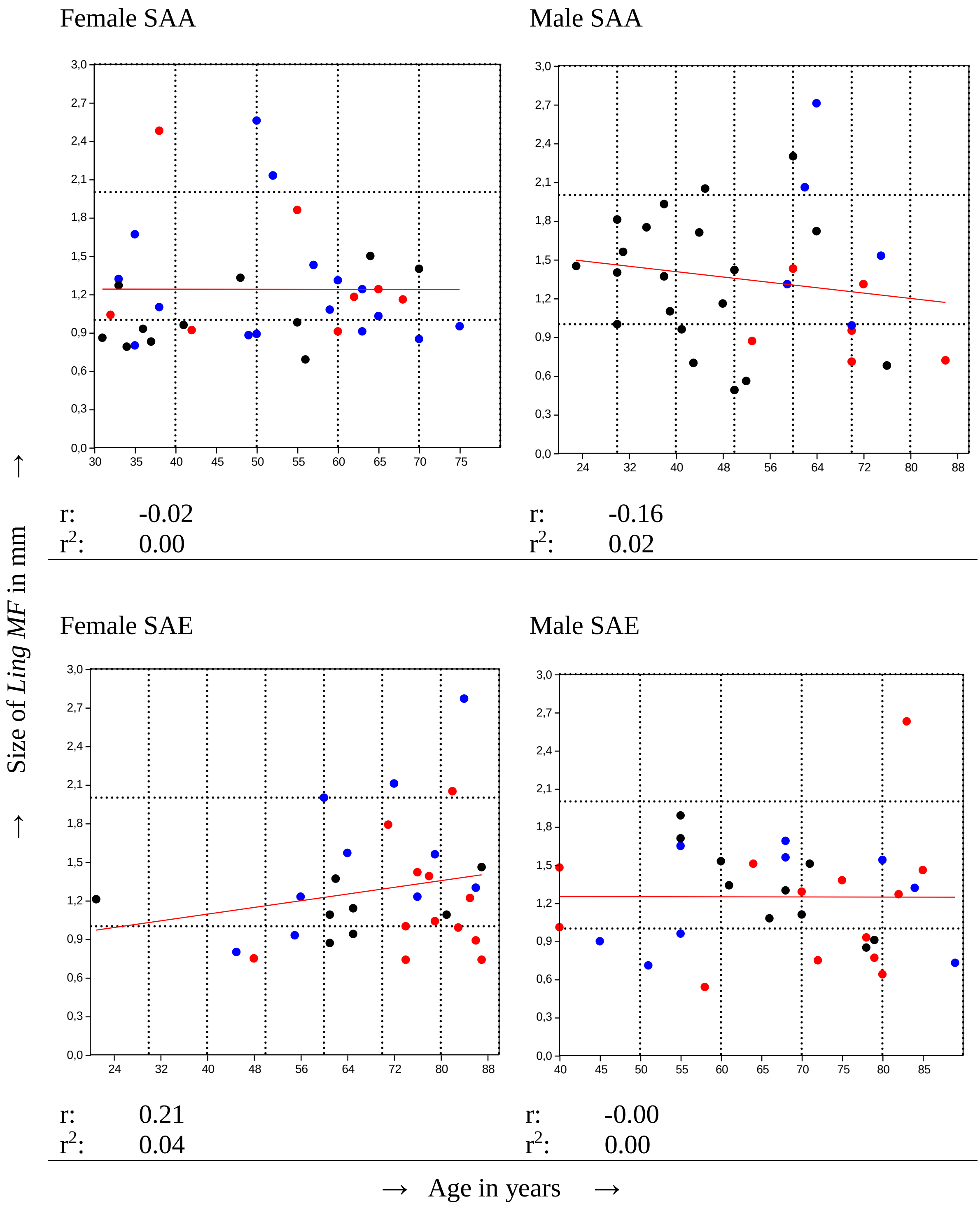
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.6 Linear regression of *Inf MF* vs. age in years in sex-ancestry groups differentiating between dentition groups



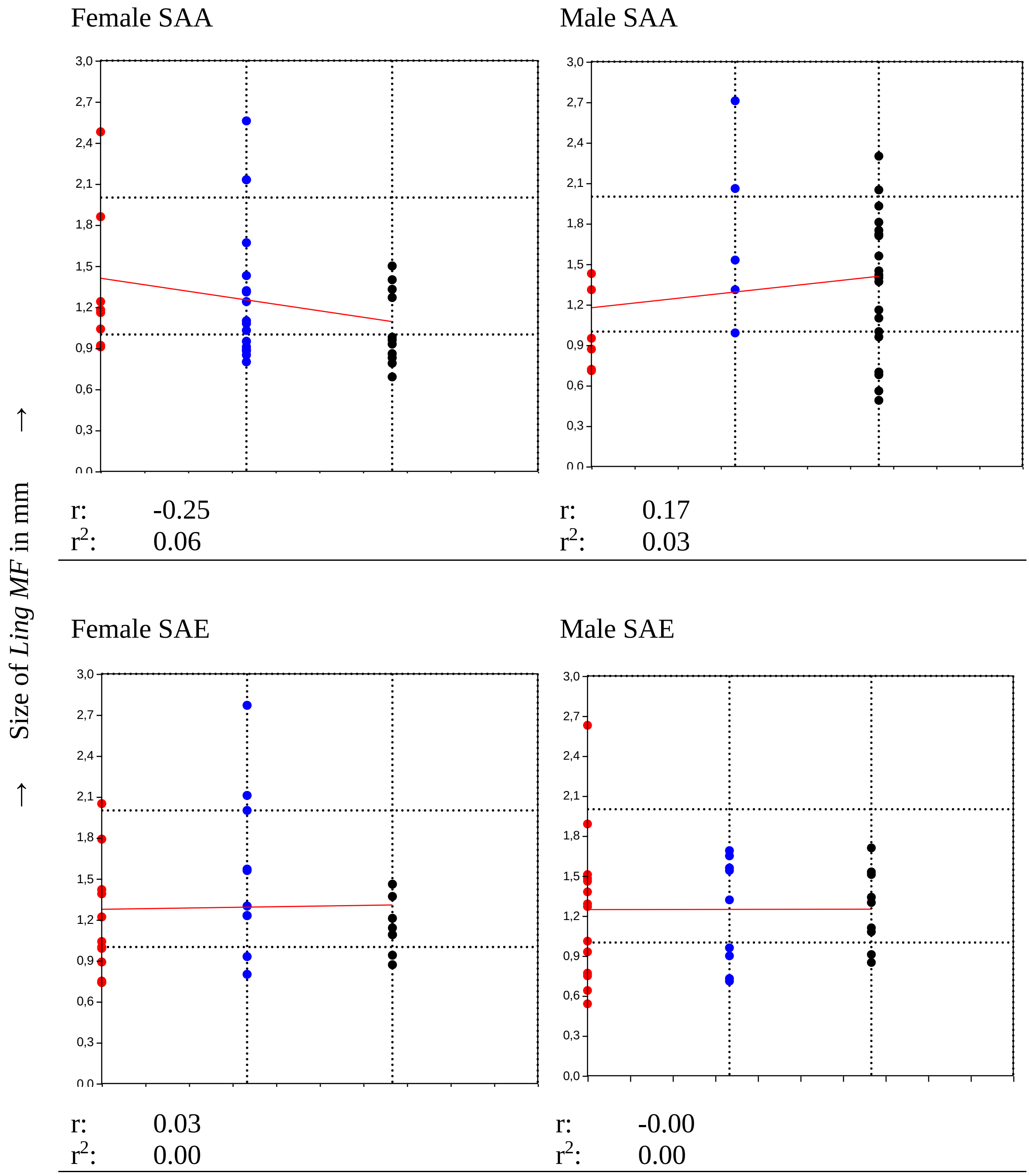
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.7 Linear regression of *Inf MF* vs. dentition group in sex-ancestry groups differentiating between dentition groups



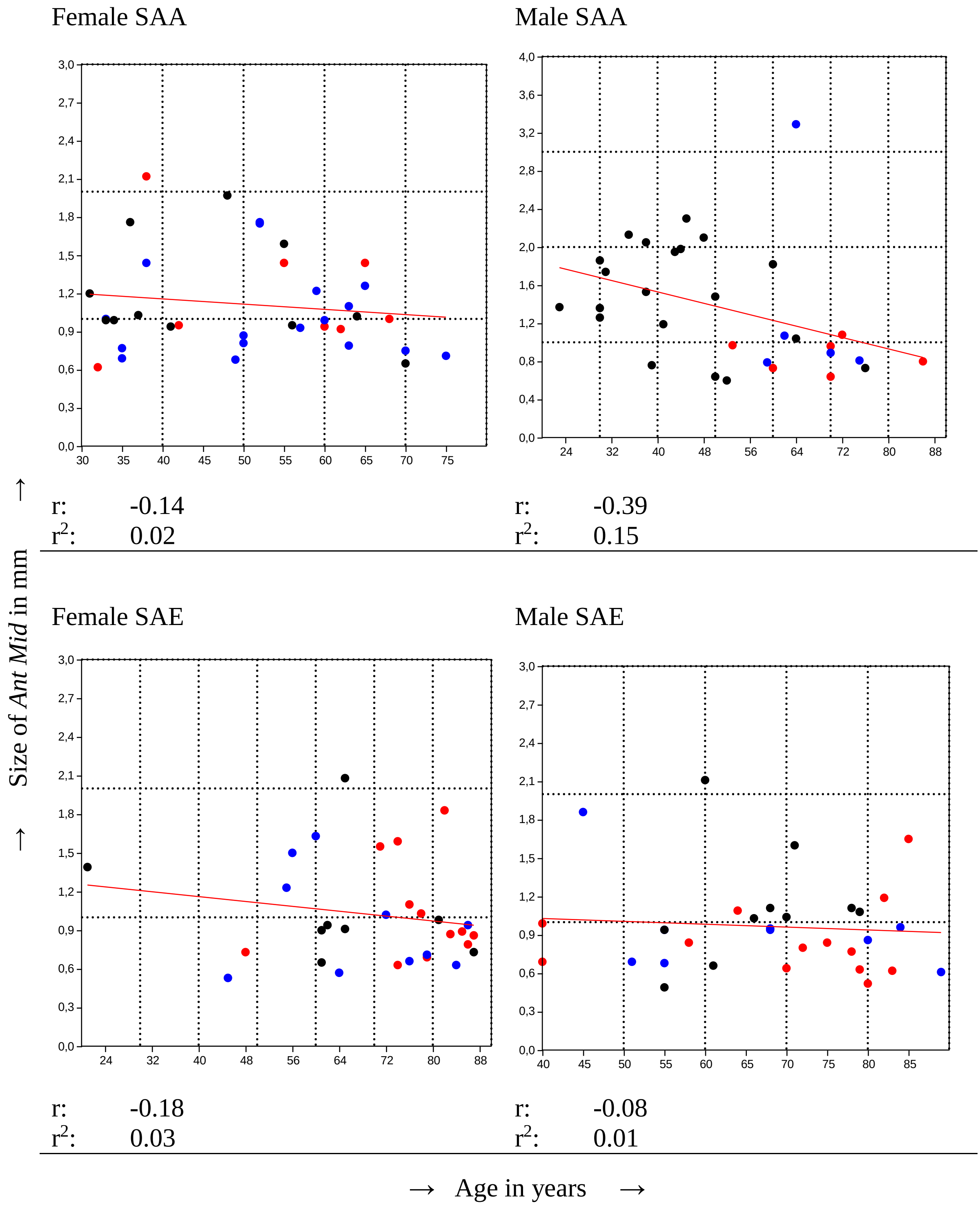
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.8 Linear regression of *Ling MF* vs. age in years in sex-ancestry groups differentiating between dentition groups



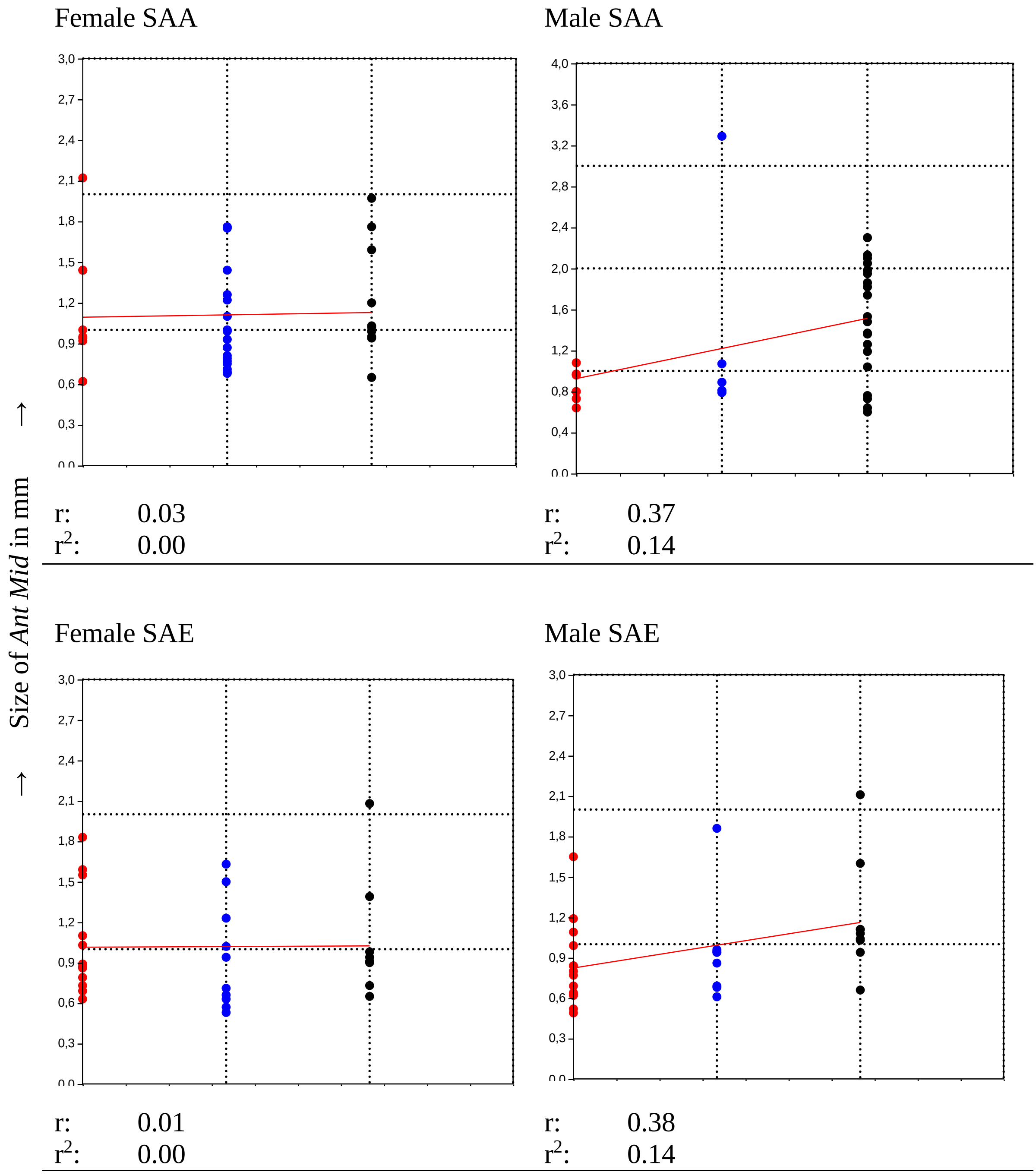
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.9 Linear regression of *Ling MF* vs. dentition group in sex-ancestry groups differentiating between dentition groups



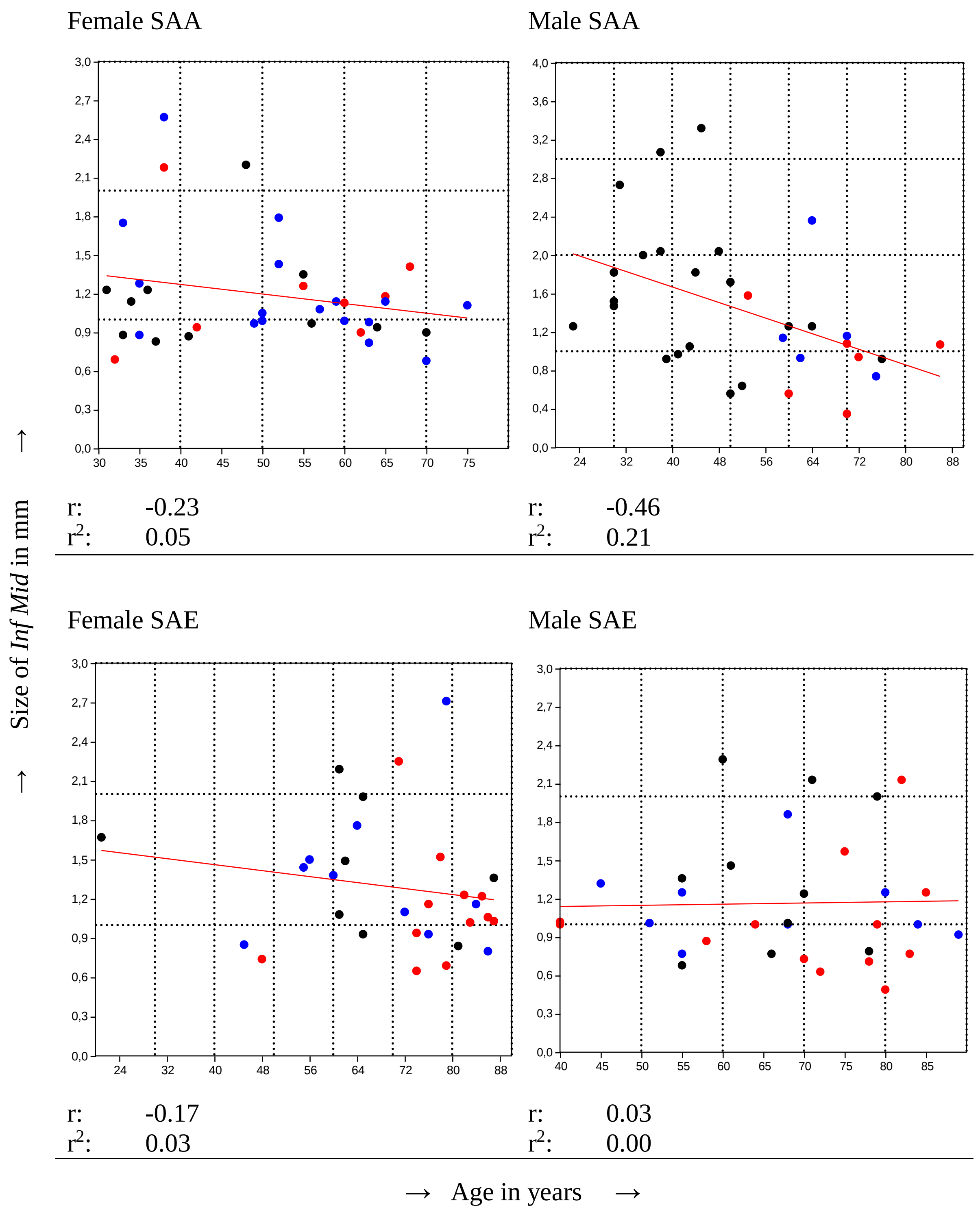
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.10 Linear regression of *Ant Mid* vs. age in years in sex-ancestry groups differentiating between dentition groups



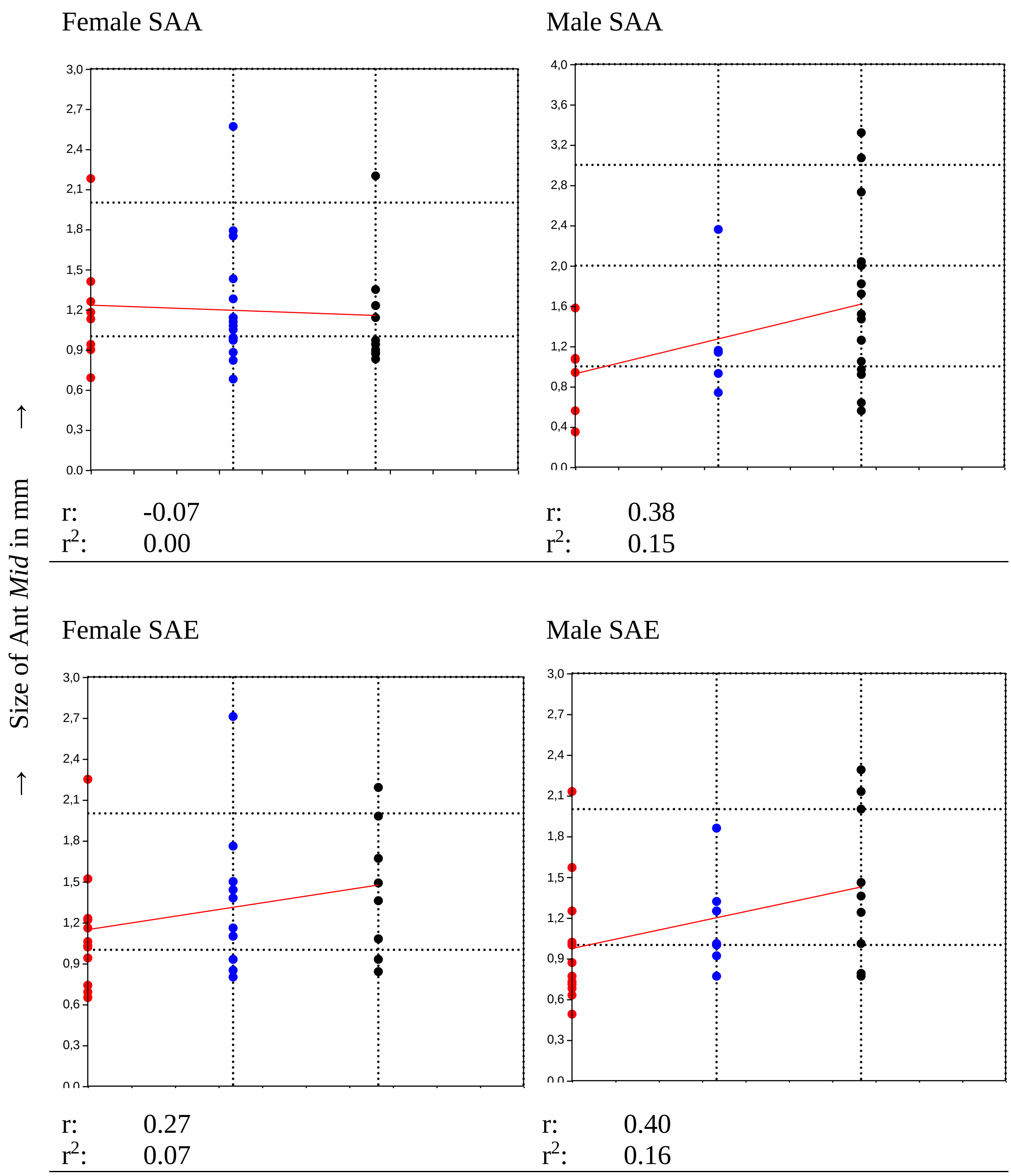
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.11 Linear regression of *Ant Mid* vs. dentition group in sex-ancestry groups differentiating between dentition groups



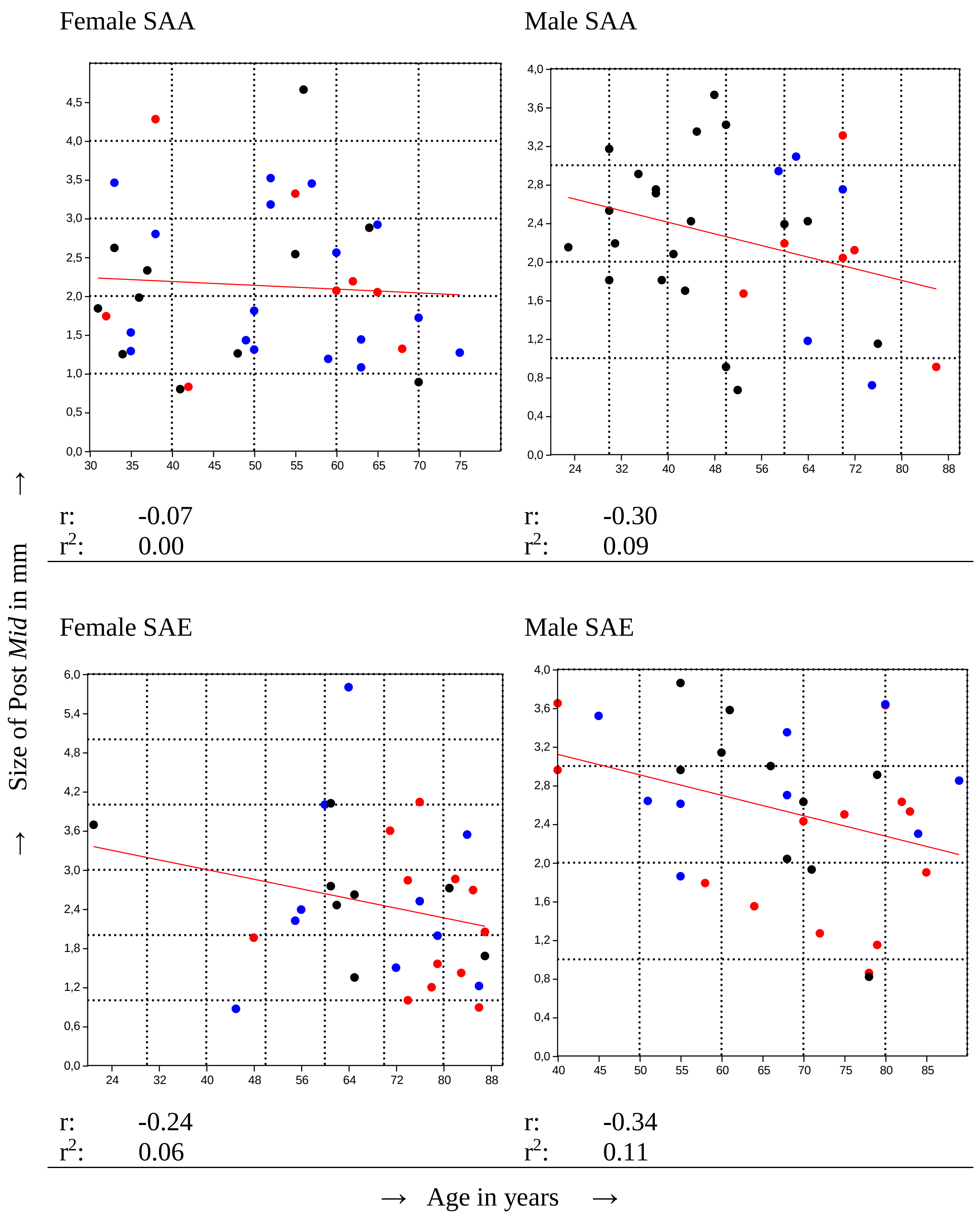
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.12 Linear regression of *Inf Mid* vs. age in years in sex-ancestry groups differentiating between dentition groups



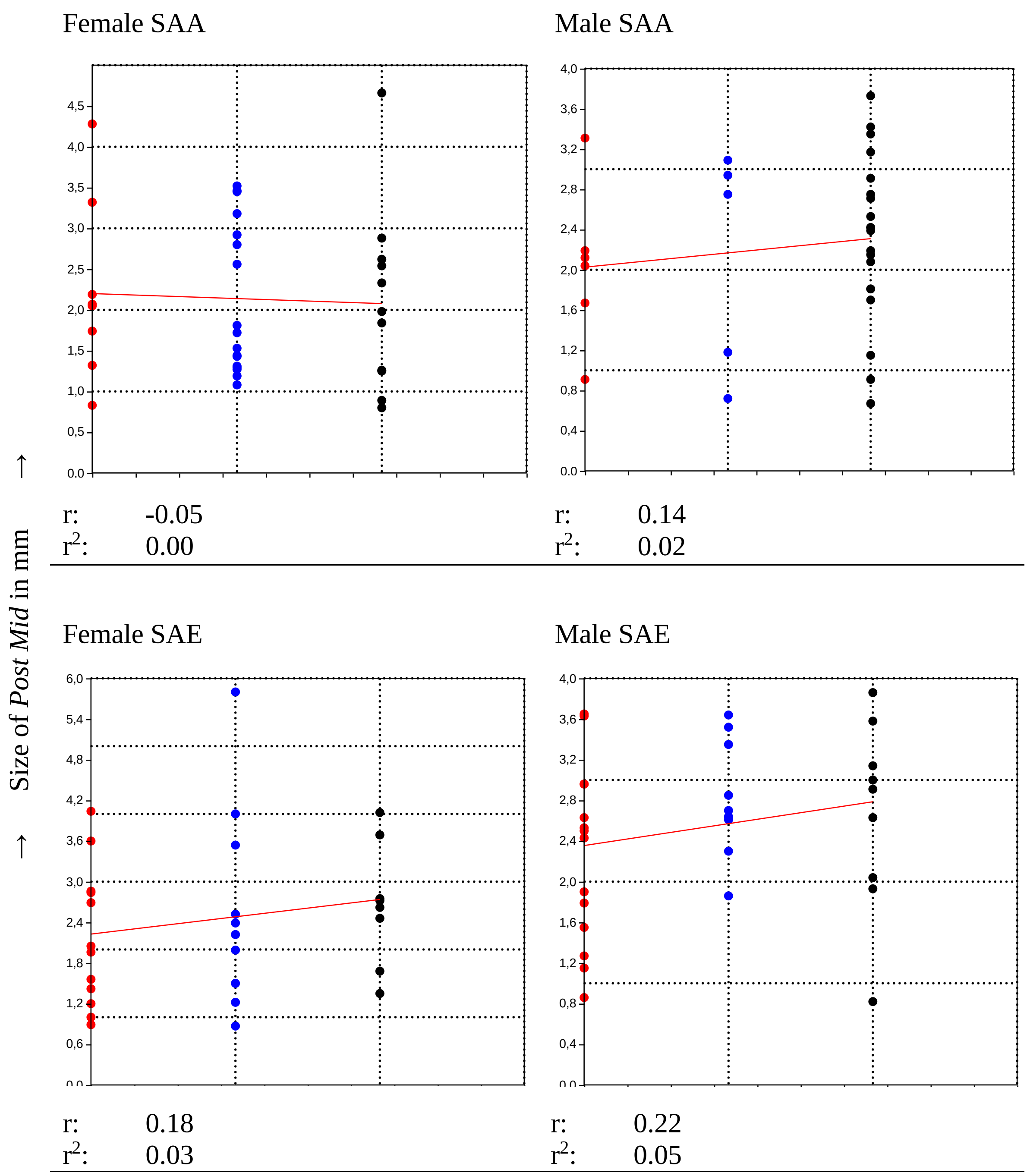
Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.13 Linear regression of *Inf Mid* vs. dentition group in sex-ancestry groups differentiating between dentition groups



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.14 Linear regression of *Post Mid* vs. age in years in sex-ancestry groups differentiating between dentition groups



Red: Dentition group 0
Blue: Dentition group 1
Black: Dentition group 2

Fig. 7.15 Linear regression of *Post Mid* vs. dentition group in sex-ancestry groups differentiating between dentition groups

Chapter 8: DISCUSSION

8.1 Introduction

The morphology of the mandible is dependent on biomechanical factors associated with mastication (Pileicikiene & Surna 2004). Although it is widely accepted that tooth loss has important effects on the action of muscles of mastication and thereby the morphology of the mandible, it is seldom taken into consideration when designing anthropological studies (Atkinson & Woodhead 1968; Enlow et al. 1976; Loth & Henneberg 1996). Ancestry and sex differences involve variations in mastication and masticatory muscles and therefore differences in the morphology of the mandible are expected (Garvin & Ruff 2012; Patriquin 2013). As some of the ancestry or sex-discriminating dimensions may be sensitive to the duration of tooth loss and senescence, the degree of tooth loss and age need to be considered when an attempt is made to identify unknown remains (Acsádi et al.1970; Parr 2005). The effects of the duration of tooth loss and senescence on the mandible also have implications for clinical dentistry.

In order to make a comprehensive assessment of the morphological changes that occur in the adult mandible with tooth loss and aging, the findings of chapter 4 to 7 were integrated and considered in this chapter. The implications of these morphological changes on sex, ancestry and possible age estimations, as frequently conducted by forensic anthropologists, were considered. From a clinical perspective, the effects of these changes on functionality of the masticatory system were also discussed. The limitations of this study were contemplated and proposed further research, which may clarify unresolved issues, formulated.

8.2 Integration of findings

The changes of the mandibular angle, linear dimensions, shape features and cortical thickness with aging and tooth loss were integrated and interpreted. The effect of tooth loss and aging were theoretically separated by statistical means as many of the older individuals presented with tooth loss and vice versa. Most of the changes in the morphology of the mandible because of tooth loss, occurs over time. Also the effect of dentition on the mandible cannot in reality be separated from the ancestral differences in teeth and the impact that it would have on the morphology of the mandible. For instance, the degree of prognathism is positively correlated to greater dentition size and with a greater occlusal surface (Patriquin 2013). The presence of third molars and their relationship with ancestry group will be considered further in the sections to follow. In an attempt to minimize the effects of the variation in dentition, the sample was selected according to the remaining dentition in occlusion. These interrelated determinants of the morphology of the mandible were further explored and the implications of tooth loss and aging on sex, ancestry and possible age estimations considered.

8.2.1 Effects of aging on the morphology of the mandible

The mandible continues to remodel throughout adulthood because of mechanical and metabolic processes, which is excacerbated by tooth loss which often accompanies senescence (Akgül & Toygar, 2002; Bishara et al., 1994; Bondevik, 1995; Martinez-Maza et al., 2013).

Overall the changes observed in the morphology of the mandible with age were in line with what have been described in the literature (Enlow et al., 1976; Sarnäs and Solow, 1980; Forsberg et al., 1991; Bishara et al., 1994; Bondevik, 1995; Akgül & Toygar, 2002; Parr, 2005; Albert et al., 2007; Martinez-Maza et al., 2013). However, some ancestry or sex specific deviations, were noted. As the changes in the dimensions of the mandible with age have been found by others to be of a relatively small magnitude (1 mm or 1° in 10 or 20 years’ time), it was not unexpected that the correlations with age, found in this study, were generally weak (Bishara et al., 1994, Bondevik, 1995, Akgül & Toygar, 2002). The age related changes were often also not significant as considerable individual variation in the pattern of aging exists (Martinez-Maza et al. 2013). Tooth loss, sex-ancestry group differences or factors such as diet and other environmental factors may be responsible for the variability in morphological aging patterns noted (Nicholson & Harvati 2006). Although most of the changes were subtle, they collectively provided for a better understanding of the ongoing changes with age (Bishara et al. 1994).

When interpreting the influence of aging on the morphology of the mandible as found in this study, the age distribution of the subgroups should be taken into account (Table 4.1). Although the age distribution in all 12 sex-ancestry-dentition groups represented individuals from a wide spectrum of adulthood, the highest crude mean ages were noted in female SAE followed by male SAE, male SAA and female SAA. Male SAE presented with a relatively narrower, older spectrum (36 - 91 years) as compared to the other sex-ancestry groups. The sex-ancestry group differences in age distributions and mean ages provided windows to different periods of remodelling. These windows could be applied in the interpretation of the changes in the dimensions of the mandible with age.

Aging was not a significant variable on its own and correlated only very weak (2.4% of the increase noted) with the size of the mandibular angle in the complete sample.
Aging can therefore most probably be dismissed as playing a significant role in the size of the mandibular angle as previously reported (Jensen & Palling 1954). As SAE, especially females, presented with older ages and larger crude mean mandibular angles, analyses were directed towards individual sex-ancestry groups. Weak correlations between mandibular angle size vs. age persisted in the four sex-ancestry groups individually. What was surprising, though, was that a weak negative correlation between mandibular angle vs. age in females existed. Seven percent of the decrease in angle size in female SAA, (who presented with younger ages and a greater number of occlusions) was associated with aging, and even in

female SAE (who presented with older ages and fewer occlusions) a very slight (1%) decrease was found, leading to a more upright mandibular angle as opposed to the obtuse angle previously expected in older ages. In male SAA, the mandibular angle remained approximately the same size with aging and in male SAE a weak positive correlation between mandibular angle vs. age existed. Aging in male SAE contributed to 2% of the increase noted in mandibular angle size. From this initial assessment it thus seems as though age in itself did not contribute much to changes in the mandibular angle.

To isolate the changes with aging in the four sex-ancestry groups to a specific dentition group or to reveal possibly overseen aging differences between dentition groups, the 12 sex-ancestry-dentition groups were further analysed by linear regressions of mandibular angle vs. age. The decrease in mandibular angle size with age in females of both SAA and SAE were the most pronounced in dentition group 2. Only weak to very weak associations existed between mandibular angle and age in males.

A decrease of the mandibular angle with age in females in dentition group 2 may support the notion that morphological features associated with effective mastication will continue despite aging. Females, especially SAA, presented with a negative relationship between mandibular angle and aging, especially in dentition group 2. Mandibles were classified as dentition group 2, when two or more posterior teeth (molar and premolar teeth) and one or more front teeth (incisors and canine) were in occlusion on each side (efficient occlusion). Because of continued eruption of teeth when present, the dental arch will close on a slightly lower position forcing the angle to become more upright (Akgül & Toygar 2002).

Male SAE presented with a narrower age spectrum and the slight increase in mandibular angle that was noted was limited to later adulthood and senescence and in those with fewer dental occlusions. The age changes in the mandibular angle in male SAA, who had a wider age range, were negligible. Age changes in the vertical dimensions of the lower anterior face from 22 to 33 years have been shown to be greater in females than in males (Bondevik, 1995; Akgül and Toygar, 2002). In the dentoalveolar region, the main movement was continued eruption of the teeth. Changes were in the order of 1 mm or 1 degree (Akgül & Toygar 2002). The negative correlation of aging in dentition group 2 in females with mandibular angle was less prominent in female SAE. This could be due to senescence or concomitant tooth loss because of the inclusion of older individuals and will be discussed later.

It was noteworthy that the minimum ramus breadth *(Mrb)* became narrower with aging in SAE and wider in SAA as the ramus width was expected to broaden with age because of continued action of the muscles of mastication (Bondevik, 1995). The age related decrease in height of mandibular body *(Hmb),* chin height and minimum ramus breadth *(Mrb)* dimensions were not considered part of the normal remodelling process. It is suggested that the decreases in these dimension were rather because of dental alveolar regression accompanying tooth loss. In the case of minimum ramus breadth *(Mrb),* tooth loss related decrease in masticatory muscle function was implicated (Bondevik, 1995; Akgül & Toygar, 2002). These relationships will be considered further in section 8.2.2.

A slight increase in mandibular angle, maximum ramus height *(Ram_ht),* projective mandibular corpus length *(M_corpus length),* maximum projective length of the mandible *(Max m_length)* and bicondylar breadth *(Bicon)* were noted with aging in the complete sample.

Males presented with an increase in maximum projective length of the mandible *(Max m_length).* Maximum projective length of the mandible *(Max m_length)* could partially be influenced by mandibular angle size, maximum ramus height (*Ram_ht)* and projective mandibular corpus length *(M_corpus length).* Males had a greater maximum ramus height *(Ram_ht)* from the onset than females of the same group and the correlation with aging was negligible. Although a very weak correlation existed with projective mandibular corpus length *(M_corpus length)* and age, the greatest positive correlation with mandibular angle size could have contributed to a positive correlation with maximum projective length of the mandible *(Max m_length)* in male SAE. As the projective mandibular corpus length *(M_corpus length)* and maximum projective length of the mandible *(Max m_length)* have been described to increase between the ages of 20 and 40 years (Enlow et al., 1976; Sarnäs & Solow, 1980; Bishara et al., 1994; Bondevik, 1995; Albert et al., 2007), the absence of an increase in the projective mandibular corpus length *(M_corpus length)* dimension in male SAE, could be explained by the narrower age distribution. On the contrary, in male SAA, the correlation with age of the mandibular angle was negligible but the greater correlation of maximum ramus height *(Ram_ht)* and projective mandibular corpus length *(M_corpus length)* with age in male SAA could have contributed to the greater correlation with maximum projective length of the mandible *(Max m_length).*

The impression thus created in SAA males, was that positive growth or growth which potentiated function, persisted throughout life, possibly because of a longer duration of efficient mastication processes.

In all females, the maximum projective length of the mandible *(Max m_length)* decreased and the maximum ramus height *(Ram_ht)* did not increase in female SAA. The lack of increase in maximum projective length of the mandible *(Max m_length)* was thought to be due to the associated decrease in mandibular angle with age in dentition group 2. The slight increase in mandibular angle, maximum ramus height *(Ram_ht)*, projective mandibular corpus length *(M_corpus length)* and maximum projective length of the mandible *(Max m_length)* noted with aging would support the idea that the mandible grows in a forward direction as also proposed by other researchers (Parr, 2005; Martinez-Maza et al., 2013).

Bigonial breadth *(Bigon)*, which had the greatest dimension in SAE and males, increased with aging in all groups except for African females. The slight increase in bicondylar breadth *(Bicon)* noted with aging in male SAA and female SAE, could be explained by the lateral growth of the ramus to maintain contact with the slight horizontal increase in the craniofacial skeleton during the entire adult lifespan (Parr, 2005; Albert et al. 2007; Martinez-Maza et al., 2013).

Almost all cortical distances at the six chosen sites decreased with aging. The fact that almost all cortical distances decreased with aging with the highest correlations in those groups with the oldest ages, was expected (Lestrel et al. 1980, Henrikson et al., 1974, von Wowern & Stoltze, 1978, Kingsmill & Boyde, 1998, Kingsmill, 1999, Swasty et al., 2009).

Researchers, however, are not in agreement whether these aging effects are isolated from the change in dentition that often accompanies senescence, as Schwartz-Dabney and Dechow (2003) found no significant decline in density with age in dentate individuals. It was thought that cortical thickness was maintained by dentate mandibles, causing higher occlusal loads throughout later life (Schwartz-Dabney & Dechow, 2003).

As found by other researchers (Lestrel et al. 1980), the thickness of the inferior mandibular border increased slightly with age: cortical thickness at the gonion *(Gon)* in male SAE and female SAA and to a lesser degree cortical thickness inferiorly at the midline *(Inf Mid)* in male SAE. The slight increase in inferior cortical thicknesses noted in male SAE and female SAA (or at least the maintenance thereof), were suggested to be a reflection of ongoing masticatory forces when the duration of the effect of loss of teeth were confined to the narrower age ranges of these two groups. In contrast, the increase with age of the cortical thickness lingually at the mental foramen *(Ling MF)* in female SAE (with older ages and fewer occlusions), were thought to be augmented by tooth loss. The reasons for these supposedly contradictory findings will be considered along with the effects of tooth loss.

SAE had stronger correlations between age and the shape of the chin and gonial areas. The gonion has been shown to continue to grow in a lateral direction with aging (Martinez - Maza et al. 2013). The lateral growth of the gonion was evident in the bone modelling patterns of the mandible from adult humans in this Spanish dentate collection. Continual deposition of bone on the chin as an individual ages could account for the increased prominence in the older age groups (Parr 2005; Martinez-Maza et al. 2013).

8.2.2 Effects of tooth loss on the morphology of the mandible

It is expected that as teeth are lost, that the bite force that they are able to withstand and create will diminish. Along with the decrease in bite force, the muscles of mastication will reduce in size and bony attachments. As a result of the altered masticatory processes and forces, the mandible will be remodelled and resorption will take place in areas where the strain is less (Wolff 1986; Patriquin 2013). Tooth loss with or without denture wearing with time, will therefore have important effects on the morphology of the mandible (Enlow et al. 1976; Kingsmill 1999; Martinez-Maza et al. 2013). Tooth loss is expected to contribute to, or interfere with the relationship with age and these interactions will be discussed further in section 8.2.3. In this study, it was not known which of the edentulous subjects were denture wearers, and if so, for how long. For this reason findings were interpreted by taking into account the possibility of denture wearing as well. This might be true especially for females, where aesthetic demands are generally higher than males. Tooth loss and denture wearing differences amongst sexes and ancestry groups potentiated by differences in socio-economic status and diet will be considered in sections 8.2.4 and 8.2.5. Although adjustments for age were made in the statistical comparisons between groups, sex-ancestry group differences in the period from tooth loss to death could not be regulated and could contribute to some of the differences noted between individuals and sex-ancestry groups.

As described in the literature tooth loss was accompanied with widening of the mandibular angle, but this was only to a minimal degree (Keen 1945; Kasai et al. 1996; Ohm & Silness 1999; Xie & Ainamo 2004; Oettle et al. 2009). The greatest effect was noted in male SAE, where tooth loss was associated with 3% of the increase in angle size noted. The reason why male SAE exhibited the greatest correlation with tooth loss for mandibular angle, may be hidden in the fact that male SAE presented with a relatively narrower, older spectrum (36 - 91 years) as compared to the other sex-ancestry groups. The mandiblar angle in this age interval might exhibit relatively accelerated changes to the angle, thereby strengthening this correlation.

In contrast to the size of the mandibular angle, linear dimensions demonstrated greater correlations, positive or negative, with tooth loss in all sex-ancestry groups. From these correlations it was evident that the greatest and significant impact of tooth loss, in all sex-ancestry groups individually was on height of mandibular body *(Hmb)* and chin height, presumably because of early loss of the concomitant alveolar bone (Mercier & Lafontant 1979).

Female SAA and male SAE, both having narrower age ranges, presented with weaker correlations than the opposite sex in the same ancestry group, with wider age ranges. The greater possible time period from loss of teeth until death, for male SAA and female SAE, was implied in the process to diminish the height of mandibular body *(Hmb)* as well as chin height. The chin height was relatively preserved in male SAE and this could have been explained by a relative sparing of the front teeth (Fig. 4.1).

The stronger correlations between dentition group and height of mandibular body *(Hmb)* (32%) as well as chin height (29%) in male SAA was in contrast with the almost negligible effect on the mandibular angle. The reason for this discrepancy could implicate that alveolar bone loss preceded the changes in the mandibular angle. Male SAA started off with a greater height of mandibular body *(Hmb)*, but as teeth were lost, much more height was lost than in female SAA.

Male SAE also started off with a greater height of mandibular body *(Hmb)*, but did not lose as much height as female SAE. It can be suggested that the discrepancy in the effect of tooth loss on the *Hmb* were due to differences in the period since teeth were lost. Female SAE had the greatest correlation between tooth loss and height of mandibular body *(Hmb)* as well as chin height compared to the other groups and respectively contributed 36% and 32% to the decrease noted. Ongoing alveolar resorption will follow tooth loss, but denture wear can accelerate these changes (Potgieter et al. 1983; Kasai et al. 1994; Ozan et al. 2013). The greatest standard deviations were noted in dentition group 0, especially female SAE, which may be indicative of the ongoing alveolar resorption process.

In the adjusted means of the complete sample the increase in bicondylar breadth *(Bicon)* with tooth loss was statistical significant. The bicondylar breadth *(Bicon)* dimension could have been affected by the shape of the condyle, the position of the condyle articulating in the glenoid fossa or the distance between the mandibular fossae. With tooth loss, the body of the mandible rotates anteriorly and the condyle rotates posteriorly within the mandibular fossa and the condyles become flattened and shortened antero-posteriorly. Remodelling of the condyles can be considered as a functional adaptation of the joint to a new occlusal situation (Tallgren 1972; Mongini 1977; Chrcanovic et al. 2011). Further, remodelling of the condyles after puberty includes a lateral and medial growth of the condyle area regardless of tooth loss (Martinez - Maza et al. 2013). The minimal increase in the bicondylar breadth *(Bicon)* dimension noted in male SAA and to a greater extent in female SAE but not in female SAA and male SAE, may once again be related to the shorter possible time period for morphological changes after tooth loss.

The decrease in the dimensions of minimum ramus breadth *(Mrb);* projective mandibular corpus length *(M_corpus length)* and maximum ramus height *(Ram_ht)* can be understood as part of the changes associated with tooth loss. Fewer teeth can endure less strain and therefore bite force will decrease. The muscles of mastication in particular the masseter will decrease in mass and volume or their attachments with tooth loss (Kasai et al. 1994; Ceylan et al. 1998; Xie & Ainamo 2004; Knezović-Zlatarić & Čelebić 2005; Enomoto et al. 2010). Following on the wasting of the muscles of mastication, resorption of the anterior and posterior border of the ramus will take place. Minimum ramus breadth *(Mrb),* maximum ramus height *(Ram_ht)* and to some extent projective mandibular corpus length *(M_corpus length)* dimensions will therefore diminish as a result of the resorption process of the ramus (Enlow et al. 1976; Kasai et al. 1994; Ozan et al. 2013). The wider standard deviations of projective mandibular corpus length *(M_corpus length)* in group 0, is suggestive of the ongoing process of change in size of this dimension as teeth were lost. An initial shortening of maximum projective length of the mandible *(Max m_length)* with tooth loss was noticed in females in dentition group 1, followed by a lengthening in dentition group 0 approaching values of dentition group 2. The lengthening in dentition group 0 might have indicated an increase in the mandibular angle.

The opposite was true for male SAA. This resistance for male SAA to show the decrease in dimensions found in others, might be ascribed to later loss of teeth or natural stronger muscles of mastication and larger more robust mandibles associated with prognathism and male sex (Patriquin 2013).

In summary, with tooth loss much of the alveolar bone is lost within the first year (Mercier & Lafontant 1979). Loss of alveolar bone was evident from the statistically significant decrease in height of mandibular body *(Hmb)* and chin height in all groups. Female SAE presented with the greatest correlations with tooth loss and this may have been related to the longer possible duration of tooth loss or/and aggravated by the use of dentures (Tallgren 1972). Other factors that could play a role, is the association of a more gracile mandible with orthognathism and being female (St Hoyme & İşcan 1989; Patriquin 2013). The mandible of female SAE starts off with a smaller frame, which will decrease even more with aging and tooth loss. Concomitant osteoporosis in female SAE may further contribute to the effect of tooth loss on the mandible (Xie & Ainamo 2004). Although the association with systemic osteoporosis and loss of mandibular bone with tooth loss has not been confirmed by other researchers (Mohajery & Brooks 1992; Watson et al. 1995; Kingsmill 1999; Knezović-Zlatarić & Čelebić 2005).

To approximate the mandible and maxilla to the residual alveolar ridge, the mandible rotates anteriorly and the condyle posteriorly (Tallgren 1972). Difference in bicondylar breadth *(Bicon)* with tooth loss was thought to be associated with the rotation of the condyle. The mandible and maxilla would only be in contact with each other at the alveolar processes anteriorly. To restore the parallelism of the biting surfaces, the mandible will be remodelled in time by increasing the angle of the mandible (Keen, 1945). The maximum projective length of the mandible *(Max m_length)*, maximum ramus height *(Ram_ht)*, projective mandibular corpus length *(M_corpus length)* and in some cases the minimum ramus breadth *(Mrb)* decreased. A reduction in bite force, the remaining dentition could withstand, may contribute to the decrease in size of *Max m_length; Ram_ht; M_corpus length* and *Mrb* noted. A reduction in the mass of the muscles of mastication and their rameal attachment sites followed (Enlow et al. 1976; Kasai et al. 1994; Ozan et al. 2013).

Recovering of the mandibular angle to some extent, was noted in those individuals with a longer possible duration of tooth loss, e g. female SAE. An intervention such as dentures or greater efficiency in the edentulous as opposed to partial dentition could have been implicated in this finding. Male SAA seemed to have been resilient to the changes in the morphology of the mandible with tooth loss. This could either be due to stronger muscles of mastication and bony frame or a shorter duration of tooth loss before death (Patriquin 2013).

In general, the cortical thickness decreased with tooth loss at the sites examined. The moderate relationship with thinning of the cortical thickness in the inferior border of the mandible in female SAE was not unexpected as this group consisted of the oldest individuals. This effect could further have been potentiated by the wearing of dentures (Lestrel et al. 1980; Warner et al. 2006; Ausk et al. 2012; Ozan et al. 2013). Individuals with dentures cannot apply the same bite force that is possible for individuals with natural teeth. In contrast Knezović-Zlatarić and Čelebić (2005) concluded that removable partial dentures prevent alveolar bone overloading, thus allowing higher chewing forces and higher tensile forces of the masseter attachment to the lower border of the mandible preventing bone resorption.

A longer time period with fewer occlusions or denture wearing could therefore render a greater thinning effect on the inferior cortical thicknesses (Schwartz-Dabney & Dechow, 2002, Katranji et al., 2007). The moderate relationship noted in the decrease in midline cortical thicknesses with tooth loss in males was an interesting finding. Both male groups started off with thicker cortical thicknesses at these sites, which decreased to a greater extent with tooth loss than what was seen in females. The deduction could be made that a mechanism in females, as for instance dentures, prevented tooth loss to decrease cortical thickness anteriorly in the midline *(Ant Mid)*, cortical thickness inferiorly at the midline *(Inf Mid)* and cortical thickness posteriorly at the midline *(Post Mid)* to such an extent. Bite forces could so be distributed more evenly, as opposed to the detrimental effect of exposing the anterior part of the mandible as the only point of contact between the mandible and maxilla. This impression was supported by Atkinson and Woodhead, 1968 as well as Kingsmill and Boyde, 1998, who found a slight increase in thickness of cortical thickness in the inferior aspect of the mandibular symphysis in edentate individuals wearing dentures (Atkinson & Woodhead, 1968, Kingsmill & Boyde, 1998).

Tooth loss was weakly correlated with an increase in cortical thickness at the gonion *(Gon)* in female SAA and male SAE as well as cortical thickness lingually at the mental foramen *(Ling MF)*, cortical thickness inferiorly at the midline *(Inf Mid)* and cortical thickness posteriorly at the midline *(Post Mid)* in female SAA. The increase in cortical thickness on the lingual aspect represented by cortical thickness lingually at the mental foramen *(Ling MF)* and cortical thickness posteriorly at the midline *(Post Mid)* with tooth loss may represent a secondary adaptation to relatively larger strains due to a reduction in alveolar height and corpus cross section, despite overall reduced muscular and biting loads (Schwartz-Dabney & Dechow, 2002). As in female SAE, the increase in cortical thickness inferiorly at the midline *(Inf Mid)* dimension could possibly be associated with denture wearing.

Conversely these weak correlations with tooth loss may also be interpreted as an absence of thinning of the cortical thickness at the sites mentioned. As female SAA and male SAE presented with narrower age ranges, the duration of tooth loss might have been shorter, limiting its effect on the morphology of the mandible.

In summary, as far as cortical thickness is concerned, it seems that tooth loss, potentiated by the possibility of denture wearing, is associated with a general decrease in cortical bone thickness, especially of inferior cortical thicknesses. Female SAE, the oldest sex-ancestry group with the highest number of tooth losses, had the greatest correlations with cortical thickness at the gonion *(Gon)* and cortical thickness inferiorly at the mental foramen *(Inf MF)* but not with cortical thickness anteriorly in the midline *(Ant Mid)* and cortical thickness inferiorly at the midline *(Inf Mid).* The reason could be related to the longer possible duration of tooth loss in female SAE for changes in morphology to occur. Sparing of the cortical thickness anteriorly in the midline *(Ant Mid)* and cortical thickness inferiorly at the midline *(Inf Mid)* could have been associated with denture wearing. A slight increase noted in lingual cortical thicknesses, namely cortical thickness lingually at the mental foramen *(Ling MF)* and cortical thickness posteriorly at the midline *(Post Mid)*, were thought to be due to larger strains with loss of the alveolar process in female SAA. A persistent rough diet as seen in SAA in the presence of alveolar bone loss could possibly be implicated. Although the alveolar bone becomes reduced a certain critical bite force is required to masticate food for survival. Larger strains will therefore be present in the limited alveolar bone, stimulating the growth of bone lingually. Ancestry and sex group differences in cortical bone loss will further be considered in the sections 8.2.4 and 8.2.5.

The linear regressions of the overall mandibular shape only demonstrated moderate and significant correlations with tooth loss for female SAE. The correlations for all other sex-ancestry groups were weak and not statistical significant. The reason might be related once again to the longer possible duration of tooth loss in female SAE. The direction of variation or change with tooth loss could be illustrated in the extremes and mirrored the linear findings. The changes with tooth loss (comparing dentition group 0 to dentition group 2), included lowering of mandibular body height as compared to the rameal height, slimmer rami accompanied by less upright gonial angles. The dental arch or superior border of the mandible was relatively smaller than the inferior border which presented with a more prominent pogonion. The overall appearance of the mandible was relatively widened and flattened.

For the shape of the gonial area SAE especially females, differences between dentition group combinations were significant or approached significance. The gonial area in dentition group 2 was more convex involving a greater aspect of the posterior border of the mandible. In dentition group 0 the posterior curvature was more pronounced or limited inferiorly (Fig. 6.17).

The more convex gonial area noted in dentition group 2, could be explained by the more extensive masseter and medial pterygoid muscle attachment sites associated with effective mastication (Knezović-Zlatarić & Čelebić, 2005, Kasai et al., 1994, Enomoto et al., 2010, Xie & Ainamo, 2004). The prominent inferiorly placed gonial eversion in dentition group 2 was also indicative of strong muscular development. Dentition group 1 displayed the greatest shape variation, which might be a reflection of changes in the biomechanical forces as occlusions were lost (Fig. 6.13).

The differences between dentition groups in the gonial area only became statistically significant in SAA when the gnathion was added, revealing a blunter junction between body and ramus of the mandible (White et al. 2011). These differences between dentition groups were more obvious in female SAA, according to the linear regressions. The absence of significant differences between dentition groups for the cortical thickness at the gonial area without gnathion in SAA and males, may be explained by a possible shorter duration of tooth loss or more resilience of the mandible to undergo morphological changes. The larger bony framework and muscles of mastication associated with prognathism might be contributing factors (Patriquin 2013).

With regard to the gonial area with or without gnathion, females had more pronounced effects with tooth loss. This could be due to a longer duration of tooth loss or a mandibular structure more sensitive to changes in dentition.

Significant chin shape changes with tooth loss could be demonstrated with loss of teeth in SAE and especially female SAE according to the linear regressions, but not in SAA. The expected relative lowering of the height of the chin between the pogonion and the most superior point marked were noted and supposedly represented the loss of alveolar bone with loss of occlusions. These changes were not limited to loss of alveolar bone as the deepest point in the midline corresponding to the lower margin of the alveolar process also receded. This may have been caused by the detrimental effect of dentures. Other changes in the prominence of the chin markings could also have been responsible. This was, however, not noted in all individuals. The significant chin shape changes with loss of teeth in female SAE could be ascribed to the older age of this group and therefore a longer possible time without functional dentition for remodelling to take place.

The chin area was not expected to be involved in the functional demands of the mandible (Patriquin 2013). The chin is, however, the attachment site for mentalis, depressor anguli oris and depressor labii inferioris muscles (Standring ed. 2008). The shape of the chin or at least the attachment sites of the aforementioned muscles may be influenced by the change in their activity. A coordination between mentalis activity and the activity of other muscles of mastication exist during chewing (Inoko 2004). Therefore tooth loss may be involved in the change in activity of the muscles attaching to the chin as it had been for the muscles of mastication. The mentalis muscle lifts the base of the lower lip, while the depressor labii inferioris and depressor anguli oris draw the lower lip and the angle of the mouth downwards and laterally (Standring ed. 2008). The activity of the mentalis muscle alternating with the activity of the depressor labii inferioris and depressor anguli oris assist with mastication and is coordinated with the mastication process (Mercier & Lafontant 1979). When teeth are lost, mastication might be assisted by the lip muscles. Increased activity with tooth loss may accentuate the attachment markings on the mandible. Contradictory to what would be expected, a marked response of the lower lip and mentalis muscles, in long-term complete denture wearers, may be responsible for the maintenance of the bone framework of the mandible (Tallgren 1972).

8.2.3 Aging vs. tooth loss in each sex-ancestry group

Aging and tooth loss are often inseparable as many of the effects of tooth loss only present itself with time. The older the individual, the longer the possible duration of tooth loss and the greatest possible effect tooth loss might have on the deformation of the mandible. The impact of dentition that is functioning efficiently over time on the mandible as opposed to the impact of various levels of tooth loss over time on the mandible need to be considered. In this study the duration of tooth loss was not known, nor was the possibility of denture wearing. The results were therefore interpreted taking cognisance of these possibilities as applicable for each sex-ancestry group.

8.2.4 Implications for ancestry estimations

In this section comparisons of the various dimensions measured between ancestry groups were integrated and put into context with the possible influence of tooth loss. Statistical differences between ancestry groups were considered along with discriminant analyses. As mentioned before, statistical differences were calculated from means adjusted for differences in age, tooth loss and differences in the size of the samples compared. The deformation of the mandible because of tooth loss could not be reversed by these adjustments and might thus still be a confounding factor. Discriminant analyses on individual and cumulative dimensions were performed on the complete sample as well as within each dentition group.

The ancestry group differences noted in this study, may also be expressed as the differences between the prognathic and the orthognathic mandible (Garvin & Ruff, 2012). A relatively short (antero-posteriorly) and wide (medio-laterally) mandible in orthognathic individuals is found in temperate and cold-climate groups, and a long (antero-posteriorly) and narrow (medio-laterally) prognathic mandible in the tropical and subtropical populations (St

Hoyme and İşcan, 1989, Novotny et al., 1993). More specific dimensions are considered below.

The greater dimensions in SAA were not unexpected as prognathism is associated with an increase of dentition size and therefore alveolar length as reflected in height of mandibular body *(Hmb)* and chin height. Other associations with prognathism include a wider minimum ramus breadth *(Mrb)* and longer projective mandibular corpus length (M_corpus length) (Parr, 2005; Patriquin, 2013).

The greater bigonial breadth *(Bigon)* and maximum ramus height *(Ram_ht)* in SAE were unexpected and unrelated to age differences, tooth loss or sample size and were considered further in the usefulness of ancestry predictions. Increase in bigonial breadth *(Bigon)* and perhaps maximum ramus height *(Ram_ht)* have been associated with post-pubertal changes in the shape of the mandible and not tooth loss (Martinez - Maza et al. 2013). The impression that variation in tooth loss could not be the cause of differences in maximum ramus height *(Ram_ht)* was confirmed by the shape analysis of the complete mandible. Only dentition group 2 displayed a significant variance in shape amongst the ancestry groups. SAE presented with lowering of the height of mandibular body *(Hmb)* relative to a longer maximum ramus height *(Ram_ht)* and slimmer minimum ramus breadth *(Mrb).*

Discriminant analyses for total mandibular shape between ancestry groups in the complete sample and in dentition groups separately, however, fared poorly as the prediction percentages were often just above chance or lower (48.7% to 67.2%). Statistically significant differences between ancestry groups did not necessarily imply discriminant qualities. This discrepancy could be explained by the high degree of overlap noted.

When considering linear measurements, height of mandibular body *(Hmb))* and chin height were the most affected by tooth loss across all four sex-ancestry groups. It was considered the earliest and universal morphological change after tooth loss and represented the loss in alveolar bone. It was therefore expected that differentiation between ancestry groups would be enhanced by taking dentition group into consideration. In the complete sample the highest prediction for ancestry was height of mandibular body *(Hmb)* (72.2%). When dentition group 2 was considered separately, ancestry prediction increased from 72.2% in the complete sample to 76.1% for height of mandibular body *(Hmb))* and from 53.2% to 71.7% for projective mandibular corpus length (M_corpus length).

Although the other linear dimensions were less affected by tooth loss, comparisons within dentition group became significant and/or ancestry predictions were improved. This discrepancy implied that some differences were obscured when dentition group was not taken into consideration.

When considering the mandibular angle, SAA presented with smaller angles, but these differences only became statistically significant when male SAA and female SAE as well as male SAA and male SAE, dentition group 0 were compared. Male SAA and female SAE represented the extremes with regard to variation between mandibular size and capable bite force and this could explain why differences could be noted in all dentition groups. The differences between male SAA and male SAE in dentition group 0, might have been related to perhaps a longer duration of tooth loss in male SAE as opposed to male SAA. Other reasons could include a more resilient bony frame in male SAA, resisting morphological change brought about by tooth loss. Prediction percentages by discriminant analysis though, were less than 65% even when dentition group was considered.

Although the statistically significant differences between ancestry groups in individual linear measurements performed poorly in discriminant ability, it was greatly improved when considering all linear measurements simultaneously. Discriminant analysis of cumulative linear measurements without mandibular angle delivered a 90.4% correct classification of ancestry groups in the total sample. When only considering dentition group 0 in isolation: 89.7% correct ancestry classification was achieved in dentition group 1, 95.0% and in dentition group 2, 95.7%. Small differences noted in the individual linear dimensions, when considered collectively, potentiated the differences between ancestry groups.

The shape features examined in this study were thought to reflect the attachment sites of the muscles of mastication to a great extent. The stronger masticatory muscles associated with the greater dimensions of the mandible and dentition in prognathism, as seen in SAA, could have been responsible for the ancestry differences in shape of the gonial area with or without gnathion (Kasai et al. 1994; Xie & Ainamo 2004; Knezović-Zlatarić & Čelebić 2005; Enomoto et al. 2010; Patriquin 2013). Presumably to accommodate the larger masseter muscle attachment, the gonial area in SAA was broad and more convex posteriorly. The gonial eversion was more prominent and the mandibular angle upright. The wider range of shape variation seen in SAA could have been a reflection of the high growth rate during puberty, especially in males, to achieve greater mandibular features associated with prognathism (Olsson et al. 2006).

However, when dentition groups were considered separately, the only significant difference noted was between ancestry groups in those individuals with no occlusions (dentition group 0). The ancestry group differences noted in the group without occlusions (dentition group 0) could have accounted for the variations noted between ancestry groups in the complete sample. The discriminant ability of the gonial area with gnathion for ancestry prediction increased from 59.7% overall to 74.4% when considering dentition group 0 in isolation. Clearly the tooth loss associated increase of the size of the mandibular angle was included in the shape of the cortical thickness at the gonial area with gnathion facilitating discriminant properties.

The shape of the chin were assessed from five points marked on the chin. Three of these points were marked on the crests of bony prominences, namely the pogonion and the left and right mental tubercles. The relative development of these three points have often been described as determining the shape of the chin and has been claimed useful in ancestry determinations (eg. De Villiers 1968 & Parr 2005).

The mental tubercles in individuals of SAE seemed to be relatively wider apart and protruding further anteriorly in the chin of SAA, whilst the pogonion seemed relatively lower. In some individuals, the mental tubercles were more prominent than the pogonion. These findings were in agreement with previous research (De Villiers 1968; Parr 2005). The prominence of the mental tubercles have often been referred to as a square chin, while in situations where the pogonion protrudes further, the chin is referred to as pointed (Acsádi & Nemeskéri, 1970, Loth & Henneberg, 2001, Garvin & Ruff, 2012) .

Prominence of the mental tubercles has been associated with the depth of the fossa mentalis for the attachment of the mentalis muscle just superior to the mental tubercles as well as the depressions more laterally for the attachments of depressor labii inferioris, and depressor anguli oris (De Villiers 1968; Graumann & Sasse 2004; Parr 2005). The sequential action of the mentalis muscle, responsible for the lifting of the lower lip, and depressor labii inferioris, and depressor anguli oris responsible for depressing the lower lip have been found to be active in the mastication process (Mercier & Lafontant 1979; Schieppati et al. 1989; Hanawa et al. 2008). The greater depth of the depressions seen in SAE were thought to represent attachments for more powerful muscles taking part in the mastication process. It seemed that in individuals of SAE these muscles of facial expression were often well developed and could have assisted in the mastication process. The prominence of the mental tubercles were still noticeable in some individuals despite tooth loss and could therefore proof useful in ancestry estimations.

The muscles of facial expression have been described as relatively undifferentiated and differed from the usual description in SAA. More specifically, depressor labii inferioris, which usually is described as having a long, linear origin between the symphysis menti and the mental foramen, is sometimes found as an aponeurotic sheet covering the whole chin up to the midline in SAA. It thus completely obscures the underlying mentalis and lower part of the orbicularis oris (Figs. 2.2 and 2.3) (Tobias & Arnold 1985; Standring ed. 2008). It is possible that the function of the obscured mentalis in these cases may be altered affecting the size of its attachment and thereby the size and demarcation of fossa mentalis (Parr 2005; Standring ed. 2008). More diffuse attachment sites could therefore render the depressions on the chin area less sharply defined in SAA.

The resorption of the alveolar process could have contributed to the significant differences between ancestry groups in those with no occlusions. The most obvious difference was the relative decrease in the distance between the pogonion and the highest point in the anterior midline as teeth were lost. There were more variability with tooth loss and a greater extent of alveolar resorption in SAE, which could have been attributed to individuals living a longer period after tooth loss as supported by a higher age in these groups. A symphysis with a prominence at its base but no real chin may be achieved by compensatory resorptive activity of the alveolar component. Resorption occurs as a means of reducing the predominant forward and downward movement of the symphyseal region produced by growth of the ramus (Rosas & Martinez-Maza, 2010). For this reason, discriminant qualities for ancestry in chin shape increased when taking specific dentition groups into account: accuracies increased from 61.2% in the complete sample to 71.1% for dentition group 0.

In this study, although the frequency of the presence of third molars were reported, the criteria for the dentition group definitions did not specifically take the presence of third molars into consideration. The reason for this omission was that very few individuals of SAE possessed third molars as compared to SAA (Fig. 4.1). The presence of third molars is not an unimportant determinant of the morphology of the mandible and could have contributed to the ancestry group differences noted. The dimensions in this study that could have been influenced by the absence of third molars included: mandibular angle; height of mandibular body *(Hmb);* projective mandibular corpus length *(M_corpus length)* and maximum projective length of the mandible *(Max m_length)* and the cortical thickness inferiorly at the mental foramen *(Inf MF)* (Al Ali 2008; Ogawa & Osato 2012).

The only site where the cortical thickness was significantly different between ancestry groups were at the gonion *(Gon)*. Cortical thickness at the gonion *(Gon)* was surprisingly thicker in SAE. Although the cortical thickness diminished with loss of occlusions in SAE but not in SAA, the cortical thickness at the gonion *(Gon)* was still greater than the dimensions of SAA. It is postulated that perhaps a greater transmission of bite force occurred posteriorly closer to the masseter muscle attachments in the orthognathic mandible. The inferior cortical thicknesses at the left mental foramen level *(Inf MF),* as expected, was thicker in SAA, but not significantly so. Africans and individuals with prognathic faces generally present with greater cortical thicknesses (Ogawa & Osato 2012).

So, in summary cumulative linear measurements and cortical thicknesses of the mandible may be useful in assigning ancestry especially if dentition group is taken into consideration. Prediction percentages rose to 95.7% and 83.7% respectively in dentition group 2, decreasing somewhat as teeth were lost.

Although differences between ancestry groups were noted in the size of the mandibular angle, it was only significant in males without occlusions. As these effects are clearly related to the duration of tooth loss, the mandibular angle can not be considered a reliable ancestry indicator. Ancestry classification according to shape variations were disappointing and only reached percentages above 70% for chin shape and gonial area with gnathion in dentition group 0.

8.2.5 Implications for sex estimations

Many papers have been published regarding sex differences in the mandible (De Villiers, 1968, Acsádi & Nemeskéri, 1970, Krogman & İşcan, 1986, Novotny et al., 1993, Parr, 2005, Garvin & Ruff, 2012, Bejdová et al., 2013). Although variations have been found to be significantly different between the sexes (De Villiers 1968; St Hoyme & İşcan 1989; Parr 2005), the usefulness of the mandibular features in sex estimations are doubtful (Krogman & İşcan 1986; Maat et al. 1997; Galdames et al. 2009; Bejdová et al. 2013; İşcan & Steyn 2013). The lack of usefulness in sex estimation was thought to be because of the large degree of overlap between the sexes.

Size differences account for much of the sexual dimorphism seen in the mandible, with males having larger, more robust jaws and more developed muscle attachment sites (St. Hoyme & İşcan, 1989; Rosas et al., 2002; Vodanovi´c et al., 2006). Sexing differences are expected to be accentuated by tooth loss and aging because of previous reports of more bone loss after teeth extraction and denture wearing (Mercier & Lafontant 1979; Mercier 1988).

Loth and Henneberg (1996), in their review of the biological reasons for sexual diversity in mandibles, concluded that the mandible is shaped in response to hormonal influences and both directly and indirectly by the muscle development thus stimulated. Walker and Kowalski (1972) also linked this sexual dimorphism to continuing postpubertal mandibular bone growth in males in response to hormonal influences. Israel (1969) found similar jaw heights and cortical thicknesses of the mandible among young boys and girls. Size sexual dimorphism occurs around puberty presumably under steroidal influence with males gaining bone at an increasingly greater rate than females until the adult differences between sexes favour men by over 13%. This corresponds roughly to well-known findings in other parts of the body. The difference in size between men and women is to a large extent due to the differences during the adolescent spurt (Oettlé et al., 2009).

A greater difference in size of the mandibular angle between males and females within ancestry group were expected. The mandibular angle in male SAA was similar to previously reported, 120.0° as opposed to 120.6°. The mandibular angle in female SAA, however, was smaller at 123.2° as opposed to 125.0°, approximating the difference between the sexes (De Villiers 1968). This could perhaps have been due to the inclusion of greater numbers of older female dentition group 2 individuals.

All linear measurements were smaller in females. Apart from bicondylar breadth *(Bicon)* all these comparisons between the sexes were statistically significant. In general these dimensions were reduced further with loss of teeth. It would thus be important to take dentition group into account when estimating sex from linear measurements. As maximum projective length of the mandible *(Max m_length)* is a reflection of projective mandibular corpus length *(M_corpus length)*, the mandibular angle and maximum ramus height *(Ram_ht)*, the *Max m_length* may increase whenever the other dimensions increase. In males of both ancestry groups, mandibles without occlusions presented with a greater maximum projective length of the mandible *(Max m_length)* as compared to dentition group 2. Females presented with smaller maximum projective length of the mandible *(Max m_length)* and the greatest standard deviations.

Sex predictions increased by approximately 10% when dentition group was taken into account. Higher discriminant qualities existed for sex as compared to ancestry group for individual linear measurements as some predictions achieved accuracies above 80%. Cumulative discriminant analysis on all linear measurements revealed 88.8% prediction of sex on the complete sample, dentition group 0: 94.8%; dentition group 1: 97.5% and dentition group 2: 87.0%.

Shape differences between sexes were expected on the grounds of weaker muscles of mastication and therefore smaller or smoother attachment sites. Sex differences are mostly focused in the chin and the gonial area (De Villiers 1968; Acsádi et al.1970; Krogman & İşcan 1986; Novotny et al. 1993; Parr 2005; Franklin et al. 2008; Coquerelle et al. 2011; Garvin & Ruff 2012; Bejdová et al. 2013)

Mandibular shape and chin shape were not different between the sexes. It may be suggested that in previous studies which used morphological scoring systems that the size of the bony projections might have influenced the observed sex differences, rather than the shape differences itself.

However, differences approached significance in SAA for the gonial area and in SAE for the gonial area with gnathion. The greater differences between sexes in SAA for the gonial area as opposed to SAE were surprising. The shape variations between the sexes as evident in the extremes involved the greater posterior convexity of this area which manifested as a greater angulation between the most superior and inferior points in males. The most prominent lateral point on the gonial eversion, was situated more superior and posterior to the gonion in males. Males in general exhibited greater variation in shape compared to females. Sexual dimorphism has often been thought to be minimized in SAA for several reasons including socio-economic status and malnutrition (Tobias 1974). Discriminant analysis of the gonial area without the gnathion revealed a 63.7% accuracy for sex. Discriminant qualities for identification of sex in SAA for the gonial area was 73.3% in all dentition groups and in 90.9%, SAA dentition group 0. It was lower for dentition group 1 and 2.

The statistically significant difference noted between the sexes amongst SAE in the gonial area with gnathion, was associated with a greater variability in shape in females. The greater variability was postulated to be due to a greater time period for change of the morphology without teeth as reflected in the inclusion of relatively young individuals in dentition group 0. Discriminant qualities for identification of sex in the gonial area with gnathion in SAE was 73.3% for all dentition groups. Prediction percentages improved to approximately 80%, when considering dentition group 1 and 2 individually, but not for dentition group 0.

Cumulative discriminant shape analysis of sexes involving two shapes, chin and gonial area with gnathion, achieved 63.3% accuracy in the complete sample. When considering dentition group accuracies approximated 80%.

In summary higher discriminant qualities of up to 88.8% existed for sex as compared to ancestry group for individual linear measurements as well as cumulative measurements. Discriminant qualities for identification of sex in the gonial area with gnathion in SAE was 73.3% for all dentition groups. Discriminant shape analysis of sexes involving two shapes, chin and gonial area with gnathion achieved 63.3% accuracy in the complete sample. When taking dentition group into account, prediction percentages often improved in the mentioned modalities.

8.2.6 Possible age estimations based on the morphology of the mandible

Time of tooth loss and the possibility of denture wearing could not be regulated and might have affected all dimensions measured: mandibular angle, linear measurements; shape analysis and cortical thickness over time. Although tooth loss and denture wearing could therefore confound the effects of aging on these dimensions, specific age related changes could be identified. These age specific changes was however not precise enough for age estimations.

8.3 Functional considerations

The mandible acts as a lever against the bite force on the teeth in the dental arch, created by the muscles of mastication, which is responsible for the movement about the fulcrum: the temporo-mandibular joint. The masticatory muscles act on the mandible to create mechanical stress required for mastication. Temporalis, masseter and medial pterygoid are used in the elevation of the mandible (Patriquin 2013). The muscles of mastication attach to the ramus of the mandible and thereby influence the shape of the mandible. The masseter muscle is partly responsible for the shape of the ramus of the mandible. The superficial layer of the masseter is the largest and passes downwards and backwards, to insert onto the angle and lower posterior half of the lateral surface of the mandibular ramus. The middle layer of the masseter inserts onto the central part of the ramus of the mandible. The deep layer inserts onto the upper part of the mandibular ramus and onto its coronoid process (Standring ed. 2008).

Teeth, the hardest structures in the body, create a rigid occlusal surface for mastication. The greater the occlusal surface, the greater the bite force perpendicular to the occlusal plane. Prognathism noticed in SAA is associated with a greater occlusal area because of greater dentition size as well as the more frequent presence of third molars (Knezović-Zlatarić & Čelebić 2005; Patriquin 2013).Where the strain is larger, bone production is induced to accommodate mechanical reaction forces. In areas where strain is less, bone resorption takes place to be as economic with material as possible (Atkinson & Woodhead 1968a; Wolff 1986; Knezović-Zlatarić & Čelebić 2005; Patriquin 2013).

The temporalis, masseter and medial pterygoid, used in the elevation of the mandible, are capable of exerting the maximum masticatory force on the dental arch when occlusal equilibrium with maximum tooth contact occurs during mastication. The ideal pattern of dentition for effective mastication entails balanced, even distribution between sides of posterior and anterior teeth in occlusion (Kasai et al. 1994; Kasai et al. 1996; Kohakura et al. 1997; Ceylan et al. 1998; Pileicikiene & Surna 2004; Knezović-Zlatarić & Čelebić 2005; Oettlé et al. 2009b).

In dentistry the restoration of the functional integrity of the dental arch taking into consideration the ideal pattern of dentition is important for efficient mastication and therefore the development and maintenance of the muscles of mastication and the bony structure of the mandible (Pileicikiene & Surna 2004).

It seems that with ongoing effective mastication as defined before, the mandibular features remodelled and strengthened to accommodate the strains of the bite force exposed on it over the years. In two instances the aging process promoted the angulation of the mandible. In females below 49 years, it was noticed that the mandibular angle had a minimal negative effect with aging. As the person aged, the smaller the angle became. This is in agreement with previous research regarding age changes in the vertical dimensions of the face from 22 to 33 years, which have been shown to be greater in females (Bondevik 1995; Akgül & Toygar 2002). This could possibly be because of a delayed growth process in females. In the second instance male SAA between 50 and 98 years of age displayed a minimal decrease in angle size. It therefore seems that male SAA individuals who survived until old age still maintained efficient mastication.

Bicondylar breadth *(Bicon);* bigonial breadth *(Bigon);* maximum ramus height *(Ram_ht);* projective mandibular corpus length *(M_corpus length)* in all and minimum ramus breadth *(Mrb)* in SAA as well as maximum projective length of the mandible *(Max m_length)* in males were positively correlated with age regardless of dental pattern. These increases were thought to result from growth of the ramus and corpus of the mandible to accommodate greater attachment sites for the increasing size of the muscles of mastication.

It was expected that the cortical thickness will increase at least up to 49 years and to be relatively spared from the effects of osteoporosis found elsewhere in the skeleton. The maintenance of the cortical structure was thought to be due to the constant strains of the mastication processes (Atkinson & Woodhead 1968a; Henrikson et al. 1974; von Wowern &

Stoltze 1978; Kingsmill & Boyde 1998; Kingsmill 1999; Pileicikiene & Surna 2004; Knezović-Zlatarić & Čelebić 2005; Richmond et al. 2005; Humphries 2007; Swasty et al. 2009; Patriquin 2013). In this study the thickness of the cortical structure was often negatively correlated to aging. The only correlations which were significantly and negatively affected by aging were inferiorly situated: cortical thickness inferiorly at the midline *(Inf Mid)*; cortical thickness anteriorly in the midline *(Ant Mid)* and cortical thickness inferiorly at the mental foramen *(Inf MF)* (Atkinson & Woodhead, 1968, Kingsmill & Boyde, 1998). The concomitant effect of tooth loss was thought to be responsible (Schwartz-Dabney & Dechow, 2003).

The cortical thickness lingually at the mental foramen (Ling MF) was minimally affected by aging, loss of occlusions and was similar amongst sexes and ancestry. So despite aging, tooth loss, differences in sex and ancestry group a mechanism, such as the wearing of dentures, maintained the cortical thickness at this site. The relative sparing of the lingual cortical thickness at the mental foramen, were thought to be attributed to larger strains with the loss of the alveolar process in regions able to respond with a deposition of bone. It was not incidental that these regions were closer to the posterior teeth and the attachment of the masseter muscle and may have been potentiated by the wearing of dentures.

The greatest effect of tooth loss, was the loss of alveolar bone as seen in the decrease of height of mandibular body *(Hmb)* and chin height. After tooth loss, most of the alveolar bone is resorbed in the first year. This process continues for at least 25 years and may be potentiated by the wearing of dentures (Tallgren 1972; Kingsmill 1999). As teeth with the concomitant alveolar bone are lost, the condyle rotates posteriorly in the mandibular fossa. The mandible rotates anteriorly to maintain contact with the maxilla anteriorly (Tallgren 1972).

The loss of alveolar bone may expose neurovascular canals which needs to be considered when dentures are designed or other restorative work is done. For instance the proximity of the midline lingual canal to the planned implant site is pivotal when treatment options are considered (Oettlé et al. 2013). The influence of the dental pattern on the cortical thickness of the mandible has important implications in dentistry for extraction of teeth, placement of implants and sagittal split osteotomies. The internal structure of the mandible is also influenced by the loss of teeth due to changes in the forces of mastication (Schwartz-Dabney & Dechow, 2002).

To restore the parallelism of the biting surfaces, the mandible will be remodelled in time by increasing the angle of the mandible (Keen, 1945). The greatest increase in angle size occurred in females followed by male SAE, with almost no change in male SAA. It seemed that the mandibles of male SAA was the most resilient for changes in the morphology of the mandible. The greater dimensions of being male and prognathic could have provided some protective effect. The positive effects of aging and the wearing of dentures could have confounded these relationships to some degree but the wearing of dentures might have further accelerated the resorption process of the alveolar bone (Potgieter et al. 1983; Ceylan et al. 1998; Yanıkoğlu & Yılmaz 2008; Ozan et al. 2013). To be rehabilitative, dentures need to be designed with care. If the level of occlusal contact is too low, it will result in ongoing alveolar resorption, which will proceed until a proper free-way space has been re-established (Potgieter et al., 1983).

It was thought that the closer the molars to the masseter, the greater force they are able to withstand (Patriquin 2013). The effects were noticed in the greater cortical thickness lingually at the mental foramen *(Ling MF)* as compared to elsewhere. The cortical thickness lingually at the mental foramen *(Ling MF)* further increased in thickness with tooth loss in females. Cortical thickness at the gonion *(Gon)* increased in male SAE and female SAA. It seemed that the cortical bone closer to the masseter in the absence of molars increased in thickness to resist the forces of mastication. The cortical bone at the symphysis did not support the mechanical forces to such an extent and became thinner. It was preserved with the wear of dentures.

The chin area was not expected to be involved in the functional demands of the mandible (Patriquin 2013). However, the muscles of facial expression attaching to the chin were suggested to maintain the bone in edentulous individuals and may even assist progressively in mastication with tooth loss (Mercier & Lafontant 1979; Schieppati et al. 1989; Hanawa et al. 2008). Alveolar resorption and recession accompanying loss of teeth further contribute to the appearance of a more prominent chin (Parr, 2005).

8.4 Limitations of this study and unresolved issues

8.4.1 Study sample

Although the age distribution in all 12 sex-ancestry-dentition groups represented individuals from a wide age spectrum and representatives of all three dentition groups, there were differences between groups, particularly as far as age is concerned. The SAA group had few representatives in the younger age groups and female SAA had fewer representatives in the older age group. Dentition group 2 was scarce in SAE, especially females, and dentition group 1 and 2 was scarce in SAA, especially females. Very few SAE had third molars as opposed to SAA.

Although these differences were taken into account and corrected for in statistical analyses, it was not possible to correct for the effect of tooth loss with time on the mandible. The effects of tooth loss only becomes evident over a period of time. Furthermore it was not known when teeth were lost or whether dentures were worn.

It is understandable that a young person with dentition group 0 will not show all the effects of tooth loss on the mandible as compared to someone who, for example lived 60 years without teeth. An older person may display extensive changes because of tooth loss or not, depending on the duration of tooth loss before death. Aging and tooth loss will for this reason always be inseparable.

Retrospective studies involving the scans of patients where the dental history may be ascertained may add value to this research, for instance, the long term effect of wearing dentures. Furthermore it will be ideal to execute a study on individuals with a full dentition including third molars to compare the aging process between ancestry group and sex. This seems to be a theoretical possibility only in SAE and/or throughout the adult life span, as the absence of third molars or other teeth by birth or by dental pathology seem inevitable. Including more individuals of the younger ages in SAE and older ages in female SAA with a greater representation of each dentition group in each sex-ancestry group seems to be a viable possibility over time.

8.4.2 Shape analysis of bony morphological traits

Bony prominences on the gonial area and chin have been evaluated by several researchers according to a visual scoring system (De Villiers 1968; Acsádi et al.1970; Ferembach et al., 1980; St Hoyme & İşcan 1989; Novotny et al., 1993; Buikstra et al. 1994; Parr, 2005; Walker 2008; White et al. 2011). More recently with 3D surface laser scans of the chin ancestral differences in the bony projections were demonstrated (Garvin & Ruff, 2012).

In this study geometric morphometrics were used to quantify and facilitate shape analyses of variations. Landmarks were identified and marked on the 3D reconstructed images. Landmarks were marked on points on the base of the gonial area or chin and then on the crests of either the gonial eversion or the pogonion and bilaterally on the crests of the mental tubercles.

Significant differences were noted between sexes and ancestry groups in the gonial area with gnathion as well as between ancestry groups in the chin shape. The chin shape and gonial area, though, did not achieve good discriminant values. It was thought that more distinction between sexes and ancestry groups would be possible if surface scanning techniques were used. Surface scanning would enable the incorporation of the slope variation between the base landmark and the crest of the bony projection in the analysis between sexes and ancestry groups. Apart from size differences, the extent of demarcation or definition of the bony projections defined by the variation of the slope, were thought to have given the impression of prominence of a bony projection reported by other researchers to be sex and ancestry group discriminant (De Villiers 1968; Acsádi et al.1970; Ferembach et al., 1980; St Hoyme & İşcan 1989; Novotny et al., 1993; Buikstra et al. 1994; Parr, 2005; Walker 2008; White et al. 2011; Garvin & Ruff, 2012). Different interpretations of prominence of a bony projection could have implied the discrepancies between results (Garvin & Ruff 2012).

8.4.3 Cortical bone thickness

Interobserver correlations for cortical thickness measurements were disappointing. A possibility for the poor interobserver performance could have been misinterpretation of the localisation of the measurement. Very small deviations from the site chosen, might have caused variations in these delicate measurements of a spatial resolution of 0.080 mm^3. The electronic slices, could have for instance, transected the irregular translucencies in the cortical bone or have missed it by a fraction of a mm causing a measurement to be substantially different.

Newer micro-focus X-ray imaging techniques with a spatial resolution of 0.003 mm^3, may provide more focused images for more accurate and repeatable measurements of the cortical thicknesses, if the chosen sites can be precisely and repeatedly identified (Hoffman & De Beer 2012b).

8.5 Future possibilities and developments

8.5.1 Micro-focus X-ray tomography (Micro-CT)

The cortical thicknesses were measured on CBCT created images. Cortical bone thickness measurements are also performed on CBCT scans in dentistry, because of a low radiation risk to the patient, despite the relatively high resolution (Scarfe et al. 2006; Humphries 2007; Loubele et al. 2007; Quereshy et al. 2008; Baumgaertel & Hans 2009; Razavi et al. 2010; Ozan et al. 2013). CBCT images have a higher spatial resolution of 0,080 mm^3 as compared to CT of 0.6 mm^2 (Mueller 1998; De Beer 2005; de Beer et al. 2013).

With the development and acquisition of Micro-focus X-ray tomography (Micro-CT) at a workable distance from a modern growing skeletal collection such as the Pretoria Bone Collection, new opportunities may arise to improve and expand studies on the cortical bone thickness and enhance the findings of this study (L'Abbé et al. 2005; Hoffman & De Beer 2012). Micro-CT is a new research modality delivering even higher resolution images with a spatial resolution of 0.003 mm^3 which could provide more accurate and repeatable measurements of the cortical thicknesses (Hoffman & De Beer 2012). This technique is both non-invasive and non-destructive (Hoffman & De Beer 2012; Marciano et al. 2012) and employs multi-slice X-ray images that are digitally reassembled into a 3D image. Due to the smaller voxel size of Micro-CT, higher resolution results than that of cone-beam computed tomography are obtained (Marciano et al. 2012).

8.5.2 Surface scanners

Already in 1991, Vannier et al. (1991) modified Cencit's optical noncontact 3D range surface digitiser as a facial surface scanner for planning and evaluation of facial plastic surgery procedures. A light beam is shone on the surface by a projector and a profile is captured by the camera image sensor array (Vannier et al. 1991).

Since then many improvements have been made to surface scanners. Recently Garvin and Ruff (2012) reported on the NextEngine Desktop 3D Scanner (model 2020i) to evaluate morphometric features on the chin and brow. This scanner delivers high resolution optical laser scans (0.0635 mm^3 resolution) for accurate and repeatable results. The chin region could be evaluated using objectively defined landmarks and planes. Semilandmarks along transects were used for more detailed morphometric analyses. Results suggested significant effects of both sex and ancestry on chin morphologies consistent with traditional qualitative descriptions (Garvin & Ruff 2012).

Future studies on the chin by surface scanning is envisaged to be able to enhance the results of this study. Landmarks on the CBCT derived 3D models did not provide enough information between landmarks to define the bony prominences as described in the scoring systems for morphological features of the chin and gonial area.

Aging features may present in various patterns and at different rates due to culture and lifestyle (environment, gender, nutrition, working conditions) and biology (sex, ancestry or genetics, trauma and disease), as well as features such as frequency and extent of facial expressions (Acsádi, 1970, Albert et al., 2007, Martinez-Maza et al., 2013). Aging, therefore, is characterised not so much by the number of years that have passed since birth but, instead, by the condition of the individual as influenced by the before-mentioned factors (Acsádi and Nemeskéri, 1970, Albert et al., 2007).

Vertical facial heights seem to increase more in individuals with healthy dentitions from the average age of 25 to 45 years. The vertical development of the dentition is not limited to teeth eruption alone, but also involves their investing tissues, including the alveolar bone. It could be that minor periosteal bone deposition during a long period may be sufficiently great to cause vertical face changes (Forsberg et al., 1991).

8.6 Summary

The impact of tooth loss on the morphology of the mandible included the following: Much of the alveolar bone was lost. Female SAE presented with the greatest relationships and this may have been associated with the longer possible duration of tooth loss and/or aggravated by the use of dentures and/or a more sensitive mandibular structure as opposed to the other sex-ancestry groups. The bicondylar breadth and angle of the mandible increased minimally presumably to restore the parallelism of the biting surfaces after loss of alveolar bone. Recovering of the mandibular angle to some extent becoming more upright, was noted in those with a longer possible duration of tooth loss. An intervention such as dentures could have been implicated in this finding. Other dimensions of the corpus and ramus decreased, possibly initiated by a reduction in bite force the remaining dentition could withstand. Male SAA seemed to have been resilient to the changes in the morphology of the mandible with tooth loss.

A general decrease in inferior cortical bone thicknesses (at the gonion, inferiorly at the mental foramen and at the midline) could be explained by a decrease in bite force accompanying tooth loss. Cortical thicknesses in the midline in females, however, was relatively spared and could have been associated with denture wearing. The relative sparing of the lingual cortical thickness at the mental foramen, were thought to be attributed to larger strains with the loss of the alveolar process in regions able to respond with a deposition of bone.

The changes in the dimensions of the mandible with age was of a small magnitude but collectively they provided for a better understanding of the ongoing changes with age. Linear dimensions on the external mandibular morphology were maintained. This was thought to be due to the effect of ongoing action of the muscles of mastication on the growth of the mandible despite tooth loss. A slight increase in the maximum projective length of the mandible and minimum ramus breadth were most often observed in males and SAA. Females, SAA more so than SAE, presented with a slight decrease in the mandibular angle (more upright ramus) with age. This effect was more pronounced in the group with dentition that is functioning efficiently. Conversely measurements of cortical bone thickness decreased slightly and could have been influenced by dental loss. SAE had stronger correlations between age and the shape of the chin and gonial areas than SAA.

Small differences noted in the individual linear dimensions, when considered collectively, potentiated the discrimination between sex and ancestry groups. Discriminant analyses taking tooth loss into account generally improved the discriminant abilities between sexes and ancestry groups.

Regarding ancestry estimations on the mandible, SAA exhibited statistically greater dimensions than SAE, apart from maximum ramus height and bigonial breadth where greater dimensions in SAE were found than SAA, as associated with the orthognathic mandible. These differences were not confounded by age or tooth loss. Discriminant analysis of cumulative linear measurements delivered 90.4% and even higher within dentition groups. Although discriminant analysis delivered poor results between ancestry groups for chin shape and gonial area, significant differences existed. In SAE the mental tubercles were more prominent (square chin), while in SAA the pogonion protruded further (pointed chin). The gonial area in SAA was broad and more convex posteriorly and the gonial eversion more prominent and the ramus more upright than in SAE. A wider range of shape variation was seen in SAA than in SAE. Cortical thickness at the gonion was statistically significantly thicker in SAE than in SAA.

Regarding sex estimations on the mandible: All linear measurements were smaller in females than in males and apart from bicondylar breadth were statistically significant. In general these dimensions were reduced further with loss of teeth accentuating sex differences. Sex predictions on individual measurements increased by approximately 10% when dentition group was taken into account. Cumulative discriminant analysis on all linear measurements approached 90% or higher within dentition group.

The shape variations of the gonial area included the greater posterior convexity in males than in females. The gonial eversion, was situated more superior and posterior to the gonion. In SAA a greater variation in shape in males was observed, possibly on account of a greater growth trajectory in males. In SAE, a greater variability in shape in females due to a greater time period for change of the morphology without teeth was noted. Discriminant qualities for identification of sex in SAA for the gonial area with or without gnathion increased to between 80 and 90% within dentition groups. Shape variation for chin shape was not significant among the sexes. The ramus flexure of the posterior border of the ramus was not considered useful for sex estimation.

More detailed analysis of chin shape and gonial area may be possible when areas between traditional landmarks are evaluated so that more subtle variations may be perceived and this may improve the discriminant ability. With the development and acquisition of newer technologies such as Micro CT, higher accuracy cortical bone thickness determinations may be performed on dry mandibles. Retrospective records of patients with known dental history may enlighten findings regarding cortical bone thickness.

Chapter 9: CONCLUSION

This study brought together clinical and scientific truths regarding the effect of dental loss and senescence on the morphology of the mandible. From this, the following findings were made:

1. The impact of tooth loss on the morphology of the mandible included the following:

1.1 In general the dimensions of the mandible decreased and was most noticeable in female SAE. The bicondylar breadth and angle of the mandible increased minimally presumably to restore the parallelism of the biting surfaces.

1.2 Recovering of the mandibular angle to some extent, was noted in those with a longer possible duration of tooth loss.

1.3 A general decrease in the inf+erior cortical bone thicknesses was noted, but was relatively spared in the midline in females, which could implicate denture wearing. The lingual cortical thickness at the mental foramen was unaffected.

2. Changes with aging included the following:

2.1 External linear dimensions were maintained but the cortical bone thickness decreases slightly.

2.2 A slight increase in the maximum projective length of the mandible and minimum ramus breadth, most often observed in males and SAA, could be indicative that growth which potentiated function persisted throughout life.

2.3 Females, especially SAE and the group with dentition that is functioning efficiently presented with a slight decrease in the mandibular angle (more upright ramus).

2.4 SAE had stronger correlations between age and the shape of the chin and gonial areas.

3. Regarding ancestry estimations on the mandible:

3.1 SAA exhibited statistically greater dimensions, apart from maximum ramus height and bigonial breadth, where greater dimensions in SAE were found.

3.2 Discriminant analysis of cumulative linear measurements delivered 90.4% and even higher within dentition groups.

3.3 The shape of the chin and gonial area differed significantly between ancestry groups. In SAE the mental tubercles were more prominent (square chin) than in SAA, while in SAA the pogonion protruded further (pointed chin) than in SAE. The gonial area in SAA was broad and more convex posteriorly and the gonial eversion more prominent and the ramus more upright than in SAE. A wider range of shape variation was seen in SAA as compared to SAE.

3.4 Gonial cortical thickness was statistically significantly thicker in SAE than in SAA.

4. Regarding sex estimations on the mandible:

4.1 All linear measurements were smaller in females than in males. These dimensions often diminished further with loss of teeth accentuating sex differences. Cumulative discriminant analysis on all linear measurements approached 90% or higher within dentition group.

4.2 The shape variations of the gonial area included the greater posterior convexity in males. Shape variation for chin and the posterior border of the ramus were not considered useful for sex estimations

5. Future prospects:

5.1 Evaluation of the areas between traditional landmarks so that more subtle variations may be perceived, may improve the discriminant ability.

5.2 Higher accuracy cortical bone thickness determinations may be possible with Micro CT on dry mandibles.

5.3 Retrospective records of patients with known dental history may enlighten findings regarding cortical bone thickness.

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