Ancestral Variations in the Shape and Size of the Zygoma

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Abstract

The variable development of the zygoma, dictating its shape and size variations among ancestral groups, has important clinical implications and valuable anthropological and evolutionary inferences. The purpose of the study was to review the literature regarding the variations in the zygoma with ancestry. Ancestral variation in the zygoma reflects genetic variations because of genetic drift as well as natural selection and epigenetic changes to adapt to diet and climate variations with possible intensification by isolation. Prominence of the zygoma, zygomaxillary tuberosity, and malar tubercle have been associated with Eastern Asian populations in whom these features intensified. Prominence of the zygoma is also associated with groups from Eastern Europe and the rest of Asia. Diffusion of these traits occurred across the Behring Sea to the Arctic areas and to North and South America. The greatest zygomatic projections are exhibited in Arctic groups as an adaptation to extreme cold conditions, while Native South American groups also present with other features of facial robusticity. Groups from Australia, Malaysia, and Oceania show prominence of the zygoma to a certain extent, possibly because of archaic occupations by undifferentiated Southeast Asian populations. More recent interactions with Chinese groups might explain the prominent cheekbones noted in certain South African groups. Many deductions regarding evolutionary processes and diversifications of early groups have been made. Cognisance of these ancestral variations also have implications for forensic anthropological assessments as well as plastic and reconstructive surgery. More studies are needed to improve accuracy of forensic anthropological identification techniques.

INTRODUCTION

The variable prominence of the cheek, known as the zygoma, is largely attributable to the shape of the underlying zygomatic and maxillary bones (Enlow and Hans, 1996; Standring, 2008). The extent of the development of the zygoma and, therefore, its shape and size varies among ancestral groups and has important correlations with the morphology of other features of the face such as the orbit, nasal cavity and the mandible. Ancestral variations have been extensively researched and are thought to reflect subsistence, adaptation to climate, isolation and/or to historic contacts among human groups. Many deductions regarding evolutionary processes and diversifications of early groups have been made on the basis of shape and size variations of the zygoma.

The purpose of this study is to review the literature regarding the variations in gross morphology (shape and size) of the zygoma with ancestry. An overview is provided of the more commonly used craniometrics and traditional non-metric methodologies in studying variations of the zygoma. The processes involved in the development of these variations are explored, as well as the possible applications of this knowledge.

ANATOMY

Each zygomatic or malar bone forms the prominence of a cheek or widest part of the face. The body of the zygomatic bone is roughly quadrangular and has two processes: one to the frontal and the other to the temporal bone (Fig. 1) (Standring, 2008). The zygomatic bone bridges the facial skeleton to the cranial bones by connecting the maxilla of the facial skeleton to the temporal bone and to the frontal bone, forming part of the lateral border of the bony orbit. The zygomatic arch is formed by the zygomatic process of the temporal bone posteriorly and the temporal process of the zygomatic bone anteriorly articulating at the zygomaticotemporal suture. The most prominent suture is the zygomaxillary suture between the zygoma and the maxilla (Fig. 2). The temporal fascia is attached to the frontal process and upper border of the zygomatic arch. The posteroinferior border is roughened for the attachment of the masseter muscle (Standring, 2008; Mounika and Yuvarajbabu, 2015).

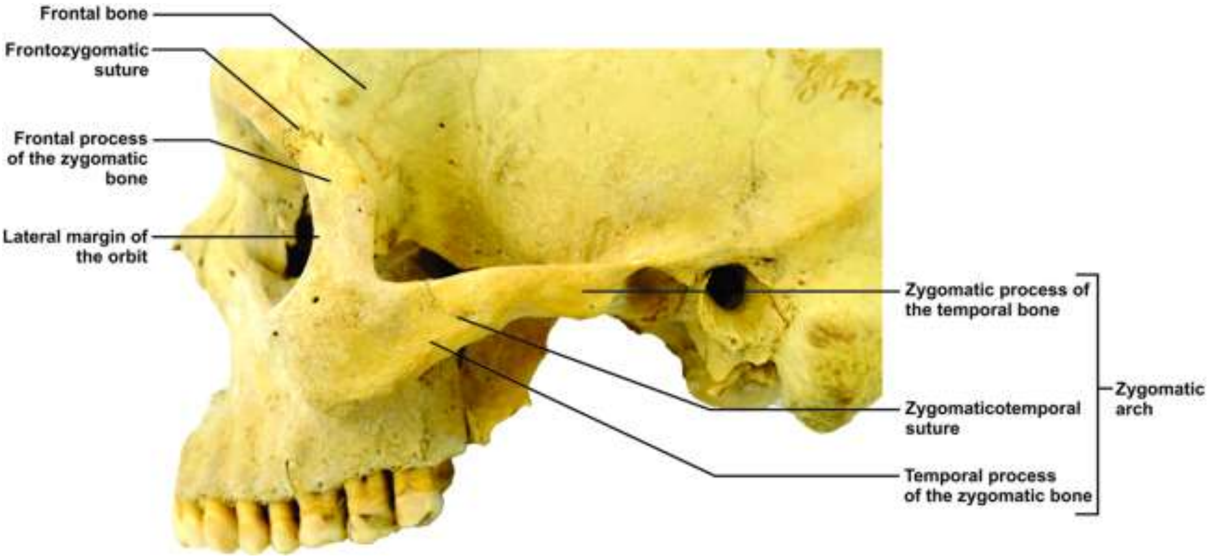

Figure 1. Bony landmarks on Skull in norma lateralis.

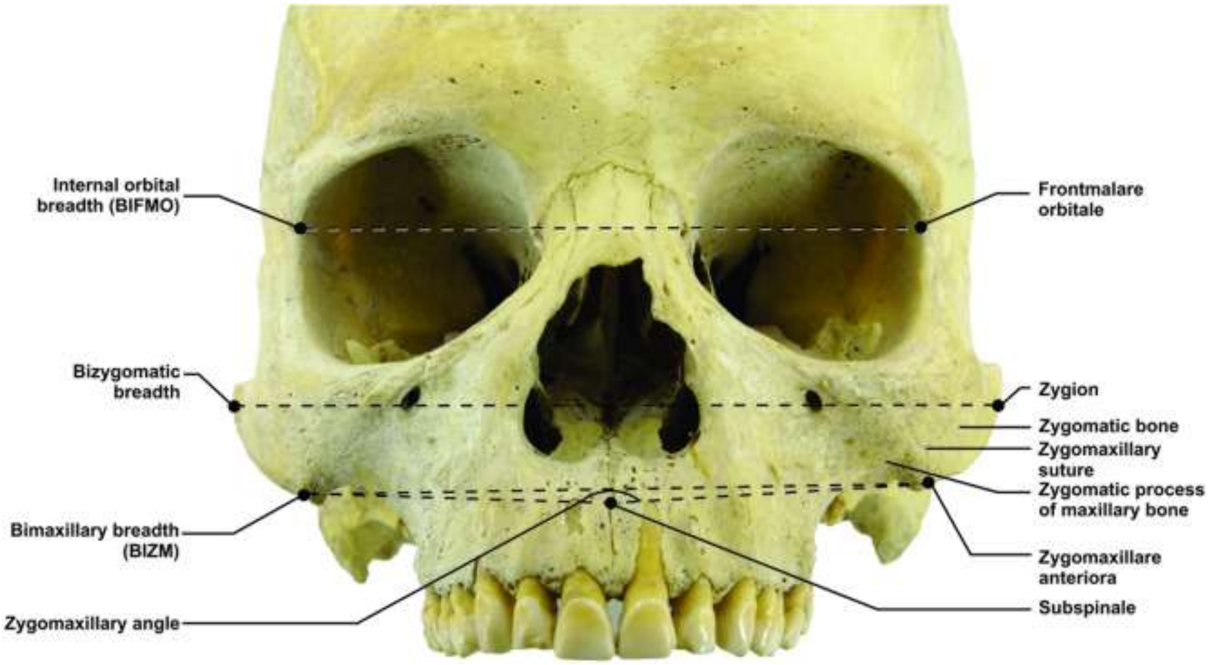

Figure 2. Landmarks and distances.

GROWTH

The zygomatic arch grows laterally and inferiorly along with all the other cranial structures by progressive deposition on the lateral-facing and downward-facing periosteal and endosteal surfaces, with resorption from the opposite cortical sides. The projecting malar area remodels posteriorly with continued deposition of new bone on its posterior side and resorption from its anterior side. As deposition exceeds resorption, the whole malar protuberance and zygomatic arch relocates posteriorly as it enlarges vertically. These deposition and resorption processes require adjustment within the -sutural connective tissue development. The separate zygomatic bone is displaced inferiorly in association with bone growth at the frontozygomatic suture and anteriorly in relation to growth at the zygomaticotemporal suture (Enlow and Hans, 1996). By the increase in size of the arches, the growing muscles attached to them are accommodated. Displacement is driven by the functional relationships established by the soft tissues that surround and interact with a given bone. So, although these bony features are said to be inherited separately, they do have an interaction with the growth of each other. Further displaced zygomatic arches, for instance, suggest a more developed and bulkier masseter (Gatliff, 1998; Ousley et al., 2003; Wilkinson and Rynn, 2012).

POSSIBLE FACTORS IMPLICATED IN ANCESTRAL VARIATION

Ancestral variation in facial morphology may be considered a reflection, among other things, of the geographic pattern of heterozygosities across human populations. Ramachandran et al. (2005) have shown that the geographic pattern of heterozygosities is in keeping with a serial-founder effect that starts at a single origin. Given this serial-founder effect, the relationship between genetic and geographic distances allows assessment of the proportion of genetic drift or natural selection involved in determining genetic variation. The fraction of the variation in heterozygosity across human populations that is explained by genetic drift is at least 76%–78%. Genetic drift is particularly important in isolated groups (Allendorf, 1983). For instance, isolation has been the reason proposed for the intensification of Asian features, which developed during the upper Paleolithic period in the archaic Asians. The “upper Paleolithic type of cheekbone” of the archaic Asians was transmitted to their descendants among whom it has become a fundamental ancestral characteristic (Oschinsky, 1962; Chen et al., 2011). The residual 22%–24% of genetic variation is generated by population-specific factors; e.g. natural selection (Ramachandran et al., 2005).

Natural selection does not only act on genetic variation alone, as epigenetic changes could underlie rapid adaptation of species in response to natural environmental fluctuations and then later change back a few generations, if needed (Cropley et al., 2012). Populations in different environments are exposed to different selective conditions, which could be expressed in the variation in the shape and size of the zygoma and include diet and climate variations and possible intensification by isolation.

Because the face takes longer to develop than the rest of the skull, external influences such as masticatory stresses have a longer interval to exert an effect on facial morphology compared to other cranial components (Freidline et al., 2015). Greater plasticity of the face is therefore possible compared to – for instance – the basicranium and the neurocranium. The face may be used to study micro-evolutionary processes presenting as morphological adaptations to a given environment (Oschinsky, 1962; Freidline et al., 2015).

Although morphological traits are individually inherited and facial bones may grow independently to some degree under the influence of localized factors, they have an interaction on the growth of each other and on the surrounding soft tissues and remains a functional whole throughout the course of development (Gatliff, 1998; Ousley et al., 2003; Novita, 2006; Wilkinson and Rynn, 2012). The research of Lahr and Wright (1996) as well as of Baab et al. (2010) on cranial robustness further supports this viewpoint. All craniofacial traits (including the zygomaxillary tuberosity and the zygomatic trigone), except the occipital torus area, were positively correlated with each other. Shape was significantly correlated with inter-population differences in robusticity.

Ancestral variation in the zygoma, therefore, not only reflects genetic drift and natural selection involving heterozygosities but also epigenetic changes to adapt to environmental factors including diet and climate, which may have intensified by isolation (Paschetta et al., 2010). Similarity of environmental factors cannot always predict morphology, as the duration of exposure and possible isolation as well as the underlying nature of the genetic drift and the epigenetic response might vary between groups.

Environmental factors influence the morphological traits of facial bones but it is unclear how climatic adaptations and variations in dietary or masticatory practices could account for variations among groups. In the sections to follow, these external influences on the shape and size of the zygoma are explored.

Masticatory stress

Masticatory loading in response to variations in hardness, toughness, and particle size in diet is thought to be a particularly important factor in the evolution of the face. Increased masticatory forces generally lead to an intensification of the overall robustness of the skull, an increase in facial size relative to total size and alteration in shape of craniofacial structures related to mastication (Paschetta et al., 2010).

As increased masticatory forces are generated through the need to process more mechanically resistant food stuffs, possible adaptations occur. These are: (1) overall enlarged and more anterior positioning of the temporalis and masseter muscles; (2) enlarged attachment sites of the masseter muscle on the zygomatic arch and of the temporalis muscle on the lateral side of the cranium; and (3) a larger cross-section of the infratemporal fossa for the temporalis muscle. The zygomatic bone becomes relatively larger and more laterally and vertically arched with a greater height and lateral projection of the zygomatic arches (Noback and Harvati, 2015). Examples of this extensive development of the zygoma noted in the facial morphology of the Inuit and the Fueguians are considered to result rather from biomechanical adaptations to hard chewing than climatic adaptations. The malleable response of the morphology of the face to masticatory stress during an individual's life and a selection process favoring craniofacial proportions that best respond to biomechanical stress may give rise to a prominent zygoma (Kato et al., 1997)..

In hunting and fishing societies, individuals tend to exhibit large and anteriorly placed masticatory muscles with relatively large attachment sites in the temporal fossa to enable greater masticatory forces. As the culture of gathering increases, the vertical height of the maxilla becomes shorter. The zygomatic arch becomes relatively wider anteriorly with large masseter muscle attachment sites. The dental arches become larger and more anteriorly placed, giving the face a wider and more prognathic appearance. Prognathism contributes to a lower mechanical advantage and the accompanying greater overall robusticity might indicate a way of dissipating high masticatory stress (Noback and Harvati, 2015).

Conversely, societies depending on agriculture and processed grains for their subsistence, present with relatively smaller and shorter and more posteriorly placed muscle attachments. The dental arch and the shorter zygomatic arch are placed closer to the temporomandibular joint, rendering the face more orthognathic. In this way the mechanical advantage is improved and the overall robusticity of the face is reduced. (Baab et al., 2010; Noback and Harvati, 2015).

Fishing increases and plant eating declines as latitudes increase. For this reason, the influence of diet is difficult to separate from cranial adaptations to climate (Noback and Harvati, 2015).

Cold

In the study by Hernández et al. (1997) the robusticity of the facial morphology of South American groups of the extreme south was ascribed to the cold climate and the associated masticatory stresses of diets in harsh environments. The projection of the zygoma was also noted, along with other robusticity features, in Arctic groups such as in the Inuit as well as in Scandinavian Nordics such as medieval islanders, Greenland vikings and Laplanders. The possibility exists that these traits may share a pattern of adaptation to extreme cold conditions; this possibility has been considered by other researchers as well (Oschinsky, 1962; Lahr, 1995). Facial shape in extreme cold-dwelling arctic populations was found to retain a climatic, rather than a genetic, signature among 13 globally distributed human populations (Harvati and Weaver, 2006). Bernal and colleagues (2006) provided more support that the cold climate was responsible for the robusticity of the face, mediated by endocrine changes, rather than the retention of ancestral characters. In their study, earlier samples from south Patagonia showed less development of robust features than later populations.

Researchers have hypothesised that the projection of the zygoma provides a surface area that is smaller and less exposed under cold circumstances, but this hypothesis was found to be incorrect in a study by Friess et al. (2002), who analyzed the volume-to-surface-area ratios of the skull. An increase in relative facial surface area with decreasing temperature was found; therefore, the model for craniofacial cold adaptations could not be confirmed (Friess et al., 2002).

Another possible explanation for the prominence of the zygoma associated with cold conditions might be attributed to differences in nasal cavity shape and size. Variations of the nasal cavity are an adaptation for heating and humidifying inspired air. For instance, the Inuit with distinctive Asian features exhibit a greater and longer postnatal growth and development trajectory of the midface. During growth, as the nasal cavity increases, the lateral nasal walls grow outwards and the zygomatic bone moves posteriorly and enlarges vertically and laterally (Freidline et al., 2015).

METRIC AND NON-METRIC FEATURES OF THE ZYGOMA

Ancestral estimations are usually based on morphological traits or a combination of measurements (Ousley et al., 2009; L'Abbé et al., 2011). The evaluation of the malar area is complicated by a lack of anthropometric or cephalometric landmarks along its complex three-dimensional curvature (Bettens et al., 2002). Landmarks and possible measurements and indices incorporating distances between landmarks are listed in Table 1 and illustrated in Figure 2.

Table 1. Landmarks, measurements, and indices to describe the variations of the Zygoma

Landmark	Description	Measurement	Index
Zygomaxillare anterior(a) (Hanihara, 2000)/Zygomaxillare (İşcan and Steyn, 2013)	The limit of the attachment of the masseter muscle on the zygomaxillary suture (Hanihara, 2000) corresponding to lowest point on the zygomaxilary suture (İşcan and Steyn, 2013)	Bimaxillary breadth (zygomaxillary chord between the zygomaxillaria anteriora) (Hanihara, 2000) or middle facial breadth (BIZM) (Kato et al., 1997) Zygomaxillary subtense (distance from the subspinale to the zygomaxillary chord) (Hanihara, 2000) Z*ygomaxillary angle* (the angle at subspinale formed by the right and left lines from subspinale to each zygomaxillare anterior) (Hanihara, 2000;Wang et al., 2002)	Facial flatness index or zygomaxillary index (Hanihara, 2000)
Zygion (Farkas, 1994; Wilkinson and Rynn, 2012; İşcan and Steyn, 2013)	A point on the maximum lateral outer curvature of the zygoma	Bizygomatic/Interzygomatic breadth (Kato et al., 1997) or face width (Fernandes, 2004;Gatliff, 1998;İşcan and Steyn, 2013;Novita, 2006b)	Face shape index
Subspinale (Hanihara, 2000)	The deepest point below the anterior nasal spine on profile (Hanihara, 2000)	Zygomaxillary subtense and angle (Hanihara, 2000;Wang et al., 2002)	Facial flatness index or zygomaxillary index (Hanihara, 2000)
Frontmalare orbitale (Kato et al., 1997)	Most medial point on the zygomaticofrontal sutures (Kato et al., 1997)	The internal orbital facial breadth (BIFMO: bifrontomalaria orbitalia) (Kato et al., 1997)	BIFMO < BIZM when the zygoma is projecting The index: (BIZM/BIFMO x 100) (Kato et al., 1997)

The facial flatness index or zygomaxillary index is calculated where the zygomaxillary chord between the zygomaxillaria anteriora (bimaxillary breadth) is the denominator and the numerator is the zygomaxillary subtense (distance from the subspinale). The smaller the value (the greater the bimaxillary breadth or/and the smaller the zygomaxillary subtense) the greater the flatness and the relatively greater the zygomatic projection (Hanihara, 2000). The zygomaxillary angle (the angle at subspinale formed by the right and left lines from subspinale to each zygomaxillare anterior) measures the facial flatness at the subspinale relative to the bimaxillary diameter: the higher the angle, the flatter the maxillary region in this respect (Hanihara, 2000). Kato et al. (1997) compared the relationship of the internal orbital facial breadth and middle facial breadth as an Asian trait among populations around the world. In this relationship the middle facial breadth, which reflected the maxillary bone form and especially the elongated zygomatic process of the maxilla, was generally greater in Asian crania than the internal orbital facial breadth (Chen et al., 2011). This relationship was regarded useful and effective to discriminate Asian crania from European and African crania (Kato et al., 1997).

As shape and size features of cranial robusticity are correlated, the widely used bizygomatic breadth may provide some information regarding the degree of development of the zygoma among both broadly ancestral and more narrowly defined population groups (Lahr and Wright, 1996).

Mean bizygomatic distances of males are represented on the map (Fig. 3) and are tabulated according to size in Table 2. Distances ranged from 125.10 mm to 147.50 mm. From the map, population groups from African and European ancestry presented with the smallest measurements. The values rose slightly in Eastern Europe and in the Middle East. The greatest measurements were found, as expected, in Inner Mongolians, Thais, Japanese and Azerbaijanis. Higher than expected values were found among North American Whites (137.10 mm), as well as in North American Blacks (138.70 mm). Although many factors may be responsible for the greater than expected bizygomatic breadths noted in North Americans, the possibility of admixture needs to be considered. The bizygomatic distance was also wider in Kenyan’s of 140.20 mm and lower than expected values in Inuit of 138.70 mm.

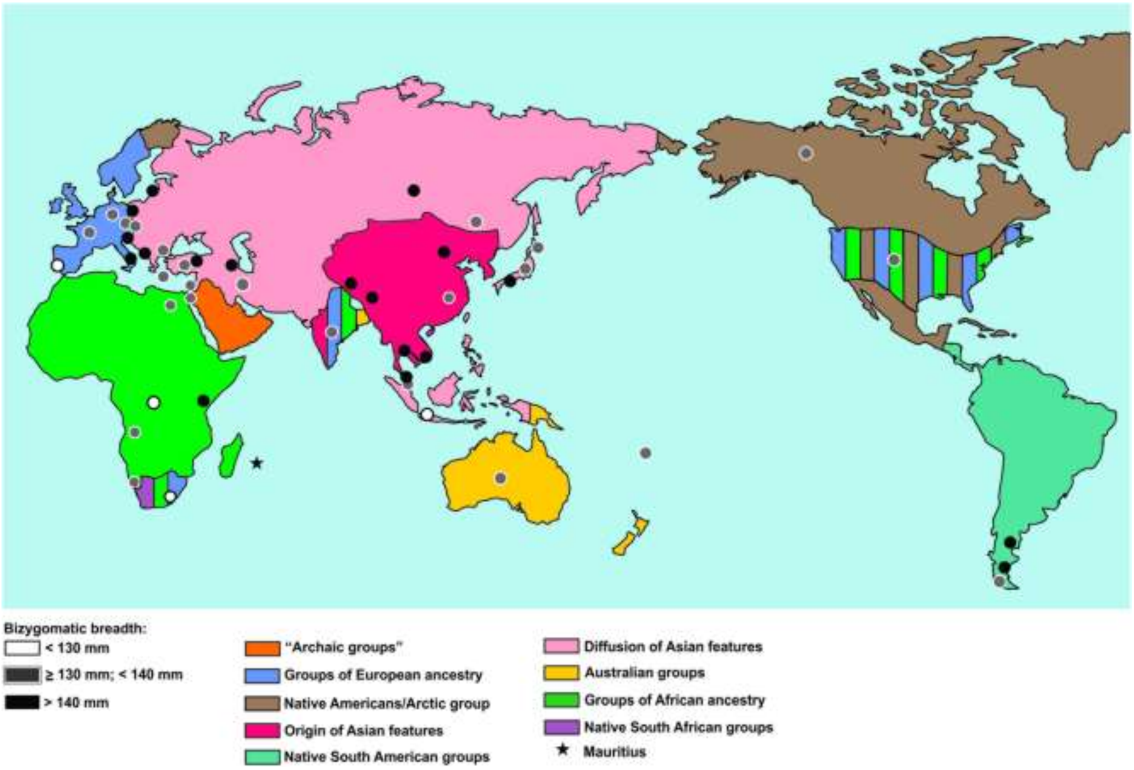

Figure 3. World map indicating demic groups with bizygomatic breadths.

Table 2. Mean bizygomatic breadths in males among groups (mm)

Portuguese (Farkas et al., 2005)	125.10
Sub-Saharan Africans (Lahr, 1995)	126.50
Greek (Farkas et al., 2005)	128.60
Southeast Asians (Lahr, 1995)	128.80
Zulu (Farkas et al., 2005)	129.30
Rwala Bedouins (Shanklin, 1935)	130.00
Australians (Lahr, 1995)	130.10
Creatan (Kranioti et al., 2008)	130.54
!Kung San from Namibia (Winkler and Kirchengast, 2014)	131.50
Europeans (Lahr, 1995)	132.30
Northern Chinese (Wu et al., 2007)	132.60
German (Farkas et al., 2005)	133.20
Tonga (Farkas et al., 2005) and East Asians (Lahr, 1995)	133.30

Japanese:Ainu (Hanihara, 1990)	133.80
Japanese:Tohoku (Hanihara, 1990)	133.90
Japanese:Kanto (Hanihara, 1990)	134.20
Slovak (Farkas et al., 2005)	134.70
Czech (Farkas et al., 2005)	134.90
Japanese: Kinki (Hanihara, 1990)	134.50
Indian (Farkas et al., 2005)	135.80
Slovenian (Farkas et al., 2005)	136.20
Americans of European ancestry (Farkas et al., 2005)	137.10
Yahgan-Alacaluf (Lahr, 1995)	137.80
Turkish (Kayis and Özok, 1991)	138.00
Iranian (Farkas et al., 2005)	138.40
Americans of African ancestry (Farkas et al., 2005) and Eskimo (Lahr, 1995)	138.70
Bulgarian (Farkas et al., 2005)	139.50
Egyptian and Angolan (Farkas et al., 2005)	139.80
Kenyan (Winkler and Kirchengast, 2014)	140.20
Turkish (Farkas et al., 2005)	140.40
Croatian (Farkas et al., 2005)	140.70
Patagonians (Lahr, 1995) and Russian (Farkas et al., 2005)	141.20
Hungarian (Farkas et al., 2005)	142.10
Polish (Farkas et al., 2005)	142.60
Central Tibetians (Bhalla, 1976)	142.80
Eastern Tibetians (Bhalla, 1976)	144.30
Italian (Farkas et al., 2005) and Ona (Lahr, 1995)	143.20
Sarakatani: Balkan area (Poulianos, 1980)	143.60
Indo-Mauritian population (Agnihotri et al., 2011)	143.90
Vietnamese (Farkas et al., 2005)	144.00
Singaporean Chinese males (Farkas et al., 2005)	144.60
Sarakatani: Pundus area (Poulianos, 1980)	145.00
Inner Mongolians (Buxton, 1926)	146.06
Thai (Farkas et al., 2005)	147.10
Japanese (Farkas et al., 2005)	147.20
Azerbaijan (Farkas et al., 2005)	147.50

Unfortunately, the widely used zygion points on either side defining the maximum interzygomatic or bizygomatic distance do not correspond to the areas of maximum malar prominence. With the scoring of non-metric trait features an attempt is made to quantify the projection of the zygoma as well as the degree of protrusion of the zygomaxillary tuberosity in an anterior direction on the anterior facial plane (Bettens et al., 2002). Two methods have been employed and are described in Table 3 and illustrated in figures 4 and 5. The extent of growth and development of the zygoma at the zygomaxillary suture will influence its angulation. The shape of this suture is therefore an indirect means to assess the direction of growth and degree of projection of the zygoma (see Table 3 and Fig. 6).

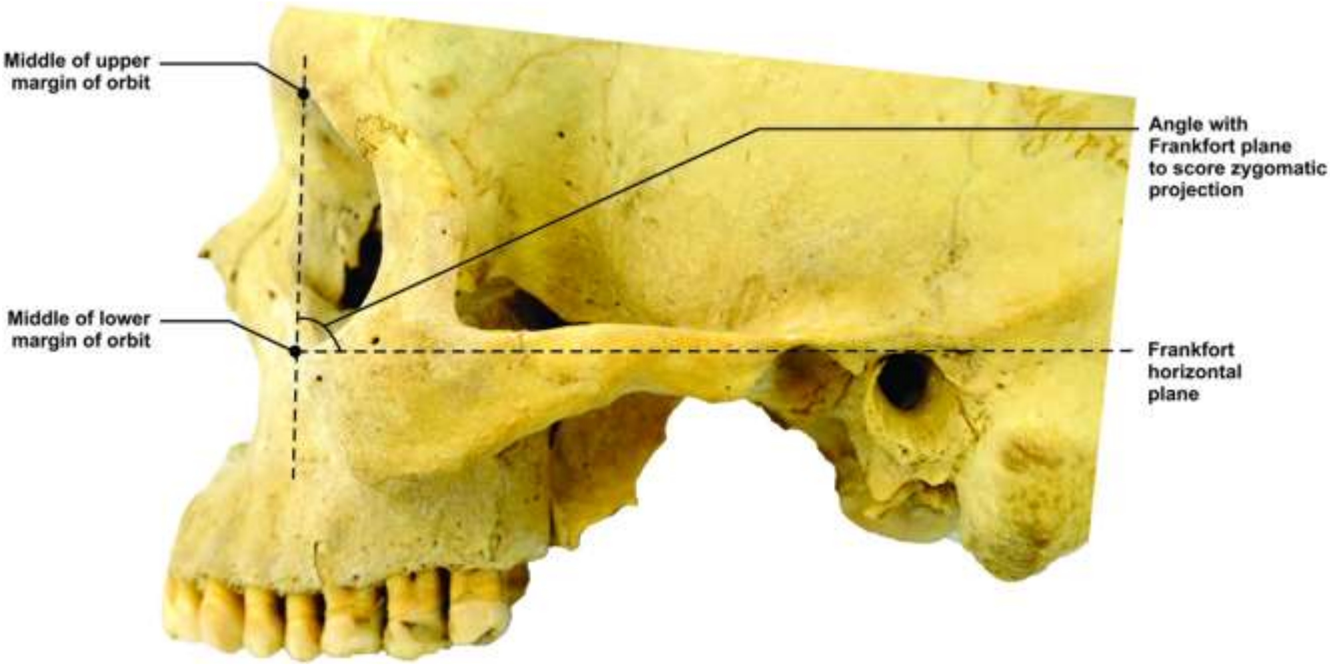

Figure 4. Vitek's scoring technique for the projecting zygoma.

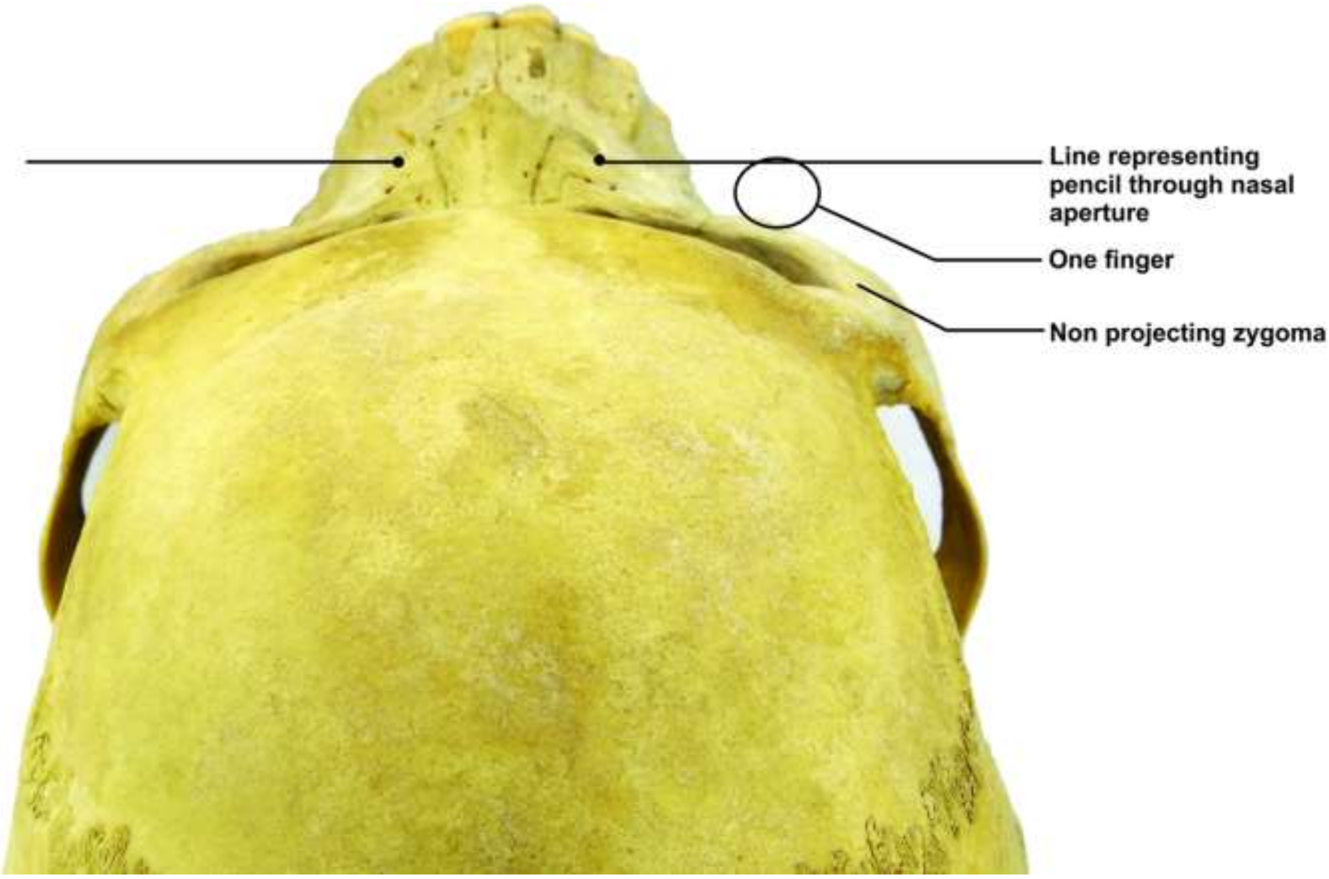

Figure 5. Bass's method for scoring the Zygomatic projection.

Figure 6. Bony landmarks on Skull in norma frontalis.

Table 3. Non-metric traits involving the zygoma

Trait	Scoring technique
Zygomatic projection: Vitek's method (Fig. 4) adapted from (Buikstra and Ubelaker, 1994): A line is dropped from the middle of the upper margin of the orbit to the middle of the lower margin that produces an angle with the Frankfort plane (Vitek, 2012). Bass's method (Fig. 5): The skull is held at the occipital region and a pencil placed across the nasal aperture (L'Abbé et al., 2011).	Vitek's method. Three grades: retreating, vertical and projecting Bass's method. Three grades: non-projecting, retreating and projecting zygoma
Zygomaxillary tuberosity: An elevation on the malar surface between its orbital and free margin (Oschinsky, 1962; Baab et al., 2010).	Four grades range from smooth to a distinct ridge
Malar (Whitnall's) tubercle: Attachment for the lateral palpebral ligament on the orbital aspect of the frontal process of the zygomatic bone, within the orbital opening and about 1 cm below the frontozygomatic suture (Standring, 2008). A tubercle is associated with an acute angle between the frontal and zygomatic bone (Baab et al., 2010).	Three grades: no angle and tubercle absent; obtuse angle with smooth tubercle; acute angle with tubercle and possible cresting
Malar tubercle: A caudally projecting tubercle located on the inferior margin of the maxilla and zygomatic bone in the region of the zygomaxillary suture (Hefner, 2009; L'Abbé et al., 2011 and Vitek, 2012)	Assessments are based on the protrusion beyond the ruler's edge. Flour grades: no projection; 2 mm or less; 2-4 mm; 4 mm or more (Vitek, 2012)
Zygomaxillary suture shape: Hefner, 2009; L'Abbé et al., 2011; İşcan and Steyn, 2013	This suture has three variants: smooth; angled or s-shaped (Hefner, 2009)
Zygomatic trigone: The lateral portion of the supraorbital area formed by the zygomatic process of the frontal bone (Baab et al., 2010)	Four grades ranging from small to pronounced

Some conflicting descriptions of the malar tubercle exist (İşcan and Steyn, 2013) (Table 3 and Fig. 6). According to Hefner (2009), a malar tubercle may appear on the maxilla, the zygomatic bone, or on the zygomaxillary suture. By this definition of the malar tubercle the zygomaxillary tuberosity will be included and the Whitnall's tubercle excluded (Hefner, 2009). For the sake of clarity, the zygomaxillary tuberosity will be defined according to Oschinsky (1962) and Baab et al. (2010) as a projection on the malar surface of the zygoma between its orbital and free margin. The other two types of malar tubercle will be referred to as either the “Whitnall’s tubercle” or just “malar tubercle” when they are located on the inferior border of the maxilla or zygomatic bone close to the zygomaxillary suture.

The zygomaxillary tuberosity, zygomatic trigone and malar tubercle have also been considered as robusticity characters. Cranial robusticity and cranial size are closely related (Oschinsky, 1962; Lahr and Wright, 1996; Baab et al., 2010). Larger skulls are associated with greater development of bony projections (cranial superstructures). These bony projections are correlated in their expression and do not develop as independent phylogenetic traits (Lahr and Wright, 1996).

ANCESTRAL VARIATIONS

Not all authors agree that geographical variation in the form of the facial skeleton is of great significance (Relethford, 1994; Novita, 2006). However, as prominence of the zygomatic arch has been especially associated with Asian groups, its presence has been attributed to the spread of this feature by early contacts between groups of people (Ngcongco, 1979; Lahr, 1995; Harris, 2003; Kamal and Rathee, 2015). Variations in the morphology of the zygoma in the three ancestral groups generally described – Asian, European and African – are provided in this section. In this literature review, terminology is in accordance with Sauer (1992) where “Groups of European ancestry” includes Europeans, North Africans, Middle Easterners and Indians (Gatliff, 1998; Hamilton, 2008; Gibson, 2010; Blumenfeld, 2011; Kamal and Rathee, 2015), as well as “Groups of African ancestry” and “Australian groups” (see Fig. 3). The area where the Asian features were thought to have intensified is referred to as “Origin of Asian features” (Oschinsky, 1962; Hanihara, 2000). Groups exhibiting features of both European and Asian ancestry were termed “Diffusion of Asian features” and included Eastern Europeans and Russians. Special reference is made in the literature to groups thought to represent “Archaic groups” (Shanklin, 1935; Poulianos, 1980) as well as “Native Americans/Arctic” (Kato et al., 1997; Kozintsev et al., 1999), “Native South Americans” (Lahr, 1995) and certain “Native South African groups” (Winkler and Kirchengast, 2014; Freidline et al., 2015).

Asian ancestral groups

Groups of Asian ancestry are highly variable and comprise a large geographical area whose populations include: East Asians, North East Asians, Native Americans, Inuit and Arctic groups (Huxley, 1870). High cheek bones or a projecting zygoma is strongly associated with Asians. The projecting cheek bones render the appearance of a flat face as well as narrow and oblique eyes (Hamilton, 2008). Very flat faces in the transverse plane are the most common condition in Eastern Asians, especially in North East Asians (Japan and Koreans) (Hanihara, 2000). The zygomatic bones protrude not only laterally and forward, but they also project inferiorly, below the inferior border of the maxilla (Baba and Narasaki, 1991; Hwang et al., 1997; Gatliff, 1998; Kim et al., 2001; Bettens et al., 2002; Gibson, 2010; Blumenfeld, 2011; Chen et al., 2011). In the study done by Kato et al. (1997), Native American groups and most of the Asian groups presented with an internal orbital facial breadth that was smaller than the middle facial breadth and reflected the greater extent of the projection of the zygoma.

When the skulls of Asian ancestry groups are viewed in the norma basalis the zygo-maxillary junction appears as a 90-degree angle, but this angle is beaklike in Arctic groups (Novita, 2006; Chen et al., 2011), while a more obtuse zygomaxillary angle has been reported in Chinese, indicative of an even greater extent of facial flatness (Wang et al., 2002). In addition, midfaces exhibit more anteriorly situated frontal processes of the zygomatic bones and more or less flat nasal bones (Hanihara, 2000). In more than half of cases the zygomaxillary suture is s-shaped in Asians and Native Americans (Hefner, 2009), while others have found it to be more angled (Chen et al., 2011). Native Americans further have a stronger expression of the zygomaxillary tuberosity, zygomatic trigone and malar tubercle than the other groups studied (Baab et al., 2010)

According to Hefner (2009), the malar tubercle is less often absent in Asians than in other groups. Among Arctic groups the zygomaxillary tuberosity may project in such an extreme manner that two fossae are created on the zygomatic process of the maxilla. In other Asian groups, the zygomaxillary tuberosity projects to a lesser degree forward and the mentioned fossae are usually absent. In the Greenland Vikings the plane for scoring the zygomatic projection is extremely oblique compared to the Frankfort plane as is typical of groups of European ancestry (see Fig. 4) (Oschinsky, 1962; Novita, 2006; Chen et al., 2011). An important general feature of Asian groups is that the zygomatic process of the maxilla is considerably long relative to the length of the zygomatic arch and is the cause of the relative lack of obliquity of the zygomatic arch (Novita, 2006).

Groups from Australia, Malaysia and the Oceanians (Hamilton, 2008) show Asian features to a certain degree (Lahr, 1995), and it is postulated that an undifferentiated Southeast Asian population may have occupied Australia in at least two stages, or possibly more (Lahr, 1995). Australian groups have been reported to have on average zygomatic bones that are medium to large and are visible from above (Gatliff, 1998). However, these groups present with a high value of the zygomaxillary index (less flat faces) (Hanihara, 2000) and have a weaker expression of the zygomaxillary tuberosity (Baab et al., 2010).

The Southwest Hispanics, comprising mainly Mexicans, presented with a prominent anterior malar projection and tubercles as well as a wide frontal process of the zygomatic bone (İşcan and Steyn, 2013). In the South African "Coloured" group shown to be 32%-43% Khoesan, 20%- 36% Bantu-speaking Africans, 21%- 28% European and 9%-11% Asian genetically (De Wit et al., 2010), 73% presented with projecting zygomatic bones and smooth zygomaxillary suture shape whereas the malar tubercles were incipient in 55% of cases (L'Abbé et al. 2011).

The native South American groups presented with a unique and very robust morphology that is more extreme than the typical Asian pattern. Accentuated facial flatness was noted, along with vertically and horizontally enlarged zygomatic bones (Kato et al., 1997). The degree of robusticity seems to be related to long-standing isolation and more pronounced use and development of the muscles of mastication (Lahr, 1995). Differential retention of levels of robusticity is thought to be the reason for the long-observed relationships between the natives of South America and Australian aborigines. The various levels of robusticity should not be interpreted as the degree of phylogenetic correspondence (Lahr, 1995).

European ancestral groups

Population groups of European ancestry include groups from Europe (Northern, Central and Southern), North Africa, Middle Easterners and Indians, as well as groups from other continents such as Americans and South Africans of European origin. Skulls from European ancestry have narrower faces with retracted zygomatic bones and zygomatic sutures curving backwards (Gatliff, 1998; Gibson, 2010; Blumenfeld, 2011). In the European groups studied by Kato and co-workers, (1997), the internal-orbital facial breadth was always larger than the middle-facial breadth, indicating the absence of a projection of the zygoma. In the white South African group, the malar tubercle was absent in 80% of cases in the study carried out by L'Abbé et al. (2011), and in 51.4% of white North Americans (Hefner, 2009).

The angulation of the zygomaxillary suture varied greatly between groups studied (Hefner, 2009; Blumenfeld, 2011; L'Abbé et al., 2011; İşcan and Steyn, 2013; Freidline et al., 2015). In the South African White group the zygomaxillary suture was angled in 49%, smooth in 49% and s-shaped in 2% of cases (L'Abbé et al., 2011) and in the group consisting mainly of American Whites it was found to be smooth in 1.5%, angled in 37%, s-shaped in 42.2% and 19.3% had a variable position for the greatest lateral projection (Hefner, 2009). Vitek (2012) found that American Whites show a greater variability in the appearance of zygomaxillary suture, with a slightly higher tendency of being angled than the more gracile groups (e.g., South European). These last-mentioned groups display a more anteriorly positioned zygomatic projection (Blumenfeld, 2011).

Prominent cheekbones are associated with Eastern European groups, but this was not evident from the internal-orbital facial breadth and middle-facial breadth relationship (Swan, 1975; Vonderach, 2006). Populations of Eastern Europe contain a substantial proportion of Asian admixture that was thought to be associated with invasions from Central Asia. According to blood groups and morphological studies, however, it seems that Eastern Europe and the Near East clusters together as opposed to the Northern and Central Asia (Swan, 1975).

Populations from the Far East Siberia or Russia present with craniometric traits for facial flatness. Cranial evidence suggests that people of Far East Siberia possess features of European ancestry (Kozintsev et al., 1999). Another group from

Asia presenting with European features are the Indians. A less developed zygomatic trigone of the frontal bone (slight to medium) was present in 96.61% of cases of Indian population groups and was thought to reflect archaic European features (Kamal and Rathee, 2015).

African ancestral groups

Groups of African ancestry include all populations south of the Sahara as well as black North Americans. African groups present with retracted zygomatic bones (L'Abbé et al., 2011). Apart from North African groups, the other African groups studied by Kato et al. (1997) presented with a greater internal-orbital facial breadth than middle-facial breadth. The African ancestral group has a weaker expression of the zygomaxillary tuberosity than the European or Asian groups (Baab et al., 2010; Vitek, 2012). The South African black group presented with an absent malar tubercle in 37% and an incipient malar tubercle in 56% of cases (L'Abbé et al., 2011) and in the African group studied by Hefner (2009) the malar tubercle was absent in 50.5% of cases or incipient in 27.5% of cases.

In the assessment of the shape of the zygomaxillary suture, the American Black group and the Black South African sample presented more commonly with a smooth suture rather than either angled or s-shaped. In Hefner's (2009) study, however, the African group had a greater chance of an angled or s-shaped suture than a smooth suture (Hefner, 2009; L'Abbé et al., 2011; Vitek, 2012). However, the overlap among groups was considerable and could not be used to separate groups (L'Abbé et al., 2011).

Some Sub-Saharan Africans share similar characteristics with eastern Asians for flat faces and projecting zygomaxillary regions (Hanihara, 2000). The Khoesan sample, more specifically, expresses more anterolaterally projecting zygomatic bones although smaller facial breadths and heights are reported than for Kenyan tribes (Winkler and Kirchengast, 2014; Freidline et al., 2015). Not only must the Khoesan of the Cape area but also the Tswana of Southern Africa or Sothos be regarded differently to other African groups (Huxley, 1870). Tswana, especially those living in the southern regions tend to present with some Asian features and in particular with prominent cheek-bones, which was thought to be as a result of inter-marriage with Khoesan groups. The Tswana or 'Sotho-Tswana' at the very earliest stage of their history shared a number of cultural characteristics that distinguished them from other Bantu speakers of southern Africa (Ngcongco, 1979).

Chinese admixture with South Africans is a real possibility, as China had a highly advanced ship-building capacity and historic evidence of interaction before 1433 exists for these two populations (Harris, 2003). During the monsoon, a great number of Chinese gathered on the eastern shores of Africa for up to six months during which time possible interbreeding with the Tswana/Sotho people could have occurred. Morphologically the high cheek bones may be evidence of this admixture in the Khoesan and Tswana groups (Harvati and Weaver, 2006). The appearance of high cheek bones is not reflected in a greater bizygomatic breadth. This discrepancy between findings could be explained by possible growth retardation as all head measurements are smaller in the Khoesan as compared to other black African groups with the exception of the intercanthic diameter (Winkler and Kirchengast, 2014).

IMPORTANT APPLICATIONS

Knowledge of the variation in the morphology of the zygoma among ancestral groups such as European, Asian and African is important in forensic anthropological assessments, facial reconstructions plastic surgery, and it can give insights into the diversifications of archaic groups.

Forensic anthropological assessments

When unidentified human remains are found without known family relationships, and it is not possible to identify the person with more conventional methods such as DNA comparison, other forensic anthropological assessments such as forensic facial reconstruction are often used (Cavanagh, 2011; Ruedell and Schlager, 2013). Craniofacial reconstruction, superimposition, and presumptive identification standards all require an estimation of ancestry. The ancestry-associated features of the zygoma are also implicated in the evaluation of unknown remains for repatriation purposes, as required by some authorities (Ousley et al., 2003).

Morphological features/traits of the skull – especially the midfacial region, including the features of the zygoma – are often thought to enable distinction between groups (Swan, 1975; Katz and Suchey, 1989; Fernandes, 2004; Novita, 2006; Hefner, 2009; Prieels, 2011; Vitek, 2012; İşcan and Steyn, 2013; Ruedell and Schlager, 2013; Kamal and Rathee, 2015). This is contrary to the viewpoint that the cranial base possesses a stronger signal of phylogeny and population history than the facial bones, which would more likely be a reflection of climate variations (Harvati and Weaver, 2006). Osteometric standards of the skull, for instance those reflecting the projection of the zygoma, are also used and considered population specific (Majumder et al., 1990; Kamal and Rathee, 2015). Features relating to facial flatness, such as the degree of zygomatic projection, have often been selected for studies of interpopulation variation (Hanihara, 2000).

During the facial reconstruction process, the degree of anterior undulation of the zygoma/cheekbones also dictates the tissue depth that needs to be considered. The greater the projection anteriorly of the zygoma the greater the tissue depth. (Wilkinson and Rynn, 2012). The prominence of the zygomas will also affect the general appearance of the eyes (Gatliff, 1998). High cheek bones often accompany slanting/oblique eyes (Vonderach, 2006).

Surgical implications

Anthropometric studies of various population groups form an integral part of craniofacial surgery and syndromology. Standards based on population group data are desirable because these standards reflect the potentially different patterns of craniofacial growth resulting from inherent variations among groups (Novita, 2006; Kamal and Rathee, 2015). In reconstructive surgery, the ancestral associated features of the zygoma need to be taken into account when reconstructing the face, as indicated in trauma or cancer situations (Ruedell and Schlager, 2013). As aesthetic procedures evolve along with the growing number of indications, a detailed understanding of the complex anatomy of the face is crucial in the selection and performance of the appropriate surgical procedure (Tan et al., 2011).

Cognisance of the ancestral variations of the shape and size of the zygoma is of importance for aesthetic zygomatic arch recontouring. The prominence of the zygomatic arch has a profound influence on facial form and aesthetics. The zygomatic arch augmentation for instance is a popular procedure in Western culture, whereas zygomatic arch reduction is considered in Eastern groups (Hwang et al., 1997; Bettens et al., 2002; Yim et al., 2015). An overly projecting zygoma in Eastern cultures could give the impression of a life time of misfortune. A flattened zygoma on the other hand would imply cheerfulness and harmonious while in Western groups it could make the nose and chin appear more prominent and, therefore, overall more masculine (Hwang et al., 1997). If the zygomatic prominences are either too small or too large they may affect the aesthetic importance of the other prominences (i.e. the nose and the mandibular jawline) (Chen et al., 2011).

With aging and as the facial soft tissue shrinks, the temporal area and cheek depress, which results in an increased protrusion of the zygoma in Asians. When cosmetic procedures and face lifts are planned variations in the prominence of the zygoma need to be taken into account (Chen et al., 2011). Binder et al. (2002) devised a classification system for the zygoma and midfacial deficiencies to aid in the choice of implants and procedures: Type 1: midfacial fullness but insufficient malar development: a malar shell implant is used; Type 2: atrophy of the midfacial soft tissues seen in the aging patient with adequate malar development: submalar implants are used to fill these depressions; Type 3: atrophy of the midfacial soft tissues with little subcutaneous fat and an exceptionally prominent malar eminence: a second generation submalar implant is used to fill the midfacial hollow; Type 4: atrophy of the midfacial soft tissues and malar hypoplasia: a single implant must serve two purposes: to augment the deficient malar skeletal structure and the midfacial void (Binder et al., 2002). Caution and experience are still needed, as excessive midfacial elevation causes downward traction from the mouth, which results in traction on the lower eyelid (Binder, 2002).

Diversifications of archaic groups

Variation in the morphology of the zygoma among groups offers the possibility to study the origins and diversification of anatomically modern human populations. As prominence of the zygomatic arch has been associated with especially the archaic Asian groups and other populations of Central Asia, the distribution of this feature may be a reflection of early interactions between groups of people (eg. Ngcongco, 1979; Lahr, 1995; Harris, 2003; Chen et al., 2011; Singh, 2011; Kamal and Rathee, 2015). The prominence of for instance the zygoma and zygomaxillary tuberosity are considered diagnostic for certain Asian groups as these features are (1) not found outside the various populations in question, (2) consistent in their distribution and frequency over time and (3) there is no interruption of their presence in the geographical continuum (Oschinsky, 1962; Novita, 2006). Although these features are said to be inherited separately, a projecting zygoma contributes to the appearance of facial flatness which often is accompanied by slanting eyes and brachiocephaly (Hanihara, 2000; Ousley et al., 2003; Blumenfeld, 2011). In the literature the term “mongolian” is used in reference to the epicanthic eyelid fold linked to this bony relationship: “Epicanthic” refers to the downward folding of the eyelid crossing the inner canthus of the eye (Singh, 2011).

In general, all native Americans are considered to have an Asian ancestry. However, no consensus has been reached as to whether there exists a more recent common ancestor for native Americans and Asians (Kato et al., 1997; Ousley et al., 2003). The native Americans could be descendants of ancestral Asians, possibly from northern China, across the Bering land bridges, which connected Asia and America several times during the Pleistocene glaciations, the last episode occurring about 20,000 years ago (Kato et al., 1997; Kozintsev et al., 1999).

More recent information regarding the demographic history of native Americans is provided by Wang et al. (2007) from a large genetic study. As the geographic distance from the Bering Strait into the Americas increases, the correspondence to Siberians decreases, as well as the genetic diversity of the native Americans. These findings are consistent with the view that a single wave of migration was responsible for the genetic ancestry of the native American. Further reductions are noted when the heterozygosity of the western populations from South America is compared to the eastern populations. The inference is that native American populations might have used coastal routes during ancient migrations (Wang et al., 2007).

CONCLUSION

Significant variations in the size and shape of the zygoma among groups of people have been reported in more than a century of published literature. Asian features in extant populations involve the prominence of the cheekbone, the slanting of the eyes and often various other phenotypic characteristics that have been used extensively in evolutionary studies.

Various factors for the development of these traits, which are not entirely separable, have been proposed – such as genetic drift, selection, epigenetic changes, cold, diet and isolation. The presence of Asian features has further been implicated as evidence of archaic (eg. across the Bering Sea) and more recent interactions between people (eg. Khoesan and Chinese). Cognisance of the variations between ancestral groups also has implications for forensic anthropological assessments as well as plastic and reconstructive surgery.

Each metric and non-metric measurement considered, including geometric morphometrics, has revealed some aspect of the shape and size of the zygoma. As the zygomaxillary tuberosity/malar tubercle is the most constant feature of Asian populations, assessments revealing its shape and size seem to be the most valuable. In contrast, as robustness of which the prominent zygoma is a feature cannot be separated from size, absolute measurements of, for example, bizygomatic breadth, may also be of some value to assess the prominence of the cheekbone. Exceptions for this proposal would include Australian aborigines who demonstrate size reduction with the maintenance of robusticity and the Khoesan who presents with overall smaller dimensions regardless of the observed prominence of cheekbones.

Multiple modalities may provide a better overall morphological assessment of variation of the zygoma. Evaluation of other traits along with that of the zygoma may improve estimation of ancestry from the cranium (Blumenfeld, 2011).

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