Hacettepe University Graduate School Of Social Sciences
Department of Anthropology

HEADSHAPING IN ANATOLIA:
A QUALITATIVE AND QUANTITATIVE RESEARCH

Valentina D'AMICO

Ph.D. Dissertation

Ankara, 2023

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ETİK BEYAN

Bu çalışmadaki bütün bilgi ve belgeleri akademik kurallar çerçevesinde elde ettiğimi, görsel, işitsel ve yazılı tüm bilgi ve sonuçları bilimsel ahlak kurallarına uygun olarak sunduğumu, kullandığım verilerde herhangi bir tahrifat yapmadığımı, yararlandığım kaynaklara bilimsel normlara uygun olarak atıfta bulunduğumu, tezimin kaynak gösterilen durumlar dışında özgün olduğunu, **Prof. Dr. Yılmaz Selim ERDAL** danışmanlığında tarafımdan üretildiğini ve Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Yazım Yönergesine göre yazıldığını beyan ederim.

Valentina D'AMICO

to Giovanni…

To all the goals achieved together even though apart

AKNOWLEDGEMENT

I would like to express my deepest gratitude to my advisor Prof. Yılmaz Selim Erdal for supporting me not only during all my Ph. D Programme, in the Lab work, during the academic courses and archaeological excavations, but also for being a point of referment during all my university carrier, firstly as co-advisor of my MA thesis, then by welcoming me as a guest at the Biological Anthropology Department of Hacettepe University, the place in which he initiated me to this field of studies and transmitted all his love for this subject.

As head of the Anthropology Department, I want also to thank him for the chance to work at the Husbio_L where I have had the opportunity to improve my theoretical knowledge, to get access to one of the richest human skeletal collections of the world as well as to meet new friends.

I would like to sincerely thanks all the Professors of the Department, in particular Prof. Ömür Dilek Erdal for her support during the preparatory stage of the Proficiency Exam, Prof. Serpil Eroğlu Çelebi and Kameray Özdemir for their important contribution to my anthropological training as well as for their help and advice.

I would like to express my appreciation to Prof. Dr. Serpil Eroğlu Çelebi, Prof. Dr. Handan Üstündağ, Prof. Dr. Başak Boz, and Prof. Dr. Arzu Demirel as members of the Defence Committee for their precious contribution to the improvement of my thesis.

Special thanks to Prof. Marcella Frangipane and Prof. Francesca Balossi Restelli for the chance to analyse skeletal materials from the archaeological site of Arslantepe, and to the photographer Roberto Ceccacci for his help in the photographic documentation of the analysed sample.

I would like to extend my thanks to all my lab mates and especially to Dr. Öğr. Üyesi Melis Koruyucu, Arş. Gör. Demet Delibaş, Arş. Gör. Gamze Sönmez, Merve Göker, Megumi Tashiro and Mine Dürür, that have always support me not only from an academic point of view but also in times of difficulties and discouragement by making my life in Turkey more funny and lovely.

Finally, I want to immensely thank my mother, my father and especially my husband Giovanni, for being patient during these years of distance, for believing in me and in my abilities and for their support in any circumstance.

ABSTRACT

D'AMICO, Valentina. *Headshaping in Anatolia: A Qualitative and Quantitative Research*, Ph.D. Thesis, Ankara, 2023.

Several studies worldwide, by applying different methods, have investigated different aspects of intentional headshaping and, especially in the last decades, have tried to elaborate standardised quantitative analysis methods. Research in Anatolia instead, by morphoscopic approaches, have exclusively focused on severe cases of circular headshaping, mostly dated to the prehistoric periods, aiming at the identification of the most recurrent morphological cranial alterations as well as at suggesting shaping techniques or at hypothesizing reasons and meanings. Moreover, while almost all the existing studies have employed data of well-preserved skeletal materials from adult individuals, the fragmented status of the most ancient Anatolian skeletal remains as well as the presence of a high number of subadults for some chronological periods has led to propose an alternative approach for the investigation of this topic in this geographical context. In fact, although the high informative potentiality of subadult data, the incomplete cranial development of this age group makes quantitative investigations difficult. The present study, by the statistical analyses of metric and morphological data collected on both adults and subadults coming from ten different archaeological sites dated from the Neolithic to the Post-Medieval Age, has tried, for the first time, to identify morphological and metric alterations diagnostic of the different headshaping types identified in Anatolia as well as to shed light on the relationship between artificial cranial modification and the development of Wormian bones or metopism and pathological conditions such as craniosynostosis and Porotic Hyperostosis. Nevertheless, the most important contribution of the work is the elaboration of a quantitative method able to discriminate, with a high percentage of accuracy, between unmodified and circularly and tabularly shaped crania by the application, for the first time, of proportional metrics computed on data of both adults and subadults.

Keywords

Headshaping, Anatolia, method, craniometrics, morphology, non-metric traits, pathologies

ÖZET

D'AMICO, Valentina. *Anadolu'da Baş Biçimlendirmesi: Nitel ve Nicel Bir Araştirma,* Doktora Tezi, Ankara, 2023.

Dünya üzerinde birçok çalışma, farklı yöntemler uygulayarak, istemli kafa şekillendirmenin farklı yönlerini araştırmış ve özellikle son yıllarda, standartlaştırılmış nicel analiz yöntemlerini oluşturmaya çalışılmıştır. Anadolu'daki araştırmalar ise biçimsel gözlemlere dayanan yaklaşımlarla sadece en yaygın morfolojik kafatası değişikliklerini tanımlayarak, yaygın olarak tarih öncesi dönemlere ait belirgin yuvarlak kafa şekillendirmesi vakalarına odaklanmıştır. Bu çalışma ise uygulamanın nedenleri, anlamı ve baş şekillendirme tekniklerini belirlemeyi amaçlamaktadır. Ayrıca, şimdiye kadara yapılan çalışmaların neredeyse tamamı yetişkin bireylere ait iyi korunmuş kafatası verilerini kullanırken, eski Anadolu iskelet kalıntılarının parçalanmış durumu ve bazı kronolojik dönemler için çok sayıda çocuk iskeletin varlığı, bu konunun bu coğrafi bağlamda araştırılması için alternatif bir yaklaşım ihtiyaç duyulmuştur. Esasen, çocuklara ilişkin verilerinin ileri derecede bilgi sağlayacak potansiyel sahip olmasına rağmen, bu yaş grubunun kafatası gelişiminin tamamlanmamış olması, nicel araştırmaları güçlestirmektedir. Bu çalışma, Neolitik'ten Orta Çağ sonrasına kadar tarihlenen on farklı arkeolojik alandan gelen hem yetişkinler hem de çocuklar üzerine toplanan metrik ve morfolojik verilerin istatistiksel analizlerine dayanmaktadır. Morfolojik ve metrik değişikenlerle Anadolu'da tanımlanan farklı kafa şekillendirme tiplerinin tanısını koymakla kalmayıp, aynı zamanda ilk kez yapay kafatası değişiklikleri ile wormian kemiklerinin gelişimi, metopism, kraniosinostoz ve porotik hiperostoz gibi patolojik durumlar arasındaki ilişkiyi açıklamayı amaçlamaktadır. Bununla birlikte, bu çalışmanın en önemli katkısı, birbirleritle ilişkili metrik verilerden hesaplanan oransal verilerin ilk kez uygulanmasıyla, hem çocuklar hem de yetişkinleri içeren işlem görmemiş, yuvarlak ve yassılaşmış kafatası şekillendirmeleri yüksek bir doğruluk oranıyla ayırabilecek nicel bir yöntem geliştirilmesini hedeflemektedir.

Anahtar Sözcükler

Baş bicimlendirmesi, Anadolu, metod, kraniyometrik, morfoloji, metrik olmayan özellikler, patoloji

TABLE OF CONTENTS

ABBREVIATIONS

PC: Principal Component

PCA: Principal Component Analysis

CBL: Cranial breadth/length index

CHL: Cranial height/length index

CHB: Cranial height/breadth index

FBL: Frontal breadth/length index

FAC: Frontal arc/chord index

PAC: Parietal arc/chord index

PLABL: Pterion-lambda/Asterion-bregma length

OBL: Occipital breadth/length index

OAC: Occipital arc/chord index

OIAC: Obelion-inion arc/chord index

TABLES LIST

FIGURES LIST

GRAPH LIST

INTRODUCTION

Among different cultures and in different historical periods, for several reasons, humans have temporarily and permanently decorated and even modified their bodies (Garve et al., 2017; Stone, 2012; Ortner, 2003; Flower, 1881). Manipulation of the human body represents the perception of this latter as media by which to construct forms of individual/social identity and group membership as well as differentiation.

When temporary forms of body decoration such as body paintings, henna, jewellery, or traditional dresses, are no longer perceived satisfactory for the purpose of body embellishment or even to reflect inherited forms of social identity, permanent forms of body modification such as scarring, circumcision, foot binding, shaping of chest, neck, teeth, or head, and even severing of body parts are preferred (P. Gerszten & E. Gerszten, 1995). Tiesler (1999) defined body modification as the alteration of body physiognomy. Magitot (1885) even talked about ethnic mutilation. Body modification and/or mutilation, due to their high visual impact, may be considered as markers and symbolic means of communication that go beyond the individual sphere and that are rather related with the need of validation of already-given forms of social identity (Joyce, 2005). Differences in types of body modification firstly depend on their degree of intentionality and durability (Tiesler & Oliva, 2010). Intentional modification of the shape of the head, due to its highly visual impact as well as its very early practice (immediately after birth) lends itself well to transmit and strengthen already-constructed forms of social identity.

Since prehistory it has been thought that the head is the place of the mind, the locus of the thought, the centre of life and the most important part of the human body. At the same time, it has been considered as a long-lasting body-component that best reflects personality, identity and even the genetic makeup of a person. Ethnographic research, historical documents, archaeological findings, and anthropological investigations confirm its importance both in vivo and post-mortem (Bonogofsky, 2011). Examples of post-mortem treatments of the skull such as trepanation, skull removal, decoration and caches, and in vivo manipulation of the head such as mutilation, scalping and intentional cranial modification are known from different geographical contexts and chronological periods (Tiesler, 2014; Croucher, 2012; Bonogofsky, 2011; Ortner, 2003; Aufderheide et al., 1998; Dingwall, 1931).

Morphology of the human being is shaped by both genetic and environmental factors (Larsen, 2015; Lasker & Harrison, 1995; Hauser & De Stefano, 1989; Susanne, 1975). This feature allows the body to be plastic and flexible and thus easily deformable under particular conditions during the ontogenetic development (Tiesler, 2014). The human skull can be shaped under different circumstances such as developmental anomalies (Barners, 2012; Ridgway & Weiner, 2004), secondary pathological conditions (Waldron, 2009; Mann & Hunt, 2005; Ortner, 2003; Aufderheide et al., 1998), childbirth, intrauterine and postnatal positional conditions (Graham & Sanchez-Lara, 2015; Bronfin, 2001) and cultural practices (Tiesler, 2014; Dingwall, 1931) such as intentional headshaping. This latter, most commonly known with the name of intentional cranial deformation, represents one of the most ancient and worldwide practiced, other than investigated, form of body shaping (Dingwall, 1931).

CHAPTER 1
CONCEPTUAL AND THEORETICAL BACKGROUND

1.1. HISTORY OF WORLDWIDE ANTHROPOLOGICAL STUDIES ON INTENTIONAL HEADSHAPING

The earliest report on intentional headshaping is attributed to Hippocrates and dated back to around B.C 400 (Tubbs et al., 2006). In “Liber Aeribus Aquis et Locis”, Hippocrates defined as Macrocephales people living in the coast of the Black Sea in the current region of Crimea (as cited in P. Gerszten & E. Gerszten, 1995, para. 4) characterized by headshaping achieved by both manual moulding and the application of bands and other deforming devices (Falkenburger, 1938; Gosse, 1835). Herodotus (ca. B.C 450), Apollonius Rhodios (B.C 295-215) and Pliny the Younger (ca. 25 A.D) called them “makrones”, Strabo instead (B.C ca. 63) “makrokephaloi” (as cited by P. Gerszten & E. Gerszten, 1995, para. 4). In 1557, Girolamo Cordano compared various methods for the investigation of intentional headshaping (as cited by P. Gerszten & E. Gerszten, 1995, para. 5). Nevertheless, it is only in the 19th century that studies on the topic began, especially in the New World where the number of examples was very high (Tiesler, 2014). In 1815, Virey wrote about children affected by intentional headshaping (as cited by P. Gerszten & E. Gerszten, 1995, para. 5). In 1839, Morton, in his work “Crania Americana”, although without providing any classification, proposed a description of the main morphological traits characterizing the skulls of forty Indian tribes from both North and South America, with special attention to shaped crania of Peruvians, Charibs, Natchez, and from Oregon. He distinguished four types of skulls: cuneiform fronto-occipital, symmetric elongated fronto-sincipito-parietal, irregularly compressed and dilated, and quadrangular. Years later, Gosse (1855) published the first detailed essay on the topic by expanding Morton’s classification by farther 12 headshaping types. According to the researcher (Gosse, 1855), together with a certain degree of heritability, changes in the shape of the head could be explained by considering the effects of cradle boarding. In 1875, Broca (as cited by Lambert, 1979, p. 51; Falkenburger, 1938, p. 2) distinguished five different forms of intentional headshaping (simple, annular, frontal simple, frontal elevated and frontal tabular) based on the type of shaping device. Topinard (1879), in “Ethnic Deformities of the Skull", shifts his attention to the ethnic aspect of this practice by identifying four headshaping types: simple occipital, frontal simple, fronto-occipital and fronto-sincipitooccipito-parietal. The last two forms were further divided into three groups: elongated, intermediate, and erect. In “Elements of General Anthropology", the same researcher (Topinard, 1879) added a fifth group, the “miscellaneous”, that included cases not easily fitting with the other types (as cited by P. Gerszten & E. Gerszten, 1995, para. 6; as cited by Falkenburger, 1938, p. 2). In 1880, Magitot provided a more elaborated classification system based on applied shaping apparati and geographical distribution. He distinguished frontal, occipital, fronto-occipital, nasoparietal or mongoloid, lateral or fronto-parietal, fronto-sincipito parietal, fronto-sincipito occipital, quadrangular, circular, or spherical and annular intentional headshaping. In 1890, Boas proposed a classification system based on the names of the North American Indian tribes Cowichan, Ghinock and Koskimo. While the first two groups were representative of erect intentional headshaping or posterior flattening, the latter instead was circularly shaped (as cited by Falkenburger, 1938, p. 3). In 1892, Virchow, in his work “Crania Ethnica Americana", classified three forms of artificial headshaping: hypsicephales that could be brachycephalic or not according to the applied shaping techniques (bands or boards) and chamaecephales that in turn could be divided into two large groups, one with a shortened occipital caused by the application of small boards, the other instead with an elongated occiput achieved by the application of bandages (as cited by Falkenburger, 1938, p. 3). At the beginning of the 1900s, Delisle (1902) refused Gosse’s theory and stated that intentional headshaping could not be inherited. In 1912, Hrdlička (as cited by Falkenburger, 1938, p. 3), simplified the previous classification systems by distinguishing just two types of headshaping: fronto-occipital (flat head) and circumferential (Macrocephaly or Aymara type). The studies conducted by Dembo and Imbelloni represent one of the most important contributions to the history of anthropological investigations on intentional headshaping in South America. According to Imbelloni (1928), who was the first to use geometric and trigonometric techniques, different headshaping types are the product of well-defined deforming apparati and as such not exclusively distinguishable according to cranial morphology. Based on shaping devices, two main headshaping types may be identified: tabular and orbicular or symmetric. Tabular type included oblique fronto-occipital modification obtained by boards fixed to the head of the babies, and erect subtype caused by the long-lasting dorsal decubitus of the babies on a flat surface. Orbicular or symmetric headshaping instead was the result of the application of bandages or caps (Imbelloni, 1928, 1925). In 1931, Dingwall published the work “Deformation: A Contribution to the Study of Ethnic Mutilations”, the most complete review on intentional headshaping that describes in detail headshaping features, procedures, apparati and geographic distribution. Similarly to Imbelloni, although by using a different nomenclature, Falkenburger (1938) distinguished two types and two subtypes of intentional headshaping: antero-posterior and circular straight and oblique. Intermediate types were identified as well. According to the scholar, differences in headshaping types depend on both headshaping processes and the presence of skull deformities. In 1939, Stewart identified the practice of intentional circular headshaping in the regions of the Mississippi Valley. According to the researcher (Stewart, 1939), in this geographical area, circular headshaping was not the result of the exclusive application of bandages, rather of bandages and boards, that was why it was named pseudo-circular. In 1942, Neumann proposed a classification system based on the morphology of skulls coming from different regions of the Eastern America. Six headshaping types were distinguished: obelionic, lambdoid, occipital, bifronto-occipital, fronto-parieto-occipital, fronto-vertical occipital, and parallelo-fronto-occipital. Their chronology and association with specific archaeological contexts were investigated as well. The link between headshaping and ethnic cultures reached the highest expression with Weiss. The scholar (Weiss, 1958), in his work “Cultural Osteology", distinguished different types of Peruvian intentional headshaping not only according to the employed modifying devices (cradle and bandages) and the morphological characteristics of the skulls but also by referring to their geographical distribution and their associated material culture. He suggested (Weiss, 1958) that, while headshaping obtained by means of cradles was widespread among coastal populations, that performed by the application of bandages instead was mostly common among inland groups. The same author also provided a strictly morphological description of circular headshaping for specific Peruvian cultural periods. After 1960, Romano studied examples of intentional headshaping from Central America by applying a morphological and craniometric method ('cranio-trigonometry') (as cited by Tiesler, 2014, p. 69). Compared to the classification proposed by Imbelloni (1928, 1925), and Falkenburger (1938), Romano provided general information on the cranial shaping process, types, and techniques (as cited by Tiesler, 2014, p. 69). In 1987, Munizaga (1987) based on the classification systems of Imbelloni (1928, 1925), Stewart (1939), and Weiss (1958), published a work in which tabular, circular and pseudo circular headshaping were distinguished according to both applied deforming devices and head morphology.

The development of statistical multivariate analyses as well as of X-rays images, represented a new phase in this field of studies. Moreover, after the beginning of the 21st century, the application of 3D geometric morphometric methods provided significant contributions to the traditional approaches by maximally reducing observer errors. Nevertheless, analyses based exclusively on morphoscopic methods and shaping apparati are known until nowadays (Tiesler, 2014; Lorentz 2010; Bautista Martínez & Romano Pacheco, 2001; Buikstra & Ubelaker, 1994).

1.2. HEADSHAPING: INTENTIONAL AND UNINTENTIONAL

The process of head shaping depends on various factors, in primis, circumstances producing the alteration of the cranial shape and applied devices (Lorentz, 2009). According to the circumstances, infants' skulls can be subjected to forms of intentional or unintentional headshaping. The border line between the two forms is very feeble. In fact, in some instances, although the purpose of shaping the head is not primary such as in the case of therapeutic treatments and cultural practices related to the care of the babies, the obtained effects are well accepted and aesthetically appreciated (Dingwall, 1931).

Intentional headshaping represents a form of cultural body modification, necessarily performed by others, whose results, under specific way and time of performance, can be permanent and irreversible (Tiesler, 2014; Lorentz, 2010, 2009; Dingwall, 1931). Forms of unintentional head-shape modification instead are consequences of natural circumstances such as genetic, congenital not hereditary, postural, or pathological conditions.

1.2.1. Intentional Headshaping

Moss (1958) defined intentional headshaping as a distortion of the normal vectors of the neurocranium growth caused by the effects of external forces. Tiesler (Tiesler, 2014) instead interpreted this process as a ‘dynamic interaction between culturally induced extrinsic mechanical stresses and intrinsic compensatory forces, which redirect head expansion’ (p. 34). Since the skull is a matrix of functional components affecting each other, both intrinsic and extrinsic forces acting on one portion of the neurocranium can be transmitted to all the other portions via dura mater and sutures. Thus, beyond neurocranium, secondary changes can also be observed in basicranium and splanchnocranium (Moss, 1958). Nevertheless, although several studies have been conducted on secondary basicranial and facial changes (Cottin et al. 2017; Ketoff et al. 2017; Ferros et al. 2016; Ferros et al. 2015; Boston et al. 2015; Khonsari et al. 2013; Jiménez et al. 2012; Cocilovo et al. 2010; Roos, Ubelaker 2009; Rhode, Arriaza 2006; Ogura et al. 2006; Kohn et al. 1993; Cheverud et al. 1992; Cheverud, Midkiff 1992; Antón 1989; Schendel et al. 1980; Mcneill & Newton 1965; Björk & Björk 1964; Moss, 1958; Oetteking 1924), a wide consensus on the relationship between headshaping and cranial components has not been achieved yet. According to Moss (1958), osteological neurocranial changes are mainly associated with the encephalic mass reshaping. In fact, shaping forces firstly influence the direction of the neural growth in turn affecting the development of the cranial bones. Hence, although the growth of the brain size is not affected, its direction changes.

Intentional headshaping can be obtained by manual moulding (FitzSimmons et al., 1998; Hasluck, 1947; Dingwall, 1931), cradling, or by the application of shaping devices such as bandages, headdresses, boards, stones, barks, pads, and strings (Munizaga, 1987; Dingwall, 1931). It is generally practiced immediately after birth for about six months/one year or more (Tiesler, 2014; Dingwall, 1931; Imbelloni, 1928). Ethnographic (FitzSimmons 1998; Hasluck, 1947; Dingwall, 1931) and coroplastic evidence (Tiesler, 2014; Lorentz, 2009, 2002) prove that it is generally practiced by women, most probably mothers or midwives. Its duration may depend on several factors such as desired degree of severity, techniques, applied devices, physical and behavioural development of the baby as well as on other cultural factors. For instance, in some cultures, headshaping duration depends on the ability of the baby to sit up or walk (Ewing, 1950; Hrdlikča, 1908). It has been stated that cranial growth slows down after the first two years of age when bones interlock at the sutures through bony accretion and absorption (Ridgway & Weiner, 2004). Hence, the effects of intentional headshaping may be permanent and irreversible only if practiced at least until that age, otherwise, its signs are removed by biological cranial growth forces (Tiesler, 2014; Lorentz, 2009).

Differences in headshaping types, variations within the same type and degree of severity depend on several factors such as type of deforming apparatus (Lambert, 1979), flexibility in material (Van Duijvenbode, 2012; Imbelloni, 1925), size, shape and number of applied devices (McKenzie & Popov, 2015; Aufderheide et al., 1998), thickness (Imbelloni, 1925), area of application (Erdal, 2013a; Van Duijvenbode, 2012; Aufderheide et al., 1998; Imbelloni, 1925), orientation (Antón, 1989; Imbelloni, 1925), amount and nature of the pressure (McKenzie & Popov, 2015; Erdal, 2013a; Tiesler, 2012; Tiesler & Oliva, 2010; Daems & Croucher, 2007; Aufderheide et al., 1998; Kohn et al., 1995; Lambert, 1979; Stewart, 1941), its duration (McKenzie & Popov, 2015; Tiesler, 2012; Van Duijvenbode, 2012; Tiesler & Oliva, 2010; Lambert, 1979; Ewing, 1950; Stewart, 1941; Dingwall, 1931), chronological age of the individual at the beginning of the headshaping process (Van Duijvenbode, 2012; Özbek, 2001; Lambert, 1979; Dingwall, 1931), presence of congenital or genetic morphological cranial anomalies that can accelerate or hinder the headshaping process (Lorentz, 2009), reaction of the bone tissue to external mechanical pressures and presence of diseases such as D vitamin deficiency (craniotabes) that can accelerate the shaping process (Waldron, 2009; Ortner, 2003; Aufderheide et al., 1998; Özbek, 1974b). It has been proposed that intentional headshaping resulting from the application of shaping apparati generally produces more evident effects than manual moulding (Trinkaus, 1982; Antón & Weinstein, 1999). According to Dingwall (1931) and also as reported by FitzSimmons (1998), manual shaping does not produce permanent results even if carried out for a long period. That is why additional modelling devices, such as bandages or headdresses have to be applied in order to maintain the obtained shape.

The most widely accepted headshaping types include tabular (also known as antero-posterior, although it represents just a subtype of tabular headshaping) and circular, also known as circumferential or annular. According to the orientation of the occipital plane in relation with facial (Moss, 1958) and Frankfurt planes (Munizaga, 1987; Imbelloni, 1928, 1925), both types have been in turn classified into oblique and vertical. Dembo and Imbelloni identified another type, the so-called mimetic, that shared a combination of morphological features from both circular and tabular types (as cited by Natahi et al., 2019, p. 419). Similarly, Stewart (1941) talked about a pseudo-circular type showing morphological characteristics typical of circular headshaping although performed by means of both bands and boards. Also according to Tiesler (2010, 2012), the Mayan Olmec type was a pseudo-circular erect modification performed by combining bandages with cradleboard.

1.2.1.1. Tabular Type

Tabular headshaping has been defined as the result of the application on the head of a baby of free boards or stones fastened by bands, leather straps (Weiss, 1958; Dingwall, 1931; Imbelloni, 1925) or strings (Tiesler, 2014; Lorentz, 2009), or of the persistent dorsal decubitus on cradleboards or cradles (Pomeroy et al., 2009; Kohn et al., 1995; Antón, 1989, Mason, 1889, 1887). Based on the employed devices, mechanical forces may originate from one or two sides so to affect either only the anterior (frontal) region, or only the posterior, or both (Kohn et al., 1995; Antón, 1989; Munizaga, 1987). Depending on the influenced cranial regions, shaped skulls may acquire different morphological features and inclinations (vertical or oblique). As stated by Imbelloni (1928, 1925), oblique and vertical subtypes result from the application of different modifying apparati: cradles for vertical headshaping and planks for the oblique one. According to the same researcher (1928, 1925), beyond shaping devices, the two subtypes may also be distinguished by considering the degree of inclination of posterior flattening in respect to the Frankfurt plane (ca. 120º for oblique headshaping, and less than 100º for the vertical one), the direction of the flattening plane (tangent to the *protuberantia occipitalis exterior* in oblique headshaping while parallel to the vertical basion-bregma plane in the vertical one) as well as the position of posterior flattening (vertically extended on the whole occipital surface in oblique headshaping, while affecting both lambdoid region and parietal occipital angles in the vertical one).

According to some scholars (Clark, 2013; Clark et al., 2007), only antero-posterior tabular headshaping may be accepted as intentional.

Frontal flattening is not a common type of tabular intentional headshaping. According to some scholars (Tiesler, 2014; Buikstra & Ubelaker 1994), its unintentional origin is related to daily activities performed at a very early age such as the use of tumplines. Nevertheless, its intentional practice is known among some American groups as well (Munizaga, 1987; Dingwall, 1931). For instance, the Choktah Indians employed small bags of sand to flatten the frontal (Mason, 1889). Morton (1839) described the practice of frontal flattening and the related antero-posterior elongation of the head among some Caribbean groups.

According to the position of the infant’s head on the cradleboard/cradle, posterior flattening may affect different cranial areas. Based on the angle of flattening in respect to the Frankfurt plane and on the landmarks nearest to the flattened area, three main headshaping subtypes have been distinguished: occipital, lambdoid and obelionic (Nelson & Madimenos, 2010; Buikstra & Ubelaker,1994; Stewart, 1937). Asymmetry (plagiocephaly), caused by the freedom of movement of the baby's head in supination and by his preferences in sleeping position, is generally characterizing of this headshaping type (Kohn et al., 1995; Weiss, 1958; Neumann, 1942; Imbelloni, 1925). Asymmetric flattening of the posterior portion of the skull produces the ipsilateral reduction in length and width of the skull and the contralateral increasing of the same measurements (Kohn et al., 1995). It is known that, among some cultures, accessory devices such as bandages were applied to fix the baby’s head to the cradle/cradleboard in order to obtain a more symmetric flattening (Dingwall, 1931). Occipital or plano-occipital flattening is characterized by the flattening of the area comprised between lambda (parietal) and the external occipital protuberance in such a way that all the occipital planum results affected by forming a roughly right angle (generally comprised between 75º and 90º) with the Frankfurt plane (Nelson & Madimenos, 2010; Munizaga, 1987). In lambdoid flattening, compression is visible at lambda or in the area immediately above it so that the angle of flattening in relation to the Frankfurt plane is about 50º-70º. The shelf-like appearance of the occipital protuberance in sagittal view and the exaggerated parietal tubera are diagnostic morphological traits of this subtype (Nelson & Madimenos, 2010; Neumann, 1942; Stewart, 1937). Watson stated that lambdoid flattening is most probably caused by the use of neck rolls changing the area of contact between the infant's head and the surface of the cradleboard/cradle (as cited by Clark et al., 2007, p. 601). Obelionic flattening instead is characterized by an angle of flattening equal or inferior to 50º in respect to the Frankfurt plane (Nelson & Madimenos, 2010; Neuman, 1942; Stewart, 1939). The flattened area generally extends about from behind the bregma up to the lambda (Neuman, 1942; Stewart, 1939) or to the superior portion of the occipital planum of the occipital squama (Nelson & Madimenos, 2010). The skull is characterized by exaggerated parietal tubera that elongate supero/anteriorly-infero/posteriorly giving to the skull an ovoid appearance in norma lateralis, a bun like occipital (Nelson & Madimenos, 2010), an anterior parietal and temporal broadening (Neuman, 1942) as well as by a bulging of the forehead (Stewart, 1939).

Antero-posterior headshaping influences the growth of the skull toward an antero-posterior shortening, medio-lateral development of parietals and temporals, increased height (Cocilovo et al., 2011; Antón, 1989; Kohn et al., 1995; Imbelloni, 1928, 1925) as well as more acute parietal angles and exaggerated parietal tubera (Nelson & Madimenos, 2010; Pomeroy et al., 2009). Some antero-posteriorly deformed skulls also display a triangular or bilobed shape in norma superioris (Lorentz, 2009; Antón, 1989). The bilobed appearance might be the result of the application of an additional bandage passing on the sagittal suture (Tiesler, 2012; Pomeroy et al., 2009; Clark et al., 2007) or of some kind of headdress (Pomeroy et al., 2009). Bilobed examples are morphologically characterized by a severe flattening of both occipital and frontal bones and compared to posterior tabular modification, do not develop in height most probably because of the compressional forces coming from the sagittal area (Pomeroy et al., 2009).

1.2.1.2. Circular Type

According to the existing literature, circular headshaping occurs when bandages, threads or strings envelop the head from the frontal to the occipital or lambdoid area passing through temporal and parietal bones. In some examples, behind fronto-posterior bandaging, the application of a post coronal bandage has been proposed as well (Erdal, 2013a; Meiklejohn et al., 1992; Munizaga, 1987; Lambert, 1979; Özbek, 1974a, 1974b; Weiss, 1958). Contrary to tabular headshaping, this shaping technique produces multiple forces that, although with different intensities, affect neurocranium from different sides so to allow a more symmetrical shaping of the head by causing a posterior and/or superior cranial growing and by preventing its mediolateral development (Clark et al., 2007; Kohn et al., 1995; Kohn et al., 1993; Antón, 1989). According to the inclination of the obtained cranial shape, oblique and vertical subtypes are distinguished (Munizaga, 1987; Moss 1958; Imbelloni, 1928; 1925). In oblique subtype, neurocranium generally develops in length (postero-superiorly) while height and width are prevented. This developmental pattern determines an ovoid shape of the cranium in norma lateralis. Conversely, in vertical subtype, height develops more than length and width so that the cranium appears more conically shaped (Cocilovo et al., 2011; Kohn et al., 1993). A decrease in breadth, more obtuse frontal and occipital curvatures and a more acute parietal curvature characterize both the two subtypes (Antón, 1989).

Post coronal depression instead has been defined as a linear depression located slightly behind the coronal suture on both the parietals and extending inferiorly towards the temporal fossae up to below the mandible (Meiklejohn et al., 1992; Lambert, 1979; Özbek, 1974a, 1974b).

1.2.1.3. Possible Reasons for Intentional Headshaping

Due to its high visual impact and permanent physical effects, aestheticism has been accepted as the most important reason behind this cultural practice (P. Gerszten & E. Gerszten, 1995; Özbek, 1978, 1975; Hasluck, 1947; Dingwall, 1931). In New Papua Guinea, the Arawe conceived headshaping as a means of attractiveness toward the opposite sex (Blackwood & Danby, 1955). Some cultures have strengthened this sense of beauty by accompanying intentional headshaping with particular hairstyles, hats, or haircuts (Tiesler, 2014; Lorentz, 2010; Weiss, 1958; Morton, 1839).

Beyond aesthetic purposes, differentiation in terms of social status might be a plausible explanation as well. A relationship between intentional headshaping and socioeconomic status has been observed in different cultures worldwide and from ancient times. In the

Northwest Pacific Coast of America, intentional headshaping was practiced as privilege or as a mark of nobility (Dingwall, 1931). Strangest shaped heads were considered as the noblest among Columbia River populations. In fact, while normal heads were attributed to servitude, noble and wealthy children, and particularly chiefs, were severely shaped (Dingwall, 1931). Franciscan Torquemada in his “Monarquia Indiana" reported that certain Peruvian nobles allowed their lords to shape the head of their children to resemble that of their families. The discovery of gold and silver filets encircling some of these shaped crania may prove that this custom was a privilege for individuals with high social status (cited by Dingwall, 1931, p. 218). Noble Mayan families of the Classical Period distinguished themselves from the lower classes by means of different headshaping types (Romero-Vargas et al., 2010). Vera Tiesler (1998) stated that oblique intentional headshaping was mostly related to Mayan individuals of elevated social ranks. At the Classic site of Teopancazco in the southern area of Teotihuacan in Mexico, headshaping (both tabular erect and oblique) was observed on individuals likely coming from the area of the Gulf Coast and belonging to elevated social ranks. Funerary rituals, contexts and grave goods connect these individuals to groups of leaders or elites perhaps involved in some sort of craft production (Alvarado-Vinas & Manzilla, 2018). Noble Incas shaped the heads of their children to resemble the members of the royal family (Tubbs et al., 2006). Arauquinoid societies, living during the Early Ceramic Age in Suriname, performed intentional headshaping for intra-group social differentiation (Van Duijvenbode, 2012). In the Aragua Valley, intentional headshaping represented a very common practice performed exclusively by special classes (Dingwall, 1931). In Egypt, during the Akhenaten Kingdom, portraits, sculptures, and reliefs of the members of the royal family, such as Queen Nefertiti and Tutankhamen's mother, showed cranial morphological traits typical of intentional headshaping. The discovery of Tutankhamen’s mummy proved that this cultural practice was really performed during that period (Ayer et al., 2010). As noted by Ayer and others (2010), the beginning of a new religious and political period characterized by the centralization of the government and the dissolution of the local cults in favour of monotheism, might have encouraged the adoption of intentional headshaping to validate the royal power. It is known that this phenomenon was common among the purest lineages and aristocratic classes of Ashanti people in the Western Africa (Dingwall, 1931). In Europe, modification of the shape of the head was likely a mark of aristocratic lineage (Dingwall, 1931). According to most Bulgarian anthropologists, it is possible that in this geographical context headshaping was firstly used as a means to express the upper social status of tribal leaders and their relatives and later adopted as a symbol of ethnic membership (Enchev et al., 2010). Hippocrates reported that, at his time, Caucasian people elongated their skulls as a mark of nobility and aristocratic lineage (as cited by Dingwall, 1931, p. 36). Also in Melanesia, headshaping seems to be connected to the idea of nobility and chieftainship (Dingwall, 1931). The suggestion of a connection between intentional headshaping and high social status may be proposed for the Middle East as well. At the site of Kition and Kalavasos, (Cyprus) grave goods such as Mycenaean pottery, gold jewellery and Hittite silver figurines were found in burials of shaped individuals thus suggesting their higher social status (Bolger, 2003). At the site of Ganj Dareh Tepe in Iran, intentional headshaping was reserved to a constraint number of individuals half of which recovered from a single mudbrick sarcophagus, unique in the site; the remaining instead was found in discrete burial pits (Lambert, 1979). This evidence may imply the exclusivity of the practice to members of a particular group perhaps of elevated social rank. As proposed by Campbell and Molleson (1995) for the site of Tell Arpachiyah in Iraq, intentional headshaping might be related to members of a hereditary group or class-priests, potters, or princes. Intentionally shaped individuals were also found in very rich tombs of the Late Cypriot Bronze Age sites of Enkomi and Kalavasos-Ayios Dhimitrios in Cyprus (Lorentz, 2009). Egami (1958) mentioned the discovery of an intentionally moulded subadult (Skeleton No. 42) at the Iraqi site of Telul eth-Thalathat. The skeletal remains were found within a jar-coffin in a layer dated to the Ubaid Period in the area C-R.3. Although the scholar (Egami, 1958) did not provide detailed information about headshaping techniques, he suggested a special destination of area C-R.3, and especially of C-R.2, most probably employed as dwelling room for a chief, as an assembly-hall or as a storehouse of common property (Egami 1958: 5). New anthropological investigations conducted by Erdal (2019) at the sites of Çadır Höyük and Arslantepe in Turkey have added new information about the practice of intentional headshaping in Anatolia during the Chalcolithic period. At Arslantepe, two shaped individuals (one female and a subadult) were respectively discovered in a pot burial and in a simple pit grave, dated to the Late Chalcolithic Period, in the area of an elite residential building under the Temple C. At Çadır Höyük instead, two shaped individuals were found in the Chalcolithic layers of the Burnt House and Omphalos Building for which a ritual destination has been suggested (Steadman et al., 2017; Yıldırım et al., 2018). The presence of metal jewellery in one burial also corroborates the hypothesis of the elevated social or socio-economic status of these individuals.

Other reasons instead seem related to the necessity of establishing ethnic and socio-economic relationships of affiliation or differentiation. For instance, the ethnic distinction between Mayan and non-Mayan groups during the Classic Mayan Era is well known not only linguistically but also in terms of intentional headshaping. In fact, while the Western Ch'olan Maya of the Usumacinta basin displayed narrow, elongated, and inclined shaped heads, non-Mayan population showed short and broad heads, sometimes bilobed (Tiesler & Lacadena, 2018). The highlands and coastline inhabitants of San Pedro de Atacama in South Chile used intentional headshaping as means of ethnic differentiation as well (Torres-Rouff, 2002). In the Andes, differences between highland and lowland inhabitants were recognizable in the different intentional headshaping types: circular in the highlands, fronto-occipital tabular in the western coasts (Blom, 2005). Intentional headshaping visually represented socio-economic differences between fishermen and agriculturalists of the Chiribaya community of South Peru as well (Lozada, 2011; Blom, 2005).

Emulation of ethnic groups, deities, supernatural beings, or natural forces has been also proposed to explain the practice of intentional headshaping. According to some scholars (Tiesler, 2012, 2010; Romero-Vargas, 2010; Miller, 2009), the Great Pakal was shaped to resemble Sun and Maize gods. The inhabitants of the Eurasian Steppes tried to imitate the new conquerors, such as Huns, by reproducing their shaped heads (Torres-Rouff & Yablonsky, 2005). Huns and Peruvians, this latter at the time of Spanish invasion, performed intentional headshaping with the aim of acquiring a ferocious appearance in war (Tubbs et al., 2006; P. Gerszten & E. Gerszten, 1995; Morton, 1839).

Magical and religious purposes have been suggested as well (Tiesler, 2011; Duncan & Hofling, 2011; Tiesler & Oliva, 2010; P. Gerszten & E. Gerszten, 1995). For instance, it is known that Modern Maya encircled children heads by bandages to prevent the entering of bad spirits through cranial fontanelles (Duncan & Hofling, 2011).

1.2.2. Unintentional Headshaping

Alterations of the normal shape of the head may be caused by different circumstances such as delivery compressions (Ridgway & Weiner, 2004; Bronfin, 2001), anomalies in the cranial development (like macrocephaly, microcephaly, hydrocephalus and craniosynostosis), hormonal disorders (such as acromegaly), metabolic disorders (such as D Vitamin deficiency) (Cartwright & Chibbaro, 2013; Barners, 2012; Ridgway & Weiner, 2004; Ortner, 2003; Aufderheide et al., 1998), postural constraints (intrauterine and postnatal) (Captier et al., 2011; Graham, 2007) and cultural practices related to the care of the infants (Tiesler, 2014; Lorentz, 2009; P. Gerszten & E. Gerszten, 1995; Dingwall, 1931). Post-depositional and badly performed excavation and restoration activities may be accepted as causes affecting the shape of the cranium as well (Tiesler, 2014, 2012).

1.2.2.1. Deformation caused by delivery compressions.

Deformation of the head may be caused by the antero-posterior compression forces occurring during the passage of the infant through the birth canal (Ridgway & Weiner, 2004). This deformation is characterized by a vertical development of the neurocranium and is generally transient by disappearing during the first week of the baby's life (Captier et al., 2011; Ridgway & Weiner, 2004).

1.2.2.2. Anomalies of cranial development

Congenital disorders of the cranial shape can be distinguished in acquired (extrinsic) and genetic or hereditary (intrinsic). The former includes pathologies such those related to metabolic diseases, maternal infections such as syphilis or rubella, or environmental factors such as maternal nutritional conditions and environmental harmful contaminants (Barners, 2012; Aufderheide et al., 1998). They can affect the morphogenesis of the developing embryo only if they cross the placental barrier at a specific sensitive threshold event of the development. Conversely, genetic disorders develop exclusively during embryogenesis (Barners, 2012). Developmental anomalies are characterized by different degrees of severity that may differently affect the duration and the quality of an individual's life (Aufderheide et al., 1998). The most severe case of congenital cranial malformation is anencephaly (absence of encephalus), a defect of the neural tube that causes the anomalous development of the brain tissue and the related absence of cranial vault (Mann & Hunt, 2005; Ortner, 2003; Aufderheide et al., 1998). Other congenital cranial malformations include microcephaly, macrocephaly, hydrocephalus and craniosynostosis. Microcephaly is generally caused by an unsuccessful development of the brain components (Barners, 2012; Mann & Hunt, 2005; Aufderheide et al., 1998; Richards, 1985). It is most probably genetically determined but may also be related to environmental conditions (Krauss et al., 2003; Richards, 1985). Microcephalic heads are generally characterised by a low cranial capacity, a circumference smaller than 46 cm, an irregular thickness of the bones (*lacunae*), a conical shape, a recession of frontal and parietal bones, occipital flattening, partial or complete premature closure of sutures and of the anterior fontanel (Barners, 2012; Mann & Hunt, 2005; Aufderheide et al., 1998; Richards, 1985). Macrocephaly is characterized by an increase in weight of the brain resulting in an abnormal development of the cranial vault (Aufderheide et al., 1998). Enlargement of the cranial vault, bony thinning, and formation of extra sutural bones at fontanels are diagnostic (Ortner, 2003; Aufderheide et al., 1998). Hydrocephalus is a disease of the central nervous system characterized by an abnormal enlargement of the cranium due to the absence of equilibrium between cerebrospinal fluid secretion and its absorption (Barner, 2012; Richards & Antón, 1991) so that an abnormal accumulation of liquid occurs in the lateral third and fourth ventricles and/or in the subarachnoid space (Aufderheide et al., 1998). It may be congenital or acquired and can be caused by developmental disorders of the foetus (Barners, 2012). Affected skulls appear enlarged, globular, with frontal bossing, bony thinning, bulging of the fontanels, enclosure of the anterior fontanel, separation of the sutures, and formation of Wormian bones (Aufderheide et al., 1998; Richards & Antón, 1991).

1.2.2.2.1. Craniosynostosis

Craniosynostosis or pathological premature closure of cranial sutures is a rare pathological condition usually observed at birth, caused by genetic mutation or, rarely, by environmental factors (Ridgway & Weiner, 2004). The early closure of sutures affects the growth and the development of the brain leading in turn to the deformation of the skull (Ortner, 2003; Aufderheide et al., 1998). Due to the developed intracranial pressure, open sutures may split up and a deep digital impression may appear on the endocranial surface (Ortner, 2003). Craniosynostosis may be syndromic (including Apert's, Crouzon and Pfeiffer's syndromes) and non-syndromic (affecting only one suture) (Cartwright & Chibbaro, 2013; Morriss-Kay & Wilkie, 2005; Ridgway & Weiner, 2004). Generally, synostosis of multiple sutures is less frequently observed and may develop completely or partially (Cartwright and Chibbaro 2013) by not affecting the surrounding bones or causing some sort of rigid wide bridge (Ridgway & Weiner, 2004; Aufderheide et al., 1998).

Craniosynostotic deformation varies in relation with the affected suture/sutures (Cartwright & Chibbaro, 2013; Mann & Hunt, 2005; Ridgway & Weiner, 2004; Aufderheide et al., 1998). In fact, according to the affected area, cranial bones and brain start a balancing development perpendicular to that (Morriss-Kay & Wilkie, 2005; Ridgway & Weiner, 2004). Sagittal synostosis is the most frequently encountered, followed by coronal, metopic and lambdoid ones (Cartwright & Chibbaro, 2013). Scaphocephaly or dolichocephaly is caused by the early closure (complete or partial) of the sagittal suture (Ridgway & Weiner, 2004). This condition prevents the transversal growth of the head while causing an excessive sagittal development. Skull appears overly long and narrow in shape (Ridgway & Weiner, 2004) with frontal bossing and occipital bulging (knob) (Delashaw et al., 1989). Turricephaly, acrocephaly or acrobrachycephaly are caused by the bilateral closure of the coronal suture, in some cases, accompanied by the closure of the spheno-frontal and sagittal sutures as well. Because of the lack of parietal growth, the head overly develops in width and height, while bony growth in temporal squamosa suture leads to the formation of a bilateral temporal bony relief (Delashaw et al., 1989). Trigonocephaly is caused by the early closure of the metopic suture during the intrauterine life or immediately after birth (Aufderheide et al., 1998). Due to the lack of frontal growth, bone accumulation symmetrically occurs in the parietals so that the head appears characterized by bitemporal narrowing, parietal bossing and a general triangular shape (Cartwright & Chibbaro, 2013; Ridgway & Weiner, 2004; Delashaw et al., 1989). Plagiocephaly originates from the asymmetrical closure of the coronal or/and the lambdoid suture and is characterized by a laterally or antero-posteriorly asymmetrical development of the head. Three types of plagiocephaly can be distinguished: frontal, occipital and hemicranial. Synostotic plagiocephaly must be distinguished from the postural one. In fact, although they are characterized by very similar cranial morphological changes, their aetiology and development are completely different. In fact, postural plagiocephaly is caused by the compression of the posterior region of the head for a quite long time due to the posterior decubitus of the baby in the cradle/cradleboard. In general, diagnostic features of craniosynostotic plagiocephaly are the bridge-shaped bony protrusion in the area of the closed suture and the parallelogram-shape of the head in *norma superioris* (Cartwright & Chibbaro, 2013; Ridgway & Weiner, 2004; Huang et al., 1996). Oxycephaly is a very rare form of craniosynostosis caused by the premature closure of the coronal and the lambdoid sutures. It is characterized by the antero-posterior shortening and the infero-superior development of the head that acquires a high conical shape (Ridgway & Weiner, 2004; Aufderheide et al., 1998). Trifillocephaly is caused by the closure of several sutures and is characterized by a trilobular shape of the head. Lambdoid-squamosal narrowing, frontal and temporal swelling as well as occipital flattening and anterior-posterior shortening are diagnostic (Aufderheide et al., 1998).

1.2.2.3. Postural deformation: intrauterine and postnatal

Intrauterine deformation is the result of intra-utero crowding and foetus positioning and is generally asymmetrical (usually on the right side) and more common in males (Captier et al., 2011). Congenital or acquired torticollis, caused by the tightening of the sternocleidomastoid or cervical muscles or muscle hypertonia (unilateral both myogenic and neurogenic, and bilateral neurogenic) caused by the restriction of the cervical vertebra movement, can also be considered as indirect cause of postural head deformation (Cartwright & Chibbaro, 2013; Captier et al., 2011; Ridgway & Weiner, 2004; Bronfin, 2001).

Post-natal postural deformities, such as plagiocephaly and brachycephaly (both non-synostotic), can be defined as gravitational dynamic processes determining an irregular/regular distribution of the posterior cranial mass with or without deformation of the forehead. They are generally caused by the exclusive or persistent dorsal decubitus of the baby's head on a relatively hard and flat surface during both sleeping and waking hours, such as occurs in the swaddling practices. According to the position of the infant's head on the cradle/cradleboard, positional flattening can appear at different areas of the posterior cranial region (Graham, Sanchez-Lara 2015; Captier et al., 2011; Lekovic et al., 2007; Graham et al., 2005). Generally, deformity is absent at birth while appearing during the first two months of life (Captier et al., 2011). Diagnostic traits of postural plagiocephaly are contralateral posterior bossing of the occipital region, ipsilateral frontal bossing, absence of ipsilateral occipito-mastoid bossing and forward displacement of the ipsilateral ear region. Head appears unmodified *in norma dorsalis* by acquiring a parallelogram-shape in *norma superioris* (Cartwright & Chibbaro, 2013; Ridgway & Weiner, 2004). Contrary to plagiocephaly, brachiocephalic heads symmetrically antero-posteriorly shorten and bi-parietally develop (Graham & Sanchez-Lara, 2015; Graham et al., 2005).

1.3. LITERATURE BACKGROUND ON INTENTIONAL HEADSHAPING IN THE NEAR EAST

Intentional headshaping represents a cultural practice performed all over the world not only in ancient times but also nowadays. Prehistoric and historical examples have been also found in the Near East, in the geographical area that from the Levantine region, throughout Turkey and Iraq, arrives in the Iran territories. Archaeological findings such as clay figurines or vessel paintings, likely representing long-headed figures, also prove that artificial headshaping was deeply rooted in this geographical context since very ancient time (Erdal, 2013a; Stein, 2010; Fletcher et al., 2008; Daems & Croucher, 2007; Molleson & Campbell, 1995; Dingwall, 1931).

Even still debated, the earliest evidence of this practice dates to the Upper Mousterian period and comes from the site of Shanidar Cave, in northern Iraq (Trinkaus, 1982). According to Trinkaus (1982), the so-called Shanidar 1 and 5 crania presented morphological traits such as frontal flattening and parietal curvatures typical of intentionally shaped crania. Based on the comparative results of the osteometric analyses conducted on Neanderthal samples of Europe and Near East, Ivanhoe (Ivanhoe & Trinkaus, 1983) contrary proposed a possible case of cranial deformation caused by rickets.

Based on the existing investigations, diachronic typological differences seem to characterize this cultural practice in this geographical area. In general, circular headshaping most frequently occurs in ancient prehistoric periods, while tabular modification characterizes the most recent phases of both prehistoric and historical periods.

Levantine examples of tabular headshaping are known from the sites of Jericho (Neolithic period) (Fletcher et al., 2008; Kurth & Röhrer, 1981), Ain Jebrud (Chalcolithic period) (Özbek, 2001), Megiddo (Late Bronze Age) (Angel, 1936), Ras Shamra (Bronze Age, and BC 18th-13th centuries) (Soto-Heim, 1986; Angel, 1936), Tell Duweir (Lachish, BC 8th–7th century, ca. BC 700) (Özbek, 2001), Sidon (Phoenician Period and 19th century AD) (Lorentz, 2010; Özbek, 2001, 1974a, 1974b) and Tyre (Phoenician Period and 19th century AD) (Özbek, 2001), En Gedi and Yavne Yam (Hellenistic-Byzantine period) (Lorentz, 2010), and Beirut (recent time) (Özbek, 1974a, 1974b). Specimens of circular headshaping instead are known from the sites of Bouqras (Neolithic period) (Meiklejohn et al., 1992), Byblos (Chalcolithic period, second half of BC 4th millennium) (Vallois, 1937; Özbek, 1975; 1974a, 1974b), Tell Zeidan (Chalcolithic period) (Stein, 2011), Tell Duwer (BC 8th-7th century, ca. BC 700) (Risdon, 1939), and Beirut (modern time) (Melconian & Schaepelynck, 1947).

Conversely, in the island of Cyprus, the most ancient evidences of tabular headshaping are practiced at least from the Neolithic period by continuing during the Bronze Age as well, such as demonstrated by the discoveries at the sites of Khirokitia (Neolithic period) (Lorentz, 2009; Le Mort, 2007; Angel, 1936), Kissonerga-Mylouthkia (Neolithic period) (Lorentz, 2010; Lorentz, 2009; Harper & Fox, 2008; Kurth & Röhrer, 1981), Kalavasos-Tenta (Neolithic period) (Le Mort, 2007), Cap Andreas-Kastros (Neolithic period) (Le Mort, 2007), Melia (Late Cypriot Bronze Age) (Harper & Fox, 2008; Angel, 1936), Kourion-Bamboula, Hala Sultan Tekke, Pendayia, Kition and Akhera (Late Cypriot Bronze Age) (Bolger, 2003). With the exception of the sample from the site of Khirokitia (Early Neolithic) (Angel, 1976, 1936), circular headshaping has been observed in the most recent sites of Enkomi (Cyprus, Late Bronze Age) (Lorentz, 2009; Harper & Fox, 2008), Hala Sultan Tekke (Late Bronze Age) (Bolger, 2003), Kalavasos-Ayios Dhimitrios (Late Bronze Age) (Lorentz, 2009), Bamboula (Late Bronze Age) (Angel, 1936), Pendayia, Kition, Akhera (Late Bronze Age) (Bolger, 2003), Lapithos (Late Bronze Age/Iron Age) and Dali (Early Iron Age) (Angel, 1936).

In Iraq, circular headshaping, obtained by the application of both one and two bands, represents the most common type, especially in the most ancient chronological periods. Examples are known from Shanidar Cave (Upper Mousterian and Proto-Neolithic Period, BC 8650) (Meiklejohn et al., 1992; Trinkaus, 1982), Telul eth-Thalathat (Ubaid) (Lorentz, 2010; Egami 1958), Tell Arpachiyah (Halaf and Ubaid, BC 4300) (Molleson & Campbell, 1995), Eridu (Late Ubaid) (Lorentz, 2010; Meiklejohn et al., 1992; Kiszely 1978) and Tell Madhur (Ubaid) (Downs, 1984). Tabular cranial modification instead seems related to more recent times such as observed at some districts such as Sheikhan, Bashiqa and Bahsany (Field, 1948).

In Iran, although intentional headshaping is mostly represented by examples of circular type such those from Tepe Ghenil (Neolithic period) (Meiklejohn et al., 1992), Ganj Dareh Tepe (Neolithic period, BC 7500–6500) (Meiklejohn et al., 1992; Lambert, 1979), Ali Kosh (Neolithic period, BC 7th millennium) (Meiklejohn et al., 1992; Lambert, 1979), Choga Sefid (Neolithic period, ca. BC 6500) (Meiklejohn et al., 1992), Choga Mish (Late Middle Susiana, BC 4500-4000) (Ortner, 1996), Seh Gabi (Ubaid) (Meiklejohn et al., 1992; Lambert, 1979) and Qumrud (Ubaid, BC 5th millennium) (Lorentz, 2009, 2010), tabularly shaped crania have been also found at the sites of Tepe Sialk (BC 4th-5th millennium), Ghalecoti (BC 250-200 AD) and Balghasian (622-700 AD) (Soto-Heim, 1986) and among the modern communities of Ghilan, Mazandaran and Gorgan (Soto-Heim, 1986). At the site of Tepe Abdul Hosein, dated back to the Neolithic Period, the presence of both the types has been explained by attempts of sex differentiation (Lorentz, 2010; Croucher 2008; Daems & Croucher, 2007).

In Anatolia intentional headshaping is known from the Neolithic up to the Byzantine period (Aytek et al., 2021, 2020; Eroğlu, 2016, 2015; Erdal, 2013a, 2011; Duyar & Atamtürk, 2010; Miyake, 2010; Özbek, 2001; Alpagut, 1986; Özbek 1984; Angel, 1976; Mellink & Angel, 1968; Şenyürek & Tunakan, 1951) by persisting also among modern populations. Chantre (1891) mentioned the practice of tabular posterior and circular fronto-occipital headshaping among the Kurdish people living between Turkey and Caucasus. Hasluck (1947) reported its practice among the modern populations of Greece, Macedonia, and Anatolia. Özbek (2001) stated that circular intentional headshaping is practiced among the Yürük nomads living in the southern regions of Turkey whose heads are characterized by occipital flattening and a protrusion at the point of inion, the "yurukluk", representing their ethnocultural membership (Lorentz, 2010). According to ethnographic research conducted by Erdal (2013a, 2011), circular headshaping is still performed by Kurds, Arabs and Turkmens living in the district of Bismil (Diyarbakir). At West of Diyarbakir, in the province of Malatya instead, plano-occipital flattening is the most common type (Erdal & D'Amico, 2020).

1.3.1. History of anthropological studies on intentional headshaping in Anatolia

The first anthropological study on artificial headshaping in Anatolia was carried out on the skeletal materials of the site of Şeyh Höyük by Şenyürek and Tunakan in 1951. Moulded crania, belonged to female individuals, were characterized by morphological features typical of circular headshaping. Özbek (1975, 1974a, 1974b), by comparing mandibular measurements of shaped skulls from Byblos and Şeyh Höyük, suggested that, unlike Byblos, shaped skulls from Şeyh Höyük were affected by circular headshaping performed without the application of a transversal bandage. Angel and Mellink (1968, 1976) reported the presence of artificially modified skulls at the Bronze Age site of Karataş. According to the scholars (Angel, 1976; Mellink & Angel, 1968), both occipital flattening and the so-called 'Cypriot Type' were practiced. In 1984, Özbek observed a possible case of intentional circular headshaping on an adult female coming from the Bronze Age site of Hayaz Höyük. In 1985, the same scholar found 13 intentionally shaped skulls among the 31 subadult individuals of the Chalcolithic site of Değirmentepe. According to the scholar (Özbek, 2001, 1985) skulls were circularly shaped by the application of both one and two bandages. Like for shaped crania from Byblos (Özbek, 1974a, 1974b), intentional headshaping was more pronounced in younger individuals by decreasing in severity with the increasing of the age (Özbek, 2001). According to Özbek (2001), differences in headshaping type could were related to the different age groups. In fact, while infants of age between 0 and 1,5 years were modified by the application of a single bandage (oblique subtype), infants and children between 1,5 and 5 years of age as well as adolescents were shaped by applying both oblique and transversal bandages. In 1986, Alpagut noted the presence of an intentionally modified skull in the skeletal material found in the site of Kurban Höyük and dated to the Halaf Period. The skull, belonging to an adult female, was characterized by post-bregmatic and temporal depressions originated from a single bandage diagonally applied from the post-coronal region up to the lower portion of the occipital bone. In 2010, Duyar and Atamtürk, in a study on Early Bronze Age burial customs, health conditions and lifestyle of Resuloğlu population, included a macroscopic anthropological description of intentionally shaped crania. Four individuals showed signs of a bandage enveloping the head from the post-bregmatic region up to the inferior occipital. According to the same researchers (Duyar & Atamtürk, 2010), headshaping type resembled that observed by Angel and Mellink at Karataş (Angel, 1976; Mellink & Angel, 1968). In the same year, the results of the anthropological analyses conducted on the skeletal material recovered at Salat Cami in 2008 were published (Miyake, 2010). According to Erdal, who conducted the anthropological analysis (Miyake, 2010), circular intentional headshaping affected the skull of a 3-3.5-year-old child. In 2013, the same anthropologist (Erdal, 2013a) published a study on the skeletal materials coming from the site of Hakemi Use. Examples of intentional headshaping were encountered in all the archaeological strata of the Late Neolithic period. Circular type, obtained by the application of two bands, was observed on 14 infants and children and two adults (a male and a female). According to the ethnographic research conducted by the same researcher (Erdal, 2013a, 2011), circular headshaping is still performed by Kurds, Arabs and Turkmens living in the district of Bismil (Diyarbakir). In 2015, Eroğlu identified the presence of frontal and post coronal depressions on the skull of a 15-years-old juvenile from the Chalcolithic site of Havuz Mevkii. Observed cranial depressions were interpreted as the result of the application of two bandages (Eroğlu, 2015). In 2016, the same scholar (Eroğlu, 2016) analysed a case of intentional headshaping on an adult male coming from the site of Zeviya Tivilki dated to the Early Iron age (Assyrian Period, BC 8th-7th centuries). The skull presented signs of circular modification accomplished by the application of a double bandage as well. In 2019, Erdal published an article on new intentionally shaped crania found at the sites of Çadır Höyük and Arslantepe and dated to the Late Chalcolithic Period. At Çadır Höyük, frontal flattening, post-coronal depression and parietal bulging, all diagnostic morphological characteristics of circular headshaping performed by the application of two bandages, were observed on the skull of a 3-3,5-years-old child and on an adolescent. At Arslantepe instead, circular headshaping was observed on a two years-old infant and an adult female. While the skull of the infant showed the same morphological alterations observed on the reshaped skulls of Çadır Höyük, the shaped adult displayed an uncommon type of cranial modification. In fact, it was very long and narrow and did not show any sign of depression or bulging, most probably because of the application of some sort of headgear or bandages enveloping the head in such a way that almost all the vault was compressed by the same amount of pressure. Aytek and others (2020) found a case of post coronal depression on the skull of an 11-12-years-old child found in the Early Byzantine necropolis of Tefenni (4th-7th century AD) (Aytek et al. 2020). Erdal and D’Amico (2020) investigated plano-occipital flattening, its intentionality and meaning among the Medieval skeletal material from the site of Arslantepe. In 2021, Aytek and others published a case of intentional headshaping on an adult individual found at the necropolis of Myndos (Bodrum), dated between BC 4th century and 4th century AD. The skull was characterized by the presence of a post coronal depression suggesting a case of circular headshaping performed by the application of a single bandage that from behind the coronal suture crossed parietals and temporals by reaching the lower region of the mandible.

CHAPTER 2
ISSUES AND PURPOSES

2.1. ISSUES

Headshaping has been practiced from prehistory to the present days in almost all the world (FitzSimmons et al., 1998; P. Gerszten & E. Gerszten, 1995; Dingwall, 1931). That is why it represents one of the most investigated topics related to the skull. Over time, several research, conducted by applying different methods, have investigated different issues related to this cultural practice such as the identification of metric and morphological cranial alterations (Mayall et al., 2018; Cottin et al., 2017; Ketoff et al., 2017; Ferros et al., 2016, 2015; Boston et al., 2015; Khonsari et al., 2013; Jiménez et al., 2012; Roos & Ubelaker, 2009; Gómez-Valdés et al., 2006; Rhode & Arriaza, 2006; Ogura et al., 2006; Kohn et al., 1995, 1993; Cheverud et al., 1992; Cheverud & Midkiff, 1992; Antón, 1989; Mcneill & Newton, 1965; A. Björk & L. Björk, 1964; Moss, 1958; Oetteking, 1924), the relationship with some pathological conditions (Gadison, 2015; White, 2006; Langdon, 1989; Hilgeman, 1988), or the effects on non-metric traits such as the conformation complexity of sutures (White, 1996; Gottlieb, 1978), formation of extra sutural bones (Van Arsdale & Clark, 2010; Wilczak & Ousley, 2009; Sanchez-Lara et al., 2007; Del Papa et al., 2007; Dean O'Loughlin, 2004; White, 1996; Konigsberg et al., 1993; El-Najjar & Dawson, 1977; Pucciarelli, 1974; Ossenberg, 1970; Torgensen, 1951; Dorsey, 1897), variations in the intracranial vessel impressions (Dean O'Loughlin, 1996; Dean, 1995), metopism (Gerzstein, 1993; Ossenberg, 1970), or the thickness of the diplöe (Boman et al., 2016; Khonsari et al., 2013). Other studies instead have tried to trace the most ancient phases of this cultural practice (Ni et al., 2020; Zhang et al., 2019; McKenzie & Popov, 2015; Durband, 2014, 2008; Brown, 2010; 1989, 1981; Perez, 2007; Antón & Weinstein, 1999; Trinkaus, 1982).

Despite the existence worldwide of several studies investigating various issues related to this topic as well as the well-known existence of different headshaping types, Anatolian literature has exclusively focused on severe cases of circular headshaping, mostly dated to the prehistoric periods (Erdal, 2019, 2013a; Eroğlu, 2016, 2015; Duyar & Atamtürk, 2010; Miyake, 2010; Özbek, 2001, 1984; Alpagut, 1986; Şenürek &

Tunakan, 1951). The high frequency of elongated skulls, generally accepted as intentionally shaped, might be related to the prominence of their morphological features such as depressions on different parts of the skull as well as frontal and occipital flattening and inclination. Nevertheless, even though not well known and investigated, tabular type, and in particular plano-occipital flattening, represents another variant known at least from the Bronze Age (Erdal & D'Amico, 2020; Angel, 1976; Mellink & Angel, 1968; Chantre 1891). The exclusive interest in circular headshaping may depend not only on the anthropological consensus on the genetic nature of posterior cranial flattening rather than its artificial origin (Özbek, 1994, 1979; Kherumian, 1943, 1941; Coon, 1939; Kansu, 1931; Kappers 1931; Krogman, 1930; Günther, 1927; Dixon, 1923; Morton,1839; Gosse, 1835) but also on the inadequate methods of anthropological investigations. Many scientists have accepted occipital flattening as a biological trait characterising the Armenoid and Dinaric "racial" groups. Until about the 1940s, posterior cranial flattening of both European and Asiatic Dinarics was explained by two main schools of thought: one accepting it as a natural and racially determined morphological trait (Kherumian, 1943, 1941; Kansu, 1931; Günther, 1927; Dixon, 1923; Gosse, 1835), the other instead supporting the hypothesis of an artificial influence. Morton (1839) explained occipital flattening of Peruvians as a "racial trait" most likely affected by cradling practices, especially by the way babies were placed on cradles. Filipović (1935) stated that it was very likely that a significant portion of predominant brachycephaly in various regions of the Balkans was artificially produced either unintentionally (by cradling) or intentionally (by bandages or handkerchief) or under both the influences. Coon (1939) pointed out that occipital flattening was an inherited trait of Dinaric Albanians, despite, in some instances, it could be intensified by cradling practices. Since cradling was regionally performed, the geographical distribution of this cranial trait appeared wholly racial in pattern. After the 1940s, environmental factors began to assume a more decisive role. Ehrich and Coon (1948) observed evident differences in the head dimensions of Dinarics of Albania and Montenegro compared to those of other racial groups such as Alpines, Mediterranean, and Nordics. According to the same scholars (Ehrich & Coon, 1948), although the genetic origin of this morphological cranial trait cannot be excluded, influences of cradling practices should be considered as well. Research conducted on both native and

American born Albanian Tosks by two graduated students of the above-mentioned scholars (Coon, 1950; Ehrich & Coon, 1948) showed that the degree of occipital flattening was more severe in native Albanians because of cradling. In 1950, Coon, in his study on Albanian Gheg tribes, found that differences in flattening position and degree were due to both cradling and cradle typology. In the same year, Ewing (1950), by comparing cephalic indices of both native and American born Lebanese Maronites, noticed that cephalic differences were related to the use of traditional cradles in Lebanon, instead absent in America. About two decades later, Ducros (1967) claimed that this cranial feature was common and artificially caused among European (Alps, Carpathians, Balkans, Caucasus) and Middle Eastern (Anatolian and Arabian) populations. Nevertheless, its very different degrees of development as well as its wide geographical distribution may have led to accept it as a genetic trait. In Anatolia, examples of this cranial morphological feature are known from Kussura, Müsgebi and Bozhöyük (Özbek, 1994; Saatçioğlu, 1982; Krogman, 1937) dated back to the Early Bronze Age, as well as from the Iron Age settlements of Dilkaya and Dirmil, from the Hellenistic strata of Troy and from the later communities of İznik (Nicaea), Dilkaya, Erzurum and Çavuşoğlu (Özbek, 1994; Saatçioğlu, 1982). Until two decades ago, flattening of the rear of the head in this geographical context was also conceived as a "racial" trait characterising the Dinaric and the Armenoid component of the Turkish population (Özbek, 1994, 1979). Kansu (1976) stated that a highest incidence of brachycephalism (93,16%) was observed in the central part of Turkey, followed by the western (76,69%) and the eastern (62,61%) provinces. According to Özbek (1994, 1979), a higher concentration of posterior cranial flattening was common in the northern and central regions of the peninsula. Krogman (1930) reported that the Armenoid cranial type appeared in Anatolia during the Seljuk Period (11th century AD). As proposed by Coon (1939), it was observed in 54% of Turks, especially in the northern and eastern regions. According to Kappers (1931), it was likely that Anatolian hyper brachycephaly was an Armenian feature since Armenia Major and Minor incorporated a large part of the Anatolian territories. Pittard and Dellanbach (1937) considered Alpines and Dinarics as the most significant "racial" presence in Anatolia. According to other scholars (Kherumian, 1943, 1941; Günther, 1927), Armenians, generally considered genetically linked to the Dinarics or as a variety of this "racial" group, were widely present in Turkey. Although for a long time anthropological interpretations have accepted posterior cranial flattening as a biological and "racial" morphological cranial trait characterising European and Asian Dinaric and Armenoid groups, the results of the anthropological study conducted on the well preserved human skeletal remains of the Medieval settlement of Arslantepe (Erdal & D'Amico, 2020) has provided a valid support to the suggestions of many scholars (Ducros, 1967; Ewing, 1950; Ehrich & Coon, 1948; Coon, 1939). According to the results of this study (Erdal & D'Amico, 2020), the decrease in frequency and in degree of severity of posterior cranial flattening by the increasing of the age, becoming almost indiscernible in old adults, does not suggest the biological origin of this cranial trait.

It is a matter of fact that the application of free-standing shaping devices such as bandages or headgears in circular headshaping implies a certain degree of intentionality. Conversely, the use of devices directly linked to infant's care-related cultural practices, such as cradles/cradleboards in tabular headshaping, can make difficult to suggest its intentionality. Many scholars have interpreted plano-occipital flattening caused by cradles/cradleboards as an unintentional modification of the natural shape of the head (Tiesler & Zabala, 2017; Tiesler, 2014; Özbek, 1979; Neumann, 1942; Dingwall, 1931; Lortet, 1884). According to Tiesler (2014), changes in the shape of the head such those caused by the positioning of the baby on the crib were cultural but not customs per se since they were caused by habitual daily activities, and so, not intentional. On the other hand, many ethnographic resources suggested the intentional use of cradleboards/cradles among many cultures all over the world. For instance, Dingwall (1931) stated that, although cradleboards were not employed to intentionally shape the head of babies, they could have been used in such a way among some American Indian tribes. Colonial reports mentioned the use of cradleboards to reduce the occipital eminence conceived as harmful to the harmony of the body functions and a risk-factor for baby's health and soul (Tiesler & Zabala, 2017; Tiesler 2012, 2011). Lorentz (2009) stated that moulded skulls from Cyprus (Lorentz, 2009; 2002; Le Mort, 1995; Angel, 1936) were unintentionally caused by cradling practices (Lorentz, 2009; Bergoffen, 2000). Nevertheless, the same scholar (Lorentz, 2009) suggested that the effects of cradling on the head, observed and re-observed over time, were progressively intentionally reproduced. According to Filipović (1935), in some regions of the Balkans such as Serbia, Kosovo, Belgrade, and Montenegro, babies were kept in small cradles of planks to obtain small and flat heads, judged beautiful and ethnically distinct from the Gypsies living in the same regions and rather characterised by long heads. Fitzsimmons and others (1998) reported that Serbian infants were placed on hard pillows not only to sleep but also to intentionally flatten the rear of their head, considered more appealing.

The wide distribution and the relevant cultural role of cradle is confirmed not only for many cultures worldwide but also for Anatolia. In fact, cradle represents a deeply rooted cultural device in this geographical context as well. Dixon (1923) reported the use of cradles among the Takhtadjy and other marginal Anatolian populations. Özbek (1979) mentioned the use of cradles among Middle Eastern Armenians and Anatolians. According to Eraslan (2016), the cradle, comfortable and suitable for the nomadic life, has had a prominent role in the life of Turkish populations. Ethnographic research conducted in Malatya and other regions of Turkey (Erdal & D'Amico, 2020) have revealed that cradling is a widespread custom in Anatolia still nowadays. Erdal and D'Amico (2020) reported that, although some traditional Anatolian people do not have any explanation for posterior cranial flattening, others try to obtain this cranial shape for aesthetic reasons as well as to visually express and establish forms of social 'identity'. In fact, at Ordüzü, tabular headshaping obtained by cradling is intentionally practised to distinguish Kurds living in this area from those groups characterised instead by long heads and identified as 'Kurdish' (Erdal & D'Amico, 2020).

Several worldwide research have been conducted on well preserved skeletal samples belonging to adult individuals coming from the New World, a geographical context where the frequency of shaped skulls is very high and the severity degree of artificial headshaping is very prominent. Anatolian studies instead have been conducted by using morphoscopic approaches aiming at the identification of the most recurrent morphological cranial changes that have allowed scholars to suggest employed shaping devices, cultural meanings, and reasons. Unlike New World samples, the poor state of preservation of the oldest Anatolian skeletal remains have made investigations more difficult. Moreover, it is well known that Neolithic and Chalcolithic periods in Anatolia as well as in the entire Middle East are characterised by important changes in burial customs indicated by the low number of adult burials found in the settlements dated to these chronological periods (Erdal, 2019; Akkermans & Schwartz, 2003). That is why the number of subadults belonging to these chronological phases is very high. As proposed by some researchers (Tiesler, 2014; Lorentz, 2009), headshaping becomes permanent and irreversible when a shaping device is applied longer than the first two years of the baby's life. As observed on crania from the Chalcolithic sites of Byblos (Özbek, 1975, 1974a, 1974b) and Değirmentepe (Özbek, 2001) as well as from the Medieval settlement of Arslantepe (Erdal & D'Amico, 2020), headshaping frequency and severity are greater in subadults while decreasing with the increasing of the age. Nevertheless, although the high informative potential of subadult skeletal material, the incompleteness of cranial development in this age group has led worldwide studies to exclusively consider data belonging to adult individuals. Moreover, despite several works have investigated different aspects of this topic by applying different approaches, a methodological standardisation has not been achieved yet. The main goal of many of the most recent studies has been overcoming the morphoscopic intra and inter-observer errors by elaborating standardised quantitative methods able to objectively identify the presence of intentional headshaping as well as to discriminate between its different types and subtypes. In 2003, Friess and Baylac applied Elliptic Fourier method (a morphometric approach that investigates cranial morphology and its changes by a two-dimensional outline drawing) and statistical analyses on a Peruvian adult sample to distinguish between shaped (circular type) and unmodified crania and between erect and oblique subtypes. In 2007, Clark and colleagues tried to discriminate between shaped (tabular antero-posterior modification) and unmodified adult crania coming from several archaeological sites of the Philippines (from 14th to 16th centuries AD) by statistically processing standard cranial measurements. In 2009, Pomeroy and others investigated different types of shaped (posterior flattened, bilobed and circular) and unmodified adult crania coming from four sites of the North-Central Peru by using standard craniometric techniques and statistical discriminant analyses. The main goal of this study was the identification of the most evident cranial morphological changes caused by the three different headshaping types as well as the extent they could be employed to discriminate between types and, more in general, between shaped and unmodified crania. In 2010, Cocilovo and others analysed a very large sample of adult crania found in South-Central Andes. Morphometric data were statistically elaborated to distinguish between tabular and circular types and between erect and oblique subtypes.

In 2013, Dean O'Brien and Stanley proposed a quantitative method based on a multivariate statistical analysis of metric dimensions aimed at distinguishing between shaped and unmodified adult crania and between headshaping types on a sample coming from different geographical contexts such as Argentina, Chile, Bolivia, and Peru. In 2016, Kuzminsky and other colleagues, by using Next Engine 3D Laser Surface Scanner to generate high resolution images of artificially modified adult crania coming from four archaeological sites of Chile and Peru, tried to discriminate between circular and tabular headshaping. Jung and Woo (2016) applied geometric morphometrics and multivariate statistical methods on an adult Korean sample to investigate morphological changes of shaped crania and identified artificial headshaping typologies. In 2018, Lucea and others analysed modern adult crania of three different ethnic groups from South America by applying a two-phase macroscopic and quantitative classification method. While macroscopic investigation allowed the researchers to identify severe forms of headshaping, the quantitative approach ensured a more objective classification of the less severe cases. In 2021, Natahi and colleagues proposed 3D geometric morphometric techniques to quantify shape variation in isolated calvaria bones of a small sample including adult and subadult individuals coming from West and Central Mesoamerica and including five different types of intentional headshaping.

2.2. PURPOSES

Based on the above-presented issues, the main purposes of the present study can be summarized as follows:

1) Shed light on intentional headshaping in Anatolia, on the existence of other types besides the circular one such as posterior cranial flattening.
2) Employ data from a fragmented sample.
3) Employ data from subadult individuals.
4) Identify metric and morphological cranial effects caused by the different headshaping types.

5) Define, for the first time, a standard quantitative method of analysis able to identify the most discriminant metric variables by which to objectively recognize the presence of intentional headshaping, even in the mildest cases, as well as to distinguish between its different types in Anatolia.
6) Investigate, for the first time, on the possible relationship between intentional headshaping and the development of some non-metric variations as well as of some pathological conditions in Anatolia.

CHAPTER 3
METHOD OF ANALYSIS

3.1. METHODS FOR THE DETERMINATION OF SEX AND AGE AT DEATH

Almost all the skeletal material selected for the present analysis was sex and age estimated. Nevertheless, for unknown sample, estimation of sex and age at death has been conducted according to standard criteria of evaluation. Anatomic and size-related discriminant characteristics of the skull and the pelvis, along with the general size and degree of robusticity of the post cranial skeleton have been considered for unknown sex in adult individuals (Mays, 2010; White & Folkens, 2005; Buikstra & Ubelaker, 1994). Specific skeletal changes associated with degenerative processes such as closure of cranial sutures and spheno-occipital synchondrosis (Buikstra & Ubelaker, 1994), morphology of the *symphisis pubis* (Brooks & Suchey, 1990; Todd's, 1921), morphology of the sternal termination of the ribs (İşcan, 1989) and morphological variations of the sacro-iliac auricular surface (Lovejoy, 1985) have been considered for the estimation of the age at death of this age group. Epiphyseal union has been taken into account for adolescents and very early adults according to the standards proposed by Flecker (1942) and Webb and Suchey (1985). Dental development (dental calcification) instead has been considered for unknown age at death of infants and children (Ubelaker, 1989) (Appendix 3: Form 1).

3.2.METHODS FOR THE ANALYSIS OF INTENTIONAL HEADSHAPING

Intentional headshaping analysis has been carried out based on two main approaches: macroscopic (morphological, non-metric and pathological) and craniometric. All the data have been recorded in forms elaborated *ad hoc* within the scope of this study (Appendix 3).

3.2.1. Macroscopic analysis

Macroscopic analysis has been conducted in four steps: identification and classification of morphological alterations of the normal shape of the crania/skulls, collection of measures, identification of the presence of specific nonmetric variations and evaluation of the presence of specific pathological conditions.

3.2.1.1. Morphological analysis

The investigation on morphological cranial alterations produced by intentional headshaping has been carried out in order to discriminate between headshaping types and subtypes. Due to the well not preserved conditions of many crania, each cranial region and subregion has been individually inspected by visual and tactile method. A good lighting and the tilting of the cranium are recommended for an easier and rapid identification. Four main cranial regions have been distinguished: frontal, temporal, parietal and occipital. Parietal region has been in turn distinguished into four subregions: bregmatic, divided into bregmatic and post bregmatic areas, tuberial, parieto-temporal and posterior, this latter divided into obelionic and lambdoid areas. Occipital region instead has been divided in inionic and squamosal subregions. For each cranial subregion, morphological changes have been described by three types of modifications (depression, flattening and bulging) and by different degrees of development (slight, moderate, severe, and very severe) (Appendix 3: Form 2) (Figures 1-4).

Figure 1. Slight frontal depression and moderate frontal bulging in a circularly shaped subadult cranium (17JDF24) from Değirmentepe

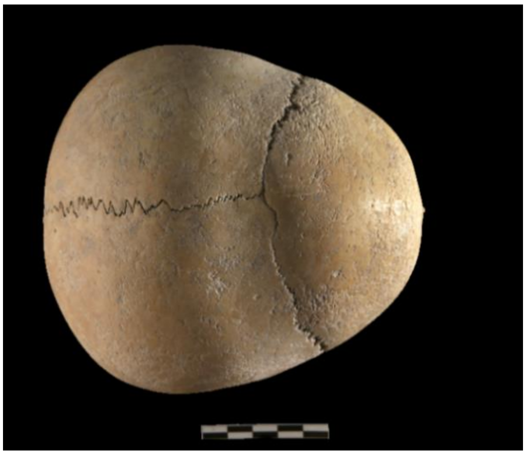


Figure 2. Moderate post coronal depression in a compositely shaped subadult cranium (G14) from Arslantepe

Figure 3. Severe parieto-temporal and tuberial bulging, slight parieto-temporal depression in a compositely shaped subadult cranium (S70) from Arslantepe

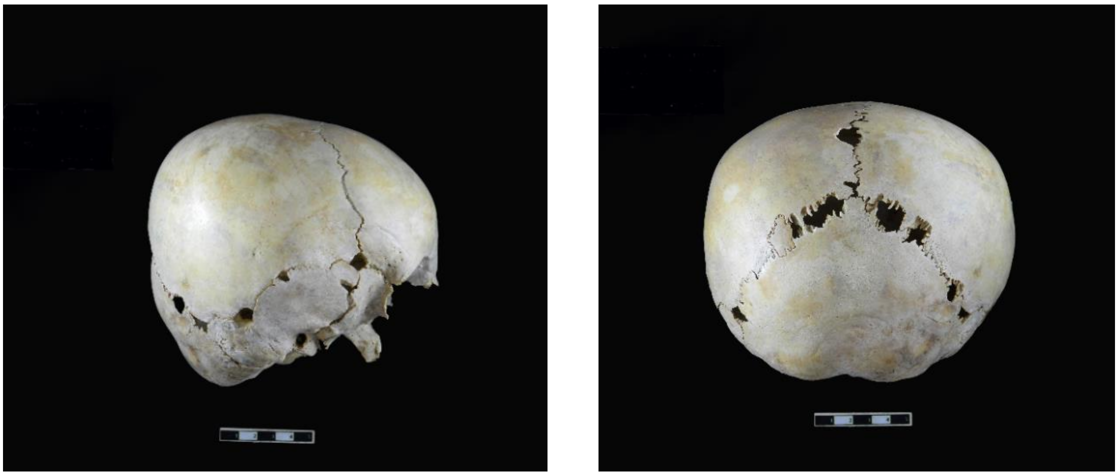


Figure 4. Very severe lambdoid and occipital pars squamosa flattening in a tabularly shaped subadult cranium (SK95) from Oluz Höyük

The presence of circular and tabular headshaping has been identified based on the presence of at least two morphological alterations recognized in the previous works such as frontal depression or flattening, post coronal depression, parieto-temporal depression, lambdoid and obelionic flattening, and occipital depression or flattening (Nelson & Madimenos, 2010; Erdal, 2013a; Özbek, 2001; Meiklejohn et al., 1992; Lambert, 1979). Since morphological characteristics belonging to both circular and tabular headshaping have been observed at once in some crania, another type, the composite, has been proposed. After the determination of the headshaping type, its severity degree (slight, moderate, severe, and very severe) has been defined as well (Appendix 3: Form 2).

Based on the existing literature (Erdal, 2013a; Özbek, 2001; Meiklejohn et al., 1992; Lambert, 1979), fronto-posterior (when the presence of modification regarded both frontal and the posterior portion of the cranium), coronal/post coronal (if modification was present exclusively in the region of bregma or immediately behind) and fronto-posterior-coronal/post coronal subtypes have been distinguished in circular headshaping. For tabular type instead, frontal, posterior and fronto-posterior subtypes have been defined. The discrimination between oblique and erect subtypes instead has been based on the method proposed by Imbelloni (1928, 1925) that consider the degree of inclination of the posterior portion of the cranium in regard to the Frankfurt plane (ca. 120º for oblique subtype and less than 100º for vertical), the direction of the plane of flattening (tangent to the exterior *protuberantia occipitalis* in oblique headshaping, parallel to a vertical line passing through basion and bregma in vertical headshaping) and its position (vertically extended on the whole occipital surface in oblique headshaping, affecting lambdoid region and both parieto-occipital angles in vertical). Posterior movement of bregma and coronal suture conformation, this latter defined according to its developmental severity (straight, slight V-shaped, and severe V-shaped) have been also considered (Figures 5-7) (Appendix 3: Form 2). The presence of Postural plagiocephaly has been inspected according to the occurrence of specific morphological cranial alterations such as contralateral posterior parieto-occipital bossing, ipsilateral frontal bossing, ipsilateral anterior auditory meatus displacement and asymmetric bulging of parietal tubera (Ridgway & Weiner, 2004). Its side (occipital, lambdoid or both), and degree of development (slight, moderate, and severe) have been considered as well (Figures 8-10) (Appendix 3: Form 5).

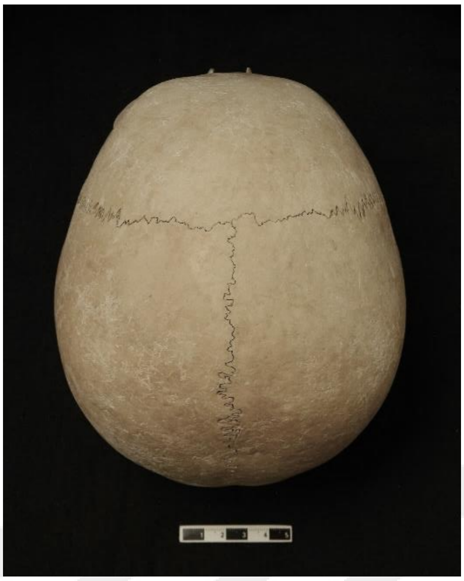


Figure 5. Straight coronal suture conformation in a tabularly shaped subadult cranium (S180 H263) from Arslantepe

Figure 6. Posterior movement of bregma and slight V shaped coronal suture conformation in a compositely shaped cranium of an adult female (SK 193 H276) from Arslantepe

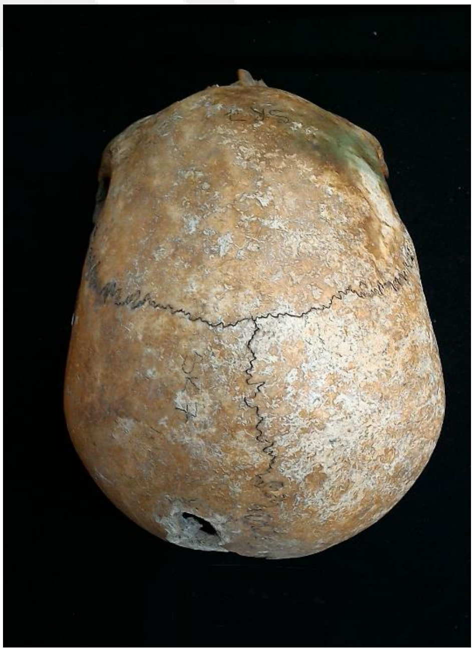


Figure 7. Posterior movement of bregma and severe V shaped coronal suture conformation in a circularly shaped adult male individual (SK7) from Hagios Aberkios

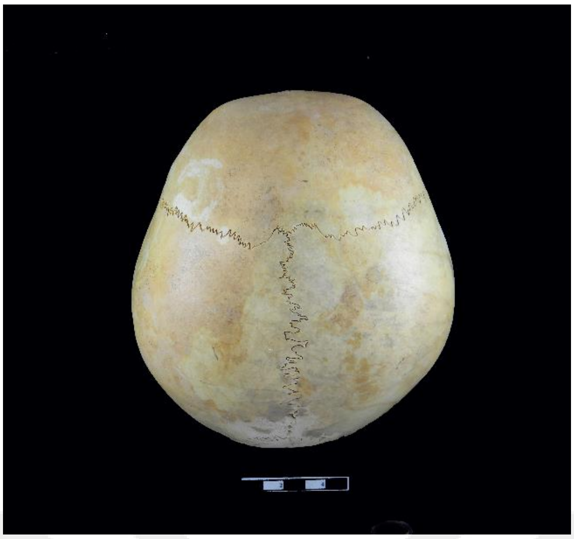


Figure 8. Slight right parietal postural plagiocephaly in an unmodified subadult cranium (SK 49) from Oluz Höyük

Figure 9. Moderate right parieto-occipital postural plagiocephaly in a moderate tabularly shaped cranium of a male individual (S125 H139A) from Arslantepe

Figure 10. Severe postural left parieto-occipital plagiocephaly in a very severe tabularly shaped subadult cranium (SK 59) from Oluz Höyük

3.2.1.2. Analysis of nonmetric traits variations

Among non-metric traits, presence, and development of extra sutural bones and metopism have been investigated by considering the approach of Hauser and De Stefano (1989). Wormian bones (epipteric, coronal, bregmatic, parietal notch bone, temporal-squamosal, Inca, lambdoid, asterionic, and occipito-mastoid) have been analysed for side, presence, number, and size. Metopism instead has been investigated by considering its extent, total or partial, this latter in turn distinguished in frontal, parietal and fronto-parietal (Appendix 3: Form 4).

3.2.1.3. Pathological analysis

Pathological analysis, conducted by the auxiliary use of hand lens, has considered malformation, craniosynostosis, Porotic Hyperostosis, occipital lesions, and synostotic plagiocephaly. For craniosynostosis, affected sutures (sagittal, coronal, lambdoid and metopic) and development of closure (anterior, posterior, or complete for sagittal suture; unilateral and bilateral for all the others) have been considered and classified according to the nomenclature and the seriation proposed by Ridgway and Weiner (2004). Hyperostosis Porotica has been evaluated for severity degree and state of activity at death according to the method proposed by Buikstra and Ubelaker (1994). For occipital lesions instead, symmetrical distribution and extent (tabula externa, tabula interna or both) have been considered. The presence of synostotic plagiocephaly has been defined by considering the most important morphological traits caused by this pathological condition such as ipsilateral occipital flattening, ipsilateral occipito-mastoid bulging contralateral frontal bossing, ipsilateral posterior auditory meatus displacement, contralateral parieto-occipital bossing, and bridge-shaped bony protrusion (Ridgway & Weiner, 2004) (Appendix 3: Form 5).

3.2.2. Craniometric analysis

Applied standards for measurements, landmarks, techniques, and instrumentation are those proposed by Howells (1973) and Buikstra and Ubelaker (1994). Sliding and spreading callipers as well as tape have been employed. Twenty-five linear measures have been selected from the standards proposed by Howells (1973) (Appendix 3: Form 3). Obelion-inion arc and chord have been considered according to the methodology suggested by Ducros (1967), while pterion-lambda, asterion-bregma and asterion-pterion distances have been proposed for the first time in the present study. Based on these linear measurements, ten indices (cranial breadth/length, cranial height length, cranial height/breadth, frontal breadth/length, frontal arc/cord, parietal arc/cord, pterion-lambda/ asterion-bregma length, occipital breadth/length, occipital arc/cord, obelion-inion arc/cord) have been calculated for the morphometric analyses of subadult examples as well (Appendix 3: Form 3).

3.2.3. Statistical analysis

SPSS 21 has been used for the statistical elaboration of both morphoscopic and metric data. Linear cranial measurements and indices have been statistically processed by using different Tests such as Anova and Manova, Multiple Discriminant Function Analysis, Principal Component Analysis and Multinomial Logistic Regression. Relationships between nominal/categorical variables instead have been investigated by Chi-Square Test of Independence.

Due to the presence of many missing metric values, a preliminary analysis of the Type of Missingness (MVA) has been accomplished in order to define the most appropriate way of processing. Little's MCAR Test (Missing Completely at Random) has been applied by using EM (Expectation-Maximization) as estimation method. Test results (χ^2: 4212,725; df: 3992; *p*: 0,007) have showed that missing data are MAR, namely missing at random rather than MCAR. The analysis of Missing Data Patterns has also revealed that their distribution is arbitrary. According to these characteristics, imputation of missing data has been considered more appropriate than listwise or pairwise deletion. Furthermore, since treated data are continuous, MCMC (Markov Chain Monte Carlo) full data imputation method has been preferred. Imputation process has been repeated five times to create five independent data sets (Garson, 2015; Howell, 2007). Each dataset has been in turn processed by Bar Procedure (Baranzini, 2018) to compress multiply imputed data into a single pooled data frame. While descriptive statistics in One-way Anova and Manova have been calculated on raw data, F values have been computed on Imputed data and outcomes of Bar procedures. Moreover, while Two-way Manova has been performed on raw data, Multiple discriminant function analysis, Multinomial logistic regression and Principal component analysis have been carried out on both Bar Procedure outcomes and raw data.

One-way Anova (Analysis of Variance) and Manova (Multivariate Analysis of Variance) are procedures that identify the presence of statistically significant differences between two or more independent groups (predictors or factors) and thus the effects that factors have on the dependent variables by comparing sample means. While One-way Anova cross-check levels of one or more factors based on a single continuous response variable (dependent variable), One-way Manova determines differences between independent groups on multiple response variables considered simultaneously. Two-way Manova instead is generally employed to understand relationships between two independent variables on two or more dependent variables (Queen & Keough, 2002). Although in almost all the cases assumptions have been met, in few cases normality and homogeneity conditions have been not satisfied. Kolmogorov-Smirnov and Shapiro-Wilk tests, as well as Skewness and Kurtosis statistics have been used to check normality in the distribution of variables. Box's M and Levene's Tests instead, have been respectively performed to explore Homogeneity of variance-covariance matrix and Homogeneity of error variances. It is well known that Box's M Test is very sensitive to large data files so to detect even small departures from homogeneity and normality. That is why a smaller alpha level ($p<0,001$) has been fixed and Levene's Test additionally checked. While Wilks' Lambda statistics have been preferred in absence of any violation of the assumptions, Pillai's trace has been preferred in case of violations because more robust (Tabachnick & Fidell, 2013). Moreover, since Anova is generally accepted as a more robust test especially in case of a large sample size, in case of violation of normality assumption, Anova p-values have been compared with those obtained in Manova in order to reach more reliable results. In addition, Welch statistics have been used to replace Anova p-values where data violated the assumption of homogeneity of error variances. Tukey and Games Howell Post Hoc Tests have been performed to identify factors discriminating between groups. In detail, Games Howell Post Hoc Test has been preferred in case homogeneity assumption was not met. Bonferroni Method of confidence interval adjustment instead has been selected for the comparison of the main effects. Measurements and proportional metrics resulting discriminant in One Way Manova performed for each headshaping type were successively processed by Multiple discriminant functional analysis and Multinomial Logistic regression.

Multiple discriminant functional analysis identifies continuous variables discriminating between more than two groups (Ho, 2013). Its main purpose is to estimate group membership from a set of predictors (Tabachnick & Fidell, 2013). Independent variables were entered together, and prior probabilities computed from group sizes. Scheffe Post Hoc Comparison Test has been performed to obtain pairwise comparison between groups. Press's Q statistic instead has been computed to define the classification accuracy of the discriminant functions (Ho, 2013). Due to the very evident differences in size of the three headshaping groups and because of the absence of assumptions about the distribution of predictor variables, Non-parametric Multinomial Logistic Regression has been additionally performed (Ho, 2013).

Principal component analysis is a statistical procedure that allows to summarise the information of a large data set by creating a reduced set of "summary components". Principal components are new variables resulting from the linear combinations of the initial selected variables. These combinations are done in such a way that the new variables' results are uncorrelated (Tabachnick & Fidell, 2013). The application of this statistical analysis in the present study aims to simplify the number of discriminant measurements statistically identified in adults and subadults to best represent cranial morphometric variation patterns in presence of artificial headshaping. Principal component analysis has been performed on metric variables resulted statistically significant in Multiple Discriminant Function Analyses and Multinomial Logistic Regression. Several rotations have been performed by using orthogonal varimax method. The absolute value below of coefficients was set at 0,33 (Ho, 2013). Many cross-loaded variables were successively deleted to progressively reduce the number of components in order to reach the simplest but statistically most meaningful components pattern. The number of principal components has been established by considering the highest percentage of total variance for each component after each rotation and according to eigenvalue size (>1). For the interpretation of principal components (PC), magnitude and directionality have been taken into consideration.

Chi-Square Test of Independence is a statistical test used to determine the relationship between related or independent nominal variables (Ho, 2013). Nonparametric Fisher's Exact Test has been preferred when more than 20% of cells expected frequencies was minor of 5. Monte Carlo Test instead has been selected in case Fisher's Exact Test could not be computed because of insufficient memory.

CHAPTER 4
SETTLEMENTS AND ANALISED MATERIALS

4.1.SETTLEMENTS

The sample analysed within the scope of this research consists of cranial skeletal material coming from several sites located in different geographical regions of Anatolia (Fig.1) dated to a chronological span that from the Neolithic period goes up to the Post Medieval Age.

Figure 11. Geographical location of the studied sample

4.1.1. Hakemi Use

The first of these sites is Hakemi Use, located in southeaster Turkey, in the modern District of Bismil in the Diyarbakir Province. Hakemi Use is a mound settlement placed in the southern bank of an old bed of the Tigris River. It rises 544 m above sea level on a piece of land today cultivated as a cotton field (Tekin, 2013a, 2011a, 2009, 2008; Yakar, 2011). The investigation of this site began in 1980 with survey activities conducted by American researchers. Systematic excavations started in 2001 within the Salvage Project of the archaeological Heritage of the Ilisu Dam Reservoir (Tekin, 2011a, 2011b, 2009) under the direction of Prof. Halil Tekin from Hacettepe University. They were suspended between 2003 and 2004 and restarted in 2005 until 2012 (Tekin, 2013a). Hakemi Use consists of two adjacent settlements: Hakemi Use I on the west and

Hakemi Use II on the east of the former (Tekin, 2013a). The second mound, which due to agrarian activities lost its original height, has not been excavated yet. A total of 150 burials were found in the first mound. Tekin (2013a) proposed that the community occupying the second mound used the first as a cemetery.

The stratigraphy of Hakemi Use is characterized by four main phases (Tekin, 2011; Yakar, 2011): Medieval Age (represented exclusively by a graveyard), Late Assyrian Period (Early Iron Age, BC 1st millennium), Middle Assyrian Period (Late Bronze Age, BC 2nd millennium) and Hassuna/Samarra Period (Late Neolithic, BC 7th-6th millennium). Some architectures of the Assyrian phases were disturbed and partially destroyed by modern agricultural activities and by Medieval/Islamic burials. The main occupation phase was dated to the Late Neolithic Period (Hassuna-Samarra) (BC 6100-5950) and is represented by the superimposition of five levels (Tekin, 2013a, 2013b, 2011a, 2009; Yakar, 2011). The Hassuna/Samarra village was rather small (about 1,5 ha) and occupied by a community of farmers and animal herders (Tekin 2013b, 2011a; Yakar, 2011). After the Late Neolithic Period, the first village was deserted and occupied again during the second half of the BC 2nd millennium /Middle Bronze Age and abandoned after the Late Assyrian Period (BC 7th century) (Tekin, 2013b, 2011a, 2009).

Skeletal remains were studied by Prof. Yılmaz Selim Erdal from Hacettepe University. He studied 95 skeletons coming from 89 intramural graves (Erdal, 2013a), 86 of which were simple pits while 3 were cyst surrounded and covered by stone slabs. Eighty-four burials contained single inhumations, while 5 were multiple graves. Totally 77 inhumations were in primary deposition. Secondary depositions include 4 multiple burials and 3 isolated skulls. No differences were observed between skeletons orientation, age, sex, and stratigraphic levels (Erdal, 2013a). More than half of the inhumations consisted of infants (55 out of 95), while adults were represented by 40 individuals (12 male, 24 female and 6 unknown). According to the scholar (Erdal, 2013a), the small number of males may suggest a different place for their inhumation. He also proposed a social stratification depending on labour distribution and gender differences.

4.1.2. Değirmentepe

The site of Değirmentepe is also located in south-eastern Turkey, 50 m south of the Euphrates River and 24 km northeast of Malatya. Excavations started in 1978 and were carried out within the framework of the Middle East Technical University Lower Euphrates Project Rescue Excavation under the direction of Prof. Ufuk Esin from Istanbul University. Work ended in 1986 when the mound was submerged by the Karakaya dam lake. Occupational levels were dated to the Chalcolithic period up to the Medieval Age (1987, 1986a, 1986b, 1984, 1982, 1980, 1979). Human skeletal remains dated to this latter period were found in cysts, while those belonging to the Chalcolithic period were discovered under the floor of houses, into niches, in pits dug up into courtyards or within cylindrical vessels (Erdal & Özbek, 2010; Özbek, 1985). Anthropological analyses were conducted by Prof. Özbek (1985) and Prof. Ömür Dilek Erdal (Erdal & Özbek, 2010) from Hacettepe University. All individuals from the Chalcolithic layers were subadults while those of the Medieval Age were almost adults (Özbek, 2003, 1985). Anthropological analyses revealed a very high frequency of infant mortality, mostly caused by infection diseases probably due to chronic malnutrition, inadequate maternal care, or maternal infection diseases (Erdal & Özbek, 2010; Özbek, 1985).

4.1.3. İkiztepe

The settlement of Ikiztepe is located in the Black Sea region, 7 Km Northwest of the Brafa District in Samsun province. Systematic archaeological excavations began in 1974 under the direction of Prof. Bahadır Alkım and continued since 1981 by the Prof. Önder Bilgi. Although its name means “twin mounds”, the site was raised on four settlement mounds. It was first occupied during the Late Chalcolithic Period (Mound II) (Alkım et al., 1988). The successive occupations coincided with the Early Bronze Age I, II and III, and with the ‘Transitional’ or ‘Early Hittit Period’ (Early Middle Bronze Age) (Mound I, III and IV) (Bilgi, 1981). After a first phase of abandonment, the site was re-occupied in the Mound III during the Late Iron Age and the Hellenistic Period (Bilgi, 1990).

The Late Chalcolithic settlement is represented by eight architectural phases (Alkım, 1981; Bilgi, 1981). It was destroyed in its final phase (Level III, 1) and subsequently reoccupied during the EBAI (Level III, corresponding to the first occupation of the Mound I) and EBAII (Level I, Mound II) (Bilgi, 1984). At the beginning of EBAIII, while the settlement in the Mound II was abandoned, Mound I started to be used exclusively as an extramural cemetery (Bilgi 1984, 1981). Contemporary, an EBAIII settlement arose on Mound III.

Except for few pithos and pot burials dated to the successive Transitional Period, burials belonging to the EBAIII were of the simple pit type. A dromos tomb dated to the Hellenistic period was found on the north of the Mound I, immediately at the east of the EBAIII cemetery. A different distribution of burials according to sex and age was suggested. In fact, while adult males were found at the centre of the cemetery, women and children were discovered in the more peripheral areas (Erdal, 2010). Almost all the grave goods consisted of bronze objects, differently distributed according to the age and the sex of the buried individuals, generally ornaments for women and weapons for men (i.e., spearheads) (Doğan 2006; Backofen 1988; Bilgi 1985, 1984, 1981; Alkım 1981). The analysis conducted on 445 skulls showed single or multiple traumas on about 84 individuals. The frequency of injuries seems to increase with adulthood. The highest frequency was encountered in adult males (42%). Traumas, although not observed in infants, were recognized in four children as well. Traumas were the cause of death in 17 individuals (15 adult males, one child and one individual of unknown sex) (Y.S. Erdal & Ö.D. Erdal 2012; Erdal 2010). The presence of these traumas in adults was explained by suggesting some form of conflict (Erdal, 2010). According to Y.S. Erdal and Ö.D. Erdal (2012), İkiztepe represents one of the Anatolian sites characterized by the most ancient traces of organized violence.

4.1.4. Gordion

Gordion (modern Hassihöyük) is located in the central Anatolian plateau, nearly 65 km southwest of Ankara and in the vicinity of the Sakarya River (Rose, 2017). The site became famous as the capital of the Phrigyan kingdom during the BC 1st millennium. It was firstly identified by Körte in 1900 (Rose, 2017; Voight & Henrickson, 2000).

Archaeological excavations started in 1950 and continued until 1974 under the direction of Rodney Young from the University of Pennsylvania Museum. Voight and Sams directed the works between 1988 and 2006 (Rose, 2017; Voight, 1951). Last activities were conducted between 2013 and 2015 under the direction of Rose (2017). The life of the site covers a very long chronological span, from the Bronze Age to the Medieval one, represented by 10 successive occupation levels (Rose, 2017; Voight & Henrickson, 2000). The Citadel mound played the role of core of the settlement, flanked by the fortified Lower and Outer Towns (Rose, 2017; Genz, 2011). Around the settlement more than 120 tumuli, dated between the BC 9th and 6th centuries, were found. They were wooden tomb chambers without dromos (Rose, 2017) containing single burials with either inhumation or cremation and rich grave goods. Burials of common people instead were found in the cemeterial area (Genz, 2011). The central area of the citadel, located on the east side of the mound, was an elite quarter most probably with an administrative function. The quarter consisted of two courts, the Inner and the Outer, separated by a wall and accessible from a monumental gate. Both courts were flanked by megara. The so-called Terrace Building Complex was an area of textile production and grain processing, consisting in a central court with two long rows of buildings located at each side. It has been suggested that the mound was divided in two areas, separated by the so-called Inter mound street, between the Early and Middle Iron Age. It is with the reign of Midas (ca. BC 740-696) that the settlement reached its highest importance in Anatolia and beyond (Rose, 2017). Few anthropological investigations have been conducted on the human skeletal material discovered in different areas of the site (Selinsky, 2015; Prag, 1989).

4.1.5. Iznik

Nicaea, modern Iznik, is a small town located in north-western Turkey, 86 km Northeast of the Bursa Province, on the eastern bank of the Iznik Lake (Yalman, 1983). It was conquered by the Mysians under the name of Helikore. After the death of Alexander the Great, it was rebuilt by Antigonos Monophthalmos and named Antigoneia. After the defeat of Antigonos in the Battle of Ipsos in BC 310, the city was ruled by Lysimachos, who rebuilt it and gave the name of his daughter, Nikaia. With the death of Lysimachos in the Battle of Kurupedion in BC 281, Nikaia was conquered by the Bithynia kingdom. It became part of the Roman Empire in BC 74 (Yalman, 1983). It was one of the most important cities of the western Anatolia during both the Hellenistic and the Roman Periods (Erdal, 2006). It maintained important military and commercial functions for centuries because of its geographical position (Yalman, 1983). The excavation of the Amphitheatre, located in the southeast area of the district, began in 1980 and continued for 12 years under the direction of Bedri Yalman. It started to be constructed by Trajanus (98–117 AD), continued by Plinius and used as a cemetery during the Byzantine Period (Yalman, 1990, 1989, 1981). The skeletal remains of about 1000 individuals were found inside and outside the cavea, inside the church and in its narthex (Erdal, 2006, 1993).

Skeletal remains found inside the cavea, were both in anatomical position and disarticulated. Other skeletons instead were discovered in the so-called mass grave (Yalman 1989, 1988, 1986, 1985). All belonged to young and middle adult males (Yalman, 1986, 1985). Some individuals, dated to the Byzantine Emperor Theodor Laskaris, showed cranial traumas caused by combat (Yalman, 1990, 1986). Skeletal materials found outside the cavea consisted of individuals belonging to all age groups and to both the sexes (Erdal, 1993). According to Erdal (1993), individuals buried in the cavea were soldiers, while those discovered outside belonged to common people. Skeletal materials found in the area of the church and dated to the 13th century (Yalman, 1990) belonged both to adults (of both the sexes) and subadults.

4.1.6. Oluz Höyük

Oluz Höyük, also known as Yassı Höyük, Tepetarla Höyük or Gökhöyük, is located in the inland of the Black Sea Region in the Amasia province (Dönmez & Beyazıt, 2014). It was discovered during the surveys conducted in the Amasya Province between 1997 and 1999. Systematic excavations began in 2007 and continued until 2013 (Dönmez & Beyazıt, 2014). The settlement was consecutively occupied from the Early Bronze Age until the Middle and Post Medieval Ages. It was part of the Pontic Kingdom until BC 47 (Dönmez & Beyazıt, 2014). A cemetery of 115 graves, imposed on the Hellenistic and Persian layers and characterized by Islamic burial customs, was found at the top of the mound, and dated before the complete abandonment of the settlement. The cemetery was characterized by two levels, one occupied by burials of children, the other instead of adults. The graves were simple pits, externally indicated by tiles and flat stones. Tiles were found in three graves, likely belonging to the Late Roman or Early Byzantine Periods. According to the C14 dating performed on the bones of two skeletons, the cemetery dated back to BC 1075 and 1077, thus about 100 years later to the date of its abandonment. With the exception of bronze earrings and a bronze fibula found in the burial of a 6 year old girl, no architectural remains and artifacts were attributed to the BC 11th century. All this evidence was explained by the presence of Turkish nomad communities (Dönmez & Beyazıt, 2014).

4.1.7. Hagios Aberkios

Hagios Aberkios Monastery is located in the Kurşunlu village, in the district of Gemlik in the Bursa province. It is situated on the seashore between Gemlik and Mudanya. The church acquired the name of Hagios Haberkios in the 19th century. Although its existence was already dated to the 9th century, according to the dating (BC 1162) of the "typkon", the church was built during the empire of Manuel Komnenos by Nikephoros Mystikos, with the name of Altar of the Sun and dedicated to Theotokos. The excavation was conducted in 1995 by Prof. İhsan Tunay from İstanbul University (Özeren & Çorum, 1997). Human skeletal remains were found in different areas of the Monastery; the burial chamber, formed by a half-barrel-vaulted pit, was found very close to the southern wall of the naos; the burial pit, covered by a broken sarcophagus lid, was placed at the narthex entrance and probably used as cripta; the area outside the narthex. Skeletal remains of the first two areas were found scattered (Erdal, 2000). According to the results of the anthropological analysis conducted by Prof. Yılmaz Selim Erdal (2000), the MNI was 27 (with only 21 crania), two-thirds of which were represented by males.

4.1.8. Arslantepe

Arslantepe is a mound located in the municipality of Ördözü in the Malatya plain (Frangipane, 2012), about 12 km from the right bank of the Euphrates River. Its occupation began at least from the BC 6th millennium until the final destruction of the Neo-Hittite town by Sargon II of Assyria in the BC 712. On the western side of the Lions Gate, some architectural remains and clay cylinders were attributed to the Neo-Assyrian Age. After a period of abandonment, the site was reoccupied during the Late Roman Period and later used as a Byzantine/Medieval cemetery. The first excavation is dated to 1930 and was conducted on the upper part of the mound by Delaport. Investigations continue until nowadays under the direction of a team of the Sapienza University of Rome (Frangipane, 2012). Arslantepe life was diachronically influenced by the presence of different cultures such as Siro-Mesopotamians during the Late Chalcolithic period, Eastern Anatolians and Transcaucasians in the early BC 3rd millennium and Hittites during the BC 2nd millennium (Frangipane, 2012). At the top of the mound in the western area, a monumental building was dated to the Chalcolithic period and interpreted as an élite residence. The monumental Temple C was discovered close to this area. Burial types differed between age-groups and followed Neolithic funeral traditions (Erdal, 2013b; Frangipane, 2012). Burials of adult individuals were simple pits and were characterized by the presence of few grave goods. Small children and infants instead were buried in pots under the house's floor (Frangipane, 2008). In the successive Period VI A (Late Chalcolithic 5/Late Uruk, BC 3350-3000), along with the abandonment of the Temple C, a new architectural complex was used for various public activities (Frangipane, 2014, 2012). No burials have been dated to this chronological period (Frangipane, 2008). The destruction of the palace due to a fire and the construction of a defensive wall at the top of the mound reflects the political instability and crisis of the successive Period VI B (Early Bronze age, beginning of BC 3rd millennium). During Period VI B1, the élite building was abandoned while groups of nomadic pastoralists seasonally occupied its ruins (Frangipane, 2014; 2012; Frangipane et al., 2001). The palace was destroyed by a fire and a new phase of occupation started on the ruins of the previous palace complex at around BC 3000 (Frangipane, 2014, 2012; Frangipane et al, 2001). A new élite or administrative power seems to be established in Period VI B2 (Frangipane, 2012). The so-called Royal tomb was dated between the end of the Period VI A and the beginning of the Period VI B. The Royal tomb was a rectangular cist tomb, located outside the fortification wall, containing the skeletal remains of an adult male, accompanied by several grave goods, and the skeletons of two adolescents (a female and a probable male). Other two individuals, young females, were found outside the tomb in the area of the foot of the adult male. A form of sacrificial rite was proposed for this burial (Frangipane et al., 2001). Several human skeletal remains, dated to the Period VI B, were also found in a simple pit southeast to the cist tomb (Sepulture 216). They were accepted as secondary burials including the remains of 16 individuals, 12 adults (between 18 and 45 years of age) and four subadults. Eight out of 16 skulls presented perimortem traumas caused by blunt force weapons. According to Erdal (2013b), based on the simplicity of the burials and the presence of both male, female, and sub-adults, it is possible to suggest a massacre, most probably connected to the hostility between Mesopotamian and Transcausian groups.

4.1.9. Erzurum

The most recently analysed materials were selected from the skeletal remains found in the sites of Erzurum and Hakmehmet. Erzurum is a city of eastern Anatolia. Its archaeological excavation started in 1992 under the direction of the Erzurum Museum after the discovery of a mass grave during the opening of a water channel. A total of 62 individuals (adults of both the sexes), dated to the Medieval Age, were unearthed. Skeletal materials were analysed in the department of Anthropology of the Hacettepe University (Bilgin et al., 1994a, 1994b). Almost all the skulls were employed in the investigation on the biological distance of Anatolian populations by Prof. Eroğlu (2005) from Hacettepe University**.**

4.1.10. Hakmehmet

Hakmehmet is a village also located in the eastern Turkey and connected to the district of Merkez in the Iğdır province. Archaeological soundings were carried out in 1999.

The skeletal remains of 17 individuals (adults, both males and females) were discovered. The skulls of 14 individuals were analysed in 2005 by Prof. Eroğlu.

4.2.MATERIALS

A total of 589 cranial remains has been selected from the skeletal materials coming from the above-mentioned archaeological sites and hosted in the biological anthropology laboratory “Husbio_Lab" of Hacettepe University. Analysed materials are dated to different chronological periods: Late Neolithic (Hakemi Use), Chalcolithic (Değirmentepe), Late Chalcolithic/Early Bronze Age (Ikiztepe), Iron age (Gordion), Medieval (Oluz Höyük, Hagios Aberkios and Arslantepe), and Post Medieval (Erzurum and Hakmehmet) (Table 1).

Table 1. Sample distribution

Site	Chronological Period	Total
Hakemi Use	Late Neolithic	126
Değirmentepe	Chalcolithic	30
İkiztepe	Late Chalcolithic/ Early Bronze Age	60
Gordion	Iron Age	2
İznik	Medieval	89
Oluz Höyük	Medieval	95
Hagios Aberkios	Medieval	16
Arslantepe	Medieval	143
Erzurum	Post Medieval	18
Hakmehmet	Post Medieval	10
Total		589

4.2.1. Hakemi Use

A total of 126 cranial remains has been selected from the skeletal remains coming from the site of Hakemi Use and dated to the Late Neolithic period. The sample consists of 61 subadults (48,4%) and 65 adults (51,6%) (Table 2). Subadults include five foetuses (8,2%), 30 infants (49,2%) and 25 children (42,6%). Sex has been estimated in 57 adults (87,7%) while remaining unknown in the 12,3% (n:8) (Table 2). Female frequency is more than twice as much as males. Sex groups consists of 18 males (27,7%) and 39 females (60%) (Table 2).

Table 2. Age and sex distribution of the sample from Hakemi Use

	Subadult		**Male**		**Female**		**Unknown**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	61	48,4	-	-	-	-	-	-
Adult	65	51,6	18	27,7	39	60,0	8	12,3
Total	**126**	**100,0**	**18**	**14,3**	**39**	**30,9**	**8**	**6,3**

4.2.2. Değirmentepe

A total of 30 cranial remains has been analysed from the skeletal material coming from the site of Değirmentepe and dated to the Chalcolithic period. All the examples belong to subadults (Table 3). More than half consists of infants (63,3%, n:19), while the 23,3% (n: 7) is represented by children and the 12,9% (n:4) by foetuses.

Table 3. Age and sex distribution of the sample from Değirmentepe

	Subadult		**Male**		**Female**		**Unknown**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	30	100,0	-	-	-	-	-	-
Adult	0	0,0	0	0,0	0	0,0	0	0,0
Total	**30**	**100,0**	**0**	**0,0**	**0**	**0,0**	**0**	**0,0**

4.2.3. İkiztepe

A total of 60 cranial remains has been selected from the skeletal materials coming from İkiztepe and dated to the Late Chalcolithic Period/Early Bronze Age. More than half (56,7%, n:36) consists of adults, while the 43,3% (n:26) is represented by subadults (Table 4). Subadults include seven infants (11,7%) and 19 children (11,7%). Sex distribution is about equal with 18 males (52,9 %) and 16 females (47,1%) (Table 4).

Table 4. Age and sex distribution of the sample from İkiztepe

	Subadult		**Male**		**Female**		**Unknown**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	26	43,3	-	-	-	-	-	-
Adult	34	56,7	18	52,9	16	47,1	0	0,0
Total	**60**	**100,0**	**18**	**30,0**	**16**	**26,7**	**0**	**0,0**

4.2.4. Gordion

Only two crania, dated to the Iron Age, have been analysed from Gordion. They belong to an adult female and a subadult (child) (Table 5).

Table 5. Age and sex distribution of the sample from Gordion

	Subadult		Male		Female		Unknown	
	n	%	n	%	n	%	n	%
Subadult	1	50,0	-	-	-	-	-	-
Adult	1	50,0	0	0,0	1	100,0	0	0,0
Total	**2**	**100,0**	**0**	**0,0**	**1**	**50,0**	**0**	**0,0**

4.2.5. İznik

A total of 89 cranial remains has been selected from the site of İznik. Sample is dated to the Medieval Age. Adults represent 88,8% (n:79) of the sample, while 10 individuals (11,2%) are subadults (Table 6). These latter include two foetuses (20%), five infants (50%) and three children (30%). Almost all the adults (86,1%, n:68) belong to males, while 11,4% (n:9) to females. Sex has not been estimated in 2,5% (n:2) of cases (Table 6).

Table 6. Age and sex distribution of the sample from İznik

	Subadult		Male		Female		Unknown	
	n	%	n	%	n	%	n	%
Subadult	10	11,2	-	-	-	-	-	-
Adult	79	88,8	68	86,1	9	11,4	2	2,5
Total	**89**	**100,0**	**68**	**76,4**	**9**	**10,1**	**2**	**2,2**

4.2.6. Oluz Höyük

A total of 95 cranial remains has been selected from the skeletal material of Oluz Höyük, dated to the Medieval Age. Subadults represent 71,6% of the sample, while 27 individuals (28,4%) are adults (Table 7). Age remains unestimated only in 1,5% (n:1) of the cases (Table 7). Subadults include seven foetuses (10,3%), 44 infants (64,7%) and 16 children (23,5%). Sex ratio is about equal with the presence of 13 males (48,1%) and 14 females (51,8%) (Table 7).

Table 7. Age and sex distribution of the sample from Oluz Höyük

	Subadult		Male		Female		Unknown	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	69	71,6	-	-	-	-	-	-
Adult	27	28,4	13	48,1	14	51,8	0	0,0
Total	**95**	**100,0**	**13**	**13,7**	**14**	**14,7**	**0**	**0,0**

4.2.7. Hagios Haberkios

A total of 16 cranial remains has been selected from Hagios Haberkios. The sample is exclusively represented by adults (Table 8) including 14 males (87,5%) and two females (12,5%) (Table 8).

Table 8. Age and sex distribution of the sample from Hagios Haberkios

	Subadult		Male		Female		Unknown	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	0	0,0	-	-	-	-	-	-
Adult	16	100,0	14	87,5	2	12,5	0	0,0
Total	**16**	**100,0**	**14**	**87,5**	**2**	**12,5**	**0**	**0,0**

4.2.8. Arslantepe

A total of 143 crania and skulls has been selected from the Medieval material found at Arslantepe. Subadults represent 63,6% (n:91) of the sample, while 36,4% (n:52) are adults (Table 9). Subadults included four foetuses (4,4%), 45 infants (49,5%) and 42 children (46,1%). Sex ratio is about equal, with 48,1% (n:25) of males and 44,2% (n:23) of females (Table 10). Sex remains unestimated in 7,7% (n:4) of adults (Table 10).

Table 9. Age and sex distribution of the sample from Arslantepe

	Subadult		Male		Female		Unknown	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	91	63,6	-	-	-	-	-	-
Adult	52	36,4	25	48,1	23	44,2	4	7,7
Total	**143**	**100,0**	**25**	**17,5**	**23**	**16,1**	**4**	**2,8**

4.2.9. Erzurum

A total of 18 crania dated to the Post medieval age have been selected from the skeletal material found at Erzurum. Sample includes only adults (Table 10), mostly consisting of males (77,8%, n:14), while females represent only 22,2% (Table 10).

Table 10. Age and sex distribution of the sample from Erzurum

	Subadult		**Male**		**Female**		**Unknown**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	0	0,0	-	-	-	-	-	-
Adult	18	100,0	14	77,8	4	22,2	0	0,0
Total	**18**	**100,0**	**14**	**77,8**	**4**	**22,2**	**0**	**0,0**

4.2.10. Hakmehmet

A total of 10 crania was selected from Hakmehmet. Like Erzurum, the sample exclusively includes adults, more than half of which are males (60%, n:6) (Table 11).

Table 11. Age and sex distribution of the sample from Hakmehmet

	Subadult		**Male**		**Female**		**Unknown**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Subadult	0	0,0	-	-	-	-	-	-
Adult	10	100,0	6	60,0	4	40,0	0	0,0
Total	**10**	**100,0**	**6**	**60,0**	**4**	**40,0**	**0**	**0,0**

CHAPTER 5
RESULTS

5.1. SELECTION OF A CRANIUM OR ITS COMPONENTS FOR THE INTERPRETATION OF INTENTIONAL HEADSHAPING IN ANATOLIA

One of the most important issues related to the study of human skeletal materials coming from archaeological contexts is doubtless their preservation. In fact, bio-archaeologists must deal with the problem of the missing data (Buikstra, Ubelaker, 1994; Mays, 2010), which has represented an important matter in this work as well. Except for İkiztepe and İznik, where respectively 700 and 1000 skeletons were found, almost all the skeletal remains coming from the other archaeological contexts have been inspected. They consist of 200 individuals from Hakemi Use and Arslantepe, 31 from Değirmentepe, 100 from Oluz Höyük, 21 from Hagios Aberkios, 62 from Erzurum and 17 from Hakmehmet. Although examples without skulls/crania were present, they were not considered due to their bad preservation conditions caused by excavation related or post depositional damages. If on one hand the examples from settlements with a high number of individuals have been analysed as much as the sample could be represented, on the other examples coming from sites with a low number of individuals have been almost entirely investigated. A total of 589 individuals, characterised by the presence of any cranial remains, was selected (Table 12). After their restoration, 112 examples were excluded from the analysis because not suitable for the investigation. In fact, due to their bad preservation conditions, the identification of any of the most discriminant morphological features of circular and tabular headshaping were not possible.

After this first skimming, a total of 477 crania was considered for circular, tabular, and composite headshaping. Among them, 391 cranial remains have been analysed for circular modification, 364 for tabular and 252 for composite (Table 12). The presence of any morphological modification has been recognized in 53,2% (n:254) of the sample, while it has been not determined in 34 cases because two out of three headshaping types remained unobserved while the other one was absent. Almost all the sites are characterised by the presence of at least one type. Tabular headshaping is the most frequently observed (34,1%), followed by composite (25%) and circular (17,1%) types

(Table 12). By considering the distribution of each headshaping type among the different sites, it is possible to state that the highest frequency of circular headshaping occurs at Gordion (100%). Nevertheless, it must be considered that only two selected skulls are present. Thus, apart from Gordion, circular headshaping reaches the highest frequency at Değirmentepe and Hakemi Use (60,9% and 58%, respectively) (Table 12). Conversely, the lowest rate is observed at İznik and Oluz Höyük (1,3% and 1,4, respectively). Tabular headshaping is most frequently observed at Erzurum (94,1%) and Arslantepe (77,6%), while İkiztepe shows the lowest rate (3,4%) (Table 12). Composite headshaping instead is characterised by the highest frequency at Arslantepe (86,4%), while the lowest incidence is observed at İznik (1,9%) (Table 12).

Chi-squared and Monte Carlo tests show that a statistically significant relationship exists between headshaping types and investigated archaeological sites (p:<0,05) (Table1).

Table 12. Modification presence and distribution of circular, tabular, and composite headshaping according to the different archaeological sites

	Circular[1]		**Tabular[2]**		**Composite[3]**		**Modification Presence[4]**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Hakemi Use	50	58,0	31	6,5	20	25,0	51	70,6
Değirmentepe	23	60,9	17	0,0	9	22,2	23	69,6
İkiztepe	58	10,3	59	3,4	50	0,0	58	13,8
Gordion	2	100,0	2	0,0	0	0,0	2	100,0
İznik	76	1,3	81	28,4	54	1,9	78	32,1
Oluz Höyük	72	1,4	65	30,8	43	4,7	64	35,9
Hagios Aberkios	15	13,3	15	40,0	8	12,5	16	56,3
Arslantepe	68	17,6	67	77,6	59	86,4	123	93,5
Erzurum	17	0,0	17	94,1	2	50,0	18	94,4
Hakmehmet	10	0,0	10	30,0	7	0,0	10	30,0
Total	**391**	**17,1**	**364**	**34,1**	**252**	**25,0**	**443**	**57,3**

[1] χ^2:133,056; df:9; p:0,000
[2] χ^2:146,521; df:9; p:0,000 (Monte Carlo Test)
[3] χ^2:164,084; df:8; p:0,000
[4] χ^2:185,454; df:9; p:0,000 (Monte Carlo Test)

5.1.1. Craniometric characteristics of intentionally shaped and unshaped crania

The descriptive analysis of craniometrics of both shaped and unmodified crania shown in Table 13 displays high standard deviations for almost all the measurements. This condition depends on the presence of different age groups, both subadult and adult.

As well known, cranium is a plastic organ consisting of functional components that allow it to adapt to every stage of both prenatal and postnatal life (Scheuer, Black, 2000; Moss et al., 1940). Although the first three years of infant life correspond to the faster phase of the cranial development (Scheuer & Black, 2000; Davenport, 1940), this process continues until adulthood as well despite at a more reduced rate (Lewis & Roche, 1988). It is for this reason that statistical analyses on craniometrics have been exclusively conducted on data of adult individuals whose cranial growth is almost completed.

One-way ANOVA has revealed that mean differences of some cranial measurements (frontal, parietal, and occipital subtenses, parietal and occipital chords, bregma subtense fraction, pterion-lambda length, foramen magnum length, least exterior breadth across the roots of the zygomatic processes, maximum cranial length and breadth, basal length, obelion-inion arc and left porion-bregma height) are statistically significant in presence of intentional headshaping (p<0,05) (Table 13). With the aim of better understanding which measurements are particularly affected by headshaping types and their patterns of change, statistical analysis on cranial measurements has been also conducted according to each headshaping type individually.

Table 13. Descriptive analysis and Anova on all cranial measurements according to the presence of modification without age differentiation

			Absent				Present				F	
		N	**n**	$\bar{x}$	**s**	**w**	**n**	$\bar{x}$	**s**	**w**	**F**	***p***
Frontal	**Max.Fr. Breadth**	240	106	115,47	14,28525	68,00-137,00	134	117,46	10,92	75,00-140,00	1,495	0,223
	Min. Fr. Breadth	273	118	90,94	13,49650	53,00-111,00	155	91,26	9,58	62,00-111,50	0,050	0,831^
	Bisteph. Breadth	260	117	109,99	16,68793	61,00-133,50	143	111,85	12,29	70,00-132,50	1,070	0,302
	Fr. Arc	345	161	115,32	23,15608	46,00-143,00	184	115,07	14,59	16,00-143,00	0,015	0,905^
	Fr. chord	350	160	100,32	20,05051	42,00-122,50	190	101,53	11,02	64,00-124,00	0,514	0,494^
	Fr. Subtense	237	109	25,90	2,95685	14,50-33,50	128	23,09	3,38	15,50-32,00	45,343	0,000
	Nas. Subt. Fract.	239	110	49,45	4,96969	25,00-61,00	129	48,30	5,02	36,00-64,00	3,156	0,077
Parietal	**Par. Arc**	369	161	119,72	15,89968	70,00-147,00	208	117,71	10,19	86,00-149,00	2,177	0,163^
	Par. chord	374	164	106,75	14,52103	63,00-130,50	210	101,54	9,47	75,00-125,00	17,553	0,000^
	Par. Subtense	264	118	23,77	3,68097	12,50-32,00	146	24,89	3,62	12,00-35,00	6,133	0,014
	Br. Subt. Fract.	264	118	57,12	5,38603	40,00-71,00	146	54,51	5,34	38,00-73,00	15,479	0,000
	Pt.- Lamb. length	326	139	132,83	18,05128	74,50-163,50	187	128,02	11,29	91,50-151,00	8,716	0,006^
	Ast.- Br. length	347	148	129,41	17,62488	70,00-151,00	199	127,76	11,94	85,00-151,50	1,082	0,299
	Ast.- Pt. length	311	132	90,59	13,81628	48,00-110,00	179	87,97	11,40	50,00-108,50	3,346	0,068
Occipital	**Occ. Arc**	326	139	104,43	22,07148	43,00-138,00	187	107,14	10,97	72,00-140,00	2,106	0,186^
	Occ. chord	330	140	86,58	16,70117	40,00-111,00	190	90,98	8,19	65,00-115,00	9,913	0,002
	Occ. Subtense	246	95	28,23	9,81797	18,00-92,00	151	23,81	6,68	16,00-91,00	17,612	0,000
	Lamb. Subt. Fract.	246	95	48,42	8,64272	17,00-65,00	151	49,33	9,25	22,00-79,00	0,586	0,445
	Biast. Breadth	306	131	104,40	16,87170	53,00-125,00	175	105,07	9,29	68,00-124,00	0,198	0,681^
	For. Mag. length	170	66	36,23	2,20876	32,00-42,00	104	35,27	2,89	28,00-42,00	5,243	0,023
	For. Mag. Breadth	167	63	30,53	2,22214	26,00-35,00	104	29,95	2,73	19,00-36,00	2,048	0,154
Temporal	**Zyg. Proc. Breadth**	201	84	120,45	6,93195	100,00-136,00	117	116,71	11,34	85,00-137,00	7,191	0,004^
Cranium	**Max. length**	308	138	174,98	20,83590	103,50-204,00	170	163,09	15,71	112,50-194,00	32,563	0,000
	Max. Breadth	283	123	135,54	15,50132	79,00-159,00	160	140,49	10,41	96,00-166,00	10,276	0,002
	Height (Ba-B)	175	72	131,92	6,74362	112,00-142,00	103	129,80	9,57	85,00-151,00	2,627	0,107
	Basal length	170	71	99,28	6,20238	79,00-120,00	99	96,20	8,72	69,00-126,00	6,473	0,012
	Ob.- In. Arc	343	143	105,91	14,93609	56,00-130,00	200	101,08	11,40	70,00-128,00	11,533	0,001^
	Ob.- In. chord	344	145	92,73	13,74129	50,00-116,00	199	92,24	9,74	51,00-114,00	0,150	0,699^
	R. Por.- Br. Height	240	102	125,05	8,25590	78,00-140,00	138	123,52	8,77	100,00-138,50	1,884	0,171
	L. Por.- Br. Height	240	102	125,65	6,22705	107,00-139,00	138	122,57	9,01	91,00-138,00	8,781	0,002^

^Welch Test

5.1.1.1.Circular headshaping

The statistical analysis conducted on craniometric alterations caused by circular headshaping in adult individuals has revealed that a great number of measurements decreased in both the groups (Table 14). Nevertheless, despite the general similarities between the two groups, some metrics show differences in patterns and degrees of alteration.

By considering sexes individually, it is possible to state that, apart from frontal and occipital chords and pterion-lambda and foramen magnum lengths that increase in shaped males, all the remaining craniometrics decrease (Table 14). Frontal and occipital regions show the highest percentages of alterations (Table 14). The most significant variations of frontal measurements regard the decrease of frontal subtense (-30,4%) and nasion subtense fraction (-13%) (Table 14). Compared to the development in length of this cranial region (frontal chord 1%), maximum (-5,4%), minimum (-3%) and bistephanic (-6,2%) breadths show an evident decrease (Table 14). The highest percentages of metric alterations observed in the occipital region instead regard the decrease of occipital subtense (-23,8%), biasterionic breadth (-4,6%) and lambda subtense fraction (-4,4%), as well as the increase of foramen magnum length (12,7%) (Table 14). Nevertheless, for this latter variable, it must be considered that only one shaped cranium has been taken into account. Differently, foramen magnum breadth slightly reduces (-2,1%) (Table 14). The most prominent metric changes observed in the parietal region concern the reduction of asterion-bregma length (-5,1%), parietal chord (-3,8%) and asterion-pterion length (-3,5%), while pterion-lambda length slightly increases (1,7%) (Table 14). All the other cranial measurements decrease by showing the highest rates of alteration in basion-bregma height (-9,3%) and basal length (-7,9%) (Table 14). Nevertheless, the availability of only one example for these measurements makes these results not reliable. Changes in maximum cranial height are also reflected in the decrease of both left and right porion-bregma height (-4,7% and -2,2%, respectively).

Based on the present data, it seems that circularly shaped crania of adult males slightly antero-posteriorly shorten, narrow and lower compared to the unmodified ones. Their antero-posterior reduction is indicated not only by the decrease of maximum cranial length (-1,4%) but also by the reduction of asterion-bregma (-5,1%) and asterion-pterion lengths (-3,5%), by the antero-posterior contraction of the parietals (chord: -3,8%, arc -2,5%), as well as by the flattening of the occipital bone, also reflected in the severe reduction of its subtense (-23,8%), in the decrease of its arc (-3%) as well as in the increase of its chord (2,7%) (Table 14). Nevertheless, the slight increase of pterion-lambda length (1,7%) together with the decrease of both asterion-bregma and asterion-pterion lengths suggest a slight antero-postero/superior elongation of the cranial vault of this shaped group. Cranial narrowing instead, beyond the reduction of maximum cranial breadth (-2,3%), is also suggested by the decrease of the least exterior breadth across the roots of the zygomatic processes (-4,4%) as well as by the evident decrease of the breadth-related measurements of the frontal (maximum -5,4%, bistephanic -6,2%) and occipital (biasterionic -4,6%) bones (Table 14).

Univariate Analysis of Variance shows that frontal subtense (*p*:0,008) and Asterion-Bregma length (*p*:0,039) are characterised by statistically significant mean differences ($p<0,05$) between shaped and unmodified male crania (Table 14). Nevertheless, according to One-way Manova, the covariance of all the metric variables between the two groups is not statistically significant ($p<0,05$) (Pillai's Trace Test: F(30-118)= 1,275; *p*:0,180) (Table 14).

In shaped females instead, although about two-thirds of measurements decrease, a major number of metrics show an increase compared to the shaped males. In general, it can be stated that the highest percentages of changes have been observed in the parietal and occipital regions (Table 14). In the former, subtense (-11,7%) and bregma subtense fraction (-10,9%) show the most evident decrease followed by asterion-pterion (-5,8%) and asterion-bregma lengths (-3,9%), pterion-lambda length instead evidently develops (6,2%). The very slight increase of the parietal arc (0,5%) as well as the very slight decrease of the chord (-0,4%) appear almost irrelevant (Table 14). In the occipital region, all the metrics show very high percentages of changes; in particular, occipital subtense (-14,2%), foramen magnum length (-9,6%) and breadth (-7,9%), and biasterionic breadth (-7,5%) evidently decrease, while occipital chord (7,7%) lambda subtense fraction (6,5%) and occipital arc (4,6%) increase (Table 14). The most significant metric alterations observed in the frontal region regard the decrease of subtense (-8%) and nasion subtense fraction (-5,8%) (Table 14). Compared to the increase of frontal length (chord 3,2%), the alterations of the breadth-related frontal measurements, such as maximum (-2,8%) and bistephanic breadths (-1,2%) are less prominent (Table 14). Metric changes of minimum frontal breadth are almost indiscernible (0,04%) (Table 14). Among the other cranial measurements, significant alterations are observed in right porion-bregma height (-6,1%), basal length (-5,1%), and maximum cranial breadth (-4,6%). Contrary to males, maximum cranial length of shaped females increases (2,7%) (Table 14).

Based on these data, it can be stated that circularly shaped crania of female individuals are longer and quite narrower than unmodified female crania and shaped male crania, as well as lower than unmodified female crania but slightly higher than shaped male individuals. Compared to their antero-posterior elongation, medio-lateral narrowing is more evident (Table 14). Like in males, the reduction of maximum cranial width (-4,6%) is also reflected in the decrease of both frontal and occipital breadths (frontal maximum -2,8%, bistephanic breadths -1,2% and biasterionic breadth -7,5%) as well as in the reduction of the least exterior breadth across the roots of the zygomatic processes (-4,4%) (Table 14). Similarly to males but with a major degree of development, cranial vault antero-posterior/superiorly develops as suggested by the pronounced development of pterion-lambda length (6,2%) and the reduction of asterion-bregma (-3,9%) and asterion-pterion (-5,8%) lengths (Table 14). The elongation of both frontal and occipital (chord: 3,6% and 7,7%, respectively) (Table 14) also contribute to this postero-superior elongation of the cranial vault. Compared to males, the more evident increase of frontal chord (3,2%) and arc (1,2%) as well as the slighter decrease of frontal subtense (-8%) suggest a more evident elongation and a lesser flattening of this cranial region. Similarly, the more evident increase in length of occipital (chord: 7,7%) together with the lower decrease of its subtense (-14,2%) suggest a more evident elongation and a lesser flattening of this cranial region compared to shaped males (Table 14).

Univariate Analysis of Variance show that the most relevant statistical differences ($p<0,05$) between unmodified and shaped female crania regard pterion-lambda (*p*: 0,002) and asterion-pterion lengths (*p*: 0,050), occipital chord (*p*: 0,007), foramen magnum length (*p*: 0,017) and maximum cranial breadth (*p*: 0,017) (Table 14). One-way Manova confirms that the differences in mean between shaped and unmodified crania on a combination of dependent variables are statistically significant in female individuals (Pillai's Trace Test: F (30-39) = 2,791; *p*: 0,001) (Table 14).

Table 14. One-way Manova and Anova on cranial measurements of circularly shaped and unmodified crania of adult males and females

		Male*											Female**										
		Absent				Present			δ		F		Absent				Present			δ		F	
		N	n	x̄	s	n	x̄	s	δ	%	F	*p*	N	n	x̄	s	n	x̄	s	δ	%	F	*p*
Frontal	**Max.Fr. Breadth**	111	108	123,04	6,53	3	116,33	6,65	-6,71	-5,4	2,885	0,092	46	43	119,01	6,32	3	115,66	0,57	-3,35	-2,8	3,598	0,062
	Min. Fr. Breadth	115	112	97,81	4,51	3	94,83	6,17	-2,98	-3,0	1,231	0,269	52	49	95,27	5,44	3	95,66	6,11	0,39	0,04	0,349	0,557
	Bisteph. Breadth	117	114	118,99	6,42	3	111,50	6,26	-7,49	-6,2	3,770	0,054	48	45	114,92	7,58	3	113,50	2,29	-1,42	-1,2	1,387	0,243
	Fr. Arc	133	130	126,68	7,12	3	124,16	16,40	-2,52	-1,9	0,347	0,810^	62	58	123,13	6,14	4	124,62	4,46	1,49	1,2	0,571	0,452
	Fr. chord	132	129	110,85	5,55	3	112,00	10,81	1,13	1,0	0,127	0,722	63	59	108,33	4,63	4	111,87	3,75	3,54	3,2	3,573	0,063
	Fr. Subtense	116	114	25,16	3,20	2	17,50	2,12	-7,66	-30,4	7,257	0,008	50	46	24,75	3,23	4	22,75	2,98	-2,00	-8,0	1,890	0,174
	Nas. Subt. Fract.	118	116	51,18	3,82	2	44,50	4,94	-6,68	-13,0	2,054	0,154	50	46	50,16	3,22	4	47,25	4,36	-2,91	-5,8	3,539	0,064
Parietal	**Par. Arc**	141	138	125,20	9,25	3	122,00	10,58	-3,20	-2,5	0,323	0,571	60	56	120,41	6,77	4	121,00	11,88	0,59	0,5	0,172	0,679
	Par. chord	142	139	111,07	7,67	3	106,83	8,12	-4,24	-3,8	0,822	0,366	59	55	107,37	6,35	4	106,87	10,28	-0,50	-0,4	0,000	0,985
	Par. Subtense	131	128	24,74	3,59	3	24,33	2,88	-0,41	-1,6	0,020	0,887	49	47	23,24	3,51	2	20,50	2,12	-2,74	-11,7	0,283	0,596
	Br. Subt. Fract.	131	128	56,29	5,41	3	56,00	8,18	-0,29	-0,5	0,008	0,930	49	47	55,05	4,64	2	49,00	2,82	-6,05	-10,9	0,133	0,717
	Pt.- Lamb. length	133	130	138,85	6,61	3	141,33	9,07	2,48	1,7	0,406	0,525	52	48	135,54	6,06	4	144,00	7,70	8,46	6,2	10,384	0,002
	Ast.-Br. length	137	134	137,73	5,14	3	130,33	5,13	-7,00	-5,1	4,332	0,039	61	56	131,58	7,83	5	126,40	2,38	-5,18	-3,9	2,135	0,149
	Ast.-Pt. length	129	126	97,80	4,75	3	94,33	5,13	-3,47	-3,5	1,197	0,276	56	52	93,75	4,86	4	88,25	6,65	-5,50	-5,8	3,989	0,050
Occipital	**Occ. Arc**	121	118	115,84	8,86	3	112,33	3,51	-3,51	-3,0	0,374	0,542	51	47	111,12	8,80	4	116,25	6,55	5,13	4,6	1,991	0,163
	Occ. chord	122	119	95,68	6,69	3	98,33	4,04	2,65	2,7	0,644	0,424	51	47	92,56	5,17	4	99,75	6,19	7,19	7,7	7,723	0,007
	Occ. Subtense	115	112	28,01	9,23	3	21,33	2,08	-6,68	-23,8	1,578	0,211	45	42	26,23	10,42	3	22,50	4,92	-3,73	-14,2	0,511	0,477
	Lamb. Subt. Fract.	115	112	53,40	8,81	3	51,00	6,24	-2,40	-4,4	0,123	0,726	45	42	45,97	9,07	3	49,00	12,52	3,03	6,5	0,568	0,454
	Biast. Breadth	130	127	111,91	5,09	3	106,66	2,08	-5,25	-4,6	1,895	0,171	52	50	107,39	5,22	2	99,25	1,06	-8,14	-7,5	1,411	0,239
	For. Mag. length	91	90	36,37	2,53	1	41,00	-	4,63	12,7	1,669	0,198	39	36	35,61	2,85	3	32,16	0,76	-3,45	-9,6	6,001	0,017
	For. Mag. Breadth	88	86	31,16	2,09	2	30,50	3,53	-0,66	-2,1	0,022	0,882	37	34	30,05	2,21	3	27,66	3,78	-2,39	-7,9	1,253	0,519^
Temporal	**Zyg. Proc. Breadth**	105	103	124,04	5,44	2	118,50	0,70	-5,54	-4,4	0,961	0,329	43	40	117,87	5,08	3	115,33	3,78	-2,54	-2,1	0,526	0,471
Cranium	**Max. length**	132	129	180,23	8,32	3	177,66	9,71	-2,57	-1,4	0,232	0,631	55	51	174,36	9,17	4	179,12	13,11	4,76	2,7	2,050	0,157
	Max. Breadth	124	121	144,28	7,31	3	140,83	2,92	-3,45	-2,3	0,496	0,483	56	52	139,61	6,73	4	133,25	2,50	-6,36	-4,6	5,933	0,017
	Height (Ba-B)	99	98	134,51	5,71	1	122,00	-	-12,51	-9,3	0,048	0,827	40	37	128,56	5,78	3	126,33	4,72	-2,23	-1,7	0,224	0,637
	Basal length	95	94	100,52	4,78	1	92,50	-	-8,02	-7,9	0,258	0,613	39	36	97,65	4,07	3	92,66	7,52	-5,00	-5,1	0,014	0,906
	Ob.- In. Arc	138	135	108,83	9,10	3	108,33	14,46	-0,50	-0,4	0,000	0,985	57	53	105,45	9,86	4	106,50	8,96	1,05	0,9	0,331	0,567
	Ob.- In. chord	140	137	97,89	8,59	3	96,83	10,61	-1,06	-1,0	0,027	0,869	57	53	93,40	8,13	4	92,00	4,08	-1,40	-1,4	0,001	0,970
	R. Por.- Br. Height	118	115	128,95	4,45	3	126,00	6,55	-2,95	-2,2	0,587	0,445	52	49	123,59	5,64	3	116,00	12,67	-7,59	-6,1	2,630	0,109
	Br. Height	120	118	128,63	4,53	2	122,50	3,53	-6,13	-4,7	1,091	0,298	49	45	123,87	4,21	4	119,62	12,27	-4,25	-3,4	1,642	0,406^

* Pillai's Trace Test: F(30-118)= 1,275; *p*>0,180

** Pillai's Trace Test: F(30-39)= 2,791; *p*>0,001

^Welch Test

5.1.1.2.Tabular headshaping

Unlike circular headshaping, a higher number of measurements increases when affected by tabular headshaping (Table 15). Craniometrics changes are almost recognizable in all the cranial regions and with a similar pattern between the two sexes (Table 15). By considering each cranial region individually, it is possible to observe that the most evident alterations occurring in the frontal region of shaped males regard the decrease of subtense (-3,6%), arc (-1,8%) and chord (-1,4%), and the increase of maximum and bistephanic breadths (2,7% and 2,6%, respectively) (Table 15). In the parietal region instead, the most relevant alterations concern the decrease of chord (-5,6%), bregma subtense fraction (-4,7%) and pterion-lambda length (-4,6%) (Table 15). Except the slight increase of asterion-pterion length (1,1%), the development of parietal subtense (0,6%) and asterion-bregma length (0,2%) are almost indiscernible (Table 15). In the occipital region, the highest percentage of increased measurements is observed in biasterionic breadth (0,06%) and lambda subtense fraction (4,9%), while occipital subtense (-4,8%) and occipital arc (-3%) show the highest percentages of decrease (Table 15). Foramen magnum is characterized by a slight development in breadth (1,2%) and an imperceptible increase in length (0,3%) (Table 15). Among cranium measurements, the most evident changes regard the decrease of maximum length (-4,9%) and obelion-inion arc (-3,3%), and the increase of cranial height (4,5%) and maximum breadth (3,9%) (Table 15).

According to these data, it is possible to suggest that crania of tabularly shaped males are characterised by an evident antero-posterior shortening and a biparietal and infero-superior development. The decrease of cranial length is also well reflected in the flattening of the posterior portion of the cranium including both the posterior area of the parietals and the occipital as well as by the contraction of the parietals. In fact, the evident reduction of parietal chord (-5,6%), arc (-3,4%), bregma subtense fraction (-4,7%), pterion-lambda length (-4,6%), occipital arc (-3%), chord (-2,4%) and subtense (-4,8%) as well as the reduction of obelion-union arc (-3,3%) and the very slight increase of its chord (0,09%) (Table 15), all indicate a flattening of the rear of the cranium. The development of cranial breadth instead is also indicated by the very slight increase of asterion-bregma length (0,2%), minimum, maximum and bistephanic frontal breadths (0,5%, 2,7% and 2,6%, respectively) as well as by the least exterior breadth across the roots of the zygomatic processes (1,7%) (Table 15). The effects on height are reflected in the development of right (1,2%) and left (0,4%) porion-bregma heights (Table 15).

According to the results of ANOVA, alterations of maximum (*p*:0,000) and bistephanic frontal breadths (*p*:0,001), parietal arc (*p*:0,003) and chord (*p*:0,000), bregma subtense fraction (*p*:0,006), pterion-lambda length (*p*:0,000), occipital arc (*p*:0,027), lambda subtense fraction (*p*:0,015), least exterior breadth across the roots of the zygomatic processes (*p*:0,001), maximum cranial length (*p*:0,000) and breadth (*p*:0,000), obelion-union arc (*p*:0,030) and right portion-bregma height (*p*:0,034) show statistically significant mean differences ($p<0,05$) between shaped and unmodified crania of male individuals (Table 15). One-way Manova confirms that the differences in mean between shaped and unmodified crania on a combination of dependent variables are statistically significant in males (Wilks' Lambda: F(30-121)= 3,666; $p>0,000$) (Table 15).

Craniometric alterations in shaped females are evident in all the cranial regions as well. Contrary to shaped males the number of increased measurements is lower, nevertheless, similarly, the most relevant metric variations occurring in the frontal region regard the decrease of its subtense (-13,7%) and arc (-4,3%) as well as the increase of bistephanic (3,7%) and maximum breadth (2,4%) (Table 15). The highest percentages of changes in the parietal region instead regard the decrease of its chord (-6,1%) and arc (-3,7%), of pterion-lambda length (-4,5%) as well as the evident increase of its subtense (5,9%) (Table 15). Contrary to males, females show a slight decrease of asterion-bregma and asterion-pterion lengths (-1,5% and -1,3%, respectively) (Table 15). Occipital measurements show the most significant alterations in the decrease of occipital subtense (-20,3%), arc (-5,2%) and length of foramen magnum (-3,3%), and in the increase of lambda subtense fraction (11,9%) (Table 15). Compared to males, biasterionic breadth (-1,3%) as well as length (-3,3%) and breadth (-1,8%) of foramen magnum show a decrease (Table 15). The most significant changes among cranium measurements instead have been observed in the decrease of maximum length (-7,6%) and obelion-inion arc (-6,7%), and in the increase of maximum breadth (3,6%), cranial height and right porion-bregma height (both 2,4%). Rather than males, basal length very slightly increases (1,4%) (Table 15).

Based on all the above-mentioned metric alterations, it is possible to suggest that, similarly to males, tabularly shaped crania of female individuals evidently antero-posteriorly shorten while moderately inferno-superiorly and biparietal develop. All these morphometric alterations are the result of metric variations occurring in parietal and occipital bones. In details, antero-posterior shortening is reflected in the decrease of parietal arc (-3,7%), chord (-6,1%), pterion-lambda (-4,5%), asterion-bregma and asterion-pterion lengths (-1,5% and -1,3%, respectively) (all likely caused by the flattening of the posterior portion of the cranium) (Table 15). The development of cranial width instead is represented not only by the increase of maximum cranial breadth (3,6%) but also by the enlargement of frontal (maximum 2,4%, minimum 0,5%, and bistephanic 3,7% breadths) as well as by the increase of the least exterior breadth across the roots of the zygomatic processes (1,8%) (Table 15).

According to Univariate Analysis of Variance, changes of maximum (*p*:0,000) and bistephanic frontal breadth (*p*:0,035), frontal arc (*p*:0,003), frontal chord (*p*:0,038), frontal subtense (*p*:0,000), parietal arc (*p*:0,010) and chord (*p*:0,000), pterion-lambda length (*p*:0,000), occipital arc (*p*:0,012), occipital subtense (*p*:0,016), lambda subtense fraction (*p*:0,025), maximum cranial length (*p*:0,000) and breadth (*p*:0,001), and obelion-union arc (*p*:0,007) show statistically significant differences ($p<0,05$) between shaped and unmodified female crania (Table 15). One-way Manova confirms that differences between means of shaped and unmodified crania on a combination of dependent variables are statistically significant ($p<0,05$) in females (Wilks' Lambda: $F(30-39)= 2,396$; $p>0,005$) (Table 15).

Table 15. One-way Manova and Anova on cranial measurements of tabularly shaped and unmodified crania of adult males and females

		Male*											Female**										
			Absent			Present			δ		F			Absent			Present			δ		F	
		N	n	$\bar{x}$	s	n	$\bar{x}$	s	δ	%	F	*p*	N	n	x	s	n	$\bar{x}$	s	δ	%	F	*p*
Frontal	**Max.Fr. Breadth**	111	61	121,56	6,67	50	124,88	6,71	3,32	2,7	13,055	0,000	46	28	117,66	4,94	18	120,55	7,51	2,89	2,4	2,286	0,135
	Min. Fr. Breadth	116	61	97,56	5,05	55	98,10	3,94	0,54	0,5	0,959	0,329	52	32	95,37	5,20	20	95,87	6,19	0,5	0,5	0,004	0,950
	Bisteph. Breadth	117	65	117,43	6,55	52	120,57	6,04	3,14	2,6	11,031	0,001	49	31	113,30	6,92	18	117,58	7,29	4,28	3,7	4,613	0,035
	Fr. Arc	134	78	127,68	7,47	56	125,38	6,87	-2,30	-1,8	2,176	0,142	59	40	124,88	5,45	19	119,50	5,80	-5,38	-4,3	12,525	0,003^
	Fr. chord	133	77	111,59	5,87	56	110,05	5,22	-1,54	-1,4	1,777	0,185	60	40	109,28	4,52	20	107,30	4,61	-1,98	-1,8	4,481	0,038
	Fr. Subtense	117	63	25,48	2,97	54	24,56	3,62	-0,92	-3,6	3,468	0,065	49	34	25,64	2,90	15	22,13	2,75	-3,51	-13,7	22,818	0,000
	Nas. Subt. Fract.	119	64	50,89	3,96	55	51,33	3,86	0,44	0,9	0,796	0,374	49	34	49,61	3,42	15	50,50	3,33	0,89	1,8	0,039	0,844
Parietal	**Par. Arc**	146	86	126,84	8,88	60	122,45	8,98	-4,40	-3,4	9,349	0,003	62	40	122,20	6,97	22	117,59	6,17	-4,59	-3,7	7,020	0,010
	Par. chord	146	86	113,62	6,89	60	107,20	7,00	-6,42	-5,6	29,659	0,000	61	40	109,68	5,81	21	103,02	5,57	-6,66	-6,1	21,349	0,000
	Par. Subtense	135	77	24,61	3,65	58	24,75	3,42	0,14	0,6	0,314	0,576	50	31	22,66	3,45	19	24,00	3,43	1,34	5,9	2,348	0,130
	Br. Subt. Fract.	135	77	57,46	5,41	58	54,78	4,98	-2,70	-4,7	7,708	0,006	50	31	54,96	5,29	19	54,86	3,83	-0,10	-0,2	0,737	0,394
	Pt.- Lamb. length	134	75	141,86	5,82	59	135,29	5,82	-6,60	-4,6	26,718	0,000	53	32	138,53	5,93	21	132,33	5,59	-6,20	-4,5	20,614	0,000
	Ast.-Br. length	140	82	137,40	5,17	58	137,75	5,46	0,35	0,2	0,877	0,351	60	38	131,82	4,61	22	129,81	11,19	-2,01	-1,5	0,583	0,448
	Ast.-Pt. length	129	72	97,26	4,80	57	98,33	4,70	1,07	1,1	2,951	0,088	55	34	93,85	4,99	21	92,61	5,52	-1,24	-1,3	0,742	0,392
Occipital	**Occ. Arc**	126	71	117,39	9,38	55	113,84	7,28	-3,55	-3,0	4,972	0,027	54	31	113,80	7,66	23	107,82	8,66	-5,98	-5,2	6,744	0,012
	Occ. chord	126	71	96,80	6,76	55	94,49	6,22	-2,31	-2,4	3,161	0,077	54	31	93,58	5,63	23	92,02	5,23	-1,56	-1,7	0,489	0,487
	Occ. Subtense	119	64	28,46	8,88	55	27,10	9,21	-1,36	-4,8	0,872	0,352	48	26	28,50	12,62	22	22,70	3,01	-5,80	-20,3	6,084	0,016
	Lamb. Subt. Fract.	119	64	52,10	7,57	55	54,67	9,77	2,57	4,9	6,784	0,015^	48	26	43,75	8,82	22	48,97	8,61	5,22	11,9	5,272	0,025
	Biast. Breadth	133	76	111,78	5,48	57	111,85	4,63	0,07	0,06	0,874	0,351	54	32	107,68	5,84	22	106,27	4,33	-1,41	-1,3	0,046	0,831
	For. Mag. length	91	45	36,20	2,22	46	36,33	2,48	0,13	0,3	0,337	0,562	40	20	35,80	2,80	20	34,60	3,02	-1,20	-3,3	3,699	0,059
	For. Mag. Breadth	90	45	30,96	2,10	45	31,35	2,07	0,40	1,2	1,840	0,177	38	19	30,05	2,56	19	29,52	2,33	-0,53	-1,8	0,003	0,957
Temporal	**Zyg. Proc. Breadth**	107	59	123,01	5,61	48	125,17	4,94	2,16	1,7	11,494	0,001	44	24	116,66	4,18	20	118,72	5,39	2,06	1,8	2,024	0,159
Cranium	**Max. length**	134	75	184,25	7,10	59	175,09	6,70	-9,16	-4,9	43,110	0,000	55	37	179,18	7,66	18	165,50	4,99	-13,68	-7,6	51,634	0,000
	Max. Breadth	126	68	141,80	7,07	58	147,34	6,93	5,54	3,9	20,532	0,000	56	35	137,12	6,12	21	142,11	6,53	4,99	3,6	11,627	0,001
	Height (Ba-B)	100	52	134,36	4,95	48	134,42	6,63	0,06	4,5	0,420	0,518	39	21	127,14	5,11	18	130,22	5,98	3,08	2,4	1,757	0,189
	Basal length	95	48	100,44	5,08	47	100,42	4,61	-0,02	-0,02	0,000	0,996	39	22	96,68	5,06	17	98,02	3,59	1,34	1,4	0,010	0,921
	Ob.- In. Arc	143	83	110,33	9,79	60	106,59	7,54	-3,74	-3,3	4,296	0,030^	61	37	107,93	9,86	24	100,68	8,74	-7,25	-6,7	7,790	0,007
	Ob.- In. chord	145	85	97,80	8,34	60	97,89	8,74	0,09	0,09	0,037	0,847	61	37	92,93	9,28	24	93,81	5,39	0,88	0,9	0,344	0,559
	R. Por.- Br. Height	121	69	128,15	4,52	52	129,68	4,28	1,53	1,2	4,572	0,034	51	29	121,82	6,31	22	124,77	6,04	2,95	2,4	2,130	0,149
	Br. Height	122	69	128,23	4,64	53	128,75	4,52	0,52	0,4	3,074	0,082	49	29	122,86	5,00	20	124,67	5,41	1,81	1,5	1,425	0,237

*Wilks' Lambda: F(30-121)= 3,666; *p*>0,000
**Wilks' Lambda: F(30-39)= 2,396; *p*>0,005
^Welch Test

5.1.1.3.Composite

Like in circular headshaping, the great number of measurements affected by composite headshaping decrease in both the sexes. If we consider the two groups individually, it is possible to state that, except for minimum (even if imperceptibly) (0,02%) and maximum (3,4%) frontal breadths that increase, all frontal measurements decrease in shaped males (Table 16). In detail, frontal subtense evidently decreases (-14,2%) followed by nasion subtense fraction (-3,3%) and frontal arc (-2,2%), while maximum frontal breadth increases (3,4%). Conversely, not so evident changes affect frontal length (-0,2%) (Table 16). In the parietal region instead, except for parietal subtense that very slightly increases (0,5%), all measurements decrease (Table 16). The most evident alterations are observed in parietal chord (-9%), pterion-lambda length (-6,1%) and parietal arc (-4,2%) (Table 16). In the occipital area, arc, subtense and biasterionic breadth decrease (-3,3%, -15,2% and -3,3%, respectively), while chord and lambda subtense fraction (2,1% and 4,1%, respectively) increase. Even if not so prominently, foramen magnum length increases (0,5%) while its breadth decreases (-0,6%) (Table 16). Temporal least exterior breadth across the roots of the zygomatic processes only slightly increases (1,1%). Except for maximum cranial breadth that increases (2,5%), all cranial measurements decrease by reaching the highest rates in maximum cranial length (-6,9%) and obelion-inion arc (-5,3%), respectively (Table 16).

According to all these observations, it is possible to suggest that shaped male crania evidently shorten while slightly enlarging and lowering (Table 16). Similarly to tabularly shaped crania, the antero-posterior shortening of this shaped group is suggested by the metric alterations observed both in parietals and occipitals such as the decrease of parietal chord (-9%) and arc (-4,2%), pterion-lambda (-6,1%), asterion-bregma (-3,2%) and asterion-pterion (-1,3%) lengths, obelion-union arc (-5,3%) and chord (-0,6%), occipital subtense (-15,2%) and arc (-3,3%) as well as by the increase of occipital chord (2,1%) and lambda subtense fraction (4,1%), all related to the flattening of the posterior cranial portion or the cranium (Table 16). The development of cranial breadth instead is also supported by the slight development of the least exterior breadth across the roots of the zygomatic processes (1,1%) as well as by the development of some transversal measurements of the frontal bone, that also severely flattens (subtense: -14,2%) while almost imperceptibly contracts (chord: -0,2%) (Table 16).

Univariate Analysis of Variance shows that differences in means of frontal subtense (*p:*0,015), parietal chord (*p:*0,003), pterion-lambda length (*p:*0,027) and maximum cranial length (*p:*0,005) between shaped and unmodified crania are statistically significant ($p<0,05$) (Table 16). Moreover, One-way Manova confirms that differences between the means of shaped and unmodified male crania on a combination of dependent variables are statistically significant ($p<0,05$) (Wilks' Lambda: F(30-58)= 1,688; $p>0,044$) (Table 16).

In shaped females instead, frontal is characterised by a decrease of all measurements with an important reduction of frontal arc (-25,3%) and subtense (-21,7%) (Table 16). As observed in shaped males, except for parietal subtense that increases (14%), all parietal measurements decrease with significant changes in bregma subtense fraction (-9,7%), parietal chord (-5,8%) and pterion-lambda length (-4,1%) (Table 16). In the occipital region, the most pronounced alterations regard the decrease of occipital subtense (-28,3%) and foramen magnum dimensions (-4,9%) as well as the increase of lambda subtense fraction (25,4%) and occipital chord (4,6%) (Table 16). Compared to shaped males, temporal least exterior breadth across the roots of the zygomatic processes more slightly increases (0,8%) (Table 16). Moreover, apart from maximum cranial length (-6,8%), obelion-union arc (-3,5%) and basal length (-1,7%) that decrease, all the other cranial measurements develop with evident changes in obelion-onion chord (4,3%) and cranial height (2,6%) (Table 16).

Based on these observations, it can be stated that, similarly to shaped males, shaped females very evidently shorten and slightly enlarge, while developing in height (2,6%) (Table 16). The reduction in length of this group is also reflected in the decrease of both parietal arc (-1,9%) and chord (-5,8%), in the increase of its subtense (14%), in the decrease of pterion-lambda (-4,1%), asterion-bregma (-1%) and asterion-pterion lengths (-2,6%), in the increase of occipital chord (4,6%), obelion-onion chord (4,3%), and lambda subtense fraction (25,4%), as well as in the reduction of occipital arc (-1%), obelion-union arc (-3,5%) and occipital subtense (-28,3%) (Table 16). The mediolateral development instead is also reflected in the increase of the least exterior breadth across the roots of the zygomatic processes (0,8%) as well as in biasterionic length (4,1%) (Table 16).

According to Anova results, metric changes occurred in minimum frontal breadth (p: 0,042), frontal subtense (p: 0,000), parietal chord (p: 0,021), bregma subtense fraction (p: 0,023) and lambda subtense fraction (p: 0,011) show statistically significant differences (p<0,05) between shaped and unmodified crania of female individuals (Table 16). One-way Manova confirms that differences between the means of shaped and unmodified female crania on a combination of dependent variables are statistically significant (p<0,05) (Wilks' Lambda: F(30-13)= 3,766; p>0,007) (Table 16).

Table 16. One-way Manova and Anova on cranial measurements of compositely shaped and unmodified crania of adult males and females

		Male*											Female**										
		Absent				Present			δ		F		Absent				Present			δ		F	
		N	n	$\bar{x}$	s	n	$\bar{x}$	s	δ	%	F	*p*	N	n	$\bar{x}$	s	n	$\bar{x}$	s	δ	%	F	*p*
Frontal	**Max.Fr. Breadth**	60	57	121,46	6,03	3	125,66	8,50	4,20	3,4	0,405	0,526	29	25	117,90	5,19	4	115,00	7,11	-2,90	-2,4	0,897	0,349
	Min. Fr. Breadth	61	57	97,73	5,05	4	97,75	5,18	0,02	0,02	0,079	0,779	33	29	95,34	5,22	4	90,00	4,96	-5,34	-5,6	4,391	0,042
	Bisteph. Breadth	65	61	117,71	6,53	4	116,87	10,94	-0,84	-0,7	0,044	0,834	32	28	113,28	7,27	4	111,37	8,53	-1,91	-1,7	0,152	0,699
	Fr. Arc	78	74	127,85	7,14	4	125,00	3,55	-2,85	-2,2	0,869	0,354	40	36	124,91	5,61	4	93,25	51,90	-31,66	-25,3	15,963	0,315^
	Fr. chord	77	73	111,58	5,75	4	111,37	2,05	-0,21	-0,2	0,023	0,881	40	36	109,00	4,55	4	106,50	6,45	-2,50	-2,3	0,751	0,391
	Fr. Subtense	64	60	25,77	2,63	4	22,12	1,43	-3,65	-14,2	6,211	0,015	34	30	26,03	2,70	4	20,37	1,79	-5,66	-21,7	15,367	0,000
	Nas. Subt. Fract.	65	61	51,04	3,79	4	49,37	2,05	-1,67	-3,2	0,228	0,634	34	30	49,93	3,24	4	48,25	1,25	-1,68	-3,3	0,960	0,333
Parietal	**Par. Arc**	84	79	127,15	9,01	5	121,80	14,54	-5,35	-4,2	1,542	0,218	39	35	122,17	6,49	4	119,87	8,60	-2,30	-1,9	0,296	0,590
	Par. chord	85	80	113,88	6,90	5	103,60	10,73	-10,28	-9,0	9,368	0,003	38	35	109,88	5,29	3	103,50	6,14	-6,38	-5,8	5,794	0,021
	Par. Subtense	76	71	24,67	3,75	5	24,80	4,28	0,13	0,5	0,026	0,872	32	29	22,81	3,49	3	26,00	3,46	3,19	14,0	2,991	0,091
	Br. Subt. Fract.	76	71	57,54	5,42	5	56,00	11,26	-1,54	-2,7	0,276	0,799^	32	29	55,37	5,20	3	50,00	2,00	-5,37	-9,7	5,580	0,023
	Pt.- Lamb. length	75	71	141,80	5,73	4	133,12	7,89	-8,68	-6,1	5,048	0,027	32	28	137,75	5,36	4	131,75	10,93	-5,60	-4,1	3,612	0,379^
	Ast.-Br. length	81	76	137,63	5,03	5	134,30	5,74	-4,51	-3,2	1,039	0,311	37	33	132,65	4,31	4	131,25	6,43	-1,40	-1,0	0,120	0,731
	Ast.-Pt. length	72	68	97,35	4,81	4	96,00	4,91	-1,35	-1,3	0,509	0,478	34	30	94,60	4,34	4	92,12	5,58	-2,48	-2,6	0,566	0,456
Occipital	**Occ. Arc**	68	64	117,75	9,77	4	113,87	8,39	-3,88	-3,3	0,761	0,385	30	27	113,44	7,86	3	112,33	23,96	-1,11	-1,0	0,026	0,944^
	Occ. chord	69	65	96,83	6,98	4	98,87	11,18	2,04	2,1	0,150	0,699	30	27	92,66	5,04	3	97,00	14,00	4,34	4,6	3,229	0,436^
	Occ. Subtense	62	58	28,90	9,17	4	24,50	4,93	-4,40	-15,2	0,639	0,426	26	23	29,28	13,16	3	21,00	6,08	-8,28	-28,3	2,428	0,127
	Lamb. Subt. Fract.	62	58	51,99	7,72	4	54,12	7,44	2,13	4,1	0,161	0,689	26	23	43,06	8,36	3	54,00	10,03	10,94	25,4	7,117	0,011
	Biast. Breadth	75	70	111,95	5,47	5	108,20	3,01	-3,75	-3,3	1,082	0,301	34	30	108,25	5,58	4	112,75	7,67	4,5	4,1	3,101	0,086
	For. Mag. length	47	43	36,17	2,07	4	36,37	2,49	0,20	0,5	0,336	0,564	20	17	36,44	2,52	3	34,66	2,08	-1,78	-4,9	1,165	0,287
	For. Mag. Breadth	45	41	30,95	2,11	4	30,75	1,65	-0,20	-0,6	,373	0,543	19	16	30,50	2,15	3	29,00	2,64	-1,50	-4,9	0,002	0,966
Temporal	**Zyg. Proc. Breadth**	60	56	123,10	5,67	4	124,50	2,48	1,4	1,1	0,000	0,999	24	21	116,85	4,29	3	117,83	7,14	0,98	0,8	1,215	0,277
Cranium	**Max. length**	75	71	184,57	6,96	4	171,75	9,03	-12,82	-6,9	8,245	0,005	37	33	179,19	7,07	4	167,00	13,21	-12,19	-6,8	8,263	0,006
	Max. Breadth	67	63	141,49	6,54	4	145,00	4,22	3,51	2,5	0,551	0,460	35	31	137,62	6,29	4	140,25	8,01	2,63	1,9	0,749	0,392
	Height (Ba-B)	53	49	134,69	4,75	4	131,87	5,26	-2,82	-2,1	0,498	0,482	21	18	127,27	5,28	3	130,66	6,42	3,39	2,6	1,357	0,251
	Basal length	50	46	100,59	5,05	4	98,87	1,65	-1,72	-1,7	1,290	0,259	22	19	97,31	4,52	3	95,66	4,04	-1,65	-1,7	0,071	0,792
	Ob.- In. Arc	80	76	110,68	9,81	4	104,75	8,42	-5,93	-5,3	0,723	0,397	36	32	107,82	10,11	4	104,00	15,34	-3,82	-3,5	0,283	0,597
	Ob.- In. chord	82	78	97,92	8,49	4	97,37	9,37	-0,55	-0,6	0,011	0,916	36	32	92,67	9,67	4	96,62	10,12	3,95	4,3	0,822	0,370
	R. Por.- Br. Height	69	64	128,30	4,52	5	127,60	4,76	-0,70	-0,5	0,002	0,964	29	26	122,50	5,22	3	123,33	5,50	0,83	0,7	0,219	0,642
	Br. Height	69	65	128,46	4,64	4	128,00	4,14	-0,46	-0,3	0,005	0,942	28	25	123,38	2,89	3	124,33	7,57	0,95	0,8	0,349	0,558

*Wılks' Lambda: F(30-58)= 1,688; p>0,044

**Wılks' Lambda: F(30-13)= 3,766; p>0,007

^Welch Test

5.2. ANALYSIS OF PROPORTIONAL CRANIAL MEASUREMENTS OF ADULTS AND SUBADULTS ACCORDING TO THE SEVERITY DEGREES OF THE DIFFERENT HEADSHAPING TYPES

5.2.1. Circular Headshaping

The statistical analysis conducted on proportional metrics of adult individuals according to the severity degrees of circular headshaping shows that more than half of these variables are characterised by a decrease in shaped individuals. In detail, cranial breadth/length and height/length, frontal breadth/length, frontal arc/chord, occipital breadth/length, and arc/chord decrease, while parietal arc/chord, pterion-lambda/asterion-bregma length and obelion-inion arc/chord increase. Only cranial height/breadth does not display any change in presence of headshaping (Table 17). The most evident changes regard the decrease of occipital breadth/length ($\bar{x}$:1,07) and cranial height/length ($\bar{x}$:0,72) as well as the development of pterion-lambda/asterion-bregma length ($\bar{x}$:1,12) (Table 17).

Univariate Analysis of Variance indicates that mean differences observed in cranial height/length (*p*:0,014), frontal breadth/length (*p*:0,007), pterion-lambda/asterion-bregma length (*p*:0,000) and occipital breadth/length (*p*:0,007) are statistically significant (*p*<0,05) (Table 17). Moreover, One-way Manova shows that, according to the severity degrees, differences in mean between shaped and unmodified crania of both adults and subadults are statistically significant (*p*<0,05) (Pillai's Trace Test: F(40-864)= 2,165; *p:*0,000) (Table 17).

Similarly to adults, the number of decreased proportional metrics in subadults is higher compared to the increased ones. In detail, cranial breadth/length and height/length, frontal breadth/length, and occipital breadth/length decrease, while cranial height/breadth, occipital arc/chord, and obelion-onion arc/chord increase. Conversely, frontal arc/chord, parietal arc/chord, and pterion-lambda/asterion-bregma length do not show any alteration compared to unmodified crania (Table 18). The most evident changes regard the decrease of frontal breadth/length ($\bar{x}$:1,10) and cranial breadth/length ($\bar{x}$:0,79) as well as the increase of cranial height/breadth ($\bar{x}$:0,92) (Table 18).

Univariate Analysis of Variance indicates that mean differences observed in cranial breadth/length (*p*:0,035), frontal breadth/length (*p*:0,004) and parietal arc/chord (*p*:0,003) are statistically significant ($p<0,05$) (Table 18). Moreover, according to the results of Games-Howell Post Hoc Test, cranial breadth/length shows meaningful differences between unmodified and slightly shaped crania (*p*:0,018), frontal breadth/length between unmodified and slightly (*p*:0,014), moderately (*p*:0,003) and very severely shaped crania (*p*:0,009), while occipital arc/chord between slightly and moderately shaped crania (*p*:0,045) (Table 19). One-way Manova displays that, according to the severity degrees, the differences in mean of proportional metrics between shaped and unmodified crania of both adults and subadults are statistically not significant ($p<0,05$) (Pillai's Trace Test: $F(40\text{-}484)= 1,354$; *p*:0,077) (Table 18).

Table 17. One-way Manova on proportional cranial measurements of adult individuals according to the severity degrees of circular headshaping

	Absent ₁			**Slight ₂**			**Moderate ₃**			**Severe ₄**			**Very severe ₅**			**F**	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	164	0,80	0,06	3	0,81	0,06	0	-	-	1	0,76	-	2	0,74	0,04	1,970	0,100
Cran. Height/length	130	0,75	0,05	3	0,73	0,06	0	-	-	0	-	-	1	0,70	-	0,256	0,906
Cran. Height/Breadth	125	0,92	0,07	3	0,90	0,04	0	-	-	0	-	-	1	0,98	-	3,198	0,014
Fr. Breadth/length	147	1,10	0,07	3	1,07	0,02	0	-	-	1	1,04	-	2	1,00	0,003	3,600	0,007
Fr. Arc/chord	191	1,14	0,03	3	1,11	0,03	1	1,12	-	1	1,07	-	2	1,12	0,04	1,943	0,104
Par. Arc/chord	198	1,13	0,04	3	1,13	0,02	1	1,10	-	1	1,14	-	2	1,16	0,001	0,342	0,850
Pter. Lamb./Aster.Breg. length	175	1,02	0,07	3	1,06	0,05	0	-	-	1	1,03	-	3	1,20	0,01	5,543	0,000
Occip. Breadth/length	155	1,17	0,07	3	1,05	0,04	0	-	-	1	1,13	-	1	1,06	-	3,626	0,007
Occip. Arc/chord	170	1,21	0,06	3	1,19	0,07	0	-	-	1	1,19	-	3	1,11	0,02	1,703	0,150
Obel. In. Arc/chord	195	1,12	0,09	3	1,11	0,04	1	1,24	-	1	1,15	-	2	1,13	0,01	0,516	0,724

Pillai's Trace Test, F(40-864)= 2,165; *p*:0,000

Table 18. One-way Anova on proportional cranial measurements of subadult individuals according to the severity degrees of circular headshaping

	Absent $_1$			Slight $_2$			Moderate $_3$			Severe $_4$			Very severe $_5$			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	42	0,85	0,08	6	0,79	0,03	1	0,80	-	0	-	-	0	-	-	1,589	0,035^
Cran. Height/length	13	0,76	0,05	1	0,75	-	0	-	-	0	-	-	0	-	-	0,623	0,373^
Cran. Height/Breadth	12	0,88	0,07	1	0,92	-	0	-	-	0	-	-	0	-	-	1,021	0,399
Fr. Breadth/length	31	1,17	0,09	6	1,10	0,05	1	1,12	-	2	1,08	0,13	0	-	-	3,455	0,004^
Fr. Arc/chord	77	1,15	0,05	14	1,15	0,04	5	1,15	0,03	4	1,13	0,07	4	1,16	0,06	1,091	0,364
Par. Arc/chord	73	1,14	0,04	12	1,10	0,07	6	1,13	0,05	2	1,25	0,13	5	1,19	0,10	4,153	0,003
Pter. Lamb./Aster.Breg. length	54	1,02	0,07	6	1,02	0,06	6	0,97	0,06	2	1,07	0,08	2	1,08	0,02	2,167	0,076
Occip. Breadth/length	44	1,12	0,09	6	1,13	0,11	2	0,96	0,05	1	1,08	-	1	1,01	-	0,286	0,887
Occip. Arc/chord	70	1,17	0,04	9	1,21	0,07	3	1,17	0,04	1	1,11	-	4	1,14	0,10	4,341	0,100^
Obel. In. Arc/chord	56	1,13	0,08	9	1,18	0,06	3	1,12	0,03	1	1,12	-	5	1,15	0,11	0,605	0,660

Pillai's Trace Test, F: 1,354 (40-484) *p*:0,077
^Welch's Test

Table 19. Games-Howell Post Hoc Test on results of Table 18

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,018	0,268	1,000	0,955	0,992	0,069	0,941	0,293	0,989	0,945
Cran. Height/length	0,427	0,986	1,000	0,836	0,783	0,330	1,000	0,970	0,960	0,799
Cran. Height/Breadth	0,341	0,112	0,993	1,000	0,906	0,390	0,976	0,163	0,881	0,999
Fr. Breadth/length	0,014	0,003	0,160	0,009	0,986	0,713	0,361	0,828	0,534	1,000
Fr. Arc/chord	0,523	0,994	0,977	1,000	0,761	0,789	0,916	0,959	1,000	0,987
Par. Arc/chord	0,616	0,993	0,610	0,770	0,915	0,422	0,492	0,574	0,728	0,986
Pt. Lamb./Aster.Breg. length	0,998	0,574	0,660	0,281	0,790	0,614	0,252	0,341	0,120	0,930
Occip. Breadth/length	0,981	1,000	0,989	0,723	1,000	0,999	0,948	0,997	0,950	1,000
Occip. Arc/chord	0,107	0,997	0,463	0,976	0,305	0,045	0,541	0,470	0,962	0,999
Obel. In. Arc/chord	0,818	0,829	0,959	1,000	0,505	0,667	0,997	0,995	0,979	0,995

5.2.2. Tabular headshaping

The statistical analysis conducted on proportional metrics of adult individuals according to the degrees of severity of tabular headshaping shows that the number of increased proportions matches that of the decreased ones. In detail, cranial breadth/length, cranial height/length, frontal breadth/length, parietal arc/chord, and occipital breadth/length increase while cranial height/breadth, frontal arc/chord, pterion-lambda/asterion-bregma length, occipital arc/chord, and obelion-inion arc/chord decrease (Table 20). Cranial breadth/length represents the most evidently increased metric ($\bar{x}$:0,84), while pterion-lambda/asterion-bregma length the most decreased one ($\bar{x}$:0,99) (Table 20).

Except for occipital arc/chord (*p*:0,065), the results of One-way Anova show that mean differences between shaped and unmodified crania are all statistically significant ($p<0,05$) (Table 20). Moreover, Tukey Post Hoc Test reveals that almost all these differences occur between absent and slight, and between moderate and severe degrees of severity (Table 21). While frontal breadth/length shows meaningful differences between slight and moderate degrees (*p:*0,035), cranial breadth/length (*p:*0,000), cranial height/length (*p:*0,003) and pterion-lambda/asterion-bregma length (*p:*0,003) between moderate and severe degrees (Table 21). One-way Manova displays that, according to the different severity degrees, differences in mean of proportional metrics between shaped and unmodified crania of both adults and subadults are statistically significant ($p<0,05$) (Pillai's Trace Test: F(30-657)= 4991; *p:*0,000) (Table 20).

The pattern of alteration of proportional cranial measurements of subadults resembles that of adults (Table 22), with cranial breadth/length that is the most increased variable ($\bar{x}$:0,92), while obelion-inion arc/chord the most decreased one ($\bar{x}$:1,10) (Table 22). Contrary to adults, occipital arc/chord ($\bar{x}$:1,17) does not variate (Table 22).

According to Univariate Analysis of Variance, cranial breadth/length (*p*:0,000), cranial height/length (*p*:0,004), parietal arc/chord (*p*:0,022), pterion-lambda/asterion-bregma length (*p*:0,004) and obelion-inion arc/chord (*p*:0,000) show statistically relevant mean differences ($p<0,05$) between shaped and unmodified crania (Table 22). Games Howell Post Hoc Test indicates that these differences occur between absent and moderate, severe, and very severe degrees of severity. Only for pterion-lambda/asterion-bregma length, differences have also been observed between slight and moderate (*p:*0,004), severe (*p:*0,036) and very severe (*p:*0,005) degrees (Table 23). One-way Manova shows that, according to the different severity degrees, differences in means of metric proportions between shaped and unmodified crania of both adults and subadults are statistically significant (*p*<0,05) (Pillai's Trace Test, F:40-444=1,783; *p:*0,003) (Table 22).

Table 20. One-way Manova on proportional cranial measurements of adult individuals according to the severity degrees of tabular headshaping

	Absent ₁			Slight ₂			Moderate ₃			Severe ₄			Very severe ₅			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	95	0,77	0,04	53	0,83	0,04	10	0,86	0,06	13	0,88	0,04	-	-	-	51,147	0,000
Cran. Height/length	69	0,73	0,03	47	0,76	0,05	7	0,79	0,05	12	0,80	0,03	-	-	-	22,327	0,000
Cran. Height/Breadth	63	0,94	0,06	46	0,92	0,08	8	0,90	0,06	11	0,90	0,06	-	-	-	5,526	0,001
Fr. Breadth/length	83	1,08	0,06	48	1,12	0,06	8	1,16	0,03	13	1,16	0,06	-	-	-	14,173	0,000
Fr. Arc/chord	118	1,14	0,03	54	1,13	0,04	9	1,12	0,02	15	1,14	0,02	-	-	-	2,882	0,037
Par. Arc/chord	127	1,12	0,04	57	1,14	0,03	11	1,15	0,03	16	1,15	0,04	-	-	-	10,098	0,000
Pt. Lamb./Ast.Br. length	104	1,04	0,06	55	1,01	0,07	11	0,99	0,06	14	0,95	0,07	-	-	-	12,675	0,000
Occip. Breadth/length	89	1,16	0,07	51	1,17	0,07	12	1,21	0,07	14	1,17	0,08	-	-	-	2,894	0,036
Occip. Arc/chord	103	1,21	0,06	54	1,19	0,06	12	1,21	0,04	15	1,19	0,03	-	-	-	2,441	0,065
Obel. In. Arc/chord	124	1,13	0,08	58	1,10	0,10	12	1,08	0,07	17	1,06	0,03	-	-	-	6,990	0,000

Pillai's Trace Test, F: 4,991 (30-657) *p*:0,000

Table 21. Tukey Post Hoc Test on results of Table 20

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,000	0,000	0,000	-	0,232	0,000	-	0,507	-	-
Cran. Height/length	0,000	0,013	0,000	-	0,977	0,003	-	0,117	-	-
Cran. Height/Breadth	0,021	0,028	0,128	-	0,598	0,976	-	0,879	-	-
Fr. Breadth/length	0,007	0,000	0,000	-	0,035	0,059	-	0,971	-	-
Fr. Arc/chord	0,314	0,060	0,679	-	0,410	1,000	-	0,597	-	-
Par. Arc/chord	0,001	0,004	0,003	-	0,472	0,638	-	0,985	-	-
Pt. Lamb./Aster.Breg. length	0,015	0,073	0,000	-	0,836	0,003	-	0,256	-	-
Occip. Breadth/length	0,289	0,055	0,802	-	0,406	0,999	-	0,489	-	-
Occip. Arc/chord	0,099	0,985	0,279	-	0,857	0,982	-	0,784	-	-
Obel. In. Arc/chord	0,027	0,114	0,002	-	0,876	0,262	-	0,896	-	-

Table 22. One-way Manova on proportional cranial measurements of subadult individuals according to the severity degrees of tabular headshaping

	Absent $_1$			Slight $_2$			Moderate $_3$			Severe $_4$			Very severe $_5$			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	31	0,80	0,04	4	0,84	0,04	6	0,90	0,03	3	0,95	0,05	6	0,97	0,05	9,337	0,000
Cran. Height/length	6	0,72	0,04	2	0,74	0,02	3	0,80	0,04	2	0,83	0,02	1	0,76	-	4,039	0,004
Cran. Height/Breadth	5	0,91	0,06	2	0,90	0,02	3	0,90	0,03	2	0,89	0,07	1	0,72	-	1,606	0,294^
Fr. Breadth/length	29	1,14	0,07	5	1,16	0,08	1	1,18	-	1	1,09	-	4	1,30	0,09	0,605	0,660
Fr. Arc/chord	69	1,16	0,05	7	1,16	0,03	7	1,14	0,05	2	1,16	0,01	5	1,15	0,05	0,825	0,512
Par. Arc/chord	66	1,13	0,05	7	1,15	0,04	10	1,17	0,03	5	1,17	0,02	7	1,17	0,03	2,973	0,022
Pt. Lamb./Ast.Br. length	44	1,04	0,07	7	1,05	0,03	7	0,96	0,03	4	0,95	0,06	6	0,97	0,04	4,121	0,004
Occip. Breadth/length	36	1,09	0,10	5	1,17	0,05	8	1,18	0,07	4	1,17	0,02	4	1,17	0,06	0,565	0,689
Occip. Arc/chord	66	1,17	0,05	7	1,18	0,05	11	1,16	0,04	5	1,16	0,03	4	1,18	0,03	0,617	0,651
Obel. In. Arc/chord	51	1,16	0,08	7	1,15	0,06	10	1,09	0,04	5	1,09	0,04	7	1,06	0,01	7,767	0,000^

Pillai's Trace Test, F: 1,783 (40-444) *p*:0,003
^Welch's Test

Table 23. Games Howell Post Hoc Test on results of Table 22

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,483	0,024	0,037	0,008	0,833	0,254	0,077	0,609	0,236	0,958
Cran. Height/length	0,925	0,139	0,033	0,384	0,839	0,339	0,649	0,814	0,905	0,997
Cran. Height/Breadth	0,678	0,423	0,650	0,812	1,000	0,978	0,978	0,974	0,977	1,000
Fr. Breadth/length	0,473	0,658	0,838	0,841	0,888	1,000	0,319	0,981	0,461	0,550
Fr. Arc/chord	1,000	0,754	0,949	0,749	0,824	0,960	0,773	0,996	0,994	0,964
Par. Arc/chord	0,680	0,031	0,025	0,103	0,837	0,797	0,952	1,000	0,995	0,990
Pt. Lamb./Aster.Breg. length	0,874	0,008	0,067	0,010	0,004	0,036	0,005	0,726	0,992	0,870
Occip. Breadth/length	0,987	0,836	0,674	0,506	0,995	0,995	0,895	1,000	0,979	0,948
Occip. Arc/chord	1,000	0,641	0,543	0,924	0,883	0,863	0,980	1,000	0,998	0,998
Obel. In. Arc/chord	0,853	0,000	0,048	0,000	0,299	0,628	0,086	0,964	0,674	0,471

5.2.3. Composite headshaping

Since compositely shaped crania show the effects of both circular and tabular headshaping at once, in some cases with different degrees of severity, the alterations of proportional metrics of both adults and subadults have been investigated according to the degrees of severity of circular and tabular types individually.

The analysis on proportional metrics of adult crania have revealed that more than half of these variables decrease in presence of composite headshaping. In detail, cranial breadth/length, cranial height/length, frontal breadth/length, and parietal arc/chord increase, while cranial height/breadth, frontal arc/chord, pterion-lambda/asterion-bregma length, occipital breadth/length, occipital arc/chord, and obelion-inion arc/chord decrease (Tables 24, 26). The most evident changes regard the reduction of occipital arc/chord ($\bar{x}$:1,15) and obelion-inion arc/chord ($\bar{x}$:1,07) as well as the increase of cranial breadth/length ($\bar{x}$:0,84 circular; $\bar{x}$:0,85 tabular) (Tables 24, 26).

Statistically significant mean differences (p<0,05) between shaped and unmodified crania have been observed in cranial breadth/length (p:0,000 both in circular and tabular type), cranial height/length (circular p:0,001; tabular p:0,004), parietal arc/chord (circular p:0,000; tabular p:0,001), occipital arc/chord (circular p:0,003; tabular p:0,018), frontal arc/chord (tabular p:0,000) and occipital breadth/length (tabular p:0,018) (Tables 24, 15). Games Howell Post Hoc Test indicates that most of the statistically significant differences occur between absent and slight degree of severity. Moreover, cranial breadth/length (p:0,037) and occipital arc/chord (p:0,021) also differ between slight and moderate degrees, while occipital breadth/length between absent and moderate degree (p:0,027) (Table 25). One-way Manova shows that, according to the different severity degrees, mean differences of proportional metrics between shaped and unmodified crania of both adults and subadults are statistically significant (p<0,05) (circular, Pillai's Trace Test: F(20-254)=2,687 p:0,000; tabular, Pillai's Trace Test: F(30-381)=2,362 p:0,000) (Tables 24, 26).

The pattern of alterations of proportional metrics in compositely shaped subadults is almost identical to that of adults, except for the increase of occipital breadth/length (Table 27). Among increased proportions the most evident changes occur in cranial breadth/length (circular $\bar{x}$:0,93; tabular $\bar{x}$:0,92), cranial height/length ($\bar{x}$:0,78 both circular and tabular) and parietal arc/chord (circular $\bar{x}$:1,19; tabular $\bar{x}$:1,20). Conversely, obelion-inion arc/chord ($\bar{x}$:1,07 both circular and tabular) shows the most prominent decrease (Tables 27, 28).

One-way Anova and Welch's Test demonstrate that statistical significant differences (p<0,05) exist in the mean of cranial breadth/length (*p:*0,000), cranial height/length (*p:*0,033 circular; *p:*0,002 tabular), cranial height/breadth (*p:*0,001 circular; *p:*0,000 tabular), parietal arc/chord (*p:*0,000), pterion-lambda/asterion-bregma length (*p:*0,010 circular; *p:*0,001 tabular), occipital arc/chord (*p:*0,011 circular; *p:*0,008 tabular), obelion-inion arc/chord (*p:*0,000) and frontal breadth/length (*p:*0,003 tabular) (Tables 27, 28). Moreover, Post Hoc Test displays that differences occur between all the degrees, especially between absent and moderate, and severe and very severe degrees. Differences have also been observed between slight and severe (*p:*0,023) and very severe degrees (*p:*0,013) of cranial breadth/length, between slight and very severe degrees (*p:*0,032) of cranial height/breadth, and between slight and severe (*p:*0,038) and moderate and severe degrees (*p:*0,045) of occipital arc/chord (Table 29). One-way Manova shows that, according to the different degrees of severity, mean differences of proportional metrics between shaped and unmodified crania of both adults and subadults are statistically significant (p<0,05) (circular, Pillai's Trace Test: F(40-400)=3,077; p:0,000; tabular, Pillai's Trace Test: F(40-400)=3,213; p:0,000) (Tables 27, 28).

Table 24. One-way Manova on proportional cranial measurements of adult individuals according to the severity degrees of circular modification in composite headshaping

	Absent $_1$			Slight $_2$			Moderate $_3$			Severe $_4$			Very severe $_5$			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	89	0,77	0,04	7	0,85	0,02	1	0,81	-	-	-	-	-	-	-	10,081	0,000
Cran. Height/length	64	0,73	0,03	6	0,78	0,04	1	0,75	-	-	-	-	-	-	-	7,643	0,001
Cran. Height/Breadth	58	0,94	0,06	7	0,92	0,04	1	0,93	-	-	-	-	-	-	-	0,767	0,466
Fr. Breadth/length	77	1,08	0,06	6	1,11	0,07	1	1,05	-	-	-	-	-	-	-	0,280	0,756
Fr. Arc/chord	110	1,15	0,03	7	0,98	0,37	1	1,09	-	-	-	-	-	-	-	10,343	0,177^
Par. Arc/chord	116	1,12	0,04	7	1,17	0,04	2	1,15	0,03	-	-	-	-	-	-	8,405	0,000
Pter. Lamb./Aster.Breg. length	96	1,03	0,05	8	1,02	0,05	1	0,95	-	-	-	-	-	-	-	1,337	0,266
Occip. Breadth/length	82	1,17	0,07	7	1,11	0,12	1	1,14	-	-	-	-	-	-	-	0,861	0,058^
Occip. Arc/chord	93	1,22	0,06	7	1,14	0,06	1	1,23	-	-	-	-	-	-	-	5,978	0,003
Obel. In. Arc/chord	112	1,14	0,08	8	1,07	0,04	1	1,12	-	-	-	-	-	-	-	2,574	0,080

Pillai's Trace Test, F: 2,687 (20-254) *p*:0,000
^Welch's Test

Table 25. Games Howell Post Hoc Test on results of Table 24

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,000	0,167	-	-	0,037	-	-	-	-	-
Cran. Height/length	0,010	0,728	-	-	0,284	-	-	-	-	-
Cran. Height/Breadth	0,291	0,438	-	-	0,989	-	-	-	-	-
Fr. Breadth/length	0,777	0,777	-	-	0,654	-	-	-	-	-
Fr. Arc/chord	0,529	0,299	-	-	0,710	-	-	-	-	-
Par. Arc/chord	0,011	0,496	-	-	0,812	-	-	-	-	-
Pt. Lamb./Aster.Breg. length	0,632	0,498	-	-	0,674	-	-	-	-	-
Occip. Breadth/length	0,767	0,027	-	-	0,926	-	-	-	-	-
Occip. Arc/chord	0,019	0,907	-	-	0,021	-	-	-	-	-
Obel. In. Arc/chord	0,003	0,984	-	-	0,102	-	-	-	-	-

Table 26. One-way Manova on proportional cranial measurements of adult individuals according to the severity degrees of tabular modification in composite headshaping

	Absent ₁			Slight ₂			Moderate ₃			Severe ₄			Very severe ₅			F	
	n	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**F**	***p***
Cran. Breadth/length	89	0,77	0,04	5	0,84	0,03	2	0,83	0,03	1	0,86	-	-	-	-	6,413	0,000
Cran. Height/length	64	0,73	0,03	5	0,77	0,02	2	0,80	0,06	0	-	-	-	-	-	4,673	0,004
Cran. Height/Breadth	58	0,94	0,06	6	0,91	0,03	2	0,96	0,04	0	-	-	-	-	-	0,839	0,475
Fr. Breadth/length	77	1,08	0,06	4	1,12	0,06	2	1,03	0,02	1	1,17	-	-	-	-	0,983	0,403
Fr. Arc/chord	110	1,15	0,03	5	0,93	0,44	2	1,11	0,02	1	1,11	-	-	-	-	8,630	0,000^
Par. Arc/chord	116	1,12	0,04	6	1,17	0,04	3	1,15	0,02	0	-	-	-	-	-	5,735	0,001
Pter. Lamb./Aster.Breg. length	96	1,03	0,05	6	1,03	0,04	2	0,97	0,03	1	0,94	-	-	-	-	1,939	0,126
Occip. Breadth/length	82	1,17	0,07	6	1,09	0,13	2	1,19	0,06	0	-	-	-	-	-	3,134	0,028^
Occip. Arc/chord	93	1,22	0,06	6	1,14	0,06	2	1,18	0,07	0	-	-	-	-	-	3,461	0,018
Obel. In. Arc/chord	112	1,14	0,08	6	1,08	0,04	2	1,08	0,05	1	1,01	-	-	-	-	1,686	0,173

Pillai's Trace Test, F: 2,362 (30-381) *p*:0,000

Table 27 One-way Manova on proportional cranial measurements of subadult individuals according to severity degrees of circular modification in composite headshaping

	Absent ₁			Slight ₂			Moderate ₃			Severe ₄			Very severe ₅			F	
	n	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**n**	**$\bar{x}$**	**s**	**F**	***p***
Cran. Breadth/length	24	0,80	0,05	24	0,93	0,07	1	0,85	-	0	-	-	0	-	-	10,539	0,000
Cran. Height/length	5	0,71	0,04	12	0,78	0,03	0	-	-	0	-	-	0	-	-	2,736	0,033^
Cran. Height/Breadth	4	0,90	0,06	11	0,87	0,05	0	-	-	0	-	-	0	-	-	5,259	0,001
Fr. Breadth/length	21	1,16	0,07	24	1,17	0,05	1	1,14	-	0	-	-	0	-	-	1,889	0,118^
Fr. Arc/chord	50	1,15	0,05	35	1,13	0,03	1	1,11	-	2	1,13	0,10	0	-	-	1,098	0,361^
Par. Arc/chord	43	1,12	0,04	45	1,19	0,04	1	1,20	-	2	1,28	0,10	1	1,19	-	19,040	0,000
Pter. Lamb./Aster.Breg. length	30	1,05	0,07	38	0,98	0,05	1	1,07	-	0	-	-	0	-	-	3,517	0,010
Occip. Breadth/length	25	1,08	0,09	38	1,13	0,08	1	1,00	-	1	1,21	-	0	-	-	0,545	0,703
Occip. Arc/chord	46	1,17	0,04	42	1,15	0,03	1	1,20	-	2	1,13	0,05	0	-	-	3,462	0,011
Obel. In. Arc/chord	31	1,17	0,08	43	1,07	0,04	1	1,11	-	2	1,10	0,03	1	1,17	-	15,235	0,000^

Pillai's Trace Test, F: 3,077 (40-400) *p*:0,000
^Welch's Test

Table 28. One-way Manova on proportional cranial measurements of subadult individuals according to the severity degrees of tabular modification in composite headshaping

	Absent $_1$			**Slight** $_2$			**Moderate** $_3$			**Severe** $_4$			**Very severe** $_5$			**F**	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	24	0,80	0,05	6	0,86	0,02	7	0,90	0,04	7	0,94	0,06	5	1,01	0,05	13,915	0,000
Cran. Height/length	5	0,71	0,04	6	0,77	0,03	3	0,76	0,03	3	0,82	0,01	0	-	-	3,448	0,002^
Cran. Height/Breadth	4	0,90	0,06	5	0,88	0,05	3	0,83	0,07	3	0,89	0,04	0	-	-	6,758	0,000
Fr. Breadth/length	21	1,16	0,07	6	1,14	0,03	8	1,17	0,05	7	1,19	0,05	4	1,18	0,04	2,222	0,003^
Fr. Arc/chord	50	1,15	0,05	11	1,13	0,05	9	1,13	0,02	10	1,13	0,03	8	1,14	0,05	1,124	0,349
Par. Arc/chord	43	1,12	0,04	16	1,17	0,06	15	1,20	0,04	10	1,21	0,02	8	1,23	0,03	19,253	0,000
Pter. Lamb./Aster.Breg. length	30	1,05	0,07	11	1,02	0,03	12	0,99	0,04	9	0,97	0,02	7	0,92	0,07	5,106	0,001^
Occip. Breadth/length	25	1,08	0,09	12	1,09	0,08	13	1,12	0,07	9	1,14	0,08	6	1,20	0,08	0,682	0,606
Occip. Arc/chord	46	1,17	0,04	13	1,16	0,03	15	1,16	0,04	10	1,14	0,02	7	1,14	0,03	3,652	0,008
Obel. In. Arc/chord	31	1,17	0,08	14	1,10	0,04	15	1,07	0,03	11	1,05	0,04	7	1,07	0,09	15,223	0,000^

Pillai's Trace Test, F: 3,213 (40-400) *p*:0,000

^Welch's Test

Table 29. Games Howell Post Hoc Test on results of Table 28

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,431	0,001	0,000	0,002	0,247	0,023	0,013	0,637	0,156	0,584
Cran. Height/length	0,946	0,454	0,001	0,060	0,986	0,109	0,378	0,075	0,452	0,992
Cran. Height/Breadth	0,700	0,009	0,078	0,001	0,430	0,796	0,032	0,971	0,453	0,214
Fr. Breadth/length	0,007	0,019	0,394	0,588	0,978	0,131	0,067	0,308	0,164	0,993
Fr. Arc/chord	0,644	0,509	0,183	0,991	0,998	0,995	0,990	0,887	0,998	0,933
Par. Arc/chord	0,070	0,000	0,000	0,000	0,790	0,299	0,085	0,883	0,380	0,771
Pt. Lamb./Aster.Breg. length	0,110	0,408	0,000	0,023	0,999	0,159	0,155	0,323	0,147	0,501
Occip. Breadth/length	0,890	0,902	1,000	0,824	1,000	0,923	0,531	0,930	0,542	0,881
Occip. Arc/chord	0,848	0,869	0,000	0,311	1,000	0,038	0,855	0,045	0,859	0,550
Obel. In. Arc/chord	0,000	0,000	0,000	0,170	0,561	0,069	0,999	0,525	0,997	0,858

5.3. ANALYSIS OF PROPORTIONAL CRANIAL MEASUREMENTS ACCORDING TO THE SEVERITY DEGREES OF THE DIFFERENT HEADSHAPING TYPES WITHOUT AGE GROUP DIFFERENTIATION

Since the results of the above presented statistical analyses are based on a very low number of modified crania compared to the unmodified ones (Tables 17, 18, 20, 22, 24, 26, 27, 28), it has been considered appropriate to analyse proportional measurements according to the different headshaping types without age differentiation in order to increase the number of processed examples and thus to provide as much as possible trustworthy results. Before carrying out this kind of analysis, mean differences between the two age groups have been checked according to the different headshaping types by Two-way Manova. The result of this analysis shows that mean differences between proportional cranial measurements of adults and subadults do not result statistically meaningful for any headshaping type (circular, Pillai’s Trace: F(10-90)= 0,382; *p:*0,952; tabular, Pillai's Trace: F(10-90)= 0,351; *p:*0,964; composite, Roy's Largest Root: F(10-44)= 0,000; *p:*1,000) (Tables 30-32). Based on these results, data of the two age groups have been combined.

5.3.1. Circular headshaping

The analysis on proportional cranial measurements of both adults and subadults according to the severity degrees of circular headshaping has revealed that cranial breadth/length, height/length, frontal breadth/length, occipital breadth/length, and occipital arc/chord decrease, while pterion-lambda/asterion-bregma length and obelion-inion arc/chord increase. No changes are observed in cranial height/breadth, frontal arc/chord, and parietal arc/chord (Table 33). Among decreased proportions, the most evident changes are seen in occipital breadth/length ($\bar{x}$:1,07), while obelion-inion arc/chord is the most increased variable ($\bar{x}$:1,16) (Table 33).

Table 30. Two-way Manova on proportional cranial measurements of adult and subadult individuals according to the presence of circular headshaping

	Subadult						Adult						F	
	Absent			Present			Absent			Present				
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	5	0,90	0,10	1	0,82	-	94	0,82	0,06	3	0,81	0,06	1,173	0,281
Cran. Height/length	5	0,78	0,04	1	0,75	-	94	0,75	0,04	3	0,73	0,06	0,014	0,907
Cran. Height/Breadth	5	0,87	0,09	1	0,92	-	94	0,93	0,06	3	0,90	0,04	0,924	0,339
Fr. Breadth/length	5	1,17	0,13	1	1,07	-	94	1,10	0,06	3	1,07	0,02	0,629	0,430^
Fr. Arc/chord	5	1,14	0,01	1	1,16	-	94	1,14	0,03	3	1,11	0,03	0,957	0,330
Par. Arc/chord	5	1,17	0,05	1	1,13	-	94	1,14	0,03	3	1,13	0,02	0,419	0,519
Pt. Lamb./Aster.Breg. length	5	0,99	0,07	1	1,00	-	94	1,01	0,06	3	1,06	0,05	0,234	0,630
Occip. Breadth/length	5	1,16	0,05	1	1,08	-	94	1,18	0,08	3	1,05	0,04	0,255	0,615
Occip. Arc/chord	5	1,18	0,03	1	1,18	-	94	1,20	0,06	3	1,19	0,07	0,010	0,921
Obel. In. Arc/chord	5	1,11	0,06	1	1,11	-	94	1,11	0,12	3	1,11	0,04	0,003	0,953

Pillai's Trace: F(10-90) = 0,382; *p*:0,952
^*p*<0,001

Table 31 Two-way Manova on proportional cranial measurements of adult and subadult individuals according to the presence of tabular headshaping

	Subadult						Adult						F	
	Absent			Present			Absent			Present				
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	1	0,82	-	5	0,90	0,09	44	0,78	0,04	53	0,84	0,05	0,054	0,816
Cran. Height/length	1	0,75	-	5	0,78	0,04	44	0,73	0,04	53	0,77	0,04	0,177	0,675
Cran. Height/Breadth	1	0,92	-	5	0,87	0,09	44	0,94	0,05	53	0,92	0,06	0,152	0,697
Fr. Breadth/length	1	1,07	-	5	1,17	0,13	44	0,94	0,05	53	0,91	0,06	0,494	0,484
Fr. Arc/chord	1	1,16	-	5	1,14	0,01	44	1,14	0,03	53	1,14	0,04	0,039	0,844
Par. Arc/chord	1	1,13	-	5	1,17	0,05	44	1,12	0,03	53	1,15	0,03	0,046	0,832
Pt. Lamb./Aster.Breg. length	1	1,00	-	5	0,99	0,07	44	1,04	0,05	53	0,99	0,06	0,255	0,615
Occip. Breadth/length	1	1,08	-	5	1,16	0,05	44	1,17	0,08	53	1,18	0,08	0,560	0,456
Occip. Arc/chord	1	1,18	-	5	1,18	0,03	44	1,21	0,07	53	1,19	0,06	0,159	0,690
Obel. In. Arc/chord	1	1,11	-	5	1,11	0,06	44	1,14	0,12	53	1,09	0,11	0,122	0,727

Pillai's Trace: F(10-90) = 0,351; *p*:0,964
^*p*<0,001

Table 32. Two-way Manova on proportional cranial measurements of adult and subadult according to the presence of composite headshaping

	Subadult						**Adult**						**F**	
	Absent			**Present**			**Absent**			**Present**				
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	-	-	-	10	0,90	0,04	41	0,78	0,04	6	0,83	0,02	-	-
Cran. Height/length	-	-	-	10	0,78	0,04	41	0,73	0,04	6	0,77	0,04	-	-
Cran. Height/Breadth	-	-	-	10	0,86	0,05	41	0,94	0,05	6	0,93	0,04	-	-
Fr. Breadth/length	-	-	-	10	1,16	0,05	41	1,08	0,06	6	1,09	0,06	-	-
Fr. Arc/chord	-	-	-	10	1,09	0,06	41	1,15	0,03	6	0,95	0,39	-	-
Par. Arc/chord	-	-	-	10	1,18	0,03	41	1,12	0,03	6	1,17	0,04	-	-
Pt. Lamb./Aster.Breg. length	-	-	-	10	1,00	0,02	41	1,03	0,05	6	1,01	0,05	-	-
Occip. Breadth/length	-	-	-	10	1,12	0,05	41	1,17	0,07	6	1,11	0,13	-	-
Occip. Arc/chord	-	-	-	10	1,15	0,02	41	1,22	0,07	6	1,15	0,07	-	-
Obel. In. Arc/chord	-	-	-	10	1,07	0,02	41	1,14	0,12	6	1,08	0,04	-	-

Roy's Largest Root: F(10-44) = 0,000; *p*:1,000
^*p*<0,001

One-way Manova shows that, according to the different severity degrees of circular headshaping, mean differences between shaped and unmodified crania of both adults and subadults are statistically significant ($p<0,05$) (Pillai's Trace: F(40-1400)= 2,381; *p:*0,000) (Table 33). The discriminant relevance of some of the above-mentioned proportional metrics is confirmed by their statistical significance in Anova and Welch's Test, such as parietal arc/chord (*p:*0,001), pterion-lambda/asterion-bregma length (*p:*0,000), occipital breadth/length (*p:*0,001) and occipital arc/chord (*p:*0,002) (Table 33). Based on the results of Tukey Post Hoc Test, these differences appear statistically meaningful between absent/slight and severe and very severe degrees. No differences exist between unmodified and slightly shaped crania. Only pterion-lambda/asterion-bregma length shows differences (*p:*0,001) between moderate and very severe degrees (Table 34).

5.3.2. Tabular headshaping

The statistical analysis on proportional metrics of both adults and subadults according to the severity degrees of tabular headshaping has provided the same patterns of changes observed when the two age groups were considered individually (Tables 31, 33, 35). In detail, while cranial breadth/length, cranial height/length, frontal breadth/length, parietal arc/chord and occipital breadth/length increase, cranial height/breadth, frontal arc/chord, pterion-lambda/asterion-bregma length, occipital arc/chord, and obelion-inion arc/chord decrease (Table 35). The most evident changes regard the increase of cranial breadth/length ($\bar{x}$:0,86) and the decrease of obelion-inion arc/chord ($\bar{x}$:1,08) (Table 35).
Except for frontal arc/chord, occipital breadth/length, and occipital arc/chord, mean differences of all the other metric proportions result statistically significant (Table 35). Moreover, based on One-Way Manova results, a statistically significant relationship ($p<0,05$) exists between mean differences of shaped and unmodified crania according to the different severity degrees of tabular headshaping (Pillai's Trace: F(40-1372)= 4,845; *p:*0,000) (Table 35). Contrary to circular headshaping, Games Howell Post Hoc Test shows that almost all the metric differences occur between unshaped or slightly shaped crania and all the other degrees of headshaping severity. Instead, no differences occur between moderate and severe or very severe degrees (Table 36).

Table 33. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the severity degrees of circular headshaping

	Absent 1			Slight 2			Moderate 3			Severe 4			Very severe 5			F	
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	206	0,81	0,07	9	0,80	0,04	1	0,80	-	1	0,76	-	3	0,73	0,04	0,515	0,725
Cran. Height/length	143	0,75	0,05	4	0,74	0,05	0	-	-	0	-	-	1	0,70	-	0,395	0,812
Cran. Height/Breadth	137	0,92	0,07	4	0,91	0,03	0	-	-	0	-	-	1	0,98	-	0,685	0,603
Fr. Breadth/length	178	1,11	0,07	9	1,09	0,04	1	1,12	-	3	1,07	0,10	2	1,00	0,003	1,789	0,131
Fr. Arc/chord	269	1,14	0,04	17	1,15	0,04	6	1,14	0,03	5	1,11	0,06	7	1,15	0,05	1,624	0,168
Par. Arc/chord	271	1,13	0,04	15	1,11	0,07	7	1,13	0,04	7	1,13	0,04	8	1,17	0,08	4,937	0,001
Pt. Lamb./Aster.Breg. length	230	1,02	0,07	9	1,03	0,06	6	0,97	0,06	3	1,06	0,06	5	1,15	0,07	7,673	0,000
Occip. Breadth/length	199	1,16	0,08	9	1,10	0,10	2	0,96	0,05	2	1,10	0,04	3	1,04	0,03	3,859	0,004
Occip. Arc/chord	241	1,20	0,06	12	1,21	0,07	3	1,17	0,04	2	1,15	0,06	8	1,12	0,07	4,354	0,002
Obel. In. Arc/chord	251	1,12	0,09	12	1,16	0,07	4	1,15	0,06	2	1,13	0,02	8	1,16	0,09	0,712	0,584

Pillai's Trace Test, F: 2,381 (40-1400) *p*:0,000

Table 34. Tukey Post Hoc Test on results of Table 33

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,995	0,987	0,954	0,818	1,000	0,923	0,969	0,904	0,994	0,748
Cran. Height/length	0,976	0,990	0,910	0,990	0,946	0,831	1,000	0,991	0,962	0,860
Cran. Height/Breadth	0,998	0,760	1,000	0,797	0,777	1,000	0,807	0,952	1,000	0,960
Fr. Breadth/length	1,000	0,984	0,772	0,119	0,995	0,844	0,307	0,963	0,666	0,995
Fr. Arc/chord	0,328	0,999	0,468	1,000	0,873	0,131	0,792	0,554	1,000	0,630
Par. Arc/chord	0,739	1,000	0,005	0,113	0,905	0,002	0,052	0,039	0,480	0,533
Pt. Lamb./Aster.Breg. length	0,998	0,993	0,732	0,000	0,985	0,866	0,000	0,710	0,000	0,251
Occip. Breadth/length	0,106	0,721	0,686	0,048	0,989	1,000	0,945	0,995	0,995	0,990
Occip. Arc/chord	0,659	0,906	0,399	0,007	0,533	0,179	0,003	0,868	0,367	0,991
Obel. In. Arc/chord	0,621	0,999	1,000	0,869	0,961	0,989	1,000	1,000	0,984	0,995

Table 35. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the severity degrees of tabular headshaping

	Absent $_1$			**Slight $_2$**			**Moderate $_3$**			**Severe $_4$**			**Very severe $_5$**			**F**	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	127	0,78	0,05	57	0,83	0,04	16	0,88	0,05	16	0,89	0,05	6	0,97	0,05	36,190	0,000^
Cran. Height/length	75	0,73	0,03	49	0,76	0,05	10	0,79	0,05	14	0,81	0,03	1	0,76	-	18,084	0,000
Cran. Height/Breadth	68	0,94	0,06	48	0,92	0,07	11	0,90	0,06	13	0,90	0,06	1	0,72	-	5,396	0,000
Fr. Breadth/length	112	1,10	0,07	53	1,12	0,06	9	1,17	0,03	14	1,15	0,06	4	1,30	0,09	3,485	0,000^
Fr. Arc/chord	188	1,15	0,04	62	1,14	0,04	16	1,13	0,03	17	1,14	0,02	5	1,15	0,05	2,351	0,054
Par. Arc/chord	194	1,12	0,04	64	1,14	0,03	21	1,16	0,03	21	1,15	0,03	7	1,17	0,03	9,805	0,000
Pt. Lamb./Aster.Breg. length	148	1,04	0,06	63	1,01	0,07	18	0,98	0,05	18	0,95	0,07	6	0,97	0,04	12,711	0,000
Occip. Breadth/length	126	1,14	0,09	56	1,17	0,07	20	1,20	0,07	18	1,17	0,07	4	1,17	0,06	2,367	0,053
Occip. Arc/chord	170	1,20	0,06	62	1,19	0,06	23	1,19	0,05	20	1,18	0,03	4	1,18	0,03	1,632	0,166
Obel. In. Arc/chord	176	1,14	0,08	65	1,10	0,10	22	1,08	0,06	22	1,06	0,03	7	1,06	0,01	11,064	0,000

Pillai's Trace Test, F: 4,845 (40-1372) *p*:0,000
^Welch's Test

Table 36. Games Howell Post Hoc on results of Table 35

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,000	0,000	0,000	0,002	0,041	0,000	0,013	0,506	0,094	0,318
Cran. Height/length	0,002	0,005	0,000	0,225	0,774	0,002	0,548	0,208	0,771	0,994
Cran. Height/Breadth	0,279	0,005	0,222	0,525	0,410	0,928	0,770	0,979	0,968	0,916
Fr. Breadth/length	0,925	0,002	0,585	0,094	0,000	0,269	0,069	0,871	0,376	0,248
Fr. Arc/chord	0,464	0,090	0,541	0,876	0,696	0,999	0,986	0,876	1,000	0,994
Par. Arc/chord	0,012	0,000	0,004	0,019	0,033	0,376	0,159	0,934	0,993	0,847
Pt. Lamb./Aster.Breg. length	0,066	0,000	0,000	0,009	0,281	0,002	0,168	0,144	0,950	0,581
Occip. Breadth/length	0,124	0,201	0,563	0,785	0,953	1,000	1,000	0,938	0,998	0,998
Occip. Arc/chord	0,800	0,637	0,132	0,275	0,983	0,809	0,559	0,997	0,829	0,888
Obel. In. Arc/chord	0,019	0,000	0,000	0,000	0,638	0,060	0,077	0,848	0,790	0,999

5.3.3. Composite headshaping

The results of the statistical analysis conducted on proportional metrics of both adults and subadults according to the severity degrees of composite headshaping reflect the patterns of changes observed in the analysis performed on adult data (Tables 25, 26). The most evident changes regard the decrease of obelion-inion arc/chord ($\bar{x}$:1,07) and the increase of cranial breadth/length ($\bar{x}$:0,91) (Tables 37, 38).

Except for occipital breadth/length (*p*: 0,055), all proportional metrics show statistically meaningful mean differences (Tables 37, 38). Moreover, according to One-Way Manova results, a statistically significant relationship ($p<0,05$) exists between mean differences of proportional metrics and severity degrees of both circular and tabular modification in composite headshaping (circular, Pillai's Trace: F(40-952)= 4,849, *p:*0,000; tabular, F(40-952)= 5,987, *p:*0,000) (Tables 37, 38). Games Howell Post Hoc Test displays that almost all the metric differences occur between unmodified crania and all the degrees of headshaping severity as well as between slightly and severely/very severely shaped crania. Only for frontal breadth/length and occipital arc/chord, differences are also observed between moderate and severe/very severe degrees. No differences instead are observable between severe and very severe degrees (Table 39).

Table 37. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the severity degrees of circular modification in composite headshaping

	Absent 1			Slight 2			Moderate 3			Severe 4			Very severe 5			F	
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	113	0,77	0,05	31	0,91	0,07	2	0,83	0,03	0	-	-	0	-	-	37,653	0,000
Cran. Height/length	69	0,73	0,03	18	0,78	0,03	1	0,75	-	0	-	-	0	-	-	12,695	0,000
Cran. Height/Breadth	62	0,94	0,06	18	0,89	0,05	1	0,93	-	0	-	-	0	-	-	14,674	0,000
Fr. Breadth/length	98	1,10	0,07	30	1,16	0,06	2	1,09	0,06	0	-	-	0	-	-	0,647	0,629^
Fr. Arc/chord	160	1,15	0,03	42	1,11	0,15	2	1,10	0,01	2	1,13	0,10	0	-	-	2,003	0,095
Par. Arc/chord	159	1,12	0,04	52	1,19	0,04	3	1,17	0,04	2	1,28	0,10	1	1,19	-	39,341	0,000
Pt. Lamb./Aster.Breg. length	126	1,04	0,06	46	0,98	0,05	2	1,01	0,08	0	-	-	0	-	-	5,545	0,000
Occip. Breadth/length	107	1,15	0,08	45	1,12	0,09	2	1,07	0,10	1	1,21	-	0	-	-	1,544	0,190
Occip. Arc/chord	139	1,20	0,06	49	1,15	0,04	2	1,21	0,02	2	1,13	0,05	0	-	-	11,264	0,000^
Obel. In. Arc/chord	143	1,14	0,08	51	1,07	0,04	2	1,12	0,01	2	1,10	0,03	1	1,17	-	10,701	0,000

Pillai's Trace Test, F: 4,849 (40-952) *p*:0,000

Table 38. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the severity degrees of tabular modification in composite headshaping

	Absent 1			Slight 2			Moderate 3			Severe 4			Very severe 5			F	
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	113	0,77	0,05	11	0,86	0,03	9	0,89	0,05	8	0,93	0,06	5	1,01	0,05	43,182	0,000
Cran. Height/length	69	0,73	0,03	11	0,77	0,03	5	0,78	0,04	3	0,82	0,01	0	-	-	13,581	0,000
Cran. Height/Breadth	62	0,94	0,06	11	0,89	0,04	5	0,88	0,09	3	0,89	0,04	0	-	-	16,767	0,000
Fr. Breadth/length	98	1,10	0,07	10	1,13	0,04	10	1,14	0,07	8	1,18	0,04	4	1,18	0,04	1,229	0,001^
Fr. Arc/chord	160	1,15	0,03	16	1,07	0,25	11	1,13	0,02	11	1,13	0,03	8	1,14	0,05	3,433	0,046^
Par. Arc/chord	159	1,12	0,04	22	1,17	0,05	18	1,19	0,04	10	1,21	0,02	8	1,23	0,03	39,384	0,000
Pt. Lamb./Aster.Breg. length	126	1,04	0,06	17	1,02	0,03	14	0,99	0,04	10	0,97	0,02	7	0,92	0,07	8,542	0,000
Occip. Breadth/length	107	1,15	0,08	18	1,09	0,09	15	1,13	0,07	9	1,14	0,08	6	1,20	0,08	2,352	0,055
Occip. Arc/chord	139	1,20	0,06	19	1,15	0,04	17	1,17	0,04	10	1,14	0,02	7	1,14	0,03	10,381	0,000
Obel. In. Arc/chord	143	1,14	0,08	20	1,09	0,03	17	1,07	0,03	12	1,05	0,04	7	1,07	0,09	10,466	0,000

Pillai's Trace Test, F: 5,987 (40-952) *p*:0,000
^Welch's Test

Table 39. Games Howell Post Hoc on tabular modification in composite headshaping in adult and subadult individuals (Table 38)

	p_{1-2}	p_{1-3}	p_{1-4}	p_{1-5}	p_{2-3}	p_{2-4}	p_{2-5}	p_{3-4}	p_{3-5}	p_{4-5}
Cran. Breadth/length	0,000	0,000	0,000	0,000	0,302	0,006	0,008	0,396	0,071	0,475
Cran. Height/length	0,072	0,003	0,000	0,007	0,970	0,029	0,269	0,070	0,469	0,994
Cran. Height/Breadth	0,020	0,002	0,003	0,000	0,611	0,644	0,008	1,000	0,163	0,140
Fr. Breadth/length	1,000	0,997	0,015	0,010	0,998	0,024	0,014	0,085	0,041	0,980
Fr. Arc/chord	0,713	0,193	0,113	0,999	0,866	0,920	0,800	0,949	0,981	0,900
Par. Arc/chord	0,001	0,000	0,000	0,000	0,896	0,245	0,032	0,742	0,154	0,618
Pt. Lamb./Aster.Breg. length	0,121	0,133	0,000	0,029	0,978	0,016	0,102	0,264	0,173	0,566
Occip. Breadth/length	0,110	0,357	0,989	0,990	0,971	0,687	0,468	0,927	0,688	0,963
Occip. Arc/chord	0,002	0,016	0,000	0,007	0,933	0,290	0,985	0,042	0,720	0,724
Obel. In. Arc/chord	0,000	0,000	0,000	0,317	0,864	0,033	1,000	0,214	1,000	0,806

5.4. REDEFINITION OF THE SEVERITY DEGREES OF THE DIFFERENT HEADSHAPING TYPES ACCORDING TO THE RESULTS OF POST HOC TESTS

Results of Post Hoc Tests performed on combined proportional metrics of adults and subadults according to the severity degrees of the different headshaping types show that mean differences do not regard all the degrees of severity. In fact, no differences exist between unmodified and slightly shaped crania in circular headshaping (Table 34), and between severe and very severe degrees in tabular headshaping (Table 36). In composite headshaping instead, although Post Hoc Test could not be performed for circular modification, no differences exist between severe and very severe degrees in tabular headshaping. According to these observations, it has been decided to redefine the degrees of severity of both circular and tabular headshaping in order to provide a more accurate description of the proportional metric changes occurring in shaped crania. Thus, slightly shaped examples have been merged with unmodified crania in circular headshaping, while severe and very severe degrees have been combined into a unique degree (severe) in tabular headshaping. In composite headshaping instead, while circular modification maintains the same degrees of severity, severe and very severe degrees are combined in tabular modification.

5.4.1. Circular headshaping

The statistical analysis performed on proportional metrics of combined data of adults and subadults according to the redefined degrees of severity of circular headshaping displays that cranial breadth/length, cranial height/length, frontal breadth/length, occipital breadth/length, and occipital arc/chord decrease, while cranial height/breadth, parietal arc/chord, pterion lambda/asterion-bregma length and obelion-inion arc/chord increase. Only frontal arc/chord does not present any variation ($\bar{x}$:1,14) (Table 29). Among decreased proportions, the most evident effects have been observed in occipital breadth/length ($\bar{x}$:1,03). Conversely, the most increased variable is cranial height/breadth ($\bar{x}$:0,98) (Table 40).

according to One-way Anova, mean differences are statistically significant in pterion-lambda/asterion-bregma length (*p:*0,000), occipital breadth/length (*p:*0,027) and occipital arc/chord (*p:*0,002) (Table 40). Moreover, One-Way Manova shows a statistically significant relationship (*p*<0,05) between mean differences of proportional metrics and the redefined degrees of severity of circular headshaping (Pillai's Trace: F (30-1050) = 2,624, *p:*0,000) (Table 40). Post Hoc Test displays significant differences between absent and severe degree of severity for frontal breadth/length, pterion lambda/asterion-bregma length and occipital breadth/length, and between absent and slight degree of severity for cranial height/length (Table 41). Pterion-lambda/asterion-bregma length instead shows differences between slight and severe degrees (Table 41).

5.4.2. Tabular headshaping

When considering tabular headshaping, cranial breadth/length and height/length, frontal breadth/length, parietal arc/chord and occipital breadth/length increase, while cranial height/breadth, frontal arc/chord, pterion lambda/asterion-bregma length, occipital arc/chord and obelion-inion arc/chord decrease (Table 42). The most increased proportional metric is cranial breadth/length ($\bar{x}$:0,86), while the most decreased ones are pterion-lambda/asterion-bregma length ($\bar{x}$:0,99) and obelion-inion arc/chord ($\bar{x}$:1,09) (Table 42).

Apart from occipital arc/chord (*p*: 0,109), mean differences between shaped and unmodified crania are statistically meaningful for all the proportional metrics (Table 42). Moreover, One-Way Manova shows statistically significant relationships (*p*<0,05) between mean differences and severity degrees of tabular headshaping (Pillai's Trace: F(30-1029)= 6,120, *p:*0,000) (Table 42). Games Howell Post Hoc Test reveals that differences occur between absent and all the severity degrees, and between slight and severe/very severe degrees. Instead, no differences exist between moderate and severe degrees (Table 43).

Table 40. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the redefined severity degrees of circular headshaping

	Absent $_1$			Moderate $_2$			Severe $_3$			Very severe $_4$			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	215	0,81	0,07	1	0,80	-	1	0,76	-	3	0,73	0,04	0,635	0,593
Cran. Height/length	147	0,75	0,05	0	-	-	0	-	-	1	0,70	-	0,411	0,745
Cran. Height/Breadth	141	0,92	0,07	0	-	-	0	-	-	1	0,98	-	0,885	0,449
Fr. Breadth/length	187	1,12	0,07	1	1,12	-	3	1,07	0,10	2	1,00	0,01	2,390	0,068
Fr. Arc/chord	286	1,14	0,04	6	1,14	0,03	5	1,11	0,06	7	1,15	0,05	0,976	0,404
Par. Arc/chord	286	1,13	0,04	7	1,13	0,04	3	1,21	0,11	8	1,17	0,08	6,077	0,239 ^
Pt. Lamb./Aster.Breg. length	239	1,02	0,07	6	0,97	0,06	3	1,06	0,06	5	1,15	0,07	10,228	0,000
Occip. Breadth/length	208	1,16	0,08	2	0,96	0,05	2	1,10	0,04	3	1,04	0,03	3,109	0,027
Occip. Arc/chord	253	1,20	0,06	3	1,17	0,04	2	1,15	0,06	8	1,12	0,07	5,185	0,002
Obel. In. Arc/chord	263	1,12	0,09	4	1,15	0,06	2	1,13	0,02	8	1,16	0,09	),285	),836

Pillai's Trace Test, F: 2,624 (30-1050) *p*:0,000

^Welch's Test

Table 41. Games Howell Post Hoc on results of Table 40

	p_{1-2}	p_{1-3}	p_{1-4}	p_{2-3}	p_{2-4}	p_{3-4}
Cran. Breadth/length	0,947	0,721	0,780	0,653	0,977	0,498
Cran. Height/length	0,853	0,015	0,927	0,610	0,739	0,148
Cran. Height/Breadth	0,535	1,000	0,789	0,880	1,000	0,922
Fr. Breadth/length	0,861	0,433	0,010	0,761	0,182	0,933
Fr. Arc/chord	0,996	0,750	1,000	0,735	0,999	0,811
Par. Arc/chord	0,997	0,407	0,450	0,459	0,642	0,848
Pt. Lamb./Aster.Breg. length	0,975	0,467	0,017	0,487	0,020	0,248
Occip. Breadth/length	0,758	0,816	0,042	0,991	0,714	0,980
Occip. Arc/chord	0,577	0,131	0,105	0,476	0,367	0,957
Obel. In. Arc/chord	0,996	0,969	0,772	1,000	0,919	0,906

Table 42. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the redefined severity degrees of tabular headshaping

	Absent $_1$			Slight $_2$			Moderate $_3$			Severe $_4$			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	127	0,78	0,05	57	0,83	0,04	16	0,88	0,05	22	0,92	0,06	46,191	0,000^
Cran. Height/length	75	0,73	0,03	49	0,76	0,05	10	0,79	0,05	15	0,80	0,03	23,997	0,000
Cran. Height/Breadth	68	0,94	0,06	48	0,92	0,07	11	0,90	0,06	14	0,89	0,08	6,547	0,000
Fr. Breadth/length	112	1,10	0,07	53	1,12	0,06	9	1,17	0,03	18	1,18	0,09	3,192	0,000^
Fr. Arc/chord	188	1,15	0,04	62	1,14	0,04	16	1,13	0,03	22	1,14	0,03	3,051	0,029
Par. Arc/chord	194	1,12	0,04	64	1,14	0,03	21	1,16	0,03	28	1,16	0,03	12,891	0,000
Pt. Lamb./Aster.Breg. length	148	1,04	0,06	63	1,01	0,07	18	0,98	0,05	24	0,95	0,06	16,627	0,000
Occip. Breadth/length	126	1,14	0,09	56	1,17	0,07	20	1,20	0,07	22	1,17	0,07	3,147	0,025
Occip. Arc/chord	170	1,20	0,06	62	1,19	0,06	23	1,19	0,05	24	1,18	0,03	2,035	0,109
Obel. In. Arc/chord	176	1,14	0,08	65	1,10	0,10	22	1,08	0,06	29	1,06	0,03	14,791	0,000

Pillai's Trace Test, F: 6,120 (30-1029) *p*:0,000

^Welch's Test

Table 43. Games Howell Post Hoc on results of Table 42

	p_{1-2}	p_{1-3}	p_{1-4}	p_{2-3}	p_{2-4}	p_{3-4}
Cran. Breadth/length	0,000	0,000	0,000	0,027	0,000	0,075
Cran. Height/length	0,001	0,003	0,000	0,656	0,003	0,140
Cran. Height/Breadth	0,199	0,003	0,053	0,306	0,554	1,000
Fr. Breadth/length	0,846	0,002	0,047	0,000	0,011	0,980
Fr. Arc/chord	0,351	0,061	0,313	0,572	0,963	0,894
Par. Arc/chord	0,007	0,000	0,000	0,021	0,062	0,959
Pt. Lamb./Aster.Breg. length	0,043	0,000	0,000	0,202	0,000	0,130
Occip. Breadth/length	0,084	0,142	0,267	0,893	1,000	0,892
Occip. Arc/chord	0,683	0,514	0,017	0,950	0,410	0,912
Obel. In. Arc/chord	0,012	0,000	0,000	0,511	0,022	0,676

5.4.3. Composite headshaping

When considering composite headshaping instead, cranial height/breadth, frontal arc/chord, pterion-lambda/asterion-bregma length, occipital breadth/length, occipital arc/chord, and obelion-inion arc/chord decrease, while cranial breadth/length, cranial height/length frontal breadth/length and parietal arc/chord increase. The most evident changes include the decrease of obelion-inion arc/chord ($\bar{x}$:1,07) and the increase of cranial breadth/length ($\bar{x}$:0,91) (Tables 44, 45).

One-way Anova displays that all the proportional metrics have statistically significant mean differences (Tables 44, 45). Moreover, One-Way Manova shows statistically significant mean differences only in relation with tabular modification (Pillai's Trace: F (30-753) = 7,409, *p:*0,000) (Table 45). Post Hoc Test performed according to the degrees of severity of tabular modification shows that, except for slight and moderate degrees, mean differences occur between all the degrees (Table 46).

Table 44. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the redefined severity degrees of circular modification in composite headshaping

	Absent ₁			Slight ₂			Moderate ₃			Severe ₄			Very severe ₅			F	
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	113	0,77	0,05	31	0,91	0,07	2	0,83	0,03	0	-	-	0	-	-	2,220	0,086
Cran. Height/length	69	0,73	0,03	18	0,78	0,03	1	0,75	-	0	-	-	0	-	-	1,239	0,296
Cran. Height/Breadth	62	0,94	0,06	18	0,89	0,05	1	0,93	-	0	-	-	0	-	-	0,840	0,473
Fr. Breadth/length	98	1,10	0,07	30	1,16	0,06	2	1,09	0,06	0	-	-	0	-	-	0,182	0,909
Fr. Arc/chord	160	1,15	0,03	42	1,11	0,15	2	1,10	0,01	2	1,13	0,10	0	-	-	0,236	0,872
Par. Arc/chord	159	1,12	0,04	52	1,19	0,04	3	1,17	0,04	2	1,28	0,10	1	1,19	-	6,691	0,000
Pt. Lamb./Aster.Breg. length	126	1,04	0,06	46	0,98	0,05	2	1,01	0,08	0	-	-	0	-	-	0,182	0,908
Occip. Breadth/length	107	1,15	0,08	45	1,12	0,09	2	1,07	0,10	1	1,21	-	0	-	-	0,372	0,773
Occip. Arc/chord	139	1,20	0,06	49	1,15	0,04	2	1,21	0,02	2	1,13	0,05	0	-	-	1,059	0,367
Obel. In. Arc/chord	143	1,14	0,08	51	1,07	0,04	2	1,12	0,01	2	1,10	0,03	1	1,17	-	0,205	0,893

Pillai's Trace Test, F: 1,330 (30-753) *p*:0,113

Table 45. One-way Manova on proportional cranial measurements of adult and subadult individuals according to the redefined severity degrees of tabular headshaping in composite headshaping

	Absent ₁			Slight ₂			Moderate ₃			Severe ₄			F	
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	F	*p*
Cran. Breadth/length	122	0,78	0,05	11	0,86	0,03	9	0,89	0,05	13	0,96	0,07	57,845	0,000
Cran. Height/length	73	0,73	0,03	11	0,77	0,03	5	0,78	0,04	3	0,82	0,01	18,801	0,000
Cran. Height/Breadth	66	0,94	0,06	11	0,89	0,04	5	0,88	0,09	3	0,89	0,04	20,776	0,000
Fr. Breadth/length	107	1,10	0,07	10	1,13	0,04	10	1,14	0,07	12	1,18	0,04	1,819	0,000^
Fr. Arc/chord	171	1,15	0,03	16	1,07	0,25	11	1,13	0,02	19	1,14	0,04	4,862	0,000^
Par. Arc/chord	172	1,12	0,04	22	1,17	0,05	18	1,19	0,04	18	1,22	0,03	54,828	0,000
Pt. Lamb./Aster.Breg. length	134	1,04	0,06	17	1,02	0,03	14	0,99	0,04	17	0,95	0,05	10,941	0,000
Occip. Breadth/length	115	1,14	0,08	18	1,09	0,09	15	1,13	0,07	15	1,16	0,08	2,672	0,048
Occip. Arc/chord	150	1,20	0,06	19	1,15	0,04	17	1,17	0,04	17	1,14	0,02	14,029	0,000^
Obel. In. Arc/chord	155	1,15	0,08	20	1,09	0,03	17	1,07	0,03	19	1,06	0,06	14,449	0,000

Pillai's Trace Test, F: 7,409 (30-753) *p*:0,000
^Welch's Test

Table 46. Games Howell Post Hoc on results of Table 45

	p_{1-2}	p_{1-3}	p_{1-4}	p_{2-3}	p_{2-4}	p_{3-4}
Cran. Breadth/length	0,000	0,000	0,000	0,219	0,000	0,034
Cran. Height/length	0,048	0,002	0,000	0,922	0,018	0,045
Cran. Height/Breadth	0,016	0,001	0,000	0,488	0,035	0,703
Fr. Breadth/length	0,998	0,964	0,000	0,991	0,001	0,013
Fr. Arc/chord	0,581	0,100	0,333	0,768	0,772	1,000
Par. Arc/chord	0,001	0,000	0,000	0,806	0,039	0,230
Pt. Lamb./Aster.Breg. length	0,078	0,090	0,000	0,940	0,004	0,047
Occip. Breadth/length	0,097	0,327	0,999	0,925	0,258	0,553
Occip. Arc/chord	0,001	0,008	0,000	0,860	0,458	0,082
Obel. In. Arc/chord	0,000	0,000	0,000	0,763	0,357	0,784

5.5. CHANGES OF PROPORTIONAL CRANIAL MEASUREMENTS ACCORDING TO THE PRESENCE OF THE DIFFERENT HEADSHAPING TYPES REDEFINED BY REVIEWED DEGREES OF SEVERITY

The investigation on the effects that the different headshaping types have on proportional metrics of combined adults and subadults has allowed to employ a larger sample and thus to obtain more reliable results. In order to ulteriorly increase the number of the processed sample, statistical analyses on proportional metrics have been newly performed exclusively according to the presence of the different headshaping types in turn reviewed according to the redefined headshaping severity.

5.5.1. Circular headshaping

The statistical analyses conducted in relation with the presence of circular headshaping shows that cranial breadth/length and height/length, frontal breadth/length, occipital breadth/length, and occipital arc/chord decrease, while cranial height/length, parietal arc/chord, pterion-lambda/asterion-bregma length and obelion-inion arc/chord increase. Only frontal arc/ chord does not variate. The most evident changes regard the decrease of occipital breadth/length and the increase of cranial height/breadth (Table 47).
Compared to the previous analyses, differences in proportional means regard a major number of proportional metrics such as frontal breadth/length (*p:*0,021), parietal arc/chord (*p:*0,047), pterion-lambda/asterion-bregma length (*p:*0,015), occipital breadth-length (*p:*0,004) and arc/chord (*p:*0,001) (Table 47). One-way Manova displays that mean differences between unmodified and circularly shaped crania are statistically significant (Pillai's Trace Test, F(10-350)=4,632; *p*:0,000) (Table 47).

5.5.2. Tabular headshaping

Metric effects produced by tabular headshaping appear almost opposite to those observed in circular modification. In fact, except for parietal arc/chord that increases and occipital arc/chord that decreases in both the headshaping types, cranial breadth/length and height/breadth, frontal breadth/length, and occipital breadth/length increase, while cranial height/length, pterion-lambda/asterion-bregma length and obelion-inion arc/chord decrease (Table 48). The most evident alterations regard the increase of cranial breadth/length ($\bar{x}$:0,86) and the decrease of pterion-lambda/asterion-bregma ($\bar{x}$:0,99) and obelion-inion arc/chord ($\bar{x}$:1,09) (Table 48).

One-way Anova reveals that, except for frontal breadth/length, all the proportional means display statistically relevant differences between shaped and unmodified crania (Table 47). Moreover, One-way Manova shows a statistically significant relation between mean differences and the presence of tabular headshaping (Pillai's Trace Test, F(10-343)=16,745; *p*:0,000) (Table 48).

5.5.3. Composite headshaping

The pattern of changes of proportional metrics in presence of composite headshaping almost identically reflects that observed in tabular headshaping. Only occipital breadth/length differently behaves by decreasing. The most evident changes regard the increase of cranial breadth/length ($\bar{x}$:0,91) and the decrease of obelion-inion arc/chord ($\bar{x}$:1,07) (Table 49).

According to Anova, except for the frontal arc/chord, all the other proportions have statistically significant mean differences between shaped and unmodified crania (Table 49). Moreover, One-way Manova shows a statistically significant relationship between changes in proportional means and the presence of composite headshaping (Pillai's Trace Test, F(10-251)=27,123; p:0,000) (Table 49).

Table 47. One-way Manova on proportional cranial measurements of combined age groups according to the presence of circular headshaping

	Absent			Present			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	215	0,81	0,07	5	0,75	0,04	0,443	0,506
Cran. Height/length	147	0,75	0,05	1	0,70	-	0,159	0,547^
Cran. Height/Breadth	141	0,92	0,07	1	0,98	-	2,078	0,150
Fr. Breadth/length	187	1,12	0,07	6	1,05	0,08	5,347	0,021
Fr. Arc/chord	286	1,14	0,04	18	1,14	0,05	0,412	0,521
Par. Arc/chord	286	1,13	0,04	18	1,16	0,08	9,735	0,047^
Pt. Lamb./Aster.Breg. length	239	1,02	0,07	14	1,05	0,10	12,434	0,015^
Occip. Breadth/length	208	1,16	0,08	7	1,04	0,06	8,193	0,004
Occip. Arc/chord	253	1,20	0,06	13	1,14	0,06	12,148	0,001
Obel. In. Arc/chord	263	1,12	0,09	14	1,15	0,07	0,534	0,465

Pillai's Trace Test, F: 4,632 (10-350) *p*:0,000
^Welch's Test

Table 48. One-way Manova on proportional cranial measurements of combined age groups according to the presence of tabular headshaping

	Absent			Present			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	127	0,78	0,05	95	0,86	0,06	97,819	0,000
Cran. Height/length	75	0,73	0,03	74	0,77	0,05	51,943	0,000
Cran. Height/Breadth	68	0,94	0,06	73	0,91	0,07	15,771	0,000
Fr. Breadth/length	112	1,10	0,07	80	1,14	0,07	1,621	0,135^
Fr. Arc/chord	188	1,15	0,04	100	1,14	0,04	7,731	0,006
Par. Arc/chord	194	1,12	0,04	113	1,15	0,03	30,206	0,000
Pt. Lamb./Aster.Breg. length	148	1,04	0,06	105	0,99	0,07	33,139	0,000
Occip. Breadth/length	126	1,14	0,09	98	1,18	0,07	8,971	0,003
Occip. Arc/chord	170	1,20	0,06	109	1,19	0,05	4,662	0,024^
Obel. In. Arc/chord	176	1,14	0,08	116	1,09	0,08	38,378	0,000

Pillai's Trace Test, F: 16,745 (10-343) *p*:0,000
^Welch's Test

Table 49. One-way Manova on proportional cranial measurements of combined age groups according to the presence of composite headshaping

	Absent			Present			F	
	n	$\bar{x}$	**s**	**n**	$\bar{x}$	**s**	**F**	***p***
Cran. Breadth/length	113	0,77	0,05	33	0,91	0,07	132,298	0,000^
Cran. Height/length	69	0,73	0,03	19	0,78	0,03	44,820	0,000
Cran. Height/Breadth	62	0,94	0,06	19	0,89	0,05	54,610	0,000
Fr. Breadth/length	98	1,10	0,07	32	1,15	0,06	1,688	0,036^
Fr. Arc/chord	160	1,15	0,03	46	1,11	0,15	7,742	0,074^
Par. Arc/chord	159	1,12	0,04	58	1,19	0,04	142,313	0,000
Pt. Lamb./Aster.Breg. length	126	1,04	0,06	48	0,99	0,05	22,078	0,000
Occip. Breadth/length	107	1,15	0,08	48	1,12	0,09	4,967	0,043
Occip. Arc/chord	139	1,20	0,06	53	1,15	0,04	38,202	0,000^
Obel. In. Arc/chord	143	1,14	0,08	56	1,07	0,04	39,508	0,000

Pillai's Trace Test, F: 27,123 (10-251) *p*:0,000

5.6. STATISTICAL DISCRIMINATION BETWEEN UNMODIFIED AND SHAPED CRANIA PERFORMED ON CRANIAL MEASUREMENTS AND PROPORTIONAL METRICS BY USING BOTH RAW AND IMPUTED DATA.

5.6.1. Multiple discriminant function analysis on cranial measurements of adult individuals by using raw data.

Multiple discriminant function analysis performed on adult cranial measurements by using raw data has considered 20 measurements (maximum frontal breadth, bistephanic breadth, frontal arc, frontal chord, frontal subtense, parietal arc, parietal chord, bregma subtense fraction, pterion-lambda length, asterion-bregma length, asterion-pterion length, occipital arc, occipital chord, occipital subtense, lambda subtense fraction, foramen magnum length, least exterior breadth across the roots of the zygomatic processes, maximum cranial length and breadth, obelion-inion arc and right porion-bregma height) resulted discriminant in One-way Manova. A total of 83 crania including 36 unmodified, 3 circularly shaped and 46 tabularly shaped examples have been considered (Table 50). While the first function accounted for 86,3% of the discriminating ability of the variables, the second function instead for 13,7% (Table 50). The high magnitude of the eigenvalue as well as the high value of the first function were indicative of its significant discriminating ability (Table 50).

Table 50. Summary of canonical discriminant functions calculated on cranial measurements of adult individuals (raw data)

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	2,049	86,3	86,3	0,820
2	0,326	13,7	100	0,496

F values (Table 51a) show that 12 out of 20 measurements might be potentially discriminators of the three groups. Predictor variables include: bistephanic breadth (*p*:0,028), frontal arc (*p*:0,011), frontal chord (*p*:0,035), frontal subtense (*p*:0,003), parietal arc (*p*:0,003), parietal chord (*p*:0,003), bregma subtense fraction (*p*:0,003), pterion-lambda length (*p*:0,000), occipital arc (*p*:0,028), occipital subtense (*p*:0,016), maximum cranial length (*p*:0,000) and breadth (*p*:0,004) (Table 51a).

Among discriminant loadings, maximum cranial length (-0,435), pterion-lambda length (-0,364), frontal subtense (-0,262), occipital subtense (-0,218) and occipital arc (-0,208) are substantive discriminators in Function 1 (Table 51a), while parietal chord (0,529), bregma subtense fraction (0,507), parietal arc (0,503), frontal arc (0,309), maximum cranial breadth (0,294), bistephanic breadth (0,242) and frontal chord (0,223) are substantive discriminators in Function 2 (Table 51a). By combining the statistical significance of F scores and the most substantive discriminant loadings, it is possible to state that cranial measurements that maximally discriminate between the three groups include: bistephanic breadth, frontal arc, frontal chord, frontal subtense, parietal arc, parietal chord, bregma subtense fraction, pterion-lambda length, occipital arc, occipital subtense, maximum cranial length and breadth (Table 51a). Chi-squared values calculated on the two functions together well discriminate between the groups (χ^2: 98,489; df:40; *p*: 0,000) (Table 51a). Conversely, Chi-squared value recalculated after the extraction of the first function has not statistically significance (p<0,05) (Table 51a). Multiple comparisons performed by Scheffe Post Hoc Test reveals that unmodified crania differ from circularly shaped ones both on the first (*p*:0,042) and the second function (*p*:0,000), unmodified and tabularly shaped crania only on the first function (*p*:0,000), while circularly and tabularly shaped crania differ only on the second function (*p*:0,000) (Table 51b).

Table 51a. Multiple discriminant function analysis on discriminant cranial measurements of adult individuals according to the presence of circular and tabular headshaping (raw data)

		Unmodified (34)[1]		Circular (3)[2]		Tabular (46)[3]		Wλ	F		Discriminant loadings		Canonical coefficient	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s		F	*p*	F1*	F2**	F1	F
Frontal	**Max.Fr. Breadth**	120,09	5,65	114,67	2,31	122,14	7,23	0,943	2,439	0,094	0,111	0,332	-0,110	0,136
	Bisteph. Breadth	115,44	7,14	112,50	2,60	119,17	6,66	0,914	3,760	0,028	0,191	0,242	0,114	-0,134
	Fr. Arc	128,09	6,68	119,33	7,09	123,86	7,23	0,894	4,743	0,011	-0,207	0,309	0,313	0,080
	Fr. chord	111,93	4,90	107,00	4,00	109,14	5,34	0,920	3,492	0,035	-0,186	0,223	-0,218	-0,048
	Fr. Subtense	26,00	2,95	22,33	3,51	23,38	3,74	0,865	6,258	0,003	-0,262	0,220	-0,402	-0,174
Parietal	**Par. Arc**	126,26	7,62	111,33	7,09	121,65	8,72	0,865	6,264	0,003	-0,190	0,503	0,085	-0,012
	Par. chord	112,50	6,40	98,50	4,77	106,17	6,93	0,765	12,260	0,000	-0,324	0,529	-0,040	0,053
	Br. Subt. Fract.	57,19	5,02	49,00	2,00	54,64	4,13	0,862	6,430	0,003	-0,194	0,507	-0,066	0,105
	Pt.- Lamb. length	140,19	6,00	136,33	4,93	-133,91	5,97	0,787	10,856	0,000	-0,364	0,028	0,005	-0,106
	Ast.- Pt. length	96,00	4,32	93,00	1,00	96,34	5,10	0,983	0,709	0,495	0,026	0,224	0,013	-0,054
Occipital	**Occ. Arc**	115,56	8,08	116,00	8,00	110,67	8,19	0,914	3,751	0,028	-0,208	-0,125	-0,104	-0,085
	Occ. chord	94,72	5,82	97,33	4,75	93,58	5,54	0,978	0,888	0,415	-0,071	-0,190	0,057	-0,002
	Occ. Subtense	26,57	3,11	23,67	3,79	24,54	3,23	0,901	4,372	0,016	-0,218	0,190	0,355	0,059
	Lamb. Subt. Fract.	49,54	7,03	53,33	6,66	52,43	7,86	0,962	1,570	0,214	0,133	-0,100	0,026	-0,041
	For. Mag. length	36,00	2,31	34,83	5,35	35,71	2,63	0,992	0,335	0,717	-0,038	0,129	0,108	-0,060
Temporal	**Zyg. Proc. Breadth**	121,24	5,12	115,67	4,04	122,60	5,46	0,936	2,731	0,071	0,091	0,396	0,041	0,108
Cranium	**Max. length**	181,84	7,31	169,00	9,17	172,48	6,83	0,683	18,603	0,000	-0,435	0,367	-0,261	0,055
	Max. Breadth	140,68	5,99	137,33	4,16	145,13	6,91	0,873	5,806	0,004	0,239	0,294	0,044	0,019
	Ob.- In. Arc	108,24	10,13	101,00	8,19	104,60	5,46	0,953	1,988	0,144	-0,136	0,192	0,036	0,027
	R. Por.- Br. Height	126,71	5,46	122,17	2,57	128,31	5,53	0,945	2,308	0,106	0,104	0,330	0,013	0,026
Constant													11,683	-10,956

*Wilk's Lambda 0,247; χ^2: 98,489; df:40; *p*: 0,000
** Wilk's Lambda 0,754; χ^2: 19,895; df:19; *p*: 0,401

Table 51b. Scheffe Post Hoc Test on discriminant functions of discriminant cranial measurements of adults (raw data)

	p_{1-2}	p_{1-3}	p_{2-3}
Discriminant scores from Function 1 for Analysis 1	0,042	0,000	0,084
Discriminant scores from Function 2 for Analysis 1	0,000	0,997	0,000

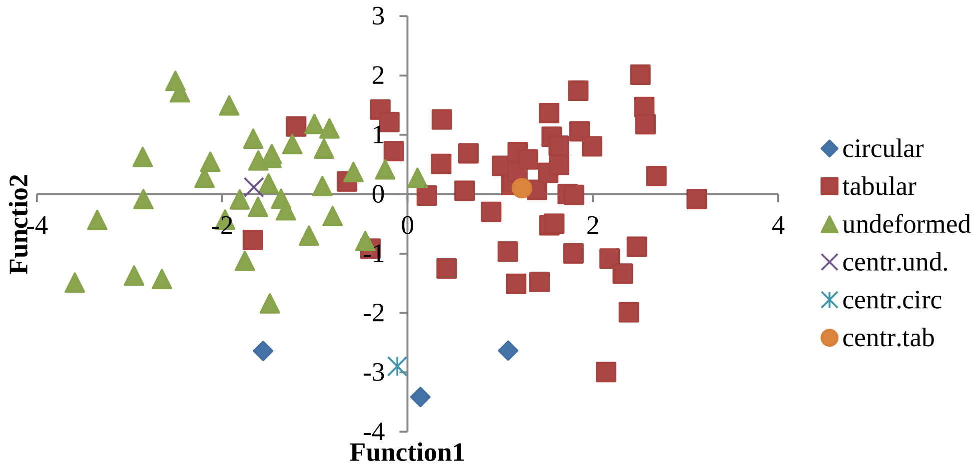
Classification results show that 92,8% of the examples have been correctly classified by the two discriminant functions. A more detailed examination of the classification indicates that predicted membership is more accurate (100%) for circular headshaping, followed by unmodified crania (94,1%) and tabularly shaped ones (91,3%) (Table 52; Graph1). Press's Q statistic for testing classification accuracy has given a value of 131,95 (<6,63). Thus, it can be concluded that classification results for cranial measurements, processed by using original data, exceeds the classification expected by chance at a statistically significant level (p<0,01).

Table 52. Predicted membership based on discriminant cranial measurements (raw data)

			Unmodified	Circular	Tabular	Total %
Original	**n**	**Unmodified**	32	0	2	34
		Circular	0	3	0	3
		Tabular	4	0	42	46
	%	**Unmodified**	94,1	0,0	5,9	100,0
		Circular	0,0	100,0	0,0	100,0
		Tabular	8,7	0,0	91,3	100,0
Correctly classified	**%**					92,8
Cross-validated	**n**	**Unmodified**	28	1	5	34
		Circular	1	0	2	3
		Tabular	7	1	38	46
	%	**Unmodified**	82,4	2,9	14,7	100,0
		Circular	33,3	0,0	66,7	100,0
		Tabular	15,2	2,2	82,6	100,0
Correctly classified	**%**					79,5

The representation in Graph 1 of the obtained discrimination visually shows that examples on the left portion of the graph (unmodified crania) have measurements with negative discriminant loadings, generally increasing, while examples on the right portion (tabularly shaped crania) conversely behave. Differently, examples located on the middle-bottom area (circularly shaped crania) are more influenced by the negative loadings of Function 2 (Table 51a).

Graph 1 Discrimination between unmodified, circularly, and tabularly shaped crania based on discriminant cranial measurements (raw data)



5.6.2. Multiple discriminant function analysis on cranial measurements of adult individuals by using multiply imputed data.

Multiple discriminant function analysis performed on statistically imputed adult cranial measurements has considered on a total of 183 adult crania including 128 unmodified, 9 circularly shaped and 46 tabularly shaped examples. While the first function accounts for 78,9% of the discriminating ability of the variables, the second one for 21,1% (Table 53). The magnitude of the eigenvalue of the first function indicates its higher discriminative power (Table 53).

Table 53. Summary of canonical discriminant functions calculated on cranial measurements of adult individuals (imputed data)

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	0,870	78,9	78,9	0,682
2	0,233	21,1	100,0	0,434

An examination of F values (Table 54a) shows that, compared to the results of raw data, a major number of measurements has a discriminant power; they include: maximum frontal breadth (*p*:0,000), bistephanic breadth (*p*: 0,000), frontal arc (*p*:0,022), frontal subtense (*p*: 0,000), parietal arc (*p*:0,002), parietal chord (*p*: 0,000), bregma subtense fraction (*p*:0,010), pterion-lambda length (*p*:0,000), asterion-pterion length (*p*:0,003), occipital arc (*p*:0,015), occipital subtense (*p*:0,018), lambda subtense fraction (*p*:0,001), least exterior breadth across the roots of the zygomatic processes (*p*:0,000), maximum cranial length (*p*:0,000) and breadth (*p*:0,004), obelion-inion arc (*p*:0,013) and right porion-bregma height (*p*:0,001) (Table 54a). Among discriminant loadings, maximum cranial length (0,568), maximum cranial breadth (-0,439), parietal chord (0,438), pterion-lambda length (0,436), least exterior breadth across the roots of the zygomatic processes (-0,282), lambda subtense fraction (-0,267), parietal arc (0,235), obelion-inion arc (0,215), bregma subtense fraction (0,207) and occipital arc (0,201) are substantive discriminators in Function 1 (Table 54a), while frontal subtense (0,510), asterion-pterion length (0,426), maximum frontal breadth (0,378), right porion-bregma height (0,336), bistephanic breadth (0,335) and occipital subtense (0,306) are substantive discriminators in Function 2 (Table 54a).

The combination of statistical significance of F values and discriminant loadings allow to conclude that maximum frontal and bistephanic breadth, frontal subtense, parietal arc, parietal chord, bregma subtense fraction, pterion-lambda length, asterion-pterion length, occipital arc, occipital subtense, lambda subtense fraction, least exterior breadth across the roots of the zygomatic processes, maximum cranial length and breadth, obelion-inion arc and right porion-bregma height (Table 54a) maximally discriminate. Chi-squared Test shows that the two functions together well discriminate between the three groups (χ^2: 174,075; df:40; *p:* 0,000) (Table 54a) as well as the value recalculated after the extraction of the first function (χ^2:43,613; df:19; *p*: 0,001) (Table 54a). Multiple comparisons performed by Scheffe Post Hoc Test displays that unmodified and tabularly shaped crania discriminate at the first function (*p*:0,000), unmodified and circularly shaped ones at the second (*p*:0,000), while circularly and tabularly shaped crania at both the function (*p*:0,000) (Table 54b).

Table 54a. Discriminant function analysis on discriminant cranial measurements of adult individuals according to the presence of circular and tabular headshaping (multiply imputed data)

		Unmodified (128)[1]		Circular (9)[2]		Tabular (46)[3]		Wλ	F		Discriminant loadings		Canonical coefficient	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s		F	*p*	F1*	F2**	F1	F2
Frontal	**Max.Fr. Breadth**	120,14	6,24	114,09	4,60	123,46	7,19	0,902	11,886	0,000	-0,295	0,378	0,036	0,000
	Bisteph. Breadth	116,06	7,03	110,46	4,85	119,87	6,78	0,897	12,468	0,000	-0,319	0,335	-0,051	0,009
	Fr. Arc	126,70	7,39	124,27	8,76	123,82	7,49	0,966	3,883	0,022	0,191	0,131	-0,008	-0,141
	Fr. chord	110,57	5,57	110,74	7,15	109,12	5,44	0,984	1,780	0,171	0,137	-0,014	0,014	0,014
	Fr. Subtense	25,69	2,62	21,91	3,37	23,84	3,47	0,886	14,033	0,000	0,280	0,510	0,105	0,314
Parietal	**Par. Arc**	125,53	8,56	120,84	9,38	121,37	8,59	0,944	6,459	0,002	0,235	0,220	-0,063	-0,001
	Par. chord	112,20	6,64	106,52	7,63	106,19	6,86	0,838	21,066	0,000	0,438	0,338	0,072	0,048
	Br. Subt. Fract.	56,83	5,13	54,80	5,43	54,75	4,60	0,958	4,738	0,010	0,207	0,165	0,035	0,005
	Pt.- Lamb. length	139,86	6,27	140,68	9,99	134,62	6,03	0,858	18,106	0,000	0,436	-0,056	0,025	-0,106
	Ast.- Pt. length	95,84	5,25	90,21	5,91	96,74	5,55	0,948	6,024	0,003	-0,123	0,426	-0,022	0,064
Occipital	**Occ. Arc**	115,35	8,81	112,62	7,46	111,92	7,99	0,962	4,268	0,015	0,201	0,130	0,019	0,032
	Occ. chord	94,86	6,39	96,39	7,68	93,72	5,83	0,988	1,288	0,278	0,104	-0,101	0,030	-0,043
	Occ. Subtense	27,97	8,78	21,66	4,07	25,42	7,99	0,964	4,097	0,018	0,135	0,306	-0,006	0,016
	Lamb. Subt. Fract.	48,97	8,17	49,14	7,89	53,41	9,48	0,941	6,773	0,001	-0,267	-0,006	-0,023	-0,004
	For. Mag. length	36,37	1,95	35,14	2,92	36,01	2,61	0,985	1,654	0,194	0,066	0,221	0,000	0,007
Temporal	**Zyg. Proc. Breadth**	120,28	7,03	116,05	4,65	123,60	6,26	0,922	9,239	0,000	-0,282	0,260	-0,030	0,005
Cranium	**Max. length**	181,98	8,48	176,90	11,69	172,76	7,36	0,773	32,087	0,000	0,568	0,247	0,059	0,049
	Max. Breadth	140,44	7,24	135,14	4,96	146,01	6,98	0,841	20,651	0,000	-0,439	0,309	-0,075	0,006
	Ob.- In. Arc	109,11	9,87	108,14	9,29	105,24	8,27	0,961	4,439	0,013	0,215	0,041	-0,005	-0,020
	R. Por.- Br. Height	126,12	5,72	121,38	8,66	128,30	5,48	0,934	7,707	0,001	-0,226	0,336	-0,014	0,060
Constant													-2,206	-5,563

*χ^2: 174,075; df:40; *p*: 0,000
** χ^2:43,613; df:19; *p*: 0,001

Table 54b. Scheffe Post Hoc Test on discriminant functions of discriminant cranial measurements of adults (multiply imputed data)

	p_{1-2}	p_{1-3}	p_{2-3}
Discriminant scores from Function 1 for Analysis 1	0,998	0,000	0,000
Discriminant scores from Function 2 for Analysis 1	0,000	0,535	0,000

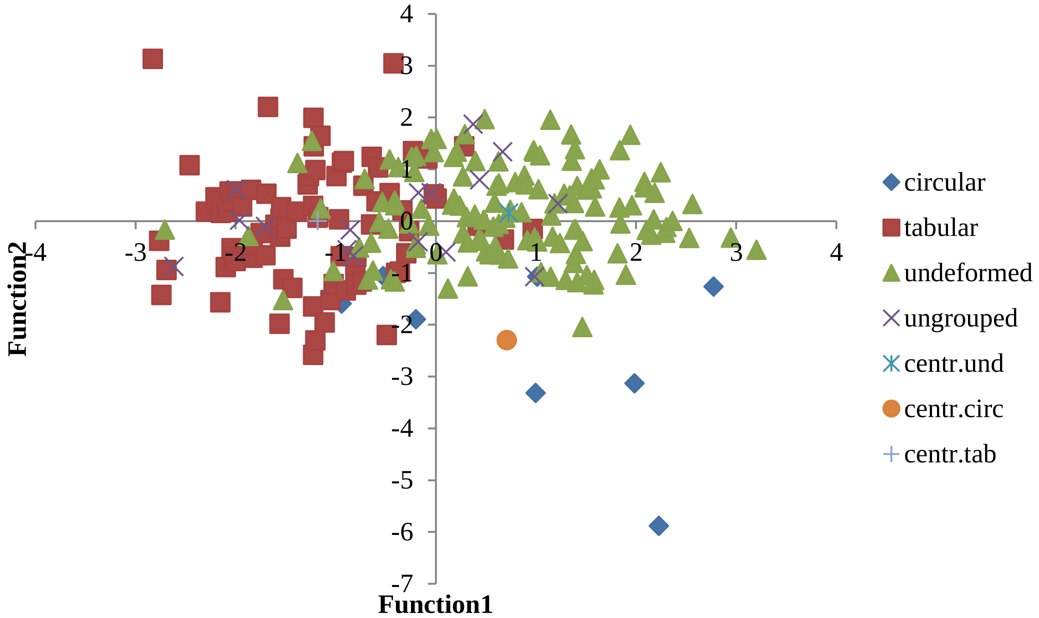
Compared to the results of the discriminant function analysis performed on the raw data, predicted membership shows a lower percentage of accuracy (82,4%) (Table 55). Press's Q statistic for testing classification accuracy has given a value of 196,89 (<6,63). Thus, also for multiply imputed data, classification results exceed the classification expected by chance at a statistically significant level (p<0,01).

Table 55. Predicted membership based on discriminant cranial measurements (multiply imputed data)

			Unmodified	Circular	Tabular	Total %
Original	**n**	**Unmodified**	11	0	17	128
		Circular	3	3	3	9
		Tabular	16	0	68	84
		Ungrouped	9	0	7	16
	%	**Unmodified**	86,7	0,0	13,3	100,0
		Circular	33,3	33,3	33,3	100,0
		Tabular	19,0	0,0	81,0	100,0
		Ungrouped	56,3	0,0	43,8	100,0
Correctly classified	**%**					82,4
Cross-validated	**n**	**Unmodified**	102	1	25	128
		Circular	3	2	4	9
		Tabular	21	2	61	84
	%	**Unmodified**	79,7	0,8	19,5	100,0
		Circular	33,3	22,2	44,4	100,0
		Tabular	25,0	2,4	72,6	100,0
Correctly classified	**%**					74,7

The discrimination between the three groups represented in Graph 2 visually shows that examples localised in the left portion (tabularly shaped crania) have measurements with negative discriminant loadings, while those localised in the right portion (unmodified crania) oppositely behave. Examples located on the middle/right bottom area (circularly shaped crania) instead are more influenced by negative loadings of Function 2 and positive loadings of Function 1 (Graph2; Table 54a).

Graph 2. Discrimination between unmodified, circularly, and tabularly shaped crania based on discriminant cranial measurements of adult individuals (multiply imputed data)



5.6.3. Multiple discriminant function analysis on discriminant proportional cranial measurements of combined age groups by using raw data

Multiple discriminant function analysis performed on discriminant proportional cranial measurements by using raw data has considered a total of 103 adult and subadult crania including 41 unmodified, 4 circularly shaped and 58 tabularly shaped examples. The statistical analysis has produced two functions that respectively account for 83,9% and 16,1% of the ability of the variables to discriminate between unmodified and shaped crania (Table 56). The magnitude of the eigenvalue of the first function indicates its higher discriminative power (Table 56).

Table 56. Summary of canonical discriminant functions calculated on discriminant proportional measurements of adult and subadult individuals (raw data)

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	0,811	83,9	83,9	0,669
2	0,155	16,1	100,0	0,366

F values (Table 57) show that more than half of the variables is a potential discriminator between unmodified and shaped crania (p<0,05). Potential predictors include cranial breadth/length (p:0,000), cranial height/length (p:0,000), frontal breadth/length (p:0,000), parietal arc/chord (p:0,000), pterion-lambda/asterion-bregma length (p:0,000) and occipital breadth/length (p:0,011). Among discriminant loadings, cranial breadth/length (-0,817), cranial height/length (-0,619), frontal breadth/length (-0,464), parietal arc/chord (0,259), pterion-lambda/asterion-pterion length (0,244) and occipital breadth/length (0,230) are substantive discriminators in Function 1 (Table 57). The combination of statistical significance of F scores and discriminant loadings allows us to identify proportional metrics that maximally discriminate between the three groups; they include: cranial breadth/length, cranial height/length, frontal breadth/length, parietal arc/chord, pterion-lambda/asterion-pterion length and occipital breadth/length (Table 57). Chi-squared values indicate that the two functions considered together well discriminate (χ^2: 70,451; df:20; p: 0,000), while there is no statistical significance after the extraction of the first function (Table 57). Multiple comparison performed by Scheffe Post Hoc Test reveals that unmodified and tabularly shaped crania differ (p:0,000) on the first function, while unmodified and circularly shaped crania (p:0,001), and these latter and tabularly shaped ones (p:0,001) on the second (Table 58).

Classification results show that 80,6% of the processed examples have been correctly classified. A more detailed examination of the classification indicates that predicted membership is more accurate for tabular headshaping (86,2%), followed by unmodified crania (75,6%) and circularly shaped ones (50%) (Table 59; Graph3). Press’s Q statistic for testing classification accuracy has given a value of 147,28 (<6,63). Thus, it can be concluded that classification results of proportional metrics elaborated by using raw data exceed the classification expected by chance at a statistically significant level (p<0,01).

Table 57. Multiple discriminant function analysis on proportional cranial measurements of adults and subadult individuals resulting discriminant in One-way Manova according to the presence of circular and tabular headshaping (raw data)

	Unmodified (41)[1]		Circular (4)[2]		Tabular (58)[3]		Wλ	F		Discriminant loadings		Canonical coefficient	
		s	$\bar{x}$	s	$\bar{x}$	s		F	*p*	F1*	F2**	F1	F2
Cran. Breadth/length	0,78	0,04	0,82	0,05	0,85	0,05	0,648	27.69	0,000	-0,817	-0,120	24,690	63,943
Cran. Height/length	0,73	0,04	0,74	0,05	0,77	0,04	0,763	15.550	0,000	-0,619	0,075	-49,496	-72,329
Cran. Height/Breadth	0,94	0,05	0,91	0,03	0,91	0,06	0,949	2.705	0,072	-0,482	0,017	32,792	66,859
Fr. Breadth/length	1,08	0,06	1,07	0,02	1,13	0,07	0,847	9.008	0,000	-0,464	0,197	-2,828	1,974
Fr. Arc/chord	1,15	0,03	1,13	0,03	1,14	0,04	0,977	1.197	0,306	0,450	-0,256	-0,465	6,119
Par. Arc/chord	1,12	0,03	1,13	0,01	1,15	0,03	0,842	9.406	0,000	0,259	0,139	-11,233	0,938
Pt. Lamb./Aster.Breg. length	1,03	0,05	1,05	0,05	0,99	0,06	0,852	8.714	0,000	0,244	0,197	2,023	-4,629
Occip. Breadth/length	1,17	0,07	1,06	0,03	1,18	0,08	0,914	4.709	0,011	0,230	0,068	-0,198	11,845
Occip. Arc/chord	1,22	0,07	1,19	0,06	1,19	0,05	0,946	2.870	0,061	-0,053	0,770	0,939	-0,923
Obel. In. Arc/chord	1,14	0,12	1,11	0,04	1,09	0,11	0,958	2.183	0,118	0,132	0,252	-0,829	1,636
Constant												1,234	-79,712

*χ^2: 70,451; df:20; *p*: 0,000
** χ^2:13,760; df:9; *p*: 0,131

Table 58. Scheffe Post Hoc Test on discriminant functions of proportional cranial measurements of adults and subadults (raw data)

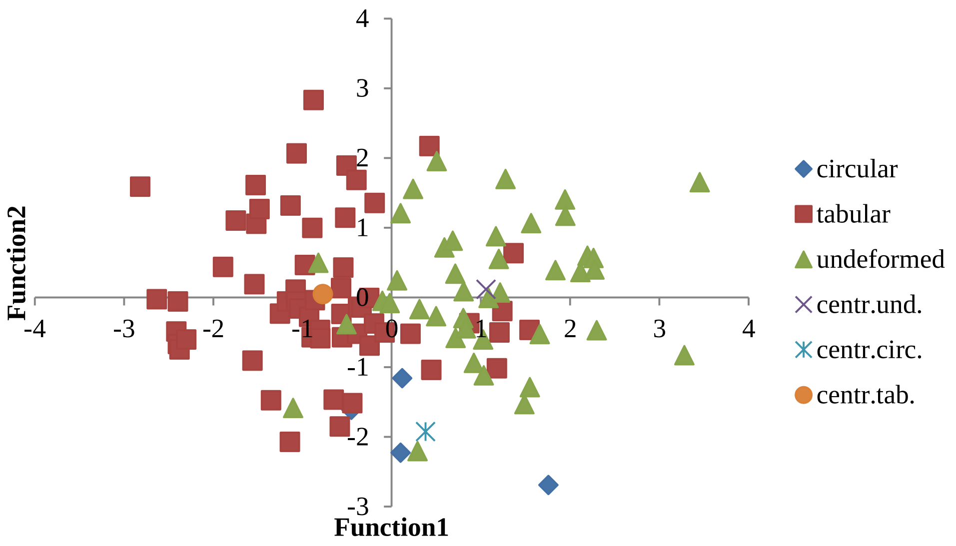
	p_{1-2}	p_{1-3}	p_{2-3}
Discriminant scores from Function 2 for Analysis 1	0,436	0,000	0,88
Discriminant scores from Function 2 for Analysis 1	0,001	0,944	0,001

Table 59. Predicted membership based on discriminant proportional metrics of adults and subadults (raw data)

			Unmodified	Circular	Tabular	Total %
Original	**n**	**Unmodified**	31	1	9	41
		Circular	0	2	2	4
		Tabular	8	0	50	58
	%	**Unmodified**	75,6	2,4	22,0	100,0
		Circular	0,0	50,0	50,0	100,0
		Tabular	13,8	0,0	86,2	100,0
Correctly classified	**%**					80,6
Cross-validated	**n**	**Unmodified**	31	1	9	41
		Circular	1	0	3	4
		Tabular	10	0	48	58
	%	**Unmodified**	75,6	2,4	22,0	100,0
		Circular	25,0	0,0	75,0	100,0
		Tabular	17,2	0,0	82,8	100,0
Correctly classified	**%**					76,7

The discrimination represented in Graph 3 visually shows that examples localised in the left portion of the graph (tabularly shaped crania) have almost all measurements with negative discriminant loadings, while those localised in the right portion (unmodified crania) with positive ones. Conversely, examples located on the middle/right bottom area (circularly shaped crania) are more influenced by negative loadings of Function 2 and positive loadings of Function1 (Table 57).

Graph 3 Discrimination between unmodified, circularly, and tabularly shaped crania based on discriminant proportional metrics (raw data)



5.6.4. Multiple discriminant function analysis on discriminant proportional cranial measurements by using multiply imputed data

Multiple discriminant function analysis performed on proportional metric of both adult s and subadults by using statistically imputed data has considered a total of 335 crania of including 186 unmodified, 35 circularly shaped and 114 tabularly shaped examples. The analysis has produced two discriminant functions that respectively account for 83,5% and 16,5% of the ability of the variables to discriminate between unmodified and shaped crania (Table 60). Similarly to the results of the analysis performed on imputed cranial measurements, except for frontal breadth/length (p>0,05), all proportional metrics represent potential discriminators (p<0,05) (Table 60). Among discriminant loadings, cranial breadth/length (-0,750), cranial height/length (-0,572) and frontal arc/chord (0,193) are substantive discriminators in Function 1, while parietal arc/chord (0,567), pterion-lambda/asterion-bregma length (0,513), occipital breadth/length (0,451), occipital arc/chord (-0,376) and obelion-inion arc/chord (0,355) are substantive discriminators in Function 2 (Table 60). The combination of statistical significance of F scores and discriminant loadings allows us to identify the most discriminant proportions of cranial measurements between the three groups: cranial breadth/length, cranial height/length, cranial height/breadth, frontal arc/chord, parietal arc/chord, pterion-lambda/asterion-pterion length, occipital breadth/length, occipital arc/chord, and occipital breadth/length (Table 60). Chi squared scores indicate that both the two functions, either together (χ^2: 164,440; df:20; *p:* 0,000) and after the extraction of the first one (χ^2:31,046; df:9; *p*: 0,000), discriminate very well (Table 60). Scheffe Post Hoc Test on discriminant functions shows that undeformed and tabularly shaped crania discriminate at the first function, while undeformed and circularly shaped at the second, as well as circularly and tabularly shaped ones (Table 61). Compared to the analysis performed on raw data, predicted membership is characterized by a lower percentage of accuracy (72,8%) (Table 62). The highest percentage of membership prediction has been obtained for unmodified crania (83,9%), followed by tabularly shaped (72,8%) and circularly shaped ones (14,3%) (Table 62). Press's Q statistic for testing classification accuracy has given a value of 235,24 (<6,63) (Table 62). Thus, it can be concluded that classification results of proportional metrics elaborated by using multiple imputed data exceed the classification expected by chance at a statistically significant level ($p<0,01$).

Table 60. Discriminant function analysis on proportional cranial measurements of adult and subadult individuals resulting discriminant in One-way Manova according to the presence of circular and tabular headshaping (multiply imputed data)

	Unmodified (186)[1]		Circular (35)[2]		Tabular (114)[3]		Wλ	F		Discriminant loadings		Canonical coefficients	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s		F	*p*	F1*	F2**	F1	F2
Cran. Breadth/length	0,79	0,06	0,80	0,06	0,86	0,06	0,779	46,979	0,000	-0,750	0,041	-1,637	5,892
Cran. Height/length	0,73	0,05	0,74	0,04	0,78	0,05	0,859	27,311	0,000	-0,572	0,052	-16,605	2,190
Cran. Height/Breadth	0,93	0,06	0,93	0,06	0,90	0,07	0,962	6,574	0,002	-0,462	0,211	13,662	4,505
Fr. Breadth/length	1,14	0,14	1,10	0,08	1,15	0,07	0,984	2,627	0,074	0,276	0,109	5,282	-5,083
Fr. Arc/chord	1,15	0,03	1,15	0,05	1,14	0,04	0,981	3,208	0,042	0,193	0,074	4,485	8,234
Par. Arc/chord	1,12	0,03	1,15	0,06	1,15	0,03	0,898	18,924	0,000	-0,218	0,567	-3,788	10,684
Pt. Lamb./Aster.Breg. length	1,04	0,07	1,06	0,09	0,99	0,07	0,894	19,651	0,000	0,428	0,513	2,321	5,486
Occip. Breadth/length	1,15	0,09	1,11	0,09	1,17	0,07	0,947	9,284	0,000	-0,432	0,451	-2,208	-4,728
Occip. Arc/chord	1,20	0,06	1,18	0,07	1,19	0,05	0,972	4,783	0,009	0,171	-0,376	0,101	-4,500
Obel. In. Arc/chord	1,15	0,08	1,15	0,06	1,09	0,08	0,899	18,559	0,000	-0,081	0,355	1,911	3,430
Costant												-7,748	-24,999

*χ^2: 164,440; df:20; *p*: 0,000
** χ^2:31,046; df:9; *p*: 0,000

Table 61. Scheffe Post Hoc Test on discriminant functions of proportional cranial metrics of adults and subadults (multiply imputed data)

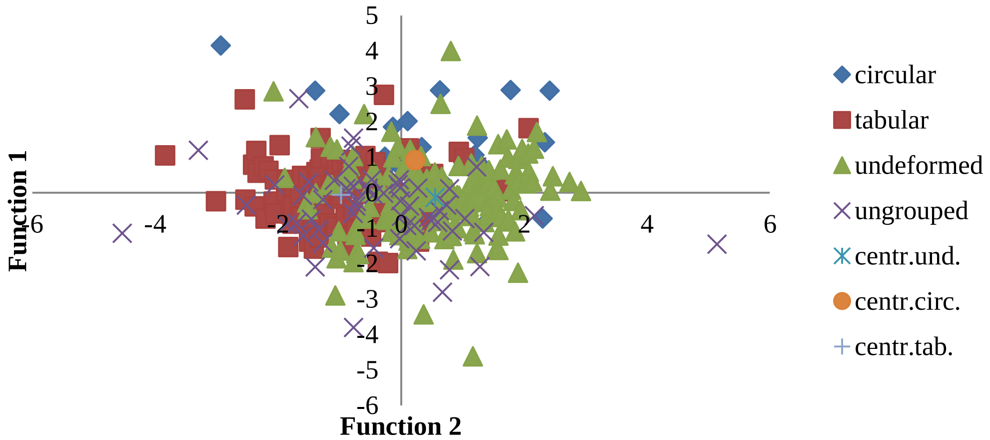
	p_{1-2}	p_{1-3}	p_{2-3}
Discriminant scores from Function 2 for Analysis 1	0,202	0,000	0,000
Discriminant scores from Function 2 for Analysis 1	0,000	0,824	0,000

Table 62. Predicted membership based on proportional cranial metrics of adults and subadults (multiply imputed data)

			Unmodified	Circular	Tabular	Total %
Original	**n**	**Unmodified**	156	3	27	186
		Circular	22	5	8	35
		Tabular	30	1	83	114
		Ungrouped	30	0	28	58
	%	**Unmodified**	83,9	1,6	14,5	100,0
		Circular	62,9	14,3	22,9	100,0
		Tabular	26,3	0,9	72,8	100,0
		Ungrouped	51,7	0,0	48,3	100,0
Correctly classified	**%**					72,8
Cross-validated	**n**	**Unmodified**	153	4	29	186
		Circular	25	2	8	35
		Tabular	33	1	80	114
	%	**Unmodified**	82,3	2,2	15,6	100,0
		Circular	71,4	5,7	22,9	100,0
		Tabular	28,9	0,9	70,2	100,0
Correctly classified	**%**					70,1

The discrimination represented in Graph 4 visually shows that examples localised in the left portion of the graph (tabularly shaped crania) almost have measurements with negative discriminant loadings, while those localised in the right portion (unmodified crania) with positive ones. Contrary, examples located on the middle/superior area (circularly shaped crania) are almost influenced by positive loadings of both function 1 and 2 (Table 60).

Graph 4 Discrimination between unmodified, circularly, and tabularly shaped crania based on discriminant proportional metrics of adults and subadults (multiply imputed data)



5.7. MULTINOMIAL LOGISTIC REGRESSION ON DISCRIMINANT CRANIAL MEASUREMENTS AND PROPORTIONAL METRICS

5.7.1. Multinomial logistic regression on discriminant cranial measurements by using raw data

A total of 83 examples consisting of 34 unmodified, 3 circularly and 46 tabularly shaped crania have been processed by using original data. Classification results show that the model has a very successful rate of prediction by reaching even 100% of discrimination for each group (Table 63). Likelihood Ratio Tests (χ^2: 134,908; df:40; *p*:0,000) and both Pearson and Deviance Chi-square statistics (χ^2: 0,000; df:124; *p*:1,000) (Table 64) indicate that the model fits data well. Among independent variables, all discriminant cranial measurements of frontal region, bregma subtense fraction, occipital subtense, maximum cranial length, maximum cranial breadth and obelion-inion arc are highly statistically significant (*p*<0,05) (Table 64).

Table 63. Classification results of Multinomial logistic regression on discriminant cranial measurements of adults (raw data)

	Predicted			
Observed	**Unmodified**	**Circular**	**Tabular**	**Total %**
Unmodified	34	0	0	100,0
Circular	0	3	0	100,0
Tabular	0	0	46	100,0
Total %	41%	3,6%	55,4%	100,0

Table 64. Multinomial logistic regression on discriminant cranial measurements of adults (raw data)

		Circular					Tabular					χ^2		
		B	**Wald**	**df**	***p***	**Exp(B)**	**B**	**Wald**	**df**	***p***	**Exp(B)**	**χ^2**	**df**	***p***
Frontal	**Max.Fr. Breadth**	-45,501	0,000	1	0,997	1.73E-20	-55,650	0,001	1	0,981	2.13E-25	21,238	2	0,000
	Bisteph. Breadth	39,493	0,000	1	0,999	1.42E17	46,848	0,001	1	0,981	2.13E-25	25,840	2	0,000
	Fr. Arc	53,850	0,000	1	0,999	2.44E23	73,886	0,001	1	0,979	2.13E-25	29,499	2	0,000
	Fr. chord	-42,126	0,000	1	0,999	5.07E-19	-54,791	0,001	1	0,974	1.60E-24	18,734	2	0,000
	Fr. Subtense	-56,979	0,000	1	0,998	1.80E-25	-93,293	0,001	1	0,976	3.04E-41	39,012	2	0,000
Parietal	**Par. Arc**	2,427	0,000	1	1,000	11.33	10,960	0,000	1	0,984	57502.53	0,000	2	1,000
	Par. chord	13,727	0,000	1	0,998	915571.66	23,355	0,001	1	0,977	1.39E10	2,573	2	0,276
	Br. Subt. Fract.	-27,290	0,000	1	0,996	1.41E-12	-29,211	0,001	1	0,974	2.06E-13	23,312	2	0,000
	Pt.- Lamb. length	-7,925	0,000	1	0,999	3.62E-4	-38,824	0,001	1	0,975	1.38E-17	0,035	2	0,983
	Ast.- Pt. length	0,886	0,000	1	1,000	2.43	8,374	0,000	1	0,986	4332.13	0,000	2	1,000
Occipital	**Occ. Arc**	8,626	0,000	1	0,998	5572.60	-30,767	0,000	1	0,985	4.34E-14	0,000	2	1,000
	Occ. chord	-7,161	0,000	1	0,999	7.76E-4	31,420	0,000	1	0,985	4.42E13	0,037	2	0,982
	Occ. Subtense	35,064	0,000	1	0,998	1.69E15	73,945	0,001	1	0,979	1.30E32	38,053	2	0,000
	Lamb. Subt. Fract.	-5,983	0,000	1	0,999	0.002	-9,383	0,000	1	0,990	8.41E-5	0,000	2	1,000
	For. Mag. length	18,228	0,000	1	0,998	8.25E7	6,042	0,000	1	0,997	420.81	0,000	2	1,000
Temporal	**Zyg. Proc. Breadth**	10,128	0,000	1	0,999	25041.18	-2,297	0,000	1	0,995	2.13E-25	0,000	2	1,000
Cranium	**Max. length**	-48,363	0,000	1	0,998	3321549.94	-56,807	0,001	1	0,976	2.13E-25	31,972	2	0,000
	Max. Breadth	15,016	0,000	1	0,998	1.73E-20	29,600	0,001	1	0,981	-	20,804	2	0,000
	Ob.- In. Arc	8,426	0,000	1	0,998	4565.99	19,459	0,001	1	0,974	2.82E8	24,690	2	0,000
	R. Por.- Br. Height	-4,790	0,000	1	1,000	0.01	7,920	0,000	1	0,992	2751.31	0,000	2	1,000

Likelikooh Ratio Tests: χ^2: 134,908; df:40; *p*: 0,000
Pearson: χ^2: 0,000; df:124; *p*: 1,000
Deviance: χ^2:0,000; df:124; *p*: 1,000

5.7.2. Multinomial logistic regression on discriminant cranial measurements by using multiple imputed data

A total of 221 examples consisting of 128 unmodified, 9 circularly and 84 tabularly shaped crania have been considered by using multiply imputed data. Classification results show that the model has correctly predicted 176 out of 221 examples, for an overall success rate of 84,2% (Table 65). The highest rate of membership prediction has been achieved for circular headshaping (100%), followed by unmodified crania (87,5%) and tabularly shaped ones (77,4%) (Table 65). Likelihood Ratio Tests (χ^2: 208,434 df:40; *p*:0,000) and both Pearson (χ^2: 293,060; df:400; *p*:1,000) and Deviance Chi-square statistics (χ^2:151,507; df:400; *p*:1,000) (Table 66) indicate that the model fits data well. Among independent variables, only frontal subtense results are statistically significant (χ^2: 22,499; df:2; *p*:0,000) (Table 66). The comparison between reference group (unmodified) and shaped crania shows that maximum cranial breadth is statistically significant (*p*:0,048) in the logit of tabularly shaped crania (Table 66).

Table 65. Multinomial logistic regression classification results based on discriminant cranial measurements of adults (multiply imputed data)

	Predicted			
Observed	**Unmodified**	**Circular**	**Tabular**	**Total %**
Unmodified	112	0	16	87,5
Circular	0	9	0	100,0
Tabular	19	0	65	77,4
Total %	59,3	4,1	36,7	84,2

Table 66. Multinomial logistic regression on discriminant cranial measurements of adults (multiply imputed data)

		Circular					Tabular					χ^2		
		B	**Wald**	**df**	***p***	**Exp(B)**	**B**	**Wald**	**df**	***p***	**Exp(B)**	χ^2	**df**	***p***
Frontal	**Max.Fr. Breadth**	-14,418	0,000	1	0,999	5.48E-7	-0,009	0,006	1	0,939	0.99	0,006	2	0,997
	Bisteph. Breadth	4,775	0,000	1	1,000	118.52	0,048	0,212	1	0,645	1.05	0,217	2	0,987
	Fr. Arc	37,896	0,000	1	0,999	2.87E16	0,045	0,287	1	0,592	1.05	0,284	2	0,868
	Fr. chord	-23,132	0,000	1	1,000	8.99E-11	-0,046	0,229	1	0,632	0.95	0,226	2	0,893
	Fr. Subtense	-58,041	0,000	1	0,999	6.21E-26	-0,268	3,628	1	0,057	0.76	22,499	2	0,000
Parietal	**Par. Arc**	-11,600	0,000	1	0,999	9.17E-6	0,129	3,394	1	0,065	1.14	3,473	2	0,176
	Par. chord	6,991	0,000	1	1,000	1087.34	-0,136	1,827	1	0,176	0.87	1,830	2	0,401
	Br. Subt. Fract.	-13,863	0,000	1	1,000	9.54E-7	-0,075	1,942	1	0,163	0.93	2,029	2	0,363
	Pt.- Lamb. length	19,334	0,000	1	1,000	2.49E8	-0,110	1,940	1	0,164	0.90	2,051	2	0,359
	Ast.- Pt. length	-5,382	0,000	1	1,000	0.004	0,075	1,371	1	0,242	1.08	1,389	2	0,499
Occipital	**Occ. Arc**	4,004	0,000	1	1,000	54.84	-0,043	0,632	1	0,427	0.96	0,640	2	0,726
	Occ. chord	4,164	0,000	1	1,000	64.33	-0,062	0,980	1	0,322	0.94	0,994	2	0,608
	Occ. Subtense	-13,602	0,000	1	1,000	1.24E-6	0,009	0,096	1	0,757	1.01	0,094	2	0,954
	Lamb. Subt. Fract.	-1,371	0,000	1	1,000	0.25	0,036	1,198	1	0,274	1.04	1,211	2	0,546
	For. Mag. length	-4,361	0,000	1	1,000	0.01	-0,041	0,151	1	0,698	0.96	0,151	2	0,927
Temporal	**Zyg. Proc. Breadth**	1,220	0,000	1	1,000	3.39	0,020	0,136	1	0,712	1.02	0,137	2	0,934
Cranium	**Max. length**	-7,059	0,000	1	1,000	8.60E-4	-0,091	1,812	1	0,178	0.91	1,881	2	0,390
	Max. Breadth	-13,457	0,000	1	0,999	1.43E-6	0,134	3,908	1	0,048	1.14	4,061	2	0,131
	Ob.- In. Arc	1,450	0,000	1	1,000	4.26	0,011	0,134	1	0,715	1.01	0,134	2	0,935
	R. Por.- Br. Height	-1,092	0,000	1	1,000	0.34	0,085	0,960	1	0,327	1.09	0,967	2	0,616

Likelikooh Ratio Tests: χ^2: 208,434 df:40; *p*: 0,000
Pearson: χ^2: 293,060; df:400; *p*: 1,000
Deviance: χ^2:151,507; df:400; *p*: 1,000

5.7.3. Multinomial logistic regression on discriminant proportional metrics by using raw data

A total of 103 examples including 41 unmodified, 4 circularly and 58 tabularly shaped crania have been processed by using raw data (Table 67). Classification results show that the model has correctly predicted 84 out of 103 examples, for an overall success rate of 81,6% (Table 67). The highest rate of membership prediction has been achieved for tabular shaped crania (86,2%), followed by unmodified (78%) and circularly shaped ones (50%) (Table 67). Likelihood Ratio Tests (χ^2: 79,353 df:20; *p*:0,000) and both Pearson (χ^2: 108,786; df:184; *p*:1,000) and Deviance Chi-square statistics (χ^2:88,784; df:184; *p*:1,000) indicate that the model fits data well (Table 68). Among independent variables, only occipital breadth/length has statistical significance (χ^2: 12.329; df:2; *p*:0,002) (Table 68).

5.7.4. Multinomial logistic regression on discriminant proportional metrics by using multiply imputed data

A total of 335 examples consisting of 186 unmodified, 35 circularly and 114 tabularly shaped crania have been used for processing discriminant proportional metrics by using multiply imputed data (Table 69). Out of 335 examples 240 crania have been successfully classified with an overall success rate of 71,6% (Table 69). The highest rate of membership prediction has been obtained for unmodified crania (83,3%), followed by tabularly shaped ones (71,1%), while circularly shaped crania have been correctly classified only for 11,4% (Table 69). Likelihood Ratio Tests (χ^2: 170,650 df:20; *p*:0,000) and Deviance Chi-square statistics (χ^2:151,507; df:400; *p*:1,000) indicate that the model fits data well (Table 70). Nevertheless, the significance of Pearson Chi-square statistic (χ^2: 784,667; df:648; *p*:0,000) does not indicate the same result (Table 70). Predictor variables such as frontal breadth/length (χ^2:28.761; df: 2; *p*:0,000), parietal arc/chord (χ^2:6.416; df:2; *p*:0,040) and occipital breadth/length (χ^2:8.791; df:2; *p*:0,012) are statistically significant (Table 70). The comparison between reference group and shaped crania shows that frontal breadth/length and parietal arc/chord are statistically significant (p<0,05) in the logits of both circularly and tabularly shaped crania, while occipital breadth/length in the logit of circular headshaping (Table 70).

Table 67. Classification results of Multinomial logistic regression on discriminant proportional metrics of adults and subadults (raw data)

	Predicted			
Observed	**Unmodified**	**Circular**	**Tabular**	**Total %**
Unmodified	32	1	8	78,0
Circular	0	2	2	50,0
Tabular	8	0	50	86,2
Total %	38,8	2,9	58,3	81,6

Table 68. Multinomial logistic regression on discriminant proportional metrics of adults and subadults (raw data)

	Circular					Tabular					χ^2		
	B	**Wald**	**df**	***p***	**Exp(B)**	**B**	**Wald**	**df**	***p***	**Exp(B)**	χ^2	**df**	***p***
Cran. Breadth/length	-1238.806	2.038	1	0.153	0,000	-1.415	0,000	1	0.989	0.243	4.015	2	0.134
Cran. Height/length	1382.920	2.159	1	0.142	-	46.502	0.183	1	0.669	1.57E20	4.237	2	0.120
Cran. Height/Breadth	-1159.569	2.111	1	0.146	0,000	-20.393	0.053	1	0.817	1.39E-9	4.299	2	0.117
Fr. Breadth/length	-8.107	0.131	1	0.718	3.02E-4	5.578	0.614	1	0.433	264.60	0.940	2	0.625
Fr. Arc/chord	-6.693	0.032	1	0.858	0.001	1.092	0.010	1	0.922	2.98	0.051	2	0.975
Par. Arc/chord	19.579	0.315	1	0.575	3.19E8	19.732	3.601	1	0.058	3.71E8	3.947	2	0.139
Pt. Lamb./Aster.Breg. length	10.228	0.207	1	0.649	27671.55	-3.118	0.200	1	0.654	0.04	0.501	2	0.778
Occip. Breadth/length	-43.584	3.750	1	0.053	1.18E-19	-1.724	0.165	1	0.684	0.18	12.329	2	0.002
Occip. Arc/chord	-6.119	0.092	1	0.762	0.002	-1.146	0.042	1	0.838	0.32	0.118	2	0.943
Obel. In. Arc/chord	-6.828	0.131	1	0.718	0.001	2.140	0.320	1	0.572	8,50	0.529	2	0.768

Likelihood Ratio Tests: χ^2: 79,353 df:20; *p*: 0,000
Pearson: χ^2: 108,786; df:184; *p*: 1,000
Deviance: χ^2:88,784; df:184; *p*: 1,000

Table 69. Multinomial logistic regression classification results based on discriminant proportional metrics of adults and subadults (imputed data)

	Predicted			
Observed	**Unmodified**	**Circular**	**Tabular**	**Total %**
Unmodified	155	4	27	83,3
Circular	23	4	8	11,4
Tabular	32	1	81	71,1
Total %	62,7	2,7	34,6	71,6

Table 70. Multinomial logistic regression on discriminant proportional metrics of adults and subadults (imputed data)

	Circular					Tabular					χ^2		
	B	**Wald**	**df**	***p***	**Exp(B)**	**B**	**Wald**	**df**	***p***	**Exp(B)**	**χ^2**	**df**	***p***
Cran. Breadth/length	2,515	0.005	1	0.946	12.372	-26.449	0.669	1	0.413	3.26E-12	0.746	2	0.689
Cran. Height/length	14.470	0.128	1	0.720	1924163.864	56.805	2.510	1	0.113	4.68E24	2.397	2	0.302
Cran. Height/Breadth	-5.674	0.031	1	0.861	0.003	-46.428	2.398	1	0.122	6.86E-21	2.373	2	0.305
Fr. Breadth/length	-10.401	9.672	1	0.002	3.0401E-5	-8.097	15.387	1	0,000	3.05E-4	28.761	2	0,000
Fr. Arc/chord	9.481	2.548	1	0.110	13114.47	-6.053	1.526	1	0.217	0.002	5.047	2	0.080
Par. Arc/chord	12.618	4.523	1	0.033	301862.51	9.312	3.842	1	0.050	11075.08	6.416	2	0.040
Pt. Lamb./Aster.Breg. length	2.861	0.966	1	0.326	17.49	-3.188	1.168	1	0.280	0.04	3.157	2	0.206
Occip. Breadth/length	-6.047	4.742	1	0.029	0.002	2.700	1.872	1	0.171	14.88	8.791	2	0.012
Occip. Arc/chord	-3.000	0.589	1	0.443	0.05	1.754	0.280	1	0.597	5.780	1.058	2	0.589
Obel. In. Arc/chord	3.518	2.042	1	0.153	33.72	-4.833	2.156	1	0.142	0.008	5.201	2	0.074

Likelihood Ratio Tests: χ^2: 170,650 df:20; *p*: 0,000
Pearson: χ^2: 784,667; df:648; *p*: 0,000
Deviance: χ^2:452,112; df:648; *p*: 1,000

5.8. PRINCIPAL COMPONENT ANALYSIS ON DISCRIMINANT CRANIAL MEASUREMENTS AND PROPORTIONAL METRICS

5.8.1. Principal component analysis on discriminant cranial measurements of adult crania by using raw data

Principal Component Analysis performed on discriminant cranial measurements of adult individuals has considered a total of 14 metric variables resulted discriminant both in Multiple Discriminant Function Analysis and Multinomial Logistic Regression (Tables 51a, 64). Employed data belong to a total of 113 individuals. The first total percentage of variance reached 68,87% and was accounted for by three main components with eigenvalue size >1. By several successive rotations, through which many cross-loaded variables were progressively deleted, three principal components have been extracted and a total of 10 discriminant cranial measurements retained in order to reach a simpler but statistically significant factor pattern of morphometric alterations occurring between unmodified and shaped crania. KMO and Barlett's Tests have shown that correlation matrix has statistical significance (p<0,05) among at least some of the variables (Table 73). The percentage of total variance reached in the final rotation was 77,24% (>60%) (Table 71). It is accounted for by three principal components, with eigenvalue size >1, that respectively represent the 38,96%, 24,65% and 13,63% of the total variance (Table 71). Parietal chord, parietal arc, maximum cranial length, pterion-lambda length and bregma subtense fraction loaded on PC1; bistephanic breadth, maximum frontal breadth and maximum cranial breadth loaded on PC2; occipital subtense and occipital arc instead loaded on PC 3 (Table 72). The first principal component has the highest positive association with parietal chord (0,945) and the least with bregma subtense fraction (0,684). The Second principal component has the highest positive association with bistephanic breadth (0,942) and the least with maximum cranial breadth (0,889). Occipital subtense and arc instead have very high coefficients in the third component (0,808 and 0,730 respectively) (Table 73). The clustering of variables has simplified the interpretation of these results. In fact, an examination of the variables loaded on each component clearly shows that the first component includes those variables related to the sagittal development of the cranium, thus to its antero-posteriorly oriented morphological variations, the second component reflects its mediolateral development, while the third component is related to the posterior region of the cranium and, in particular, to its curvature (Table 72). 2D and 3D Scatter plots (Graphs 5.a-c) well discriminate between the three groups, and especially between unmodified and tabularly shaped crania (Graphs 5a). Nevertheless, the presence of an overlapping (Graphs 5a) might be either the result of very slight cases of intentional headshaping not easy discriminable from unmodified crania or the result of the very low number of processed circularly shaped crania that influence the discriminatory ability of the analysis to neatly separate between groups.

Table 71. Description of total variance in Principal Component Analysis performed on discriminant cranial measurements of adults (raw data)

Components	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% Variance	% Cumulative	Total	% Variance	% Cumulative	Total	% Variance	% Cumulative
1	3,896	38,957	38,957	3,896	38,957	38,957	3,338	33,379	33,379
2	2,465	24,651	63,608	2,465	24,651	63,608	2,682	26,824	60,203
3	1,363	13,628	77,236	1,363	13,628	77,236	1,703	17,033	77,236
4	,709	7,093	84,329						
5	,582	5,817	90,145						
6	,415	4,147	94,293						
7	,295	2,949	97,242						
8	,142	1,415	98,658						
9	,083	,826	99,484						
10	,052	,516	100,000						

Table 72. Rotated component matrix

	PCA1	PCA2	PCA3
Parietal chord	,945		
Parietal arc	,938		
Maximum cranial length	,741		
Pterion-lambda length	,707		
Bregma subtense fraction	,684		
Bistephanic breadth		,942	
Maximum frontal breadth		,941	
Maximum cranial breadth		,889	
Occipital subtense			,808
Occipital arc			,730

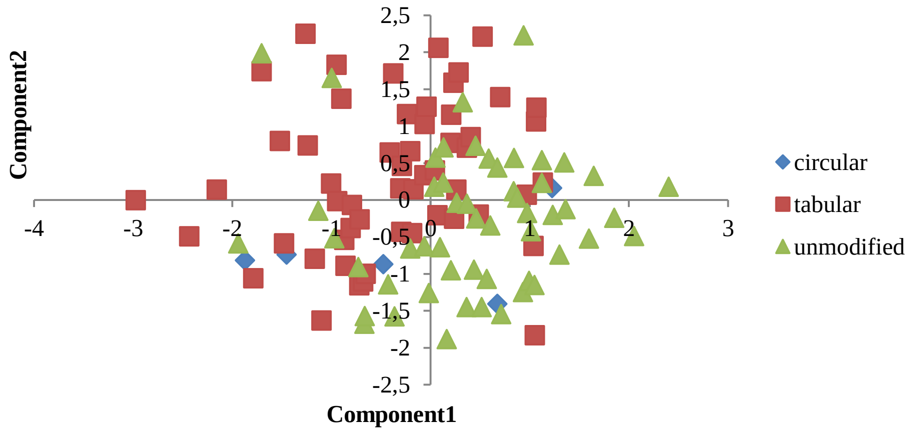
Table 73. Summary of Principal component analysis performed on discriminant cranial measurements of adults (descriptive and component score coefficients matrix) (raw data)

	$\bar{x}$	s	N	PCA1	PCA2	PCA3
Bistephanic breadth	117,51	7,19	113	-,021	,357	-,025
Parietal arc	123,43	8,87	113	,333	-,018	-,202
Parietal chord	109,02	7,58	113	,310	-,041	-,086
Bregma subtense fraction	55,70	5,13	113	,229	,079	-,141
Occipital arc	113,93	8,32	113	-,067	,038	,455
Occipital subtense	26,23	6,83	113	-,136	-,039	,545
Maximum cranial breadth	143,02	6,84	113	-,038	,338	,001
Maximum frontal breadth	121,27	6,68	113	-,013	,353	,002
Pterion-lambda length	137,03	6,45	113	,180	-,046	,158
Maximum cranial length	177,18	8,51	113	,166	-,064	,266
% of variance			77,24	38,96	24,65	13,63

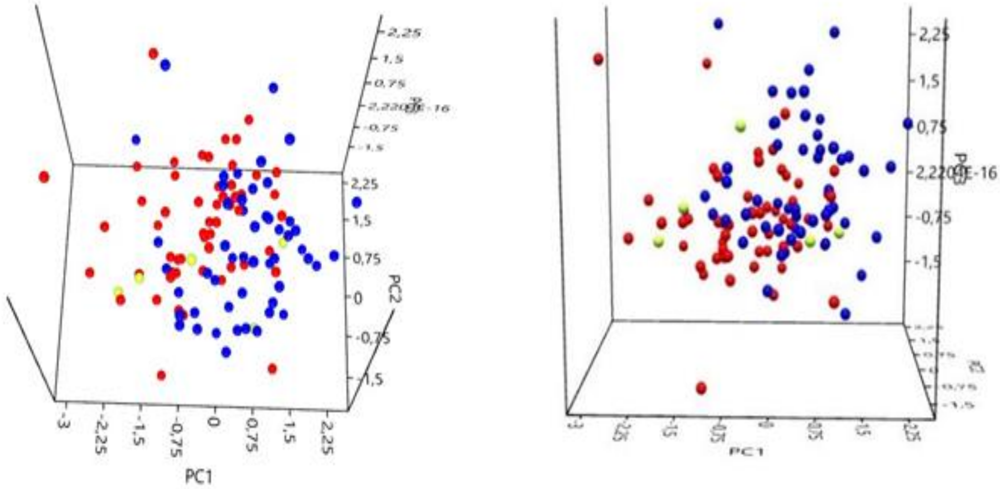
KMO and Barlett's Tests, χ^2:844,033; df:45; *p*:0,000

Graph 5 a) Scatter plot showing PCA scores for modified and unmodified crania along PC1 and PC 2; b) 3D Scatter plots showing PC scores for modified and unmodified crania along PC1, PC2 and PC3

a)



b)



5.9. PRINCIPAL COMPONENT ANALYSIS ON DISCRIMINANT PROPORTIONAL CRANIAL MEASUREMENTS BY USING RAW DATA.

Principal Component Analysis performed on proportional cranial measurements by using raw data has employed six variables resulted statistically significant in Multiple Discriminant Function Analysis and Multinomial Logistic Regression (Tables 57, 68). Employed data belong to a total of 118 individuals. After an initial percentage of total variance of 60,56% accounted for by two main components with eigenvalue size >1, two principal components have been extracted and a total of four discriminant proportional cranial measurements retained by two successive rotations. KMO and Barlett's Tests show that correlation matrix has statistically significant correlation (p<0,05) among at least some of the variables (Table 75). The percentage of total variance is 77,27% (>60%) with the two components accounting for 51,10% and 25,17% (Table 75). Cranial height/length, pterion/lambda length and cranial breadth/length loaded on the component 1, while occipital breadth/length on the component 2 (Table 74). In the first component, cranial height/length has the highest coefficient (0,835), while cranial breadth/length the lowest one (0,813) (Table 74).
The examination of the items and their clustering shows that the first component reflects cranial development according to two of the main cranial dimensions (length and breadth) (Table 74), the second instead is related to the morphometric alteration occurring in the occipital (Table 74). PCA loading biplot (Graph 6) well discriminates at least two of the three groups (unmodified and tabularly shaped crania). Nevertheless, the presence of an overlapping might be the result of cases with very slight degree of intentional headshaping as well as of a very low number of processed circularly shaped crania that have affected the ability of the analysis to neatly separate the three groups.

Table 74. Rotated components matrix

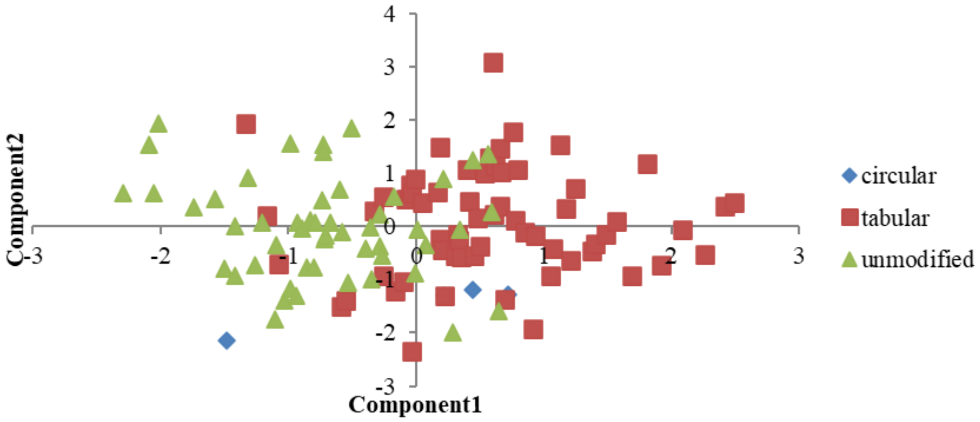
	PCA1	PCA2
Cranial breadth/length	0,834	
Pterion/lambda length	-0,828	
Cranial breadth/length	0,814	
Occipital breadth/length		0,997

Table 75. Summary of Principal component analysis on discriminant proportional metrics od adults and subadults (descriptive and component score coefficients) (raw data)

	$\bar{x}$	s	PCA1	PCA2
Cranial breadth/length	0,82	0,06	0,397	0,077
Cranial height/length	0,75	0,45	0,409	-0,084
Pterion/lambda length	136,33	6,95	-0,405	-0,004
Occipital breadth/length	1,17	0,07	-0,003	0,990
% of variance		76,27	51,10	25,17

KMO and Barlett's Tests, χ^2:88,577; df:6; *p*:0,000

Graph 6. 2D PCA plot of discriminant proportions of cranial measurements



5.10. ARTIFICIAL MORPHOLOGICAL ALTERATIONS IN INTENTIONAL HEADSHAPING ACCORDING TO THE REDEFINED DEGREES OF HEADSHAPING SEVERITY

5.10.1. Circular headshaping

The morphological analysis of the selected sample in relation with the presence of circular headshaping reveals that frontal and parietal regions are the most affected, while occipital bone is characterised by the lowest incidence of changes. Any alteration is not observed in the temporal region (Table 76). Although almost all the morphological alterations occur both in shaped and unmodified crania, the incidences in shaped crania are higher (Table 76). An exception is represented by obelionic flattening that is exclusively observed in unmodified crania (2,8%) and obelionic bulging that is instead only observed in shaped crania (4%). The statistical significance of *p* values ($p<0,05$) for those variables with higher frequencies in presence of circular headshaping reflects their discriminatory relevance (Table 76).

If we look at the frontal region, bulging (81,5%) and depression (80%) are the most frequently encountered alterations, while flattening (16,7%) has the lowest incidence (Table 76). The statistically significant results of Fisher's Exact Test ($p<0,05$) for these three variables (Table 76) suggest their discriminatory value in relation with the presence of circular headshaping.

In the parietal region, although almost all the morphological changes show higher frequencies in shaped crania (Table 76), obelionic (2,8%) and lambdoid flattening (25%) are observed only in unmodified crania (Table 76). The most affected subregions are post bregmatic and parieto-temporal, while bregmatic is the least affected (Table 76). While depression is most frequently encountered in both the two former subregions (86,7% and 70,4%, respectively), bulging mostly occurs in parietal eminences (69,1%) and parieto-temporal areas (53,8%) (Table 76). The statistical significance of all these frequencies suggests the discriminatory role of these morphological variables. Flattening instead is not observed (Table 76).

In the occipital area, although both inionic and pars squamosa are affected, their frequencies are lower than those observed in frontal and parietal bones (Table 76). Pars squamosa subregion appears as the most affected. In detail, bulging is the most frequently observed alteration (36%), followed by flattening (24%) and depression (8,7%). Conversely, in the inionic subregion, flattening shows the highest frequency (40%) followed by depression (24,6%). Bulging instead is observed only in unmodified crania (Table 76). Except for pars squamosa flattening, the statistical significance ($p<0,05$) (Table 76) of all these variables indicate their discriminatory value in the identification of circular headshaping as well.

Table 76. Distribution of morphological cranial alterations according to the redefined severity degrees of circular headshaping

			Absent		Present		Total		χ^2		
			n	%	n	%	n	%	χ^2	df	*p*
Frontal		**Depression**	356	5,3	30	80,0	386	11,1	182,012	3	0,000*
		Flattening	356	2,2	30	16,7	386	3,4	20,376	3	0,001*
		Bulging	355	5,6	27	81,5	382	11	181,623	3	0,000*
Temporal		**Depression**	304	0,0	14	0,0	318	0,0	-	-	-
		Flattening	304	0,0	14	0,0	318	0,0	-	-	-
		Bulging	304	0,0	14	0,0	318	0,0	-	-	-
Parietal	**Bregmatic**	**Depression**	346	0,0	28	0,0	374	0,0	-	-	-
		Flattening	346	0,0	28	0,0	374	0,0	-	-	-
		Bulging	346	1,2	28	10,7	374	1,9	18,386	2	0,005*
	Post bregmatic	**Depression**	347	7,5	30	86,7	377	13,0	122,198	3	0,000*
		Flattening	349	0,0	30	0,0	379	0,0	-	-	-
		Bulging	349	0,6	29	24,1	378	2,4	64,754	2	0,000*
	Tuber	**Depression**	340	0,0	24	0,0	364	0,0	-	-	-
		Flattening	340	0,0	26	0,0	366	0,0	-	-	-
		Bulging/ Prominence	340	23,5	26	69,1	366	26,9	44,716	3	0,000*
	Parieto-temporal	**Depression**	333	2,4	27	70,4	360	17,5	176,069	3	0,000*
		Flattening	333	0,0	26	0,0	359	0,0	-	-	-
		Bulging	332	2,1	26	53,8	358	5,9	117,318	2	0,000*
	Obelionic	**Depression**	321	0,0	24	0,0	345	0,0	-	-	-
		Flattening	321	2,8	25	0,0	346	0,0	0,720	3	1,000*
		Bulging	321	0,0	25	4,0	346	2,6	12,877	1	0,072*
	Lambdoid	**Depression**	317	0,0	23	0,0	340	0,0	-	-	-
		Flattening	316	25,0	23	0,0	339	23,3	7,497	4	0,172*
		Bulging	317	0,0	23	0,0	340	0,0	-	-	-
Occipital	**Inionic**	**Depression**	327	0,9	26	24,6	353	3,3	86,949	3	0,000*
		Flattening	327	0,6	25	40,0	352	3,3	114,475	2	0,000*
		Bulging	327	5,2	25	0,0	352	4,8	1,366	2	0,688*
	Pars squamosa	**Depression**	327	0,0	23	8,7	350	0,6	28,598	2	0,004*
		Flattening	327	23,9	25	24,0	352	23,9	0,687	4	0,942*
		Bulging	327	0,6	25	36,0	352	3,1	100,035	3	0,000*

*Fisher's Exact Test

5.10.2. Tabular headshaping

Unlike circular headshaping, the most important morphological alterations occurring in tabular headshaping regard the posterior portion of the skull, more in detail posterior parietals and occipital. As well as in circular headshaping, the temporal region does not show any sign of morphological alterations (Table 77). The statistical significance of the differences between the frequencies of some variables indicates the discriminatory relevance of those variables towards one of the two groups (Table 77).

In the frontal region while flattening is observed with the same rate of incidence (2,6%) both in shaped and unmodified crania, depression (9,2%) and bulging (8,4%) are recognized only in unmodified crania (Table 77). Results of Chi-squared Test are statistically significant only for these latter variables (*p:*0,002 and *p:*0,004 respectively) (Table 77). According to these observations, it might be suggested that contrary to circular headshaping the lack of frontal morphological alterations in presence of tabular headshaping is a diagnostic condition.

In the parietal region, the highest frequencies of alterations regard lambdoid flattening (71,8%) and tuber prominence/bulging (55,1%) (Table 77). Parietal post bregmatic (14,3% and 4,2%) and parieto-temporal depressions (7,9% and 1%) as well as tuber prominence/bulging (10,9% and 55,1%) and parieto-temporal bulging (7,1% and 1,7%) are observed both in unmodified and shaped crania (Table 77), despite the highest frequencies are observed in these latter. Bregmatic, post bregmatic and obelionic bulging (2,2%, 2,1% and 0,4%, respectively) are observed only in unmodified crania (Table 77). Obelionic bulging (7,2%) and lambdoid flattening (71,8%) instead are exclusively observed in shaped crania (Table 77). Based on these observations and on the statistically significant results of Chi-squared Test, it might be suggested that tuber prominence/bulging (*p*:0,000), obelionic (*p*:0,000) and lambdoid flattening (*p*:0,000) (Table 77) are discriminant changes of tabular headshaping.

In the occipital area instead, except pars squamosa depression (1%) that occurs exclusively in unmodified crania, and inionic bulging (14,6%) that is observed only in shaped crania, all morphological alterations occur both in shaped and unmodified crania (Table 77). Among them, only pars squamosa flattening shows the highest frequency (67,7%) in shaped crania (Table 78). Based on these data and on the statistical significance of the results of Chi-squared Test, pars squamosa flattening (*p*:0,000) and inionic bulging (*p*:0,000) may also be accounted as diagnostic morphological alterations caused by tabular headshaping (Table 77).

Table 77. Distribution of morphological cranial alterations according to the redefined severity degrees of tabular headshaping

			Absent		Present		Total		χ^2		
			n	%	n	%	n	%	χ^2	df	*p*
Frontal		**Depression**	228	9,2	115	0,0	343	6,1	11,283	3	0,002*
		Flattening	228	2,6	115	2,6	343	2,6	0,598	3	1,000*
		Bulging	226	8,4	115	0,0	341	5,6	10,239	3	0,004*
Temporal		**Depression**	199	0,0	116	0,0	315	0,0	-	-	-
		Flattening	199	0,0	116	0,0	315	0,0	-	-	-
		Bulging	199	0,0	116	0,0	315	0,0	-	-	-
Parietal	**Bregmatic**	**Depression**	229	0,0	120	0,0	349	0,0	-	-	-
		Flattening	229	0,0	120	0,0	349	0,0	-	-	-
		Bulging	229	2,2	120	0,0	349	1,4	2,658	2	0,408*
	Post bregmatic	**Depression**	231	14,3	119	4,2	350	10,9	8,291	2	0,009*
		Flattening	233	0,0	120	0,0	353	0,0	-	-	-
		Bulging	232	2,1	120	0,0	352	1,4	2,623	2	0,407*
	Tuber	**Depression**	228	0,0	118	0,0	346	0,0	-	-	-
		Flattening	229	0,0	119	0,0	348	0,0	-	-	-
		Prominence/ Bulging	229	10,9	119	55,1	348	25,9	84,765	3	0,000
	Parieto-temporal	**Depression**	227	7,9	119	1,0	346	5,5	7,668	3	0,046*
		Flattening	226	0,0	119	0,0	345	0,0	-	-	-
		Bulging	226	7,1	119	1,7	345	5,2	4,973	2	0,086*
	Obelionic	**Depression**	231	0,0	124	0,0	355	0,0	-	-	-
		Flattening	231	0,0	124	7,2	355	2,5	17,202	3	0,000*
		Bulging	231	0,4	124	0,0	355	0,3	0,538	1	0,651*
	Lambdoid	**Depression**	235	0,0	124	0,0	359	0,0	-	-	-
		Flattening	234	0,0	124	71,8	358	24,9	223,519	4	0,000
		Bulging	235	0,0	124	0,0	359	0,0	-	-	-
Occipital	**Inionic**	**Depression**	235	3,4	123	1,0	358	2,5	2,458	3	0,734*
		Flattening	235	4,2	123	1,0	358	3,1	3,969	3	0,455*
		Bulging	235	0,0	123	14,6	358	5,0	36,211	2	0,000*
	Pars squamosa	**Depression**	238	1,0	124	0,0	362	0,6	1,048	2	1,000*
		Flattening	240	2,5	124	67,7	364	24,7	187,178	4	0,000
		Bulging	240	3,7	124	2,4	364	3,3	1,320	3	0,839*

*Fisher's Exact Test

5.10.2.1. Correlation between parietal obelionic and lambdoid flattening, parietal lambdoid and occipital flattening, prominence of parietal tubera and degrees of severity of tabular headshaping

Correlation between parietal lambdoid and occipital pars squamosa flattening was investigated on a total of 114 examples (Table 78). The two morphological traits may occur together or singularly. In this latter case, slight occipital pars squamosa and slight parietal lambdoid flattening (90,9% and 75%, respectively) reach the highest frequencies compared to the other degrees of headshaping severity (Table 78). It seems that the degree of severity of parietal lambdoid flattening proportionally increases with the development in severity of occipital pars squamosa flattening by reaching 89,5% when occipital pars squamosa flattening is moderate, 81% when it is severe, and 100% when it is very severe (Table 78). Monte Carlo Test (χ^2:195,866; *p*:0,000) indicates the statistically significant correlation between these two morphological variables.

Table 78. Correlation between severity degrees of parietal lambdoid and occipital pars squamosa flattening in presence of tabular headshaping

	Absent (36)	**Slight** (33)	**Moderate** (19)	**Severe** (21)	**Very severe** (5)	**Total** (114)
	%	**%**	**%**	**%**	**%**	**%**
Absent	0	90,9	10,5	14,3	0	30,7
Slight	75	6,1	0	0	0	25,4
Moderate	22,2	3,0	89,5	4,8	0	23,7
Severe	2,8	0	0	81,0	0	15,8
Very severe	0	0	0	0	100	4,4

Monte Carlo Tests χ^2:195,866; *p*:0,000

The correlation between parietal obelionic and lambdoid flattening was also investigated on a total of 114 cranial remains (Table 79). The statistical analysis shows that parietal obelionic flattening exclusively occurs in presence of lambdoid flattening by increasing in degree of severity with the increase in severity of this latter variable. Slight obelionic flattening co-occurs and increases in frequency (from 3,4% up to 11,1%) by the increasing severity of parietal lambdoid flattening (Table 79). Moderate and severe obelionic flattening instead respectively occur only in presence of moderate and severe parietal lambdoid flattening by reaching a frequency of 11,1% (Table 79).

Results of Fisher's Exact Test (χ^2: 17,039; *p*:0,020) (Table 79) show the statistical significance of the relationship between these two morphological variables.

Table 79. Correlation between severity degrees of parietal obelionic and lambdoid flattening in presence of tabular headshaping

	Absent (35)	**Slight** (29)	**Moderate** (27)	**Severe** (18)	**Very Severe** (5)	**Total** (114)
	%	**%**	**%**	**%**	**%**	**%**
Absent	100	96,6	85,2	77,8	100	92,1
Slight	0	3,4	3,7	11,1	0	3,5
Moderate	0	0	11,1	0	0	2,6
Severe	0	0	0	11,1	0	1,8
Very severe	-	-	-	-	-	-

Fisher’s Exact χ^2:17,039; *p*:0,020

Prominence of parietal tubera has been investigated according to the redefined severity degrees of tabular headshaping on a total of 113 examples (Table 80). Prominence of parietal tubera results absent at any degree of severity of tabular headshaping by reaching the highest level when modification is slight (58,5%) (Table 80). Apart from slight parietal tubera prominence/bulging, the frequencies of moderate (from 12,3% up to 2,4) and severe (from 1,5% up to 32,1%) ones increase by the increasing of headshaping severity (Table 80). Moreover, although not clearly as already observed for the above presented morphological variables, its developmental severity increases with the increasing of that of the headshaping type (from 27,7 to 32,1%). According to the results of Fisher’s Exact Test (χ^2:23,767; *p*:0,000), a statistically significant correlation exists between this morphological alteration and the severity degrees of tabular headshaping (Table 80).

Table 80. Correlation between severity degrees of parietal tubera prominence/bulging and degrees of severity of tabular headshaping

	Absent (-)	**Slight** (65)	**Moderate** (20)	**Severe** (28)	**Total** (113)
	%	**%**	**%**	**%**	**%**
Absent	-	58,5	35	25	46
Slight	-	27,7	40	21,4	28,3
Moderate	-	12,3	20	21,4	15,9
Severe	-	1,5	5	32,1	9,7
Very severe	-	-	-	-	-

Fisher's Exact χ^2:23,767; *p*:0,000

5.10.3. Composite headshaping

Like in circular headshaping, except for temporals, composite headshaping morphologically affects all the cranial regions (Table 81). Moreover, apart from post bregmatic depression (1,6%), all morphological changes occur in shaped crania (Table 81).

The highest frequencies of morphological alterations observed in the frontal region regard bulging (72,1%) and depression (70,5%) (Table 81). Their statistical significance (*p:*0,000), together with that of frontal flattening (19,7%) (*p:*0,000) (Table 81), suggest their discriminatory role in the identification of this headshaping type.

In the parietal area, both anterior and posterior subregions are affected. Nevertheless, the posterior portion appears mostly influenced such as suggested by the high rates of incidences of tuber bulging/prominence (85,7%), lambdoid flattening (84,1%), parieto-temporal bulging (59%) and depression (55,7%) (Table 81). The anterior portion of the parietals instead shows a higher frequency of post bregmatic depression exclusively (38,7%). Nevertheless, despite the low frequencies of bregmatic (8,1%) and post bregmatic bulging (4,8%) (Table 81), results of Chi-squared Test show a statistical significance ($p<0,05$) of all these variables (Table 81), thus suggesting their discriminatory role as well (Table 81).

In the occipital area, both inionic and pars squamosa subregions are influenced. Nevertheless, the highest frequency regards squamosa flattening (82%), followed by bulging (4,9%) (Table 81). The statistical significance of Chi-squared results (*p:*0,000) for these two variables indicate their statistically significant relationship with the presence of this headshaping type (Table 81).

Table 81. Distribution of morphological cranial alterations according to the redefined severity degrees of composite headshaping

			Absent		Present		Total		χ^2		
			n	**%**	**n**	**%**	**n**	**%**	χ^2	**df**	***p***
Frontal		**Depression**	189	0,0	61	70,5	250	17,2	160,905	2	0,000*
		Flattening	189	0,0	61	19,7	250	4,8	39,055	2	0,000*
		Bulging	189	0,0	61	72,1	250	17,6	165,446	2	0,000*
Temporal		**Depression**	169	0,0	53	0,0	222	0,0	-	-	-
		Flattening	169	0,0	53	0,0	222	0,0	-	-	-
		Bulging	169	0,0	53	0,0	222	0,0	-	-	-
Parietal	**Bregmatic**	**Depression**	188	0,0	62	1,6	250	0,4	3,044	1	0,248*
		Flattening	188	0,0	62	0,0	250	0,0	-	-	-
		Bulging	188	0,0	62	8,1	250	2,0	15,471	1	0,001*
	Post bregmatic	**Depression**	186	1,6	62	38,7	248	10,9	66,467	2	0,000*
		Flattening	188	0,0	62	0,0	250	0,0	-	-	-
		Bulging	188	0,0	62	4,8	250	1,2	9,207	1	0,015*
	Tuber	**Depression**	186	0,0	63	0,0	249	0,0	-	-	-
		Flattening	186	0,0	63	0,0	249	0,0	-	-	-
		Bulging/ Prominence	186	0,0	63	85,7	249	21,7	203,578	3	0,000
	Parieto-temporal	**Depression**	185	0,0	61	55,7	246	13,8	119,652	3	0,000*
		Flattening	185	0,0	61	0,0	246	0,0	-	-	-
		Bulging	185	0,0	61	59,0	246	14,6	127,897	3	0,000*
	Obelionic	**Depression**	184	0,0	63	0,0	247	0,0	-	-	-
		Flattening	184	0,0	63	1,6	247	0,4	2,933	1	0,255*
		Bulging	184	0,0	63	1,6	247	0,4	2,933	1	0,255*
	Lambdoid	**Depression**	186	0,0	63	0,0	249	0,0	-	-	-
		Flattening	185	0,0	63	84,1	248	21,4	197,936	4	0,000*
		Bulging	186	0,0	63	0,0	249	0,0	-	-	-
Occipital	**Inionic**	**Depression**	187	0,0	60	0,0	247	0,0	-	-	-
		Flattening	187	0,0	60	1,7	247	0,4	3,129	1	0,243*
		Bulging	187	0,0	60	3,3	247	0,8	6,284	1	0,058*
	Pars squamosa	**Depression**	189	0,0	61	3,3	250	0,8	6,247	2	0,059*
		Flattening	189	0,0	61	82,0	250	20,0	193,648	4	0,000*
		Bulging	189	0,0	61	4,9	250	1,2	9,408	1	0,014*

*Fisher's Exact Test

5.11. RELATION BETWEEN POSTERIOR MOVEMENT OF BREGMA, CORONAL SUTURE CONFORMATION AND THE DIFFERENT HEADSHAPING TYPES

Relationship between bregma posterior movement and intentional headshaping has been investigated on a total of 349 examples for circular, 332 for tabular and 254 for composite headshaping (Table 82). The percentage of occurrence in relation with the different headshaping types is 7,7% for circular modification, 6,3% for composite and 6% for tabular headshaping. The highest frequencies in presence of intentional headshaping are observed for circular (84,6%) and composite modification (23%) (Table 82). According to the results of Chi-square and Fisher's Exact tests, this morphological alteration has a statistically significant relationship (*p*<0,05) with intentional headshaping in presence of circular and composite types (Table 82).

Table 82. Relationship between posterior movement of bregma and the presence of the different headshaping types

	Absent		Present		Total		χ^2		
	n	%	n	%	n	%	χ^2	df	*p*
Circular	323	1,5	26	84,6	349	7,7	232,618	1	0,000*
Tabular	217	8,3	115	1,7	332	6	5,706	1	0,017
Composite	193	1	61	23	254	6,3	37,713	1	0,000*

*Fisher's Exact Test

Relationship between coronal suture conformation and the different headshaping types instead has been investigated on a total of 347 examples for circular headshaping, 329 for tabular and 253 for composite headshaping. Each degree of coronal suture conformation has been observed both in shaped and unmodified crania (Table 83). If we consider each headshaping type individually, it is possible to state that, while straight (14%) and slightly V shaped suture (72,4%) are mostly observed in unmodified crania, severely V shaped coronal suture most frequently occurs in presence of circular headshaping (68%) (Table 83). Similarly, also in tabular headshaping each degree of coronal suture conformation has been observed both in shaped and unmodified crania (Table 83). Nevertheless, while straight suture occurs with a slightly higher frequency in shaped crania (18,3%), slightly (69,6%) and severely (18,2%) V shaped are most frequently observed in unmodified crania (Table 85). When considering composite headshaping instead, straight (11,5%) and slightly V shaped (74%) coronal suture is most frequently observed in unmodified crania, while severely V shaped coronal suture (19,7%) mostly occurs in shaped crania (Table 83). Statistical results of Chi-squared and Fisher's Exact tests show that a highly statistically significant relationship exists with circular headshaping (*p*:0,000) (Table 83).

Table 83. Relationship between coronal suture conformation and the presence of the different headshaping types

		Absent		Present		Total		χ^2		
		n	**%**	**n**	**%**	**n**	**%**	**χ^2**	**df**	***p***
Circular	**Straight**	322	14	25	12	347	13,8	48,300	2	0,000
	Slightly Vshaped		72,4		20		68,6			
	Severely Vshaped		13,7		68		17,6			
Tabular	**Straight**	214	12,1	115	18,3	329	14,3	2,822	2	0,246*
	Slightly Vshaped		69,6		67,8		69			
	Severely Vshaped		18,2		13,9		16,7			
Composite	**Straight**	192	11,5	61	9,8	253	11,1	0,944	2	0,624
	Slightly Vshaped		74		70,5		73,1			
	Severely Vshaped		14,6		19,7		15,8			

*Fisher's Exact Test

The relationship between posterior movement of bregma, coronal suture conformation and headshaping types has been investigated on a total of 346 examples for circular headshaping, 328 for tabular and 252 for composite (Table 84). The highest frequencies of co-occurrence of bregma posterior movement and the different grades of coronal suture conformation are observed in circular headshaping (7,5%), followed by composite (6,3%) and tabular (5,6%) (Table 84). Except for tabular headshaping, the highest frequencies are observed in presence of intentional headshaping (Table 84). In detail, by considering circular headshaping, bregma posterior movement increases in frequency with the increase in severity of the conformation of the coronal suture by reaching a rate of even 100% with severely V shaped coronal suture (Table 84). Conversely, when considering tabular modification, the rate of co-occurrence reaches the highest percentages in unmodified crania (33,3%) (Table 84). When considering tabular modification the frequency of posterior movement of bregma increases by the development in severity of the conformation of the coronal suture by reaching a rate of 66,7% with severely V shaped coronal suture (Table 84). According to the results of Chi-square and Fisher's Exact tests, a statistically relevant relationship (*p*<0,05) exists between bregma posterior movement and the different grades of coronal suture conformation in presence of circular and composite headshaping (Table 84).

Table 84. Relationship between bregma posterior movement, coronal suture conformation and the different headshaping types

		Absent		Present		Total		χ^2		
		n	**%**	**n**	**%**	**n**	**%**	χ^2	**df**	***p***
Circular	**Straight**	45	0	3	0	48	0	-	-	-
	Slightly V Shaped	232	0,4	5	80	237	2,1	150,050	1	0,000*
	Severely V Shaped	44	9,1	17	100	61	34,4	44,982	1	0,000
	Total	321	1,6	25	84	346	7,5	226,829	1	0,000*
Tabular	**Straight**	21	0	26	0	47	0	-	-	-
	Slightly V Shaped	148	2,7	78	0	226	1,8	2,146	1	0,301*
	Severely V Shaped	39	33,3	16	12,5	55	27,3	2,483	1	0,184*
	Total	213	8,0	115	1,7	328	5,8	5,332	1	0,021
Composite	**Straight**	22	0	6	0	28	0	-	-	-
	Slightly V Shaped	141	0	43	14	184	3,3	20,338	1	0,000*
	Severely V Shaped	28	7,1	12	66,7	40	25	15,873	1	0,000*
	Total	191	1	61	23	252	6,3	37,305	1	0,000*

*Fisher's Exact Test

5.11.1. Bregma posterior movement according to the severity degrees of frontal depression and flattening in circular and composite headshaping

The investigation on the posterior movement of bregma according to the severity degrees of frontal depression in circular and composite headshaping shows that, although its very high frequency (80%) in absence of frontal depression, its rate of occurrence rises with the development in severity of this morphological alteration even by reaching a rate of 100% with severe frontal depression in circular headshaping and 60% with moderate depression in composite headshaping (Table 85). When considering frontal flattening instead, posterior movement of bregma reaches a frequency of 100% both with slight and moderate frontal flattening in circular headshaping and respectively 44,4% and 33,3% with slight and moderate flattening in composite headshaping (Table 86). Nevertheless, Chi-squared Test does not show any statistically significant relationship between bregma posterior movement and degree of severity of frontal depression and flattening neither in relation with circular nor with composite headshaping (Table 85-86).

Regarding coronal suture conformation instead, it is possible to observe that, although the very high frequency of severely V shaped coronal suture in absence of any frontal depression (80%) (Table 87), its frequency progressively rises with the increase in severity of frontal depression. In fact, slightly V shaped coronal suture rises to 50% of frequency in moderate frontal depression, while severely V shaped reaches even 100% of frequency with severe frontal depression in circular headshaping (Table 87). In composite modification instead, slightly V shaped coronal suture reaches the highest frequency (73,7%) when frontal depression is slight, while severely V shaped suture most frequently occurs when depression is moderate (40%) (Table 87). Chi-squared Test does not show any statistically significant relationship between these morphological variables neither in relation with circular nor with composite headshaping (Table 87). By considering frontal flattening instead, only severely V shaped coronal suture is observed with a frequency of 100% both in presence of slight and moderate flattening in circular headshaping (Table 88). In composite headshaping instead, while slightly V shaped coronal suture shows the highest frequency (71,4%) in absence of flattening (Table 88), severely V shaped coronal suture is progressively most frequently observed with slight (22,2%) and moderate (33,3%) frontal flattening (Table 87). Chi-squared Test does not show any statistically significant relationship between conformation of coronal suture and frontal flattening depression or flattening both in circular and in composite headshaping (Table 88).

Table 85. Presence of bregma posterior movement according to the severity degrees of frontal depression in circular and composite headshaping

	Absent		Slight		Moderate		Severe		Very severe		Total		χ^2		
	n	%	n	%	n	%	n	%	n	%	n	%	χ^2	df	*p**
Circular	5	80	8	75	6	83,3	1	100	-	-	20	80	0,417	3	1,000
Composite	18	27,8	38	15,8	5	60	-	-	-	-	61	23	5,220	2	0,066

*Fisher's Exact Test

Table 86. Presence of bregma posterior movement according to the severity degrees of frontal flattening in circular and composite headshaping

	Absent		Slight		Moderate		Severe		Very severe		Total		χ^2		
	n	%	n	%	n	%	n	%	n	%	n	%	χ^2	df	*p**
Circular	16	81,3	2	100	1	100	1	0	-	-	20	80	4,766	3	0,393
Composite	49	18,4	9	44,4	3	33,3	-	-	-	-	61	23	3,116	2	0,141

*Fisher's Exact Test

Table 87. Coronal suture conformation according to the severity degrees of frontal depression in circular and composite headshaping

		Absent		Slight		Moderate		Severe		Very severe		Total		χ^2		
		n	%	n	%	n	%	n	%	n	%	n	%	χ^2	df	*p**
	Straight		20		28,6		0		0	-	-		15,8			
Circular	**Slightly V shaped**	5	0	7	28,6	6	50	1	0	-	-	19	26,3	5,823	6	0,501
	Severely V shaped		80		42,9		50		100	-	-		57,9			
	Straight		16,7		7,9		0		-	-	-		9,8			
Composite	**Slightly V shaped**	18	66,7	38	73,7	5	60	-	-	-	-	61	70,5	2,825	4	0,558
	Severely V shaped		16,7		18,4		40		-	-	-		19,7			

*Fisher's Exact Test

Table 88. Coronal suture conformation according to the severity degrees of frontal flattening

		Absent		**Slight**		**Moderate**		**Severe**		**Very severe**		**Total**		**χ^2**		
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**χ^2**	**df**	***p***
	Straight		13,3		0		0		100	-	-		15,8			
Circular	**Slightly V shaped**	15	33,3	2	0	1	0	1	0	-	-	19	26,3	7,907	6	0,366
	Severely V shaped		53,3		100		100		0	-	-		57,9			
	Straight		10,2		11,1		0	-	-	-	-		9,8			
Composite	**Slightly V shaped**	49	71,4	9	66,7	3	66,7	-	-	-	-	61	70,5	0,704	4	0,908
	Severely V shaped		18,4		22,2		33,3	-	-	-	-		19,7			

*Fisher's Exact Test

5.12. POSTURAL PLAGIOCEPHALY

The correlation between plagiocephaly presence and headshaping types has been investigated on a total of 269 examples for circular headshaping, 281 for tabular and 196 for composite (Table 89). Plagiocephaly is most frequently observed in unmodified crania when considering circular headshaping (42,5%) while reaching very high frequencies in tabularly shaped crania (61,1%) and composite modification (48,3%). Chi-square Test shows that the co-occurrence of plagiocephaly and the presence of the different headshaping types is statistically significant for all the headshaping types (p<0,05) (Table 89).

Table 89. Relationship between plagiocephaly and intentional headshaping types

	Absent		**Present**		**Total**		**χ^2**		
	n	**%**	**n**	**%**	**n**	**%**	**χ^2**	**df**	***p***
Circular	254	42,5	15	6,7	269	40,5	7,554	1	0,006
Tabular	168	26,8	113	61,1	281	40,6	32,920	1	0,000
Composite	138	26,8	58	48,3	196	33,2	8,488	1	0,004

Relationship between plagiocephaly side, affected cranial region, degree of severity and headshaping types instead has been investigated on a total of 109 examples for circular headshaping, 114 for tabular and 65 for composite (Tables 90-92).

The statistical analysis on the relationship between plagiocephaly side and headshaping types reveals that any statistically significant (p<0,05) correlation does not exist between these two variables (Table 90). Although its rate reaches 100% on the right side of circularly shaped crania, it must be noticed that only one example is affected (Table 90). When considering the other headshaping types instead, postural plagiocephaly occurs with a higher frequency (40,6%) on the left side of tabularly shaped crania, by reaching the 75% on the right side of the crania affected by composite modification (Table 90).

Table 90. Relationship between plagiocephaly side and intentional headshaping types

		Absent		Present		Total		χ^2		
		n	%	n	%	n	%	χ^2	df	*p*
Circular	**Right**	108	62	1	100	109	62,4	0,609	1	1,000*
	Left		38		0		37,6			
Tabular	**Right**	45	66,7	69	59,4	114	62,3	0,609	1	0,435
	Left		33,3		40,6		37,7			
Composite	**Right**	28	62,2	37	75	65	67,7	1,500	1	0,221
	Left		37,4		25		32,3			

*Fisher's Exact Test

If we look at the relationship between the area of development of postural plagiocephaly and headshaping types, it is possible to observe that parietal and parieto-occipital plagiocephaly are the most frequently observed (Table 91). Conversely, occipital plagiocephaly is encountered only in tabular modification with a very low frequency (5,8%) (Table 91). Despite the very high frequency of parietal plagiocephaly in circularly shaped crania (100%), it must be noticed that only one example is considered (Table 91). In tabular and composite headshaping instead, parieto-occipital plagiocephaly reaches the higher frequencies (78,6% and 68,1%, respectively), followed by parietal plagiocephaly (26,1%) in tabular modification (Table 91). The results of Chi-squared test show that a statistically significant relationship exists exclusively between plagiocephaly area and composite headshaping (p<0,05) (Table 91).

Table 91. Relationship between cranial regions affected by plagiocephaly and intentional headshaping types

		Absent		Present		Total		χ^2		
		n	%	n	%	n	%	χ^2	df	*p*
Circular	**Occipital**	108	11,1	1	0,0	109	11,0	2,784	2	0,376*
	Parietal		25,9		100,0		26,6			
	Parieto-occipital		63,0		0,0		62,4			
Tabular	**Occipital**	45	17,8	69	5,8	114	10,5	4,197	2	0,123
	Parietal		24,4		26,1		25,4			
	Parieto-occipital		57,8		68,1		64,0			
Composite	**Occipital**	37	18,9	28	0,0	65	10,8	6,502	2	0,031*
	Parietal		24,3		21,4		23,1			
	Parieto-occipital		56,8		78,6		66,2			

*Fisher's Exact Test

The investigation on the relationship between severity degrees of postural plagiocephaly and headshaping presence shows that slight plagiocephaly is the most frequently encountered (Table 92), reaching the highest frequencies in tabular (75,4%) and composite headshaping (73%) (Table 92). Although the very high frequency of slight plagiocephaly (100%) in circular headshaping, it must be considered that only one example is processed (Table 92). Compared to severe, moderate plagiocephaly shows the highest frequencies both in composite (16,2%) and tabular headshaping (13%), while no cases of both the degrees are observed in circular headshaping (Table 92). Chi-square Test shows that a statistically relevant relationship (*p*<0,05) between severity degrees of plagiocephaly and headshaping presence mildly exists only in presence of composite headshaping (Table 94).

Table 92. Relationship between severity degrees of plagiocephaly and intentional headshaping types

		Absent		Present		Total		χ^2		
		n	**%**	**n**	**%**	**n**	**%**	χ^2	**df**	***p***
Circular	**Slight**	108	73,1	1	100,0	109	73,4	0,366	2	1,000*
	Moderate		13,9		0,0		13,8			
	Severe		13,0		0,0		12,8			
Tabular	**Slight**	45	71,1	69	75,4	114	73,7	0,256	2	0,880
	Moderate		15,6		13,0		14,0			
	Severe		13,3		11,6		12,3			
Composite	**Slight**	28	50,0	37	73,0	65	63,1	5,962	2	0,051
	Moderate		14,3		16,2		15,4			
	Severe		35,7		10,8		21,5			

5.13. EFFECTS OF INTENTIONAL HEADSHAPING ON WORMIAN BONES AND METOPISM

5.13.1. Relationship between Wormian bones and headshaping types

Statistical analysis on Wormian bones shows their occurrence both in shaped and unmodified crania (Table 93). In general, they occur in all the three headshaping types, although with higher frequencies in circular and tabular headshaping (Table 93).

If we consider each headshaping type individually, lambdoid (right: 92,3%; left: 84,6%), right epipteric (60%), temporo-squamosal (right: 50%; left: 28,6%), right coronal (27,3%); lambda (27,3%), left coronal (25%), right parietal notch (20%), left asterionic (20%) left parietal notch (18,2%), and Inca (4,5%) bones increase in frequencies compared to unmodified crania (Table 93) while the rate of incidence of left epipteric (26,1%) and right asterionic (16,7%) bones increase in unmodified crania (Table 93). Sagittal (12,7%), occipito-mastoid (left: 7,1%, right: 5,5%) and bregmatic (2%) and ossicles occur only in unmodified crania (Table 93). Chi-square Test indicates that the relationship between circular headshaping and right temporo-squamosal (*p*:0,004) and lambdoid (*p*:0,039) Wormian bones is statistically significant (*p*<0,05) (Table 93).

In tabular headshaping, left epipteric (27,4%), asterionic (right: 26,8%, left: 24,3%), lambda (21,6%), parietal notch (right: 17,9%; left: 14,8%), sagittal (13,7%), right occipito-mastoid (11,1%), left temporo-squamosal (10,3%), left occipito-mastoid (5,6%), and bregmatic (2,9%) bones increase in shaped crania while lambdoid (right: left: 74%; 69,9%), right epipteric (29,8%), coronal (left: 19%; right: 13,6%), right temporo-squamosal (10,6%) and Inca (1,8%) bones are most frequently observed in unmodified crania (Table 93). Chi-square Test indicates that the relationship between tabular headshaping and asterionic (*p*:0,000, *p*:0,006) and Wormian bones at lambda (*p*:0,044) is statistically significant (*p*<0,05) (Table 93).

When considering composite headshaping instead, right epipteric (37,9%), lambda (24,5%), asterionic (left: 20%; right: 17,1%), left temporo-squamosal (9,5%), occipito-mastoid (left: 8,6%; right: 8,3%) and Inca (5,2%) bones increase in shaped crania while lambdoid (left: 75,2%; right: 70,2%), left epipteric (25,7%), coronal (left: 19,4%; parietal notch (right: 14,8%), and sagittal (11,4%), left parietal notch (10,8%), right temporo-squamosal (8,9%) Wormian bones are most frequently observed in unmodified crania (Table 93). Right coronal (13,9%) and bregmatic (1,4%) extra sutural bones instead occur only in unmodified crania. According to the Chi-squared Test, a meaningful relationship (*p*<0,05) exists between composite headshaping and ossicles at lambda (*p*:0,026) (Table 93).

Table 93. Relationship between Wormian bones and intentional headshaping types

			Absent		Present		Total		χ²		
			n	%	n	%	n	%	χ²	df	p
Circular	Epipteric	R	157	26,1	5	60,0	162	27,2	2,812	1	0,124*
		L	153	26,1	5	20,0	158	25,9	0,095	1	1,000*
	Coronal	R	205	10,7	11	27,3	216	11,6	2,791	1	0,121*
		L	205	13,2	8	25,0	213	13,6	0,916	1	0,299*
	Bregmatic		254	2,0	9	0,0	263	1,9	0,181	1	1,000*
	Temporo-squamosal	R	171	8,2	8	50,0	179	10,1	14,773	1	0,004*
		L	177	7,9	7	28,6	184	8,7	3,621	1	0,115*
	Parietal Notch	R	238	16,0	10	20,0	248	16,1	0,115	1	0,666*
		L	224	13,4	11	18,2	235	13,6	0,204	1	0,649*
	Lambdoid	R	227	64,3	13	92,3	240	65,8	4,283	1	0,039*
		L	238	69,7	13	84,6	251	70,5	1,311	1	0,356*
	Asterionic	R	209	16,7	9	11,1	218	16,5	0,199	1	1,000*
		L	209	16,3	10	20,0	219	16,4	0,097	1	0,671*
	Occipito-mastoid	R	198	7,1	6	0,0	204	6,9	0,456	1	1,000*
		L	181	5,5	7	0,0	188	5,3	0,408	1	1,000*
	Lambda		256	15,6	11	27,3	267	16,1	1,059	1	0,392*
	Inca		319	1,6	22	4,5	341	1,8	1,056	1	0,332*
	Sagittal		204	12,7	4	0,0	208	12,5	0,583	1	1,000*
Tabular	Epipteric	R	84	29,8	76	25,0	160	27,5	0,454	1	0,501
		L	85	25,9	73	27,4	158	26,6	0,046	1	0,830
	Coronal	R	118	13,6	95	8,4	213	11,3	1,390	1	0,238
		L	116	19,0	95	7,4	211	13,7	5,925	1	0,015
	Bregmatic		158	1,3	102	2,9	260	1,9	0,922	1	0,384*
	Temporo-squamosal	R	94	10,6	85	8,2	179	9,5	0,300	1	0,584
		L	96	7,3	87	10,3	183	8,7	0,533	1	0,465
	Parietal Notch	R	144	13,9	106	17,9	250	15,6	0,755	1	0,385
		L	132	10,6	108	14,8	240	12,5	0,962	1	0,327
	Lambdoid	R	146	69,9	102	55,9	248	64,1	5,101	1	0,024
		L	150	74,0	109	62,4	259	69,1	3,989	1	0,046
	Asterionic	R	131	8,4	97	26,8	228	16,2	13,890	1	0,000
		L	124	10,5	103	24,3	227	16,7	7,674	1	0,006
	Occipito-mastoid	R	116	4,3	90	11,1	206	7,3	3,472	1	0,062
		L	103	3,9	90	5,6	193	4,7	0,302	1	0,736*
	Bregmatic		158	1,3	102	2,9	260	1,9	0,922	1	0,384*
	Lambda		167	12,6	116	21,6	283	16,3	4,052	1	0,044
	Inca		227	1,8	120	1,7	347	1,7	0,004	1	1,000*
	Sagittal		119	10,9	95	13,7	214	12,1	0,377	1	0,539
Composite	Epipteric	R	75	26,7	29	37,9	104	29,8	1,260	1	0,260
		L	74	25,7	30	20,0	104	24,0	0,377	1	0,539
	Coronal	R	101	13,9	43	0,0	144	9,7	6,602	1	0,011*
		L	103	19,4	45	2,2	148	14,2	7,605	1	0,006
	Bregmatic		141	1,4	39	0,0	180	1,1	0,559	1	1,000*
	Temporo-squamosal	R	79	8,9	39	5,1	118	7,6	0,516	1	0,716*
		L	84	6,0	42	9,5	126	7,1	0,538	1	0,480*
	Parietal Notch	R	122	14,8	49	12,2	171	14,0	0,182	1	0,669
		L	111	10,8	49	10,2	160	10,6	0,013	1	0,909
	Lambdoid	R	114	70,2	45	55,6	159	66,0	3,075	1	0,080
		L	121	75,2	45	60,0	166	71,1	3,690	1	0,055
	Asterionic	R	108	9,3	41	17,1	149	11,4	1,795	1	0,246*
		L	106	9,4	40	20,0	146	12,3	3,000	1	0,083*
	Occipito-mastoid	R	103	4,9	36	8,3	139	5,8	0,595	1	0,427*
		L	87	4,6	35	8,6	122	5,7	0,729	1	0,408*
	Lambda		138	11,6	53	24,5	191	15,2	4,974	1	0,026
	Inca		181	1,7	58	5,2	239	2,5	2,217	1	0,155*
	Sagittal		102	11,8	47	6,4	149	10,1	1029	1	0,391*

*Fisher's Exact Test

5.13.2. Relationship between Wormian bones and severity degrees of the different types of intentional headshaping

The investigation on the relationship between Wormian bones and intentional headshaping conducted according to the severity degrees of each headshaping type (Tables 94-96) shows that higher frequencies of extra sutural ossicles occur at lambdoid (right: 92,3%, left: 84,6%), right epipteric (75%) and right temporo-squamosal regions (50%) in circularly shaped crania, while occipital mastoid, bregmatic and sagittal ossicles are not observed (Table 94). If we look at each Wormian bone individually, right (from 20% up to 33%) and left (from 33,3% to 50%) coronal ossicles, left parietal notch (from 20% to 25%), right temporo-squamosal (from 33,3% up to 100%), left lambdoid (from 75% to 100%) and ossicles at lambda (from 20% to 50%) increase by the increasing of the developmental degrees of intentional headshaping, especially from moderate to very severe (Table 94). Nevertheless, any statistically significant relationship has been observed between these epigenetic traits and the severity degrees of circular headshaping (Table 94).

In tabularly shaped crania, the highest frequencies of extra sutural bones occur at the lambdoid region (right: 57,9%, left: 63%) (Table 95). If we look at each Wormian ossicle individually, right and left epipteric bones (from 22,9% to 50%), ossicles at right parietal notch (from 16,0% to 25%), right and left lambdoid (from 55,4% to 73,7%), right and left asterionic (from 16,1% to 47,1%), right occipito-mastoid (from 7,5% to 15,8%), Inca (from 1,5% to 4,8%), sagittal bones (from 7,4% to 33,3%) and ossicles at lambda (from 18,3% to 33,3%) (Table 95) increase in frequency by the developing in severity of tabular headshaping. According to Chi-squared Test, the incidence of right epipteric (*p*: 0,017), right and left asterionic (*p*: 0,044 and *p*: 0,046 respectively) and sagittal (*p*: 0,035) (Table 95) extra sutural ossicles is statistically significant ($p<0,05$) in relation with the degrees of severity of tabular headshaping.

In composite headshaping instead, the highest frequencies of ossicles in relation with the severity degrees of circular headshaping are observed in the lambdoid region (right: 55,6%, left: 60%). No Wormian bones instead occur on the right coronal and bregmatic regions (Table 96). If we consider each ossicle individually, frequencies of right and left epipteric (from 17,2% to 100%), left temporo-squamosal (from 7,5% to 50%), right and left lambdoid bones (from 33,3% to 100%), ossicles at lambda (from 24,5% to 100%) and right and left parietal notches (from 8,7% to 66,7%) increase by the increasing in severity of intentional headshaping (Table 96). Nevertheless, any statistically significant relationship (*p*>0,05) has not been recognized in relation with this headshaping type (Table 96). According to the severity degrees of tabular headshaping instead, despite any statistically relevant correlation does not exist, only left lambdoid (from 53,3% to 78,6%) and asterionic (from 5,9% to 36,4%) ossicles increase by the increasing in severity of headshaping (Table 97), (Table 97).

Table 94. Relationship between Wormian bones and severity degrees of circular intentional headshaping

			Moderate		Severe		Very Severe		Total		χ^{2}*		
			n	%	n	%	n	%	n	%	χ^{2}	df	*p*
Circular	**Epipteric**	**R**	1	100	1	100	2	50	4	75	1,333	2	1,000
		L	2	50	1	0	2	0	4	20	1,975	2	1,000
	Coronal	**R**	5	20	2	0	3	33,3	10	20	0,833	2	1,000
		L	3	33,3	3	0	2	50	8	25	1,778	2	0,679
	Parietal Notch	**R**	2	0	1	0	5	40	8	25	1,600	2	1,000
		L	5	20	2	0	4	25	11	18,2	0,581	2	1,000
	Temporo-squamosal	**R**	3	33,3	1	100	2	50	6	50	1,333	2	1,000
		L	3	33,3	0	0	3	33,3	6	33,3	0,000	1	1,000
	Lambdoid	**R**	5	100	2	100	6	83,3	13	92,3	1,264	2	1,000
		L	4	75	2	50	7	100	13	84,6	3,398	2	0,192
	Asterionic	**R**	4	25	2	0	2	0	8	12,5	1,143	2	1,000
		L	4	25	2	0	4	25	10	20	0,625	2	1,000
	Occipito-mastoid	**R**	2	0	1	0	2	0	5	0	-	-	-
		L	2	0	1	0	4	0	7	0	-	-	-
	Bregmatic		4	0	1	0	3	0	3	0	-	-	-
	Lambda		5	20	2	0	4	50	11	27,3	1,925	2	0,515
	Inca		9	11,1	4	0	9	0	22	4,5	1,513	2	1,000
	Sagittal		2	0	1	0	1	0	4	0	-	-	-

* Fisher's Exact Test

Table 95. Relationship between Wormian bones and severity degrees of tabular intentional headshaping

			Slight		Moderate		Severe		Total		χ^2*		
			n	%	n	n	n	%	n	%	χ^2	df	*p*
Tabular	**Epipteric**	**R**	48	22,9	11	0	17	47,1	76	25	8,190	2	0,017*
		L	49	24,5	13	23,1	10	50	72	27,8	2,869	2	0,207*
	Coronal	**R**	54	7,4	17	17,6	22	4,5	93	8,6	2,327	2	0,354*
		L	53	9,4	19	5,3	21	4,8	93	7,5	0,647	2	0,877*
	Parietal Notch	**R**	59	16,9	19	15,8	24	25	102	18,6	0,854	2	0,732*
		L	58	15,5	20	30	24	4,2	102	15,7	5,508	2	0,079*
	Temporo-squamosal	**R**	47	10,6	16	6,3	19	5,3	82	8,5	0,634	2	0,872*
		L	48	10,4	17	17,6	20	5	85	10,6	1,556	2	0,439*
	Lambdoid	**R**	56	55,4	18	61,1	21	61,9	95	57,9	0,363	2	0,879
		L	59	59,3	19	73,7	22	63,6	100	63	1,277	2	0,508
	Asterionic	**R**	55	18,2	17	47,1	18	33,3	90	26,7	6,049	2	0,044*
		L	56	16,1	19	36,8	20	40	95	25,3	6,156	2	0,046
	Occipito-mastoid	**R**	53	7,5	15	13,3	19	15,8	87	10,3	1,199	2	0,528*
		L	50	4	15	13,3	21	4,8	86	5,8	1,892	2	0,356*
	Bregmatic		59	3,4	19	0	21	4,8	99	3	0,834	2	1,000*
	Lambda		60	18,3	21	33,3	26	19,2	107	21,5	2,178	2	0,371
	Inca		65	1,5	21	4,8	25	0	111	1,8	1,524	2	0,393*
	Sagittal		54	7,4	15	33,3	22	13,6	91	13,2	6,898	2	0,035*

*Fisher's Exact Test

Table 96. Relationship between presence of Wormian bones and severity degrees of composite intentional headshaping **(**circular)

			Slight		Moderate		Severe		Very severe		Total				
			n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**χ^2**	**df**	***p***
Composite (Circular)	**Epipteric**	**R**	28	35,7	1	100	0	0	0	0	29	37,9	1,695	1	0,379
		L	29	17,2	1	100	0	0	0	0	30	20	4,138	2	0,200*
	Coronal	**R**	42	0	1	0	0	0	0	0	43	0	-	-	-
		L	44	2,3	1	0	0	0	0	0	45	2,2	0,023	1	1,000*
	Parietal Notch	**R**	45	8,9	3	66,7	1	0	0	0	49	12,2	8,880	2	0,068*
		L	46	8,7	2	50	1	0	0	0	49	10,2	3,685	2	0,281*
	Temporo-squamosal	**R**	37	5,4	2	0	0	0	0	0	39	5,1	0,114	1	1,000*
		L	40	7,5	2	50	0	0	0	0	42	9,5	3,993	1	0,184*
	Lambdoid	**R**	42	59,5	3	0	0	0	0	0	45	55,6	4,018	1	0,080*
		L	41	61	3	33,3	1	100	0	0	45	60	1,572	2	0,735*
	Asterionic	**R**	38	18,4	2	0	1	0	0	0	41	17,1	0,666	2	1,000*
		L	37	21,6	1	0	1	0	1	0	40	20	0,811	3	1,000*
	Occipito-mastoid	**R**	36	8,3	0	0	0	0	0	0	36	8,3	-	-	-
		L	34	8,8	1	0	0	0	0	0	35	8,6	0,097	1	1,000*
	Bregmatic		35	0	2	0	1	0	1	0	39	0	-	-	-
	Lambda		49	24,5	2	0	1	0	1	100	53	24,5	4,052	3	0,489*
	Inca		52	5,8	3	0	2	0	1	0	58	5,2	0,385	3	1,000*
	Sagittal		45	6,7	2	0	0	0	0	0	47	6,4	0,142	1	1,000*

*Fisher's Exact Test

Table 97. Relationship between presence of Wormian bones and severity degrees of composite intentional headshaping (tabular)

			Slight		Moderate		Severe		Total		χ^2		
			n	**%**	**n**	**n**	**n**	**%**	**n**	**%**	χ^2	**df**	***p***
Composite (Tabular)	**Epipteric**	**R**	12	33,3	7	42,9	10	40	29	37,9	0,198	2	1,000*
		L	10	30	10	30	10	0	30	20	3,750	2	0,195*
	Coronal	**R**	16	0	12	0	15	0	43	0	-	-	-
		L	14	0	14	7,1	17	0	45	2,2	2,265	2	0,622*
	Parietal Notch	**R**	18	22,2	13	15,4	18	0	49	12,2	4,298	2	0,144*
		L	18	16,7	16	6,3	15	6,7	49	10,2	1,298	2	0,602*
	Temporo-squamosal	**R**	15	6,7	10	0	14	7,1	39	5,1	0,730	2	1,000*
		L	15	13,3	14	7,1	13	7,7	42	9,5	0,395	2	1,000*
	Lambdoid	**R**	17	52,9	13	61,5	15	53,3	45	55,6	0,266	2	0,866
		L	15	53,3	14	78,6	16	50	45	60	2,956	2	0,245
	Asterionic	**R**	17	5,9	12	16,7	12	33,3	41	17,1	3,746	2	0,217*
		L	17	5,9	12	25	11	36,4	40	20	4,146	2	0,146*
	Occipito-mastoid	**R**	15	13,3	11	0	10	10	36	8,3	1,527	2	0,607*
		L	17	11,8	9	0	9	11,1	35	8,6	1,139	2	0,790*
	Bregmatic		17	0	13	0	9	0	39	0	-	-	-
	Lambda		18	27,8	15	20	20	25	53	24,5	0,271	2	0,923*
	Inca		20	5	17	5,9	21	4,8	58	5,2	0,026	2	1,000*
	Sagittal		15	13,3	14	0	18	5,6	47	6,4	2,188	2	0,493*

*Fisher's Exact Test

5.13.3. Metopism

The statistical analysis on the distribution of metopism according to the three different headshaping types shows that this nonmetric trait occurs both in shaped and unmodified crania when considering circular and tabular headshaping, while it is not observed in presence of composite modification (Table 98). The highest frequency is observed in presence of circular modification (16%) (Table 98). According to the results of Chi-squared Test, any statistically significant relationship exists between metopism and artificial headshaping (Table 98).

Table 98. Relationship between metopism and headshaping types

	Absent		Present		Total		χ^2		
	n	%	n	%	n	%	χ^2	df	*p*
Circular	323	6,8	25	16,0	348	7,5	2,834	1	0,105*
Tabular	217	6,5	115	9,6	332	7,5	1,047	1	0,306
Composite	194	5,7	58	0,0	252	4,4	3,439	1	0,073*

*Fisher's Exact Test

The statistical analysis on the relationship between developmental degrees of metopism and the different headshaping types instead shows that total metopism is the most frequently observed by reaching the highest frequency when considering circular headshaping (91,3%), followed by tabular (90,9%) and composite (90%) (Table 99). Nevertheless, when considering composite headshaping, metopism occurs exclusively in unmodified crania (Table 99). Total metopism even reaches 100% of occurrence in the presence of circular headshaping. Frontal metopism instead is exclusively observed in tabular headshaping with a frequency of 10% (Table 99). Fisher's Exact Test has not shown any statistically significant relationship between the degree of development of this trait and the different headshaping types (Table 99).

Table 99. Relationship between metopism degree and headshaping types

		Absent		Present		Total		χ²		
		n	%	n	%	n	%	χ²	df	*p*
Circular	**Total**	20	90,0	3	100,0	23	91,3	0,329	2	1,000*
	Frontal		5,0		0,0		4,3			
	Fronto-parietal		5,0		0,0		4,3			
Tabular	**Total**	12	91,7	10	90,0	22	90,9	2,035	2	0,714*
	Frontal		0,0		10,0		4,5			
	Fronto-parietal		8,3		0,0		4,5			
Composite	**Total**	10	90,0	0	0,0	10	90,0	-	-	-
	Frontal		0,0		0,0		0,0			
	Fronto-parietal		10,0		0,0		10,0			

*Fisher's Exact Test

5.14. PATHOLOGIES

It is possible to state that no cases of malformation and synostotic plagiocephaly have been encountered.

5.14.1. Porotic Hyperostosis

The investigation on the relationship between porotic hyperostosis and intentional headshaping shows that this pathological condition is most frequently observed in intentionally shaped crania/skulls such as demonstrated by their higher frequencies (composite: 39,3%, circular: 17,2%, and composite: 13,3%) compared to the unmodified ones (Table 100). The highest rate of incidence has been observed in composite headshaping (12,6%), followed by circular (10,5%) and tabular (8,5%) ones (Table 100). It According to the Chi-squared Test, the relationship between porotic hyperostosis and intentional headshaping is respectively highly significant in composite (*p:*0,000) and tabular (*p*:0,018) types (Table 100).

Table 100. Relationship between porotic hyperostosis and headshaping types

	Absent		Present		Total		χ²		
	n	%	n	%	n	%	χ²	df	*p*
Circular	343	9,9	29	17,2	372	10,5	1,530	1	0,210*
Tabular	235	6,0	120	13,3	355	8,5	5,586	1	0,018
Composite	186	3,8	61	39,3	247	12,6	52,985	1	0,000

*Fisher's Exact Test

When considering developmental degrees of porotic hyperostosis and severity degrees of intentional headshaping instead, it is possible to notice that slight porotic hyperostosis is characterised by the highest frequencies in all the three headshaping types, while severe porotic hyperostosis is never observed (Table 101). Moderate porotic hyperostosis instead exclusively occurs in very severe circularly shaped crania (25%), while reaching a higher rate of incidence in slight tabular (16%) and composite (circular: 13,3% and tabular: 27,3%) headshaping (Table 101). When considering slight porotic hyperostosis, apart from circular headshaping, its distribution tends to increase by the increasing severity degree of intentional headshaping. In fact, it increases from 84% to 100% in tabular type, from 86,7% to 100% in composite headshaping when considering the circular type, and from 72,7% to 100% when considering the tabular one (Table 101).

Table 101. Relationship between severity degrees of intentional headshaping types and developmental degrees of porotic hyperostosis

			Total	Slight	Moderate	Severe	χ^2		
			n	%	%	%	χ^2	df	p
Circular		**Moderate**	3	100	0	0	1,143	2	1,000
		Severe	1	100	0	0			
		Very severe	4	75	25	0			
Tabular		**Slight**	25	84	16	0	1,888	2	0,553
		Moderate	8	100	0	0			
		Severe	14	92,9	7,1	0			
Composite	**Circular**	**Slight**	30	86,7	13,3	0	0,305	2	1,000
		Moderate	1	100	0	0			
		Severe	0	0	0	0			
		Very severe	1	100	0	0			
	Tabular	**Slight**	11	72,7	27,3	0	3,740	2	0,290
		Moderate	11	90,9	9,1	0			
		Severe	10	100	0	0			

*Fisher's Exact Test

5.14.2. Craniosynostosis

A total of 4 complete sagittal and 5 temporo-occipital craniosynostosis (4 bilateral and 1 unilateral) have been observed in 6 crania. One cranium presents only sagittal craniosynostosis, 2 exclusively bilateral temporo-occipital, while 3 both sagittal and temporo-occipital synostosis (2 bilateral, 1 unilateral).

The statistical analysis on the distribution of craniosynostosis according to the different headshaping types shows very low frequencies. In general, the highest incidence is observed when considering tabular headshaping (1,5%), while it shows the same frequencies (1,2%) when considering both circular and composite headshaping (Table 102). Craniosynostosis exclusively occurs in unmodified crania when considering circular headshaping (1,3%), while it is observed both in shaped and unmodified crania by considering tabular and composite headshaping. In detail, it mostly frequently occurs in compositely shaped crania (1,6%) while it has a higher frequency in unmodified crania (1,1%) when considering tabular headshaping (Table 102). Chi-squared Test does not show any statistical significance in the relationship between craniosynostosis and the three different headshaping types (Table 102).

Table 102. Relationship between craniosynostosis and intentional headshaping types

	Absent		**Present**		**Total**		χ^2		
	n	**%**	**n**	**%**	**n**	**%**	χ^2	**df**	***p***
Circular	318	1,3	24	0,0	342	1,2	0,305	1	1,000*
Tabular	220	1,8	119	0,8	339	1,5	0,508	1	0,661*
Composite	179	1,1	63	1,6	242	1,2	0,084	1	1,000*

*Fisher's Exact Test

CHAPTER 6
DISCUSSION

6.1. INTENTIONAL HEADSHAPING IN ANATOLIA

Compared to the rest of the world, investigations on intentional headshaping in Anatolia have not been systematically conducted. Despite the existence of another variant such as plano-occipital flattening, known at least from the Bronze Age (Erdal & D'Amico; Angel, 1976; Mellink & Angel, 1968), Anatolian investigations have exclusively focused on circular headshaping, mostly dated to prehistoric periods (Aytek et al. 2021, 2020; Erdal, 2019, 2013a; Eroğlu, 2016, 2015; Duyar & Atamtürk, 2010; Miyake, 2010; Özbek, 2001, 1984; Alpagut, 1986; Şenürek & Tunakan, 1951). The anthropological investigations conducted by Erdal and D'Amico (2020) on the well preserved human skeletal remains of the Medieval settlement of Arslantepe, have represented a starting point to reconsider plano-occipital flattening as environmentally originated and intentionally performed.

The results of the statistical analyses performed in the present study prove that intentional headshaping in Anatolia is widely distributed by being observed on more than half of the analysed sample (53,2%) (Table 12). Moreover, compared to the existing literature, the present study not only confirms the intentionality of posterior cranial flattening but also suggests, for the first time, the practice of another type defined as composite because of the presence at once of morphological features characterising circular and tabular headshaping. The rates of incidence of tabular and composite types are the highest (34,1% and 25%, respectively) (Table 12). From a chronological perspective, while circular headshaping is most frequently observed during the most ancient periods (Neolithic-Iron Age) by reaching the highest frequencies at the Hassuna-Samarra site of Hakemi Use (58%) and at the Chalcolithic settlement of Değirmentepe (60,9%), the frequency of tabular and composite headshaping progressively increases among the Mediaeval (77,6% and 86,4%, respectively) and post Medieval settlements (94,1% and 50%, respectively) (Table 12). Based on all these data, it is possible to suggest that intentional headshaping in Anatolia is practiced for a very long time by means of multiple techniques. The observation at once of morphological alterations proper of both circular and tabular headshaping suggest the necessity to consider at the same time the effects of more than a shaping technique during the morphoscopic investigation.

6.2. MORPHOMETRIC CRANIAL ALTERATIONS CAUSED BY INTENTIONAL HEADSHAPING

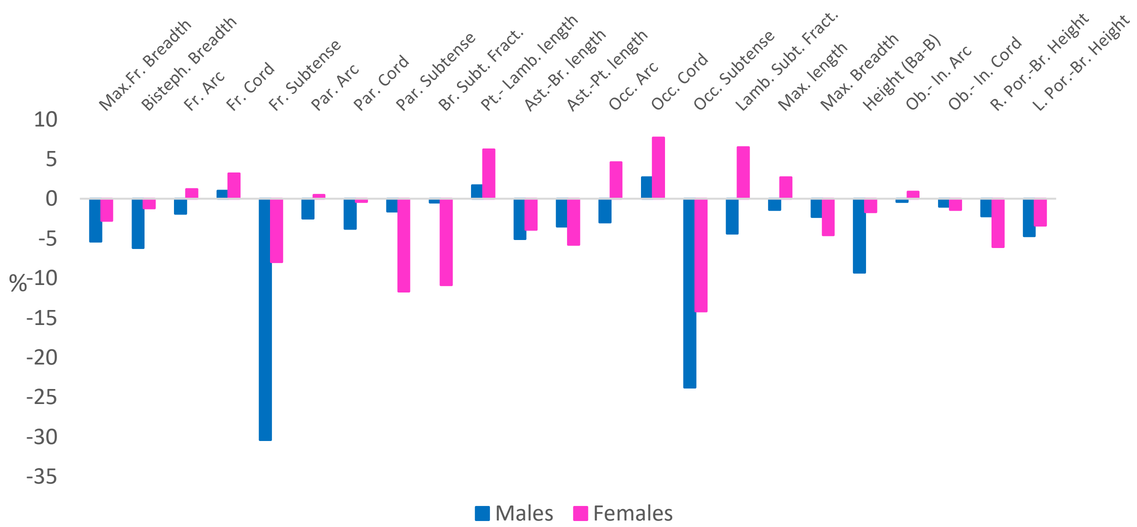
6.2.1. Cranial measurements of adults

Compared to the existing Anatolian investigations, the macroscopic discrimination between unmodified and shaped crania and between types and subtypes in a very large sample including both well preserved and fragmented adult and subadult individuals characterised by very different degrees of headshaping severity such as that selected for the present study, may result very difficult and little objective. That is why statistical analysis of craniometric data has been preferred. It has allowed not only to recognize the most relevant morphometric changes caused by the three different intentional headshaping types but also to statistically discriminate between shaped and unmodified crania as well as between types (circular and tabular) even by reaching very high frequencies of accuracy. Among measurements, asterion-bregma, pterion-lambda and asterion-pterion lengths, for the first time used in the present study, have contributed not only to a detailed interpretation of the morphometric alterations occurring in the parietal region and more in general in the cranial vault but also to the achievement of a very high frequency of predicted membership.

The statistical analysis of the selected 30 linear measurements has shown that circularly shaped crania of both the sexes latero-medially narrow and infero-superiorly lower (Table 14; Graph 7) (Figures 12-13). Cranial length instead differently behaves by slightly decreasing in males and increasing in females (Table 14; Graph 7). Both frontal and occipital latero-medially contract, flatten and elongate in both the sexes (Table 14; Graph 7) (Figures 12-13), although more prominently elongating in females and more severely flattening in males (Table 14; Graph 7). Parietals antero-superior/postero-inferiorly shorten while antero-inferior/postero-superiorly elongate and flatten, especially in females (Table 14; Graph 7) (Figures 12-13). Obelion-inion region instead slightly bends (more prominently in females) (Table 14; Graph 7) (Figures 12-13). All these morphometric alterations reflect the well-known circular oblique shaping technique performed by enveloping the head by bandages or other textiles from the frontal to the lower occipital through parietals (Tiesler, 2014; Erdal, 2013a, 2011; Özbek, 2001; Meiklejohn et al., 1992; Lambert, 1979; Dingwall, 1931). Moreover, differences in cranial length between sexes might be interpreted by considering the more evident antero-postero-superior elongation of parietals as well as the prominent backwards elongation of both frontals and occipitals in females. Conversely, the antero-posterior shortening of shaped male crania might be related to the severe flattening of occipital as well as to the less evident antero-postero-superior elongation of the parietals.

The comparison of the results of the present study with those obtained in other previous investigations shows several matches. In fact, lateromedial narrowing (O'Brien & Stanley, 2013; Tiesler, 2012, 2010; Cocilovo et al., 2011; Tritsaroli, 2010; Pomeroy et al., 2009; Ortner, 1996; Kohn et al., 1993; Antón, 1989; Brown, 1989, 1981; Özbek 1974a, 1974b; Blackwood & Danby, 1955; Dingwall, 1931) as well as flattening and elongation of frontal and occipital bones (Ni et al., 2020; Zhang et al., 2019; Lucea et al., 2018; O'Brien & Stanley, 2013; Brown, 2010; Pomeroy et al., 2009; Durban, 2008; Antón & Weinstein, 1999; Brown, 1989, 1981; Larnach, 1974; Özbek, 1974a, 1974b; Blackwood & Danby, 1955; Şenyürek & Tunakan, 1951) have been largely observed. Özbek (1974a, 1974b) found a discriminant decrease of cranial width, height, and forehead breadth as well as a reduced frontal and sagittal-occipital curvature in the circularly shaped crania of the Chalcolithic site of Byblos. Kohn and colleagues (1993) observed a medio-lateral cranial narrowing and an infero-superior reduction in the circularly shaped crania of the Pacific Southwest. According to some scholars (Cocilovo et al., 2011; Kohn et al., 1993), oblique circularly shaped crania decrease both in height and width. Contrary to cranial breadth, a consensus on the effects of circular headshaping on maximum cranial length and height does not exist. In fact, if on one hand several studies have suggested a more or less evident increase of cranial length (Cocilovo et al., 2011; Kohn et al., 1993; Brown, 1989, 1981; Özbek, 1974a, 1974b), on the other, some scholars have observed its reduction (Schendel et al., 1980) or even have not recognize any alteration (Pomeroy et al., 2009). Similarly, while some scholars have suggested the increase in height of this shaped group (Brown, 1989, 1981; Blackwood & Danby, 1955), others have proposed its decrease (Kohn et al., 1993; Özbek, 1974a, 1974b). Blackwood and Danby (1955) stated that, compared to both cranial breadth and length, cranial height has variable patterns of alteration depending on the degree of frontal and occipital flattening, on the lengthening of frontal and occipital chords as well as on the degree of rotation of frontal and occipital bones in relation with the Frankfurt Plane. According to Cocilovo and colleagues (2011), while circularly erect shaped crania increase in height, oblique shaped ones decrease. Beyond these explanations, the prevention of the development of cranial height might also depend on the pressure applied on the coronal/post coronal region by a transversal shaping device crossing the coronal/post coronal region up to the below of the jaw (Erdal, 2013a; Özbek, 2001; Meiklejohn et al., 1992; Lambert, 1979; Özbek, 1974a; 1974b; Hasluck, 1947; Dingwall, 1931; Delisle, 1902), in the present study morphologically reflected in the high frequency (86,7%) (*p*: 0,000) (Table 76; Graph 13) of post-coronal depression observed both in adults and subadults. Contrary to the results of the present study, that instead find matches with those obtained by Zhang and colleagues (2019) on circularly shaped Neolithic Chinese crania, many previous studies (Ni et al., 2020; Brown, 2010; Durban 2008; Antón & Weinstein, 1999; Antón, 1989; Larnach, 1974; Blackwood & Danby, 1955) agreed on the acute curvature of the parietals due to the decrease of their chord and the increase of their subtense.

Graph 7. Alterations of the most relevant metric variables collected on adult individuals of both the sexed under the effects of circular headshaping



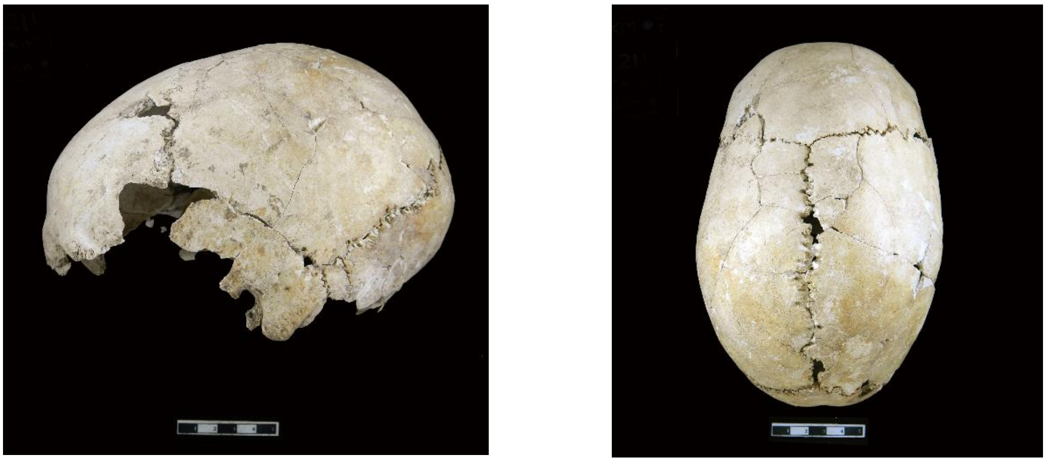


Figure 12. Lateral and superior view of a severe circularly shaped cranium of an adult female (M211) from Hakemi Use

Figure 13. Lateral view of a very severe circularly shaped cranium of an adult individual (unknown sex) (G6 M344) from Hakemi Use

The results of the statistical analysis performed on adult craniometric data in relation with the presence of tabular headshaping have shown that tabularly shaped crania of both the sexes antero-posteriorly shorten, medio-laterally enlarge, and infero-superiorly develop (Table 15; Graph 8) (Figures 14-15). Frontal longitudinally contract and flatten while developing in width (Table 15; Graph 8). Parietals evidently shorten and curve (Table 15; Graph 9) while obelion-inion region and occipital flatten (Table 15; Graphs 8) (Figures 14-15). Several matches have been found with the results of many previous studies (O'Brien & Stanley, 2013; Cocilovo et al., 2011; Pomeroy et al., 2009; Antón, 1999; Kohn et al., 1995; Cheverud et al., 1992; Antón, 1989; Soto-Heim,1986; Imbelloni, 1925). For instance, Mellink and Angel (1968) suggested an antero-posterior cranial shortening and infero-superior development in the tabularly shaped individuals of the city of Şemayuk in Turkey. Antón (1989), noticed a parietal shortening and bulging in antero-posteriorly and occipitally shaped Peruvian crania. Cheverud and others (1992) noticed the decrease of cranial length and the compensatory increase of biparietal length in the tabular antero-posteriorly modified crania of a prehistoric Peruvian Ancon sample. Pomeroy and colleagues (2009) proposed a reduction of cranial length and an increase of breadth in tabularly shaped crania of Northern-central Peru. Antón and Weinstein (1999) and Cocilovo and colleagues (2011) observed the presence of frontal flattening not only in circularly shaped crania but also in tabularly shaped ones.

Graph 8. Alterations of the most relevant morphometric variables collected on adult individuals of both the sexed under the effects of tabular headshaping

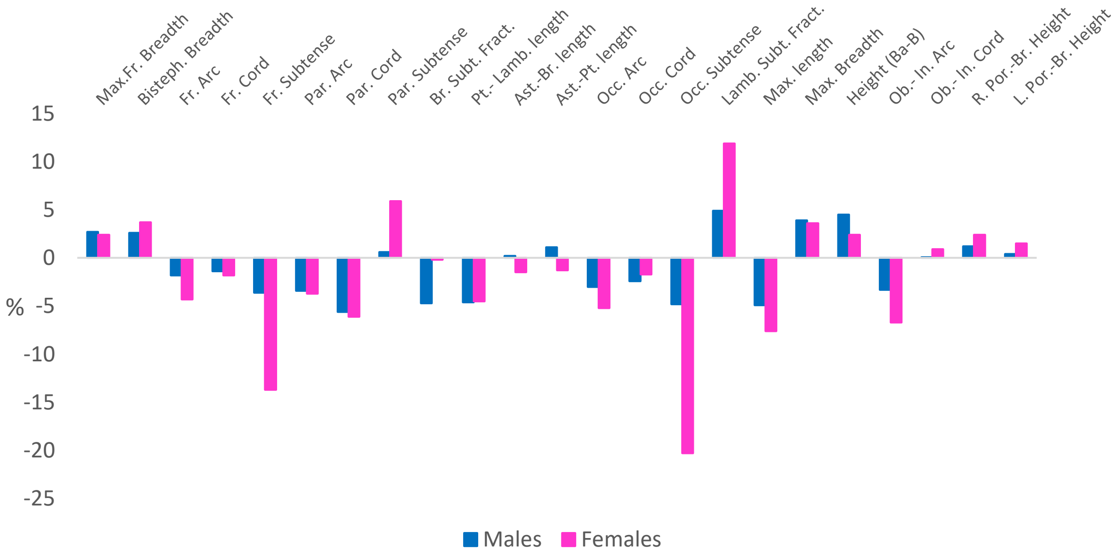


Figure 14. Lateral and superior view of a severe tabularly shaped cranium of an adult female (SK 21) from Erzurum

Figure 15. Lateral and superior view of a very severe tabularly shaped subadult cranium (SK 84) from Oluz Höyük

The results of the statistical analysis performed on adult craniometric data in relation with the presence of composite headshaping instead have shown that crania of both the sexes evidently shorten and slightly enlarge (Table 16; Graph 9) (Figure 16). Cranial height lowers in males while developing in females (Table 16; Graph 9). Parietals antero-posteriorly contract, and obelion-inion region and occipital flatten (Table 16; Graph 9) (Figure 16). Frontal flattens in both the sexes (although more prominently in females) while mediolaterally developing in males and narrowing in females (Table 16; Graphs 9) (Figure 16). Sex differences in the frontal development might be related to the effects of a circular shaping device horizontally crossing the frontal, whose presence is supported by the statistical results of the analyses conducted on morphological data that show a high frequency and statistical significance (p<0,05) of frontal depression (70,5%) and flattening (19,7%) (Table 81; Graph 15). Sexes differences in cranial height instead might depend on the application of a transversal circular shaping device, morphologically indicated by the statistically significant frequency of post coronal depression (Table 81; Graph 15).

Graph 9. Alterations of the most relevant morphometric variables collected on adult individuals of both the sexed under the effects of composite headshaping

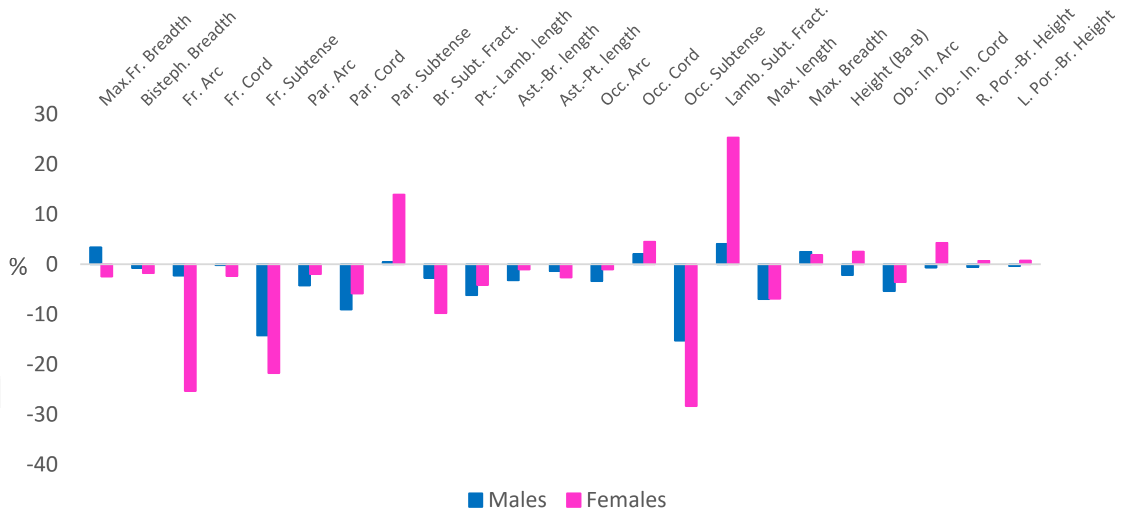


Figure 16. Lateral and superior view of a severe compositely shaped subadult cranium (S127 H143) from Arslantepe

Multiple Discriminant Analysis and Nonparametric Logistic Regression Test, performed on the raw data of 20 statistically (p<0,05) discriminant measurements have provided a high percentage of accuracy in the discrimination between unmodified and shaped (circular and tabular) crania, by correctly classifying even 92,8% (100% for circular headshaping, 91,3% for tabular and 94,1% for unmodified crania) and 100% of the analysed sample, respectively (Table 63, 52; Graph 1).

If we look at the previous studies, Pomeroy and others (2009), by statistically analysing 44 linear and 11 angular measurements as well as six indices, discriminated between different types of intentional headshaping of North-Central Peru (posterior flattened, bilobed and circularly shaped crania) by reaching 91,3% of agreement with the visual classification. Cocilovo and others (2010) predicted 83,1% of circularly shaped crania, 87,5% of tabularly shaped and 73,2% of unmodified crania by statistically processing four linear cranial measurements (maximum cranial length, width, height, and frontal chord) collected on a very large adult sample found in the South-Central Andes. Wehrman (2016), by employing 3D data collected on an adult sample, discriminated between Mississippian Middle Cumberland (central Tennessee) shaped and unmodified crania by reaching 82,7% of accuracy (81,8% of shaped crania and 80% of unmodified ones). Lucea and others (2018), by processing 63 linear and angular measurements by Logistic regression Analysis, 100% correctly discriminated between shaped and unmodified adult crania of modern Fuegians belonging to different ethnic groups. Based on these results, it is possible to state that the present study provides a very important contribution to the worldwide research aimed at the elaboration and improvement of a quantitative method able to accurately and objectively discriminate between unmodified crania and different headshaping types.

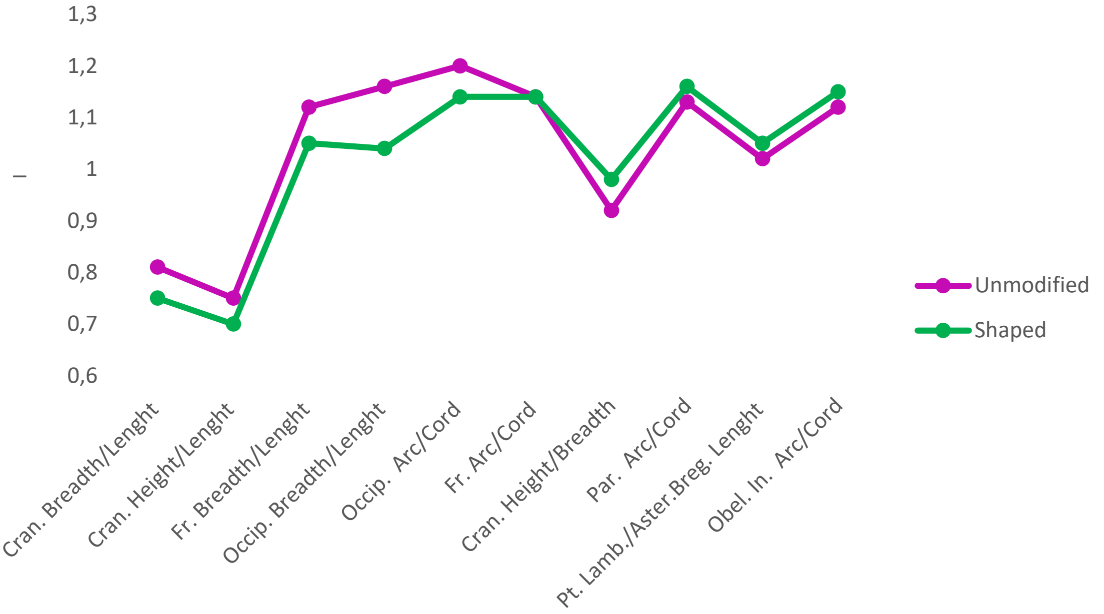
6.2.2. Proportional cranial measurements of both adults and subadults

Although statistical analyses on cranial measurements of adult individuals has allowed a highly accurate discrimination between unmodified and shaped crania, their use results worthless in a sample including not only adults but also subadult individuals. Compared to almost all the previous works that have exclusively processed data from adults, the present study for the first time has investigated intentional headshaping on the two age groups by employing proportional metrics.

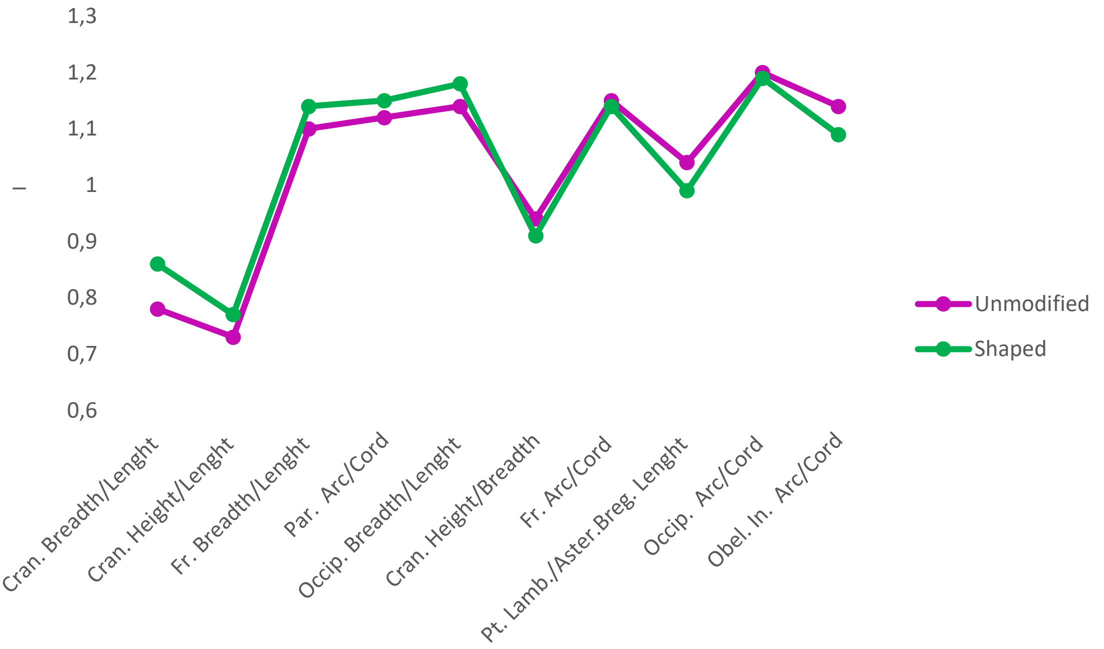
Another important contribution provided by the statistical processing of these variables is the mathematical redefinition of the “a priori" morphoscopically established degrees of headshaping development. In fact, based on the results of Manova Post Hoc Tests, the degrees of severity (slight, moderate, severe, and very severe) firstly defined for all the three headshaping types have been replaced by new ones; in detail: moderate, severe, and very severe degrees have been established for circular headshaping; slight, moderate, and severe degrees for tabular headshaping; slight, moderate, severe, and very severe when considering circular modification in composite headshaping, and slight, moderate, and severe degrees when considering the tabular one.

The results of the statistical analyses performed on the proportional metrics according to the redefined degrees of severity of the different headshaping types show that circularly shaped crania decrease in width and height compared to their length (Table 47; Graph 10). Frontal latero-medially narrows and develops in length as well as the occipital that also flattens (Table 47; Graph 10). Parietals postero-superiorly elongate and obelion-inion region bends (Table 47; Graph 10). Tabularly and compositely shaped crania instead similarly develop by increasing in breadth and height (breadth more than height) compared to their length (Tables 48-49; Graph 11-12). Frontal develops in breadth rather than in length (Tables 48-49; Graph 11-12) and flattens (Tables 48-49; Graph 11-12). Parietals antero-posteriorly narrow and curve, while obelion-inion region and occipital flatten (Tables 48-49; Graph 11-12). Compared to the results of linear measurements, the proportional metric effects produced by the circular shaping forces in compositely shaped crania, are overshadowed by the influence of the tabular shaping ones. The comparison with the results of other investigations has revealed that the cephalic index of Anatolian tabularly shaped crania (cranial breadth/length) ($\bar{x}$: 86) (Table 48) resembles those obtained by other scholars such as Falkenburger (1938) on tabularly shaped crania from South America ($\bar{x}$: 85-110), Melconian and Schaepelynck (1947) on tabularly shaped Lebanese crania ($\bar{x} >$ 0,83), Ducros (1967) on tabularly shaped Syrians and Morvans ($\bar{x}$: 82,65 and $\bar{x}$: 81,88, respectively), and Soto-Heim (1986) on Iranian and Syrian tabularly shaped crania ($\bar{x}$: 88,14 for males and $\bar{x}$: 90,22 for females). Also height/length ($\bar{x}$: 77) and height/breadth indices ($\bar{x}$: 0,91) (Table 48) match those obtained by Falkenburger (1938) ($\bar{x}$: 70-90 and $\bar{x}$: 76-96, respectively). According to Ducros (1967), the more the occiput flattens the more the value of the arc approaches that of the chord so that obelion-inion chord/arc index increases ($\bar{x}$: 94,43 for Syrians; $\bar{x}$: 90,14 for Morvans). In the present study, the decrease of both occipital and obelion-inion arc/chord indices (Table 48; Graph 11) reflects the same pattern of alteration.

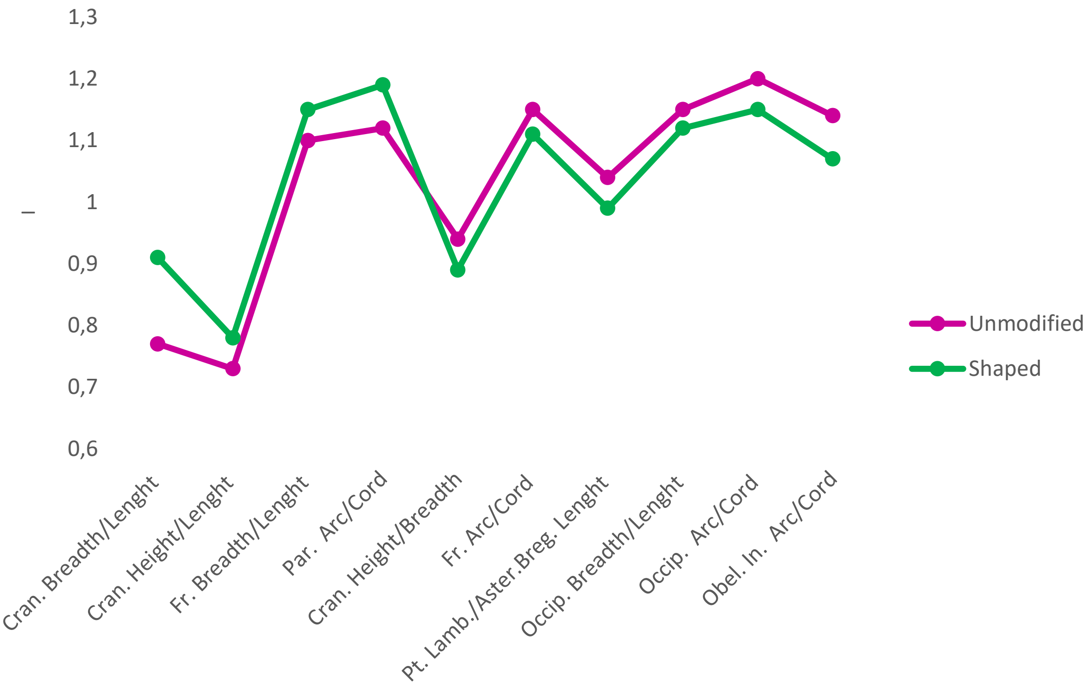
Graph 10. Alterations of proportional cranial metrics collected on both adult and subadult individuals according to the redefined severity degrees of circular headshaping



Graph 11. Alterations of proportional cranial metrics collected on both adult and subadult individuals according to the redefined severity degrees of tabular headshaping



Graph 12. Alterations of proportional cranial metrics collected on both adult and subadult individuals according to the redefined severity degrees of composite headshaping



The results of the predicted group membership obtained by Multiple Discriminant Function Analysis and Nonparametric Logistic Regression Test on raw proportional metrics of both adult and subadult individuals, resulted statistically significant in Manova (Tables 57, 68), have respectively reached a percentage of correct classification of 80,6% (86,2% for tabular headshaping, 75,6% for unmodified crania and 50% for circular headshaping) (Table 59, Graph 3) and 81,6% (86,2% for tabular shaped crania, 78% for unmodified and 50% for circularly shaped ones) (Table 67).

If we look at the previous investigations, almost all performed on data belonging to adult individuals, Clark and others (2007), by applying statistical analyses on frontal, parietals, and occipital curvature indices, discriminated between shaped and unmodified crania coming from several archaeological sites of the Philippines by reaching 91,9% (100% for unmodified 76,9% for shaped ones) of agreement with their visual classification. Compared to the present study, crania with occipital flattening were scored as unmodified. O'Brien and Stanley (2013), by using indices calculated from four cranial measurements (maximum cranial length, breadth and height and frontal chord) statistically investigated intentional headshaping on a series of prehispanic adult crania coming from different archaeological sites of South America. According to the results of their work, 81,3% of the visually classified sample was correctly identified as unmodified, 83,1% as circularly shaped and 87,5% as tabularly modified.

Based on all these results, it is possible to state that, although with a lower percentage of predicted membership compared to the above-mentioned studies, the most important contribution of the present investigation is the elaboration, for the first time, of a statistical method of discrimination between unmodified and shaped crania on a sample including both adult (males and females) and subadult individuals.

For the application of the discrimination method, the following functions must be calculated by using the selected proportional metrics and the Canonical discriminant coefficients obtained by Discriminant function analysis performed on these variables (Table 57).

$$Function\ 1:$$

$$24{,}690 * CBL - 49{,}496 * CHL + 32{,}792 * CHB - 2{,}828 * FBL - 0{,}465 * FAC - 11{,}233 * PAC + 2{,}023 * PLABL - 0{,}198 * OBL + 0{,}939 * OAC - 0{,}829 * OIAC + 1{,}234$$

$$Function\ 2:$$

$$63{,}943 * CBL - 72{,}329 * CHL + 66{,}859 * CHB + 1{,}974 * FBL + 6{,}119 * FAC + 0{,}938 * PAC - 4{,}629 * PLABL + 11{,}845 * OBL - 0{,}923 * OAC + 1{,}636 * OIAC - 79{,}712$$

The result of the functions will provide the coordinates of the analysed skull/cranium on the territorial map (Figure 17). The presence of intentional headshaping, its type and degree will be defined by the position of the analysed example into the map (Figure 17).

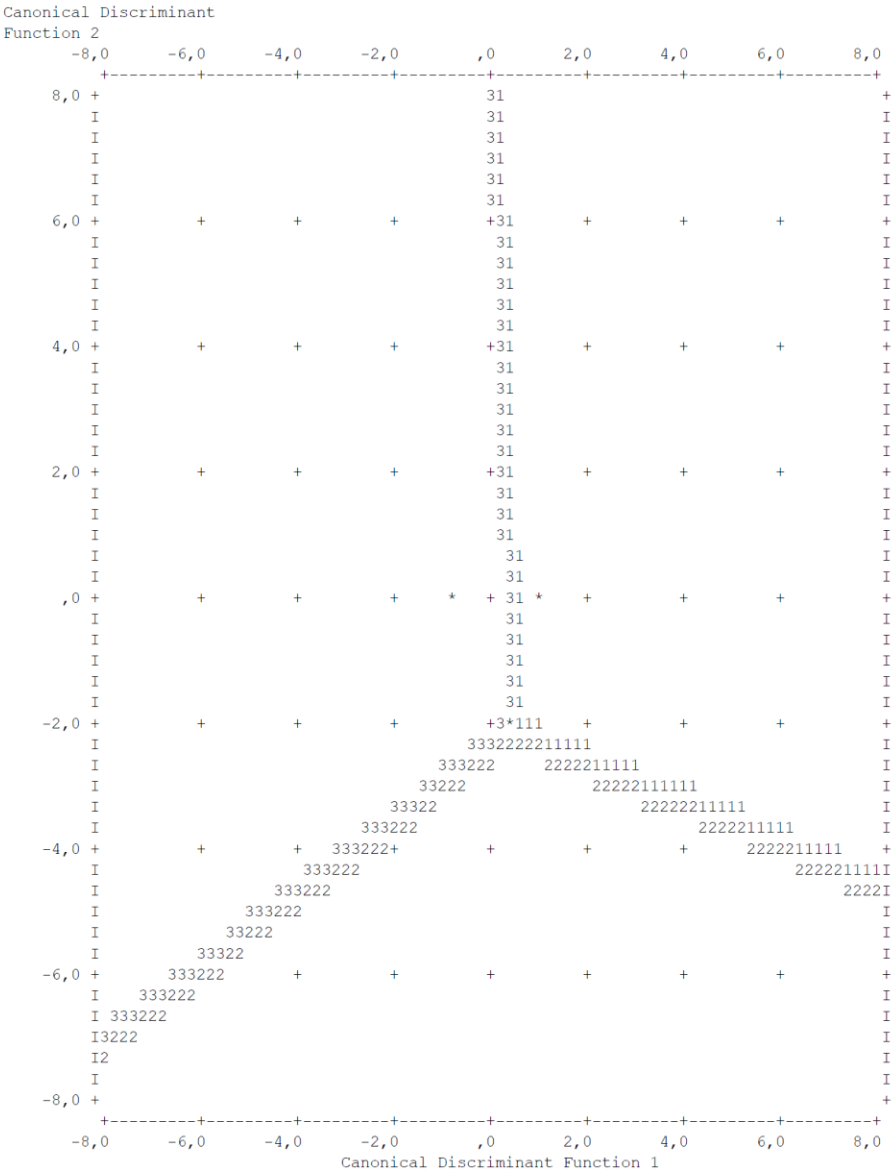


Figure 17. Territorial map of Discriminant Function Analysis for plotting results of Functions computed by proportional metrics of adults and subadults (1: undeformed, 2: circular, 3: tabular, *: group centroid)

6.2.3. Principal component analysis

The application of Principal Component Analysis on both discriminatory cranial measurements of adult individuals and proportional cranial metrics of both adults and subadults has allowed to investigate the principal components sets able to represent the patterns of morphometric cranial variations occurring in presence of intentional headshaping. The results of the analysis performed on linear measurements have provide a set of ten variables (parietal chord, parietal arc, maximum cranial length, pterion-lambda length, bregma subtense fraction, bistephanic breadth, maximum frontal breadth, maximum cranial breadth, occipital subtense and occipital arc (Tables 71, 73; Graph 5) representing 77,24% of the total variance by three main components (38,96%, 24,65% and 13,63%) (Table 71) (Graph 5a-b). While the first component reflects the morphometric variations occurring in the parietal region, the second one is related to the alterations of the cranial breadth-related measurements, the third component instead represents curvature variations of the posterior portion of the cranium (Table 72). The results of Principal component analysis performed on proportional metrics instead has provided a set of four variables (cranial height/length, pterion/lambda length, cranial breadth/length, and occipital breadth/length) (Table 74) able to reach 76,27% of the total variance (Table 75) by two components respectively accounting for 51,10% and 25,17% of the variance (Table 75; Graph 6) and related to the development of the head according to its three main dimensions and to the alterations of the posterior portion of the cranium (Table 74). If we look at the results of the previous investigations conducted by different methods, Jung and Woo (2016) reached a percentage of total variance of 75,25% by applying a 2D geometric morphometric method and multivariate statistical analysis on a sample of unmodified and antero-posteriorly shaped ancient Korean adult crania. Wehrman (2016), by using six cranial landmarks (bregma, lambda, left and right euryon, and left and right asterion), reached 70,19% of the total variance on a Mississippian Middle Cumberland sample including occipitally flattened and unmodified crania. Kuzminsky and other colleagues (2016) represented 39,64% of the total variance (PC1: 26,15% and PC2: 13,48%) on circularly and tabularly shaped crania coming from four archaeological sites of Chile and Peru by using Laser Surface Scanning techniques. Natahi and others (2019), by employing 3D geometric morphometric methods, reached 53,31% of the total variance on Post Classic Mexican fronto obelionic and tabularly erect shaped crania including both adults and subadults. Püschel and colleagues (2020), by using geometric morphometric and statistical methods, represented 34,56% (PC1: 24,39% and PC2:10,17%) of the total shape variation of antero-posteriorly and circularly oblique shaped adult crania coming from the North Chile. Based on the comparison between the above-mentioned studies, it is possible to state that, for the first time, Principal component analysis performed on proportional metrics of both adult and subadult individuals has provided the highest percentage of total shape variation.

6.3. MORPHOLOGICAL CRANIAL ALTERATIONS IN INTENTIONALLY SHAPED CRANIA

Although all the existing investigations on intentional headshaping in Anatolia are based on morphological approaches (Aytek et al., 2021; Aytek et., 2020; Erdal, 2019; Eroğlu, 2016; 2015; Erdal, 2013; Duyar & Atamtürk 2010; Miyake, 2010; Lorentz, 2009; Özbek, 2001; Meiklejohn et al., 1992; Alpagut, 1986; Özbek, 1986, 1985, 1984; Lambert, 1979; Angel, 1976; Özbek, 1974; Mellink & Angel, 1968), morphological data have never been statistically treated. For the first time, the present work has statistically evaluated the morphological effects produced by the different intentional headshaping types in order to objectively identify the diagnostic morphological alterations of each artificial modification. As proposed by Tiesler (2014), it is possible to distinguish between primary and secondary or compensatory morphological alterations. The former includes depression and flattening, while the latter, bulging and bulging/prominence.

6.3.1. Circular headshaping

Morphological cranial effects produced by circular headshaping have been observed in almost all the cranial regions, despite a very high incidence regards the anterior portion (frontal and anterior parietals) of the cranium (Table 76; Graph 13). Based on the statistical relevance (p<0,05) and the rates of occurrence of the analysed morphological variables, it is possible to state that frontal depression, flattening and bulging, post-coronal depression, bregmatic/post bregmatic bulging, parieto-temporal depression and bulging, bulging/prominence of parietal tubera, occipital inionic flattening and depression, pars squamosa depression and bulging are all diagnostic morphological alterations of this headshaping type (Table 76; Graph 13) (Figures 18-19). Moreover, posterior movement of bregma and V-shaped coronal suture, for the first time statistically analysed in the present work, represent other discriminant alterations of this headshaping type (Table 82). The more bregma moves backward the more coronal suture acquires a V shape. These results well fit with the morphometric data showing an elongation of the frontal in this shaped group (Table 14, 47; Graph 7, 10). Although without any statistical significance (*p*>0,05), the frequencies of these two morphological traits seems to develop by the increasing severity of frontal depression both in circular and composite headshaping (Tables 85, 87).

The similarity in frequencies of frontal depression (80%) and bulging (81,5%) (Table 76; Graph 13) as well as their similar pattern of extension suggest a causal connection between them. The lower incidence of frontal flattening (16,7%) compared to frontal depression (80%) instead (Table 76; Graph 13) may likely reflect variations in the shaping techniques such as differences in the dimensions or the material of the employed shaping device, or in the amount of the applied pressure. The observation of fragmented examples has also allowed to visually analyse alterations in the development of the diploë. It thins in the area of the applied pressure while thickens in the immediately posterior region, where bulging occurs. Similar to frontal flattening, post-bregmatic or bregmatic bulging (Table 76; Graph 13) (Figures 18-19) might be explained as results of the more posterior or extensive application of a shaping device on the frontal and, as such, related to variations in the headshaping techniques as well. The similarity in frequency of bulging of parietal tubera (69,1%) and parieto-temporal depression (70,4%) (Table 76; Graph 13) (Figures 18-19) suggests the compensatory development of the former under the influence of parieto-temporal compressional forces as well as of the post coronal ones. Differences in frequencies between occipital inionic flattening (40%) and depression (24,6%) and pars squamosa depression (8,7%) (Table 76; Graph 13) may also be the result of differences in shaping techniques such as different inclination (horizontal or oblique) (Antón, 1989; Imbelloni, 1925), dimensions or type of the shaping apparatus (Özbek, 2001; Aufderheide et al., 1998) or different amount or duration of the shaping pressure (Özbek, 2001). Based on the pattern of development of all the above mentioned morphological alterations, it is possible to suggest that frontal depression or flattening, parieto-temporal depression, and occipital depression or flattening are all interrelated direct morphological effects of the application of a shaping device that obliquely envelop the head from the frontal to the posterior regions by passing through the parietals (Figures 18-19) such as observed in the types B, C and D proposed by Meiklejohn and colleagues (1992) for the Neolithic shaped crania of Seh Gabi, Bouqras, Shanidar Cave and Ganji Dareh Tepe, or in the type B suggested by Özbek (1974a) for circularly shaped crania from Byblos. Post coronal depression instead reflects the Type A proposed by Meiklejohn and colleagues (1992) as well as by Özbek (1974a).

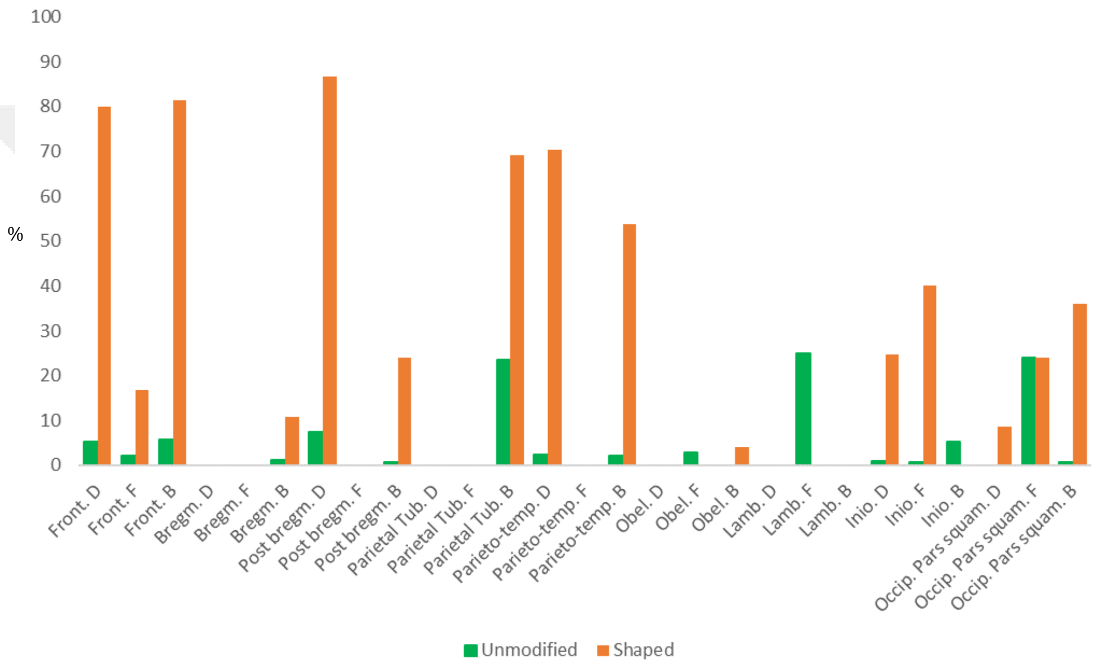
Similar morphological alterations have been widely observed in several previous investigations as well. Magitot (1885) observed a marked pre-bregmatic bulge and a series of lateral depressions bordering the midline of the frontal of deformed European crania. Blackwood and Danby (1955) noticed a medial thickening of the frontal bone immediately anterior to the bregma and a thinning of the diploë in the area of frontal depression in circularly shaped Arawe crania. Brown (2010, 1981) identified marked pre bregmatic eminences and lateral depressions bordering the midline of the frontal in shaped Arawe, Coobool and Cohuna crania. Özbek (2001) observed frontal flattening and depression as well as a bulge in the area between frontal and post-coronal depression in the circularly shaped crania found at the Chalcolithic site of Değirmentepe. Tritsaroli and others (2010) recognized a concavity in the middle of the frontal and a convexity at bregma in a circularly shaped cranium from the Early Byzantine site of Maroneia. Also Molleson and Campbell (1995) observed frontal depression and flattening in the circularly shaped crania of Tell Arpachiyah in Iraq. According to Dingwall (1931), depression of the frontal produces a shifting backwards of bregma as well as a more oblique extending backwards and upwards of the coronal suture. Schendel and others (1980) found that circularly shaped crania of adult Hawaiian Mokapu were characterised by a slight postero-superiorly movement of bregma. Bulging of parietal tubera as well as parieto-temporal depression (Table 76; Graph 13) (Figures 18-19), have been observed in the circularly shaped crania found at the Neolithic sites of Ganji Dareh Tepe, Bouqras, Shanidar Cave, Hakemi Use, and at the Chalcolithic site of Değirmentepe (Erdal, 2019, 2013a; Brown, 2010; Özbek, 2001; Meiklejohn et al., 1992; Lambert 1979). Pars squamosa bulging (Figure 19), was also recognized by Özbek (1974b) in the shaped skeletal material from Byblos as well as by Ricci and others (2008) in a Late Neolithic South-western Libyan shaped sample.

Compared to the above-mentioned morphological alterations, a consensus on the aetiology of post coronal depression has not been achieved yet. In fact, if on one hand it has been accepted as the direct result of the application of a transversal bandage that from the post bregmatic area bilaterally goes down towards parieto-temporal region by reaching the below of the jaw (Erdal, 2013; Özbek, 2001; Molleson & Campbell, 1995; Antón & Weinstein, 1999; Meiklejohn et al., 1992; Lambert, 1979; Özbek, 1974a, 1974b; Hasluck, 1947; Dingwall, 1931; Delisle, 1902), according to other interpretations it may be accepted as compensatory effect (Ricci et al., 2008, Aufderheide et al., 1998; Weiss, 1958). Delisle (1902:157) suggested that bregmatic depression results from exaggerated constricting forces applied on the posterior and superior borders of the frontal and on the anterior parietals at the level of the coronal suture. Dingwall (1931:175) reported that a transversal bandage was used to prevent the compensatory cranial pressure taking place mediolaterally because of the antero-posterior enveloping of the head. Conversely, according to Weiss (1958:186), post-coronal sulcus is causally related to the convex elevation of the frontal bone due to the pressure applied on the median frontal. Aufderheide and others (1998:35) stated that coronal depression is not the result of the application of an additional band over the vertex rather the effect of an excessive tension produced by bands causing the overlap of the frontal and the parietals and thus the consequent formation of a ridge at the coronal area and a groove in the immediately posterior region. According to Ricci and others (2008), post coronal depression is a secondary effect produced by the compression acting both on the anterior (frontal) and the posterior (lambdoidal region) portions of the skull. Tiesler (2014: 43) stated that it results from intrinsic growth tensions and assimilation forces taking place in the sutural areas when an extrinsic compression force is applied near that cranial region. For Anatolian sample, it has been accepted as the direct effect of a transversal shaping device.

The analysis of morphological data allows an easier interpretation and a better understanding of the results of the craniometric analysis as well (Tables 14, 47; Graphs 7, 10). In fact, frontal and occipital flattening, or depression (Table 76; Graph 13) represent, with different degrees of severity, the corresponding morphological signs of the metric reduction of both frontal and occipital subtenses, of the increase of their chords, of the increase/decrease of their arcs (Table 14; Graph 7), of the decrease of frontal and occipital arc/chord indices as well as of all the breadth-related frontal measurements (Table 14; Graph 7) and frontal breadth/length index (Table 47; Graph

10). Parieto-temporal depression morphologically represents the cause of biparietal narrowing and of the reduction of occipital breadth (Table 14; Graph 7), as well as of the increase of cranial and occipital breadth/length indices (Table 47; Graph 10). As already proposed by Özbek (1974b), the presence of post coronal depression (Table 76; Graph 13) may explain the reduction of maximum cranial height (Table 14; Graph 7) (Figures18-19).

Graph 13. Distribution of morphological cranial alterations according to the redefined severity degrees of circular headshaping



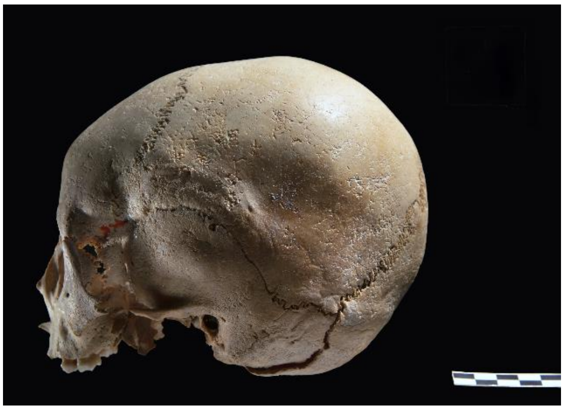


Figure 18. Lateral view of a moderate circularly shaped cranium of a subadult individual (H265) from Arslantepe

Figure 19. Lateral view of a moderate circularly shaped cranium of a subadult individual (M345) from Hakemi Use

6.3.2. Tabular headshaping

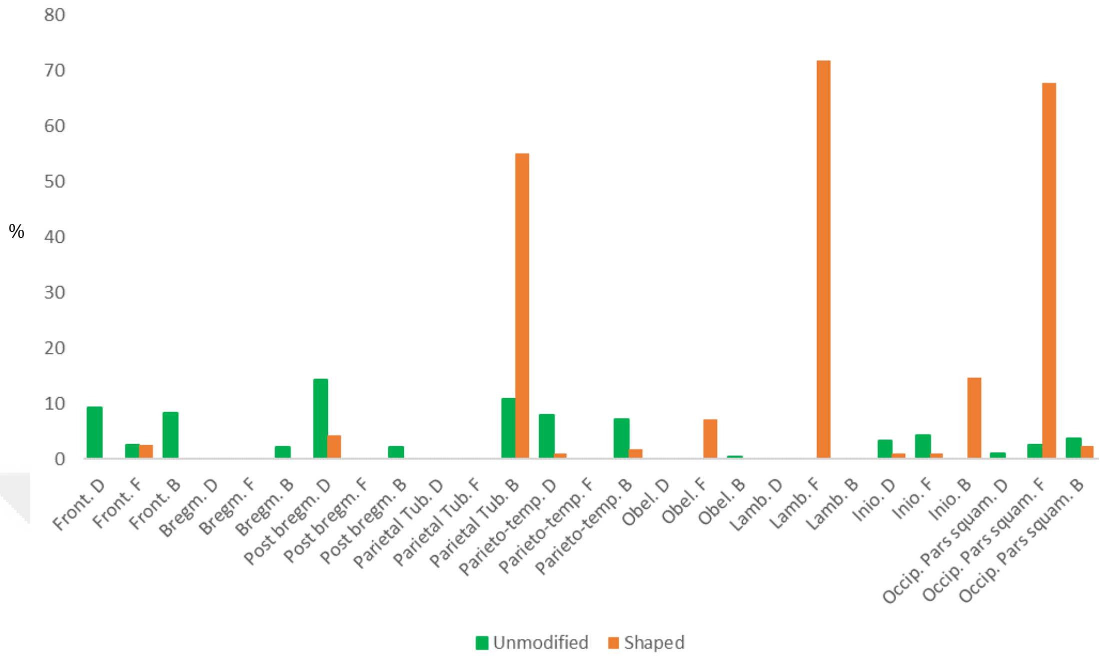
Compared to circular headshaping, tabular modification mostly affects the posterior portion of the skull, in particular posterior parietals and occipital (Table 77; Graph 14). Morphological cranial alterations such as lambdoidal and occipital pars squamosa flattening, prominence/bulging of parietal tubera, inionic bulging and obelionic flattening may be considered as diagnostic of this headshaping type (Table 77; Graph 14). Postural plagiocephaly may also be accepted as a diagnostic trait as well.

Based on the observed morphological alterations as well as on the well-known techniques of tabular modification (Erdal & D'Amico 2020; Eraslan, 2016; Kohn et al., 1995; Antón, 1989; Munizaga, 1987; Neumann, 1942; Dingwall, 1931; Imbelloni, 1928), it is possible to state that tabular intentional headshaping in Anatolia is represented by posterior flattening caused by the dorsal decubitus of the baby on a hard surface such as a cradle and resembling those observed in other regions of the Near East such as Syria (Soto-Heim, 1986; Ducros, 1967), Lebanon (Melconian & Schaepelynck, 1947), Iran (Soto-Heim, 1986), Iraq (Field, 1948), or Cyprus (Lorentz, 2009; Harper & Fox, 2008; Le Mort, 2007; Bolger, 2003; Angel, 1936).

Posterior flattening regards three main subregions: parietal lambdoid and obelionic, and occipital pars squamosa (Table 77; Graph 14). Parietal lambdoid and occipital pars squamosa subregion may be affected singularly or at once. When the flattening occurs in the two areas, the lambdoid develops in degree of severity by the increasing severity of the other. Conversely, obelionic flattening is only present when parietal lambdoid flattening occurs and increases in degree of development by the increasing of the other (Tables 78-79). Therefore, depending on the position of the applied pressure, and most likely on its amount and duration, the posterior flattened area may become more extensive and severe. The development of prominence/bulging of parietal tubera is about proportional to the increase in severity of tabular headshaping as well (Table 80). If we look at the previous works, several observations match. For instance, Nelson and Madimenos (2010) observed a pronounced and shelf-like external occipital protuberance/nuchal line complex in lambdoidal shaped Ancestral Puebloan people. Tiesler (2010) identified bulging of the lower occiput (xyphobasia) and acute lambdoid flattening in antero-posterior Olmec intentional headshaping. According to some scholars (Natahi et al., 2019; Tiesler, 2014, 2010) the occurrence of postural plagiocephaly is informative of the presence of intentional headshaping by appearing as a common secondary effect of tabular modification. Tiesler (2014, 2010), who identified the presence of this morphological alteration in Mayan skulls, suggested that posterior asymmetry occurs when the shaping device is not adjusted in a precise bilateral or anteroposterior position such as in the case of cradleboards and cradles, especially because of their multifunctional use (Tiesler, 2014, 2010, 2012). Like the results of present study (61,1%) (Table 89), the same scientist (Tiesler, 2014) observed 40% of asymmetries in tabular oblique headshaping and even 70% in tabular erect one. Also Neumann (1942) recognized the presence of posterior asymmetries in an occipitally flattened sample from the eastern United States.

The interpretation of the above presented morphological alterations well support the results obtained by the statistical analysis on measurements of adults and proportional metrics of both adults and subadults. In fact, posterior flattening is the cause of the evident decrease of occipital arc, chord and subtense, of obelion-inion arc, pterion-lambda length, parietal arc, and chord (Table 15; Graph 8), of occipital and obelion-inion arc/chord and pterion-lambda/asterion-bregma length indices (Table 48; Graph 11) as well as of the increase of obelion-inion chord, parietal subtense (Table 15; Graph 8) and parietal arc/chord (Table 48; Graph 11).

Graph 14 Distribution of morphological cranial alterations according to the redefined severity degrees of tabular headshaping



6.3.3. Composite headshaping

Composite headshaping affects both the anterior and posterior portions of the cranium (Table 81). While frontal is mainly influenced by circular shaping forces, occipital by tabular ones, and parietals instead by both. The morphological alterations observed in this shaped group are almost those recognized in circular and tabular headshaping (Tables 76-77; Graphs 13-14). Based on the statistical relevance (*p*<0,05) and the rate of occurrence of the analysed morphological variables, it is possible to state that bulging/prominence of parietal tubera, lambdoid flattening, pars squamosa flattening and bulging, frontal bulging, depression and flattening, parieto-temporal bulging and depression, post bregmatic depression and bulging, and bregmatic bulging are all diagnostic traits of this headshaping type (Table 81; Graph 15) (Figures 20-21) Posterior movement of bregma and postural plagiocephaly (especially the parieto-occipital one) represent diagnostic morphological traits of this headshaping type as well (Tables 82, 89). Nevertheless, compared to circularly shaped crania, V-shaped coronal suture may also be accepted as a diagnostic feature only if co-occurring with posterior movement of bregma (Table 83).

Compared to circular headshaping, the statistical irrelevance of the rate of incidence of occipital pars squamosa depression and inionic flattening (Table 81; Graph 15) supports the more affecting influence of the tabular shaping forces compared to the circular ones that instead are overshadowed.

Like for circular and tabular headshaping, the interpretation of these morphological data well supports the suggestions proposed for morphometric alterations (Tables 16, 49; Graph 9, 12). In fact, it is possible to state that, similarly to circularly shaped crania (Table 76; Graph 10), frontal flattening and depression represent the corresponding morphological effects of the decrease of frontal curvature (Tables 16, 49). Conversely, like tabularly shaped crania (Table 77; Graph 11), lambdoid and occipital pars squamosa flattening, whose very similar frequencies suggest a causal connection (Table 81; Graph 15), may explain the antero-posterior shortening of this group (Tables 16, 49; Graphs 9, 12), the development of the prominence/bulging of parietal tubera (Table 81; Graph 15) as well as the mediolateral cranial development (Tables 16, 49; Graphs 9, 12).

Graph 15. Distribution of morphological cranial alterations according to the redefined severity degrees of composite headshaping

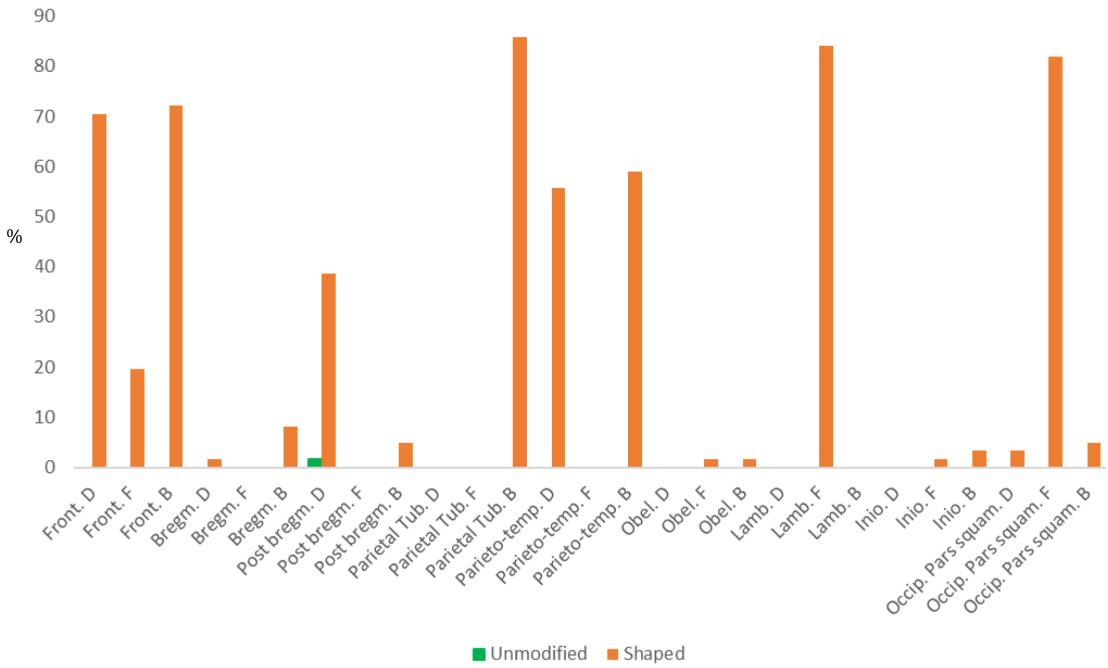


Figure 20. Lateral view of a moderate composite headshaping on a cranium of a subadult individual (H374B S224) from Arslantepe

Figure 21. Lateral view of a moderate composite headshaping on a cranium of an adult female individual (H276 S193) from Arslantepe

6.4.EFFECTS OF INTENTIONAL HEADSHAPING ON EPIGENETIC TRAITS

6.4.1. Wormian bones

Although many studies worldwide have dealt with the issue of the influence of intentional headshaping on the development of extra sutural bones (Van Arsdale & Clark, 2010; Wilczak & Ousley, 2009; Sanchez-Lara et al., 2007; Del Papa et al., 2007; Dean O'Loughlin, 2004; White, 1996; Konigsberg et al., 1993; El-Najjar & Dawson, 1977; Pucciarelli, 1974; Ossenberg, 1970; Bennet, 1967; Torgensen, 1951; Dorsey, 1897), similar investigations do not exist in Anatolia.

Dorsey (1897) was one of the first suggesting the influence of intentional headshaping on the incidence of Wormian bones. Sanchez-Lara and other colleagues (2007) considered extra sutural ossicles as a consequence of variations in dural strain and suture width due to the effects of environmental factors such as artificial headshaping. Van Arsdale and Clark (2007) stated that the development of Wormian bones is causally linked to the presence of artificial headshaping, varying according to the headshaping type as well as to the classification method. According to the same scholars (Van Arsdale & Clark, 2007), although headshaping does not directly affect extra-sutural bone formation it increases the tendency towards their formation. Ricci and others (2008) stated that the occurrence and distribution of this non metric trait may be influenced by both internal (muscular development, brain expansion, craniosynostosis) and external factors such as intentional headshaping.

The results of the statistical analyses performed not according to each population but on the entire sample show the development of Wormian bones in relation to all the three headshaping types, although higher frequencies are observed in circular and tabular headshaping (Table 93; Graphs 16-18). While circularly shaped crania show higher rates of incidence in the anterior cranial regions, composite, and tabular types in the posterior ones (Table 93; Graphs 16-18). Statistically significant high frequencies of Wormian bones have been observed in right lambdoid (92,3%, *p*:0,039) (Figure 22) and temporo-squamosal areas (50%, *p*:0,004) in circular headshaping (Table 93; Graph 16); in asterionic (right: 26,8%, *p*:0,000; left: 24,3%, *p*:0,006) (Figure 25) and at lambda (21,6%, *p*:0,044) (Figure 22) in tabular headshaping (Table 93; Graph 17); only at lambda (24,5%, *p*:0,026) (Figure 22) in composite headshaping (Table 93; Graph 18).

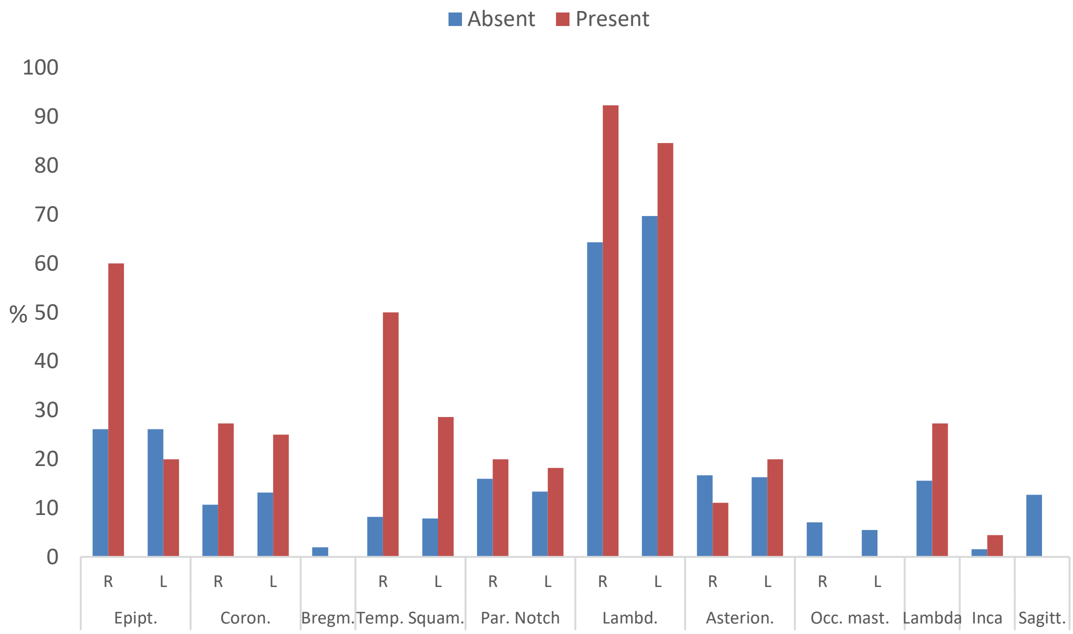
According to Dorsey (1897), extra-sutural bones in circularly shaped crania are compensatory of the altered fronto-parietal cranial development caused by the application of frontal and post coronal bandages. In the present study, despite the absence of any statistical significance, the higher frequencies of epipteric and coronal ossicles in circularly shaped crania (Table 93; Graph 16) might support Dorsey's suggestion (1897). Moreover, the increase of temporo-squamosal (p<0,05) and lambdoid bones (p<0,05) (Table 93) as well as ossicles at lambda well fits with the effects produced on the parietals and the occipital by the application of shaping devices causing the development of depressions or flattening (Table 76; Graph 14) as well as the postero-superior elongation of these cranial regions (Tables 14, 47; Graphs 7, 11). Similarly to the tabularly shaped Anatolian sample, Ossenberg (1970) observed an increased frequency of Wormian bones at lambda (62%, p<0,05), in the occipito-mastoid (70%) and asterionic regions (32%, p<0,05) as well as a decrease of coronal (30%, p<0,05), epipteric (13%) and parietal notch bones (15%) in Hopewell bifronto-occipitally shaped crania. Like the present study, Konigsberg and colleagues (1993) noticed an increasing frequency of left and right coronal ossicles in circularly shaped Nootka and Kwakiutl crania as well as a decreased frequency of left epipteric bones and an increasing rate of incidence of right parietal notch bones in circularly shaped

Kwakiutl crania. Nevertheless, while right occipito-mastoid ossicles were frequently observed in circularly shaped Kwakiutl crania (Konigsberg et al., 1993), they are not observed in circularly shaped Anatolian examples (Table 93; Graph 16). Furthermore, the increased frequency of coronal ossicles in fronto-occipital tabularly shaped Ancon crania as well as the decreased frequency of left occipito-mastoid ossicles in cradleboarded Hopi crania (Konigsberg et al. 1993) do not reflect the respectively decreasing and increasing frequencies observed in the posteriorly flattened Anatolian sample (Table 93; Graph 17). Like the present study (Table 93; Graph 16), Dean O’Loughlin (2004) found that parallelo-fronto-occipital and annular shaped crania from New World archaeological populations had greater frequencies of coronal, pterionic, apical, squamosal, and lambdoid ossicles than unmoulded crania, as well as a lower incidence of occipito-mastoid ossicles compared to both unmodified and tabularly shaped crania. According to the same scholar (Dean O’Loughlin, 2004), circular headshaping prevents the development of occipito-mastoid ossicles by compressing this cranial region, while fronto-vertico-occipital headshaping prevents the development of coronal and pterionic bones increasing instead the frequencies of almost all of the posteriorly placed extra sutural ossicles. In the present study, the absence of occipito-mastoid and bregmatic ossicles, the lower frequency of asterionic bones in circularly shaped crania as well as the decrease of coronal and pterionic ossicles and the increase of posteriorly placed bones in tabular and composite headshaping (Table 93; Graphs 16-18) may support Dean O’Loughlin’s suggestion (2004). Nevertheless, years later, Van Arsdale and Clark (2010) observed a statistically significant higher frequency of coronal ossicles in tabularly shaped Philippine crania.

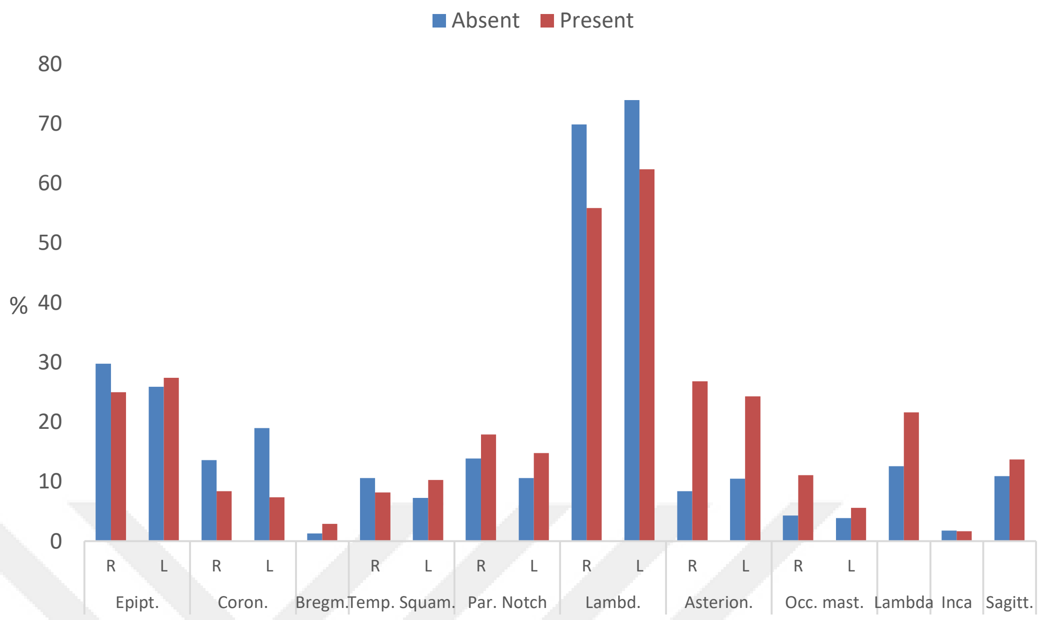
Many scholars (Papa et al., 2007; Sanchez et al., 2007; Dean O’Loughlin, 2004) have suggested that the frequency of Wormian bones vary according to the severity degree of intentional headshaping (Tables 94-97). In the present study, although the frequencies of many ossicles increase by the increasing severity of intentional headshaping, not statistically significant results have been reached (Table 94-97). Contrary to the results of Dean O’Loughlin (2004), who found that posteriorly placed lambdoid, apical, and asterionic bones have greater frequencies in moderate and severe shaped crania while anteriorly placed ossicles show similar frequencies among all the degrees, the results of the present study suggest a similar pattern of development both for anteriorly and

posteriorly placed Wormian bones. Based on the comparison with the results of other studies, it seems that the development of extra sutural bones in circularly shaped Anatolian crania does not concern those cranial regions directly affected by compressional forces. The higher frequencies of extra-sutural bones in the anterior portion of the cranium as well as the very high rate of incidence of lambdoid bones and ossicles at lambda may be explained as compensatory effects of the fronto-parieto-occipital and post coronal enveloping of the head by bandages. In tabular and composite headshaping (this latter almost not influenced by circular shaping forces) instead, except for ossicles at lambda (a region affected by compression forces), the higher frequencies of Wormian bones are generally observed in those area affected by tension forces.
Based on all these observations, it is possible to state that, although the development of some Wormian bones result statistically significantly affected by intentional headshaping, their presence should not be considered diagnostic.

Graph 16.Distribution of Wormian bones in circularly shaped crania



Graph 17. Distribution of Wormian bones in tabularly shaped crania



Graph 18. Distribution of Wormian bones in compositely shaped crania

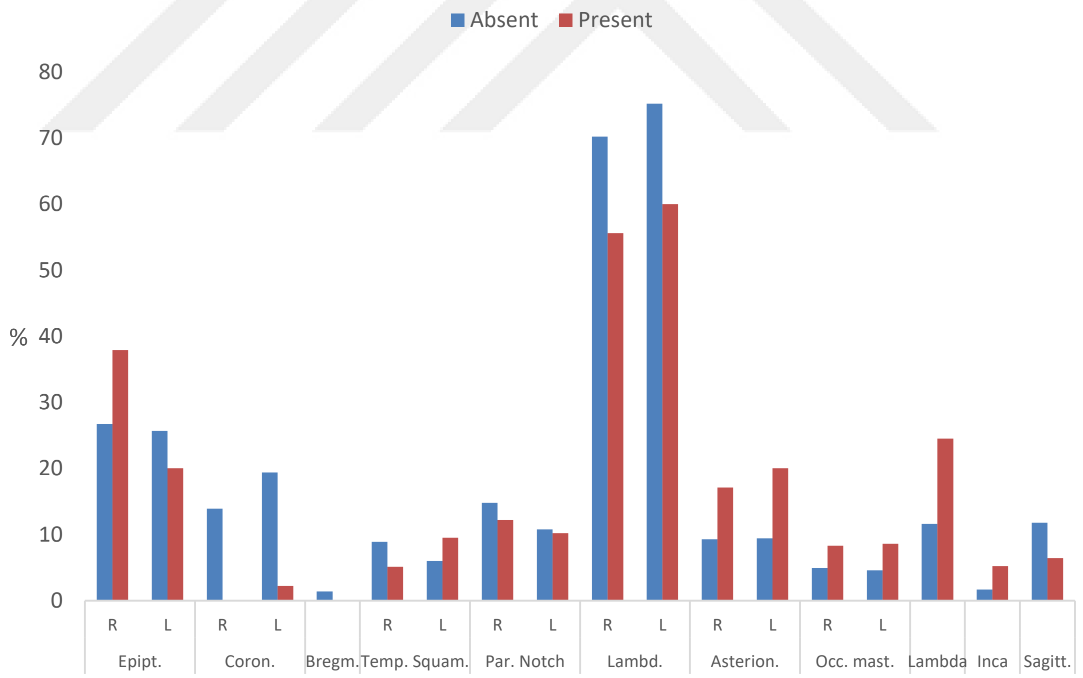


Figure 22. Wormian bones at lambda and lambdoid suture in a compositely shaped adult cranium (H106) from Arslantepe

Figure 23. Bregmatic Wormian bone in a tabularly shaped adult cranium (S 198 H288B) from Arslantepe

Figure 24. Inca bone in a circularly shaped subadult cranium (S180 H265) from Arslantepe

Figure 25. Asterionic and parietal notch Wormian bones in a tabularly shaped adult cranium (S180 H263) from Arslantepe

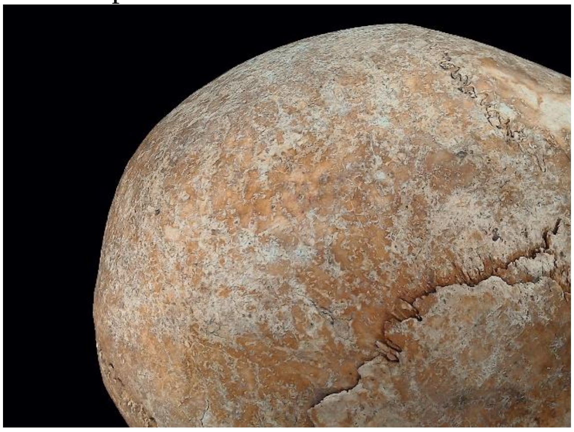


Figure 26. Temporo-squamosal Wormian bone in a circularly shaped adult cranium (SK 7) from Hagios Aberkios

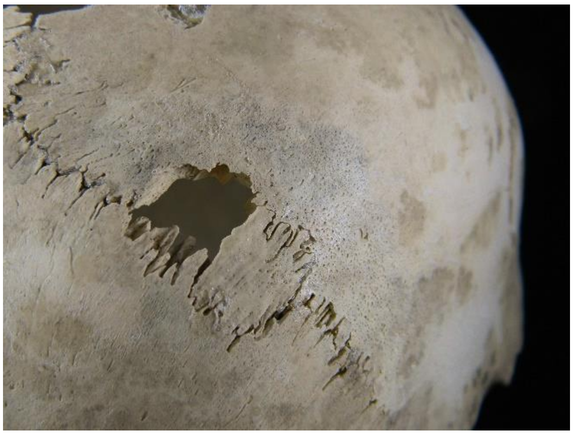


Figure 27. Lambdoid Wormian bones in a circularly shaped cranium of a subadult individual (17JDF24) from Değirmentepe

6.4.2. Metopism

Although some studies have investigated the influence of intentional headshaping on the development of metopism as well (Ossenberg, 1970; Gerzstein, 1993), any similar work does not exist in the Anatolian literature. According to the results of the statistical analyses conducted in the present study it is possible to state that, despite any statistical significance, metopism, especially the total type (Table 98) (Figure 28), occurs in tabularly (9,6%) and circularly shaped crania by reaching the highest frequency in this latter group (16%) (Table 98). If we look at the previous investigations, similar results have been reached as well. Gerzstein (1993) did not find any statistically significant association between this non-metric trait and intentional headshaping in the Pre-Columbian inhabitants of northern Chile. According to his results (Gerzstein, 1993), shaped crania showed a lower frequency (5,2%) compared to the unmodified ones (4,2%). Ossenberg (1970) instead, observed a higher but not statistically significant (p>0,05) frequency of metopism (4,2%) in bifronto-occipitally shaped Hopewellian crania compared to the unmodified ones, in which instead it did not occur. According to the same scholar (Ossenberg, 1970), a higher rate of metopism in intentionally shaped crania may be the result of the bilateral pressure placed on the frontal region that hinders the bony expansion at this suture. Even if the higher frequency of metopism in circularly shaped Anatolian crania, where a shaping force affects the frontal, may support Ossenberg’s suggestion (1970), the same explanation is not valid for the tabular group, affected only posteriorly, as well as for the compositely shaped crania that, although affected on the frontal, do not show any sign of metopism (Table 98). Based on these observations, metopism cannot be considered a diagnostic trait of the presence intentional headshaping in the Anatolian sample.

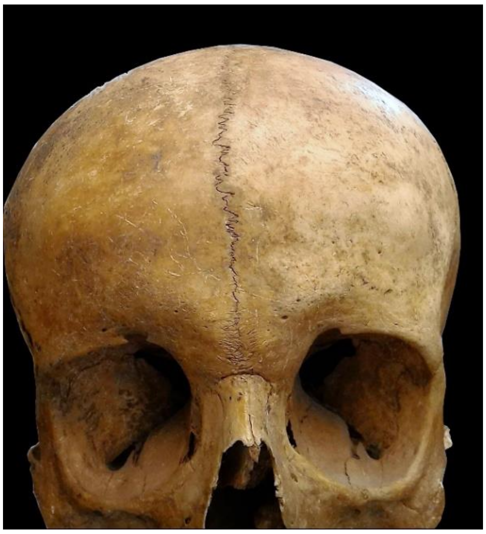


Figure 28. Total metopism in a tabularly shaped cranium of an adult female (SK21) from Erzurum

6.5. EFFECTS OF INTENTIONAL HEADSHAPING ON PATHOLOGICAL CONDITIONS

6.5.1. Porotic Hyperostosis

Compared to some studies that have investigated the relationship between intentional headshaping and some pathological conditions (Gadison, 2015; White, 2006; Langdon, 1989; Hilgeman, 1988), Anatolian research has never focused on this aspect of the topic. The result of the statistical analyses performed in the present study show that, Porotic Hyperostosis, in some cases accompanied by periosteal bony reaction (Figure 29), occurs in all the three different intentional headshaping types by reaching a higher and statistically significant frequency in composite (39,3%, *p*:0,000) and tabular (13,3%, *p*:0,018) headshaping (Table 100). Although without any statistical relevance, slight porotic hyperostosis is the most frequently observed by increasing in frequency with the increasing severity of the two headshaping types (tabular: from 84% to 100%) (composite: from 86,7% to 100%) (Table 101).

If we look at the previous investigations, similar results were reached by Hilgeman (1988), who found a statistically significant correlation between porotic hyperostosis and marked posterior and slight-to-severe anterior intentional headshaping in the skeletal material of the Mississippian Angel site, as well as by Gadison (2015), who also observed a causal connection with intentional headshaping of Chanka and Quichua Peruvian groups. Langdon (1989) instead, did not find any significant correlation with the shaped crania of Dallas society. Other studies have observed ectocranial lesions in relation with the presence of intentional headshaping. Stewart's (1976), who recognized the presence of supra-inionic depressions among some North and South American skeletal collections, stated that shaping pressures cause the necrosis of the scalp tissue even arriving to the bone involvement. Gerzstein (1993) observed the presence of bony necrosis at the point of the maximum pressure in intentionally posteriorly flattened crania. According to the same scholar (Gerzstein, 1993), necrosis was the result of the prevention of blood flow to the growing bone during infancy. Holliday (1993) suggested that pressures and frictions on infants' head placed against a cradleboard may have produced ischemic ulcers, bacterial infections or complicated the treatment of other infections appearing on the back of the scalp. Tiesler (2014) stated that subacute and chronic complications of intentional headshaping may appear in the form of ossified periosteal reactions on the external lamina of the cranial vault. According to the scholar (Tiesler 2014), some periosteal reactions may be caused by the application of more severe shaping forces, generally aligned with the sutures but not covering them, others instead may originate from the lack of blood circulation, air exposure or hygiene.

Based on the results of the present work and the comparison with the previous investigations, it is possible to suggest that cranial porosity and periosteal reaction are causally related with haemorrhages caused by severe shaping forces such those characterising the prolonged and continuous dorsal decubitus of the baby on a cradle both in tabular and composite headshaping. Although Porotic Hyperostosis cannot be considered discriminatory of the presence of intentional headshaping, its presence in some cranial areas leads us to investigate on the application of shaping force in those cranial regions.

Figure 29. Porotic Hyperostosis and periosteal reaction on a tabularly shaped cranium of a subadult individual (SK 64) from Oluz Höyük

6.5.2. Craniosynostosis

Craniosynostosis has been observed in a total of six examples, four of which with complete sagittal synostosis and five with premature closure of temporo-occipital sutures (four bilateral and one unilateral) (Figure 29). While one cranium presents only sagittal craniosynostosis, two examples have bilateral temporo-occipital craniosynostosis and three premature closures of both sagittal and temporo-occipital (two bilateral, one unilateral) sutures (Figure 29). The statistical analysis on the relationship between craniosynostosis and intentional headshaping of Anatolian skeletal material has not displayed any statistically significant correlation (Table 102). Conversely, if we look at the existing literature, White (1996) suggested a statistically meaningful relationship both in fronto-occipitally shaped and unmodified crania of Maya Lamanai population.

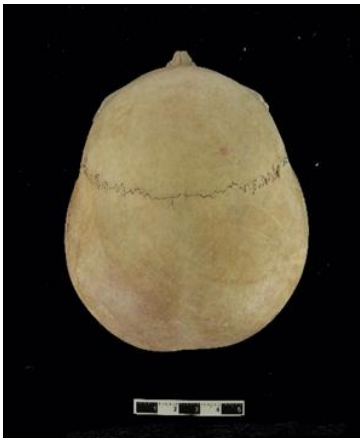


Figure 30. Sagittal and temporo-occipital (unilateral) craniosynostosis in an adult individual (S27) from Arslantepe

CONCLUSION

Intentional headshaping is a widespread cultural practice performed for several reasons (Erdal & D'Amico, 2021; Duncan & Hofling, 2011; Romero-Vargas, 2010; Tiesler & Oliva, 2010; Miller, 2009; P. Gerszten & E. Gerszten, 1995; Özbek, 1975; Blackwood & Danby, 1955; Hasluck, 1947; Dingwall, 1931) all over the world from very ancient times (Ni et al., 2020; Brown, 2010; Durband, 2008; Antón & Weinstein, 1999; Chech et al., 1999; Trinkaus, 1982; Brown, 1981) up to the present days (Field, 1948; Hasluck, 1947, Fitzsimmons, 1998; Dingwall, 1931). In Anatolia it represents a deeply rooted practice known at least from the Neolithic period up to the Byzantine one (Aytek et al., 2021, 2020; Eroğlu, 2016, 2015; Erdal, 2013a, 2011; Duyar & Atamtürk, 2010; Miyake, 2010; Özbek, 2001; Alpagut, 1986; Özbek 1984; Angel, 1976; Mellink & Angel, 1968; Şenyürek & Tunakan, 1951) and continued to be performed in the most recent times as well by traditional populations (Erdal & D'Amico, 2020; Lorentz, 2010; Özbek, 2001; Hasluck, 1947; Chantre, 1891).

Compared to the studies carried out in the rest of the world, investigating different aspects of this topic by applying several methodologies on well preserved adult samples as well as, in many cases, dealing with methodological issues aimed to quantitative discriminate between unmodified and shaped crania and between subtypes, Anatolian studies have focused exclusively on severe cases of circular headshaping by means of morphoscopic approaches.

In light of these considerations, the most important contribution provided by the present work may be summarized as follows:

1. Beyond the well-known circular oblique headshaping type performed by the application of two bandages, the present study has proved that tabular headshaping, in particular posterior cranial flattening intentionally performed by the long lasting swaddling of the baby on a cradle, together with the composite type, identified for the first time in the present study, represent other variants of intentional head modification in the Anatolian peninsula, where the practice is also attested beyond the Byzantine period up to the post Medieval Age. Although all the three headshaping types are observed in all the analysed chronological periods, circular

headshaping is most commonly encountered among the most ancient periods, while tabular and composite types characterize the most recent ones.

2. The present study has proposed an alternative method of analysis of intentional headshaping aimed to maximise the informative potentiality of the processed data even if in a large and fragmented sample. In fact, the statistical imputation of missing data as well as the morphological analysis of each cranial region and subregion has contributed to overcome the limitations implicit in the analysis of a not well-preserved sample.
3. For the first time, metric data of both adult and subadult individuals, these latter generally excluded because of their uncomplete cranial development, have been employed for the analysis of intentional headshaping by computing proportional metrics. Among measurements, asterion-bregma, pterion-lambda and asterion-pterion lengths, used for the first time in the present study, have contributed to shed light on the morphometric alterations of the cranial vault as well as to strengthen the results of the elaborated quantitative method of discrimination.
4. Proportional metrics, including cranial breadth/length, cranial height/length, cranial height/breadth, frontal breadth/length, frontal arc/chord, parietal arc/chord, pterion-lambda/asterion-bregma length, occipital breadth/length, occipital arc/chord, and obelion-inion arc/chord, have contributed to the improvement of a standardised quantitative method of analysis of intentional headshaping. In fact, despite the highly accurate (93%, 100%) discrimination between unmodified and shaped crania obtained by the statistical analyses of cranial measurements of adult males and females, proportional metrics, although with a slight lower percentage of accuracy (81%) compared to the previous studies, has allowed for the first time to discriminate between unmodified and shaped crania and between different headshaping types by using data belonging to individuals of both the sexes and of any age group. The elaboration of mathematical functions allows the application of the proposed method to any skull/cranium or sample to be analysed. The location into the territorial map of the resulting coordinates indicates the presence of intentional headshaping, its type and degree of severity. Moreover, proportional variables have provided a more objective graduation system of headshaping development by distinguishing moderate, severe, and very severe degrees for

circular headshaping; slight, moderate, and severe degrees for tabular headshaping; slight, moderate, severe, and very severe degrees for circular modification in composite headshaping, and slight, moderate, and severe degrees for the tabular one.

5. The results of the statistical analyses performed on proportional metrics suggest that circularly shaped crania decrease in width and height compared to their length. Frontal latero-medially narrows and develops in length as well as the occipital that also flattens. Parietals postero-superiorly elongate and obelion-inion region slightly bends. Tabularly and compositely shaped crania instead similarly develop by increasing in breadth and height (breadth more than height) compared to their length. Frontal develops in breadth rather than in length and flattens. Parietals antero-posteriorly narrow and curve, while obelion-inion region and occipital flatten.

   The statistical evaluation of morphological cranial alterations provides, for the first time, an objective definition of the diagnostic morphological alterations of each headshaping type. Frontal depression, flattening and bulging, post-coronal depression, bregmatic/post bregmatic bulging, parieto-temporal depression and bulging, bulging/prominence of parietal tubera, occipital inionic flattening and depression, pars squamosa depression and bulging as well as posterior movement of bregma and V-shaped conformation of the coronal suture are all diagnostic morphological alterations of circular headshaping. Lambdoidal and occipital pars squamosa flattening, prominence/bulging of parietal tubera, inionic bulging and obelionic flattening and postural plagiocephaly may all be considered diagnostic morphological alterations of tabular headshaping. Bulging/prominence of parietal tubera, lambdoid flattening, pars squamosa flattening and bulging, frontal bulging, depression and flattening, parieto-temporal bulging and depression, post bregmatic depression and bulging, bregmatic bulging, posterior movement of bregma and postural plagiocephaly instead are diagnostic morphological traits of composite headshaping.

6. For the first time the present study has statistically investigated the relationship between Anatolian intentional headshaping and non-metric cranial traits such as Wormian bones and metopism as well as pathological conditions such as

craniosynostosis and Porotic Hyperostosis. Any statistically significant relationship has not been observed with metopism. Although a statistically meaningful relationship has been recognized between the development of temporo-squamosal and lambdoid ossicles and circular headshaping, between asterionic and ossicles at lambda and tabular headshaping, and between ossicles at lambda and composite type, they cannot be accepted as diagnostic morphological trait of this cultural practice. Moreover, while any statistically significant relationship exists between craniosynostosis and intentional headshaping, the incidence of porotic hyperostosis in composite and tabular headshaping results statistically meaningful and thus should be considered in the morphological evaluation of these headshaping types.

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APPROVED.

Prof. Dr. Yılmaz Selim Erdal

APPENDIX 3: CRANIAL ANALYSIS FORM

FORM 1

SKELETON ANALYSIS FORM OF HUSBIO LAB BIOLOGICAL ANTROPOLOGY LABORATORY

SKELETON NUMBER:	CHRONOLOGY:
FINDING YEAR:	AGE:
SITE:	SEX:

AGE: ....

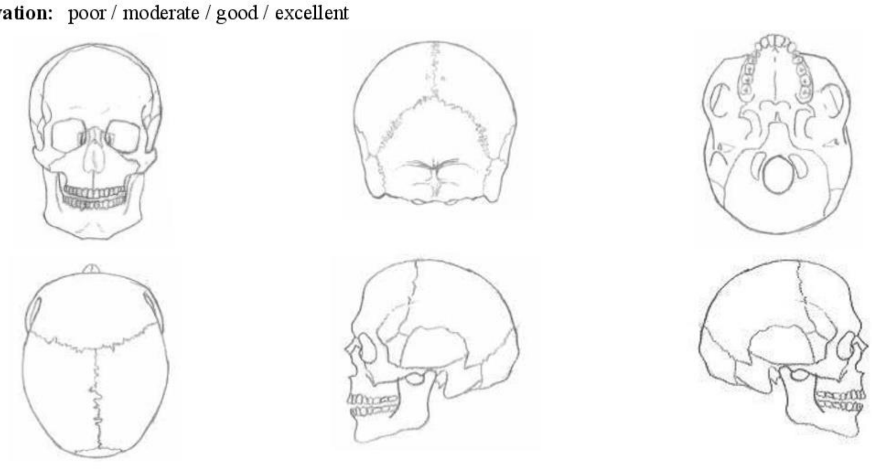
Costal:	Auricolar:	Other:
Symp. Pub (Tood):	Ep. fusion:	
Symp. Pub (S-B):	Teeth calcification:	
Ectocranial:	Postcranial bones size:	

FETUS	BABY (0-2,5)	CHILD (2,5-15)	YOUNG ADULT (15-30)	MIDDLE ADULT (30-45)	ELDER (45+)	UNCERTAIN

SEX: ....

Skull			
Crista nucale	M	F	U
Processus mastoideus	M	F	U
Tuber frontale	M	F	U
Trigonum mentale	M	F	U
Masseter muscles	M	F	U
Arcus superciliaris	M	F	U
Orbit shape	M	F	U
Orbital margin	M	F	U
Skull general appearence	M	F	U
Skeleton general appearence	M	F	U

Preservation: poor / moderate / good / excellent



Remarks

M=Male **F**=Female **U**=Undefined

FORM 2

MORPHOLOGICAL DATA

SKELETON NUMBER:	CHRONOLOGY:
FINDING YEAR:	AGE:
SITE:	SEX:

Modification presence ☐ Y ☐ N

Modification position			Type of modification	Degree of modification	Remarks
FRONTAL			☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
TEMPORAL			☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
PARIETAL	Bregmatic	☐ Bregm. ☐ Post-bregm.	☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
	Tuberial		☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
	Parieto-temporal		☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
	Posterior	☐ Lambdoid	☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
		☐ Obelionic	☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
OCCIPITAL	☐ Inion ☐ Pars squamosal		☐ Depression ☐ Flattening ☐ Bulging	☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS ☐ U ☐ A ☐ S ☐ M ☐ S ☐ VS	
Bregma posterior movement			☐ P ☐ A		
Coronal suture conformation			☐ straight ☐ slight V shaped ☐ severe V shaped		

TYPOLOGY	☐ Circular	☐ Fronto-posterior ☐ Coronal ☐ Post coronal	☐ Fronto-posterior-coronal ☐ Fronto- posterior -post coronal
	☐ Tabular	☐ Frontal	
		☐ Posterior	☐ Lambdoid ☐ Occipital ☐ Obelionic
		☐ Fronto-poster.	☐ Lambdoid ☐ Occipital ☐ Obelionic ☐ Bilobed

SUBTYPE	Inclinat.	Flatten. direct.	Flatten. position	
	☐ <100°	☐ Tangent	☐ Occipital	☐ Oblique
	☐ >100°	☐ Parallel	☐ Lambdoid	☐ Erect
APPARATUS				☐ Bandage ☐ Cradle ☐ Other …………………………….

Remarks

U=Unobserved A=Absent S=Slight M=Moderate S=Severe VS=Severe Y=Yes N=No

FORM 3

METRIC DATA

SKELETON NUMBER:	CHRONOLOGY:
FINDING YEAR:	AGE:
SITE:	SEX:

		MEASUREMENTS DESCRIPTION (mm)	VALUES	REMARKS
1	GOL	Maximum Cranial Length (G – Op)		
2	XPB	Maximum Cranial Breadth (Eu – Eu)		
3	BBH	Cranial Height (Ba – B)		
4	BNL	Cranial Base Length (Ba-N)		
5	XFB	Maximum frontal breadth at the coronal suture		
6	STB	Bistephanic breadth		
7		Minimum frontal breadth (ft-ft)		
8	AUB	Least exterior breadth across the roots of zygomatic processes (Au-Au)		
9	ASB	Biasterionic vault breadth (Ast-Ast)		
10	FAr	Frontal Arc		
11	PAr	Parietal Arc		
12	OcAr	Occipital Arc		
13		Ob-In arc		
14	FRC	Frontal cord		
15	FRS	Frontal subtense		
16	FRF	Nasion subtense fraction		
17	PAC	Parietal cord		
18	PAS	Parietal subtense		
19	PAF	Bregma subtense fraction		
20	OCC	Occipital cord		
21	OCS	Occipital subtense		
22	OCF	Lambda subtense fraction		
23		Ob-In cord		
24	FOL	Length of foramen magnum		
25	FOB	Breadth of foramen magnum		
26		Po-B height (right)		
27		Po-B height (left)		
28		Pt-L		
29		As-B		
30		As-Pt		

FORM 4

NON-METRIC DATA

SKELETON NUMBER: FINDING YEAR: SITE:	CHRONOLOGY: AGE: SEX:

TRAIT		P/A/U	Number	Size	Remarks
Epipteric Ossicles	**R**				
	L				
Coronal Ossicles	**R**				
	L				
Bregmatic Ossicles					
Parietal Notch Bone	**R**				
	L				
Temporo-squamosal	**R**				
	L				
Lambda Ossicles					
Inca					
Lambdoid Ossicles	**R**				
	L				
Asterionic Ossicles	**R**				
	L				
Occipito-Mastoid Ossicles	**R**				
	L				
Sagittal Ossicles					
Metopism	**A**	☐ Total			
	P	☐ Partial		☐ Frontal ☐ Parietal ☐ Fronto-parietal	

***P**=present **A**=absent **U**= unobserved

FORM 5

PATHOLOGICAL DATA

SKELETON NUMBER:	CHRONOLOGY:
FINDING YEAR:	AGE:
SITE:	SEX:

	P	A	U	Remarks		
MALFORMATION	☐	☐	☐			
				Degree	Activity	Remarks
HYPEROSTOSIS POROTICA	☐	☐	☐			
OCCIPITAL LESIONS	☐	☐	☐	☐ Asym	☐ Sym	☐Tab. Est. ☐Tab. Int.

		Region	Development	Remarks
CRANIOSYNOSTOSIS	P	☐ Sagittal	☐ Anterior ☐ Posterior ☐ Complete	
	A	☐ Coronal ☐ Lambdoid ☐ Metopic ☐ Temporo-occipital	☐ Unilateral ☐ Bilateral	
	U			

SYNOSTOTIC PLAGIOCEPHALY	POSTURAL PLAGIOCEPHALY	☐ Par./Occ.	☐ Occ.	☐ Lamb.
☐ Ipsilateral occipital flattening	☐ Asimmetric posterior flattening			
☐ Ipsilateral occipito-mastoid bulging	☐ Controlateral posterior parieto-occipital bossing			
☐ Controlateral Frontal Bossing	☐ Ipsilateral frontal bossing			
☐ Ipsilateral posterior aud. meatus displacement	☐ Ipsilateral anterior aud. meatus displacement			
☐ Controlateral posterior parieto-occipital bossing	☐ Asymmetric parietal tubera bulging			
☐ Bridge-shaped bony protrusion				
	Degree:			

***P**=Present **A**=Absent **U**=Undefined **L**=left **R**=right