An investigation of intentionally modified crania in Georgia and Europe in the Migration Period (4th – 7th c AD)

A thesis presented by

Peter Ronald Mayall

orcid.org/0000-0002-9714-6000

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An investigation of intentionally modified crania in Georgia and Europe in the Migration Period (4th – 7th c AD)

Abstract

This aim of this research is to examine the custom of intentional cranial modification in the Mtskheta region of Georgia during the Migration Period (4th – 7th c AD) by comparing it with that in Europe, particularly investigating the role of the Huns in intensifying the practice during this time. Thirty-two intentionally modified adult crania from Georgia were compared with thirty-one from Hungary, which included eleven juveniles, thirteen adult crania from Germany, two from the Czech Republic, one from Austria and one from Crimea. The control group comprised nineteen non-modified adult crania from worldwide collections in the department of Anatomy at the University of Melbourne. Geometric morphometric techniques were used to provide a quantitative comparison of the modified cranial shape. There were four main areas of study commencing in Georgia, moving to Hungary and then to other European sites.

1. The analysis of modified crania in Mtskheta, Georgia revealed a proliferation of the practice corresponding to the European Migration Period. The predominance of females and absence of juveniles indicated that cranial modification was not an indigenous practice but occurred due to migration.

2. To investigate the presence or influence of the Huns in the practice of cranial modification in Georgia, eigenshape analysis was used to compare modified cranial shape outlines in Georgia with Hungary, the centre of Hunnic administration and cultural influence, with modern non-modified crania for comparison. Firstly, this method could distinguish between modified and non-modified crania and secondly found that the shape of the Georgian modified crania differed significantly from those in Hungary. The Georgian crania had considerable variation in shape whereas those
from Hungary revealed great homogeneity. These findings suggested that Huns were not directly involved in the practice of cranial modification in Georgia.

3. Juvenile modified crania were common in Hungary, which confirmed that the practice was indigenous in this region and provided the impetus for a three-dimensional analysis to compare juvenile and adult modified cranial surface in Georgia and Hungary. This demonstrated that the Hungarian crania had been modified by two bindings distinguishing them from the Georgian crania which were modified with single or double bindings and thus showed greater variation. This confirmed the hypothesis that the Huns used this specific technique of cranial modification to differentiate individuals within their area of dominance.

4. Three-dimensional surface analysis of modified crania was extended to Crimea, Czech Republic, Austria and Germany. Principal component and discriminant function analyses indicated that the modified crania from these sites did not strictly conform to the Hungarian double binding form, but showed increased variation as in Georgia, indicating that there were multiple conflicting social influences in pursuing the practice of intentional cranial modification among nomadic groups in the Migration Period of Europe.

Quantitative shape analysis of three dimensional images revealed regional differences in cranial morphology and demonstrated the importance of the practice in promoting social identity. This provided an understanding of the cultural interactions taking place during this period of intense social change in Europe.
Declaration

This thesis comprises my original work towards the Doctor of Philosophy except where indicated in the preface.

Due acknowledgement has been made in the text to all other material used.

The thesis is fewer than the maximum word limit in length exclusive of tables, maps, bibliographies and appendices.

Peter Ronald Mayall

August 2018
Preface

The research on which thesis is based is contained in the four articles in Chapters 3 – 6.

**CHAPTER 3: Intentionally modified crania at Samtavro**


**CHAPTER 4: Migrating Huns and modified heads: Eigenshape analysis comparing intentionally modified crania from Hungary and Georgia in the Migration Period of Europe**


**CHAPTER 5: Generalized Procrustes analysis of an ontogenetic series of modified crania: Evaluating the technique of modification in the Migration Period of Europe (4th–7th century AD)**


**CHAPTER 6: A review of the practice of intentional cranial modification in Eurasia during the Migration Period (4th – 7th c AD)**

(submitted: Journal of Archaeological Science).

The co-authors of the articles, which are presented in Chapters 4, 5 and 6, are detailed in the co-author authorization forms together with the publication details and the student contribution which in each case was greater than 50%.

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Chapter 1
Introduction
Aims and scope

My aim is to examine the custom of intentional cranial modification in Georgia during the Migration Period (4–7th c AD) by comparing this with the practice in Europe, particularly examining the role of the Huns in intensifying the practice during this time. This study involves using quantitative shape analysis to study the modified cranial shapes. The archaeological context and issues of body modification and social identity are included to provide an understanding of the cultural interactions associated with cranial modification during this period of intense social change.

Format of thesis

Chapter one outlines the background of the practice of intentional cranial modification in Eurasia, reviews the relevant literature, examines the concept of social identity with respect to body modification and presents an overview of the archaeological context of the crania analysed in this study. Details of the materials and methods employed in the analyses are presented in chapter two. Chapter three documents the intentionally modified crania recovered at Samtavro, Georgia. The morphology of modified crania from Georgia are compared with those from Hungary in chapter four, examining the role of the Huns in propagating the practice in that region. Chapter five analyses adult and juvenile crania from Hungary to confirm their unique morphology and their use by the Huns as a form of social identification. Chapter six includes modified crania from Bavaria in the analyses comparing their morphology and archaeological context with those from Georgia and Hungary. The accounts of cranial modification in Eurasia, dating back to the Bronze age and an examination of specimens from Georgia from this period were examined to complete the record of the practice in these regions. Chapter 7 provides a discussion of the results of this study and the final thesis conclusions.
Background to Cranial Modification

Intentional cranial modification results from the application of external pressure by bindings and other devices to the infant skull to produce a permanent alteration in shape (Fig. 1). It is commenced soon after birth when the infant skull is malleable. The post-natal expansion of the cranial vault is related to the growth of the brain. With ossification occurring at the osteogenic layer at the margins of the bones, expansion of the vault occurs as additional bone is laid down with the growth of the brain. Intentional cranial modification redirects these physiological responses, causing vault expansion to occur perpendicular to the direction of the pressure applied (Tubbs, 2006). The head binding is continued for three to four years while the skull bones are soft. The shape of the cranial vault then gets fixed as the sutures become interlocked producing a permanent alteration in shape.

![Figure 1. Modified infant skull demonstrates the expansion of the parietal bone and the overlapping of the frontal over the parietal bone at the coronal suture (Natural History Museum, Brno).](image)

Plagiocephaly (distortion of cranial shape) found in skeletal remains can result from causes other than intentional cranial modification (Table 1). Many of these can be distinguished from intentional modification because they are asymmetrical. Endocrine and nutritional conditions have other associated skeletal findings. Craniostenosis usually affects a single suture but this can be difficult to distinguish as unintentional modification as craniostenosis can be secondary to cranial modification (O'Loughlin, 1996). Intentional modification is indicated by evidence of external pressure with impressions of bindings, depressed areas from pads and a generally
symmetrical cranial form. Cradle deformation, resulting from infants being bound to cradle boards with straps for prolonged periods producing flattening of the occipital region, is commonly found in Eurasian crania (Torres-Rouff and Yablonsky, 2005) and also Peruvian crania (Pomeroy et al., 2009). This type of modification is generally considered to be non-intentional although it may be a social custom in some communities and therefore be regarded as an intentional practice (Torres-Rouff and Yablonsky, 2011).

**Table 1. Unintentional Cranial Modification**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ante mortem</td>
<td></td>
</tr>
<tr>
<td>Endocrine</td>
<td>Acromegaly</td>
</tr>
<tr>
<td>Nutritional</td>
<td>Vitamin D Deficiency</td>
</tr>
<tr>
<td>Genetic diversity</td>
<td>Dolichocephalic population</td>
</tr>
<tr>
<td>Cultural practices</td>
<td>Sleeping position</td>
</tr>
<tr>
<td>Cultural practices</td>
<td>Cradle board</td>
</tr>
<tr>
<td>Occupational</td>
<td>Headband used for carrying</td>
</tr>
<tr>
<td>Craniostenosis</td>
<td>Premature closure of sutures</td>
</tr>
<tr>
<td>Post mortem</td>
<td></td>
</tr>
<tr>
<td>Mechanical pressure</td>
<td></td>
</tr>
<tr>
<td>Chemical decomposition</td>
<td></td>
</tr>
<tr>
<td>Faulty reconstruction of crania</td>
<td></td>
</tr>
</tbody>
</table>

**Classification of Intentionally Modified Crania**

Due to a variation in cultural practices, modified crania from different continents may show unique characteristics; however, a universal classification is useful for comparative purposes (Pomeroy et al., 2009). The classification may be based on various parameters. Dingwall (1931) used the technique for shaping the skull to separate the different forms. These include molding the head by massage, the
application of boards, bandages, pads or stones to the head, and the use of a cradle-board. Zhirchov (1940) developed a system for Eurasian skulls based on morphological characteristics. He recognised occipital, coronal-occipital, occipital-parietal and circular variants. Dembo and Imbelloni, (1938) established a classification for crania from the American continent which has been the basis of the system developed by Tiesler (2012) for the Mayan population and is now used more widely. The classification commences with the two main varieties of annular (circular) and tabular (produced by flat pads) forms. These are subdivided into erect and oblique forms depending on the net angle of the posterior surface in relation to the Frankfort horizontal plane – the eye-ear plane, which is the standard for orienting the human skull. Further divisions can then be made into mild, moderate or severe forms relative to the duration and degree of the pressure involved. Examples of the various types in this classification are shown in Figure 2. This is a visual classification, which is a spectrum of shapes from those with barely discernible changes through to mild and severely modified crania.

![Figure 2. Classification of Intentionally modified crania (adapted from Tiesler, 2012)](image-url)
Morphological changes

Cranial modification not only affects the cranial vault but also the base of the skull and the facial structure. These effects vary with the type of modification. These were studied with South American skulls by Cocilovo et al. (2011) and Pomeroy et al. (2009) by metric analysis of Peruvian skulls and by Anton (1989) using lateral X-rays, also with Peruvian skulls. Torres-Rouff and Yablonsky (2005) found the antero-posterior forms in Eurasia with their erect and oblique variants to be very similar to those from South America. The annular form is represented in both continents (Pomeroy et al., 2009; Torres-Rouff and Yablonsky, 2005).

Annular (Circular) modification

In the annular form of modification, the cranium is encircled with one or more strips of material from the occiput to the frontal bone (Fig. 3). This causes a flattening of the frontal bone with a transverse depression following the path of the binding that continues over the temporal bones posteriorly to the region of the lambda. A second groove posterior to the coronal suture may indicate another binding which is likely to produce an oblique modification. This groove can also result from antero-posterior compression causing abnormal growth at the coronal suture when the compression is close to the suture after closure of the bregma (Tiesler, 2013). The encircling of the vault results in a narrowing of the skull beneath the binding, with a compensatory expansion superiorly. The frontal, squamous temporal, parietal and occipital bones are elongated with the superior parts of the parietal and occipitals extended postero-superiorly. The postero-superior changes in the vault also narrow the base of the skull and lengthen the foramen magnum. This also results in most facial measurements being narrower. The orbital height is increased with the movement of the vault in the postero-superior direction (Anton, 1989). A further sub-type, known as pseudo-annular, is also included in this category. In this group pads are inserted into the encircling bandages anteriorly and posteriorly to accentuate flattening in these regions (Cocilovo et al. 2011).
Tabular (Antero-posterior) modification

The tabular group are flattened in the antero-posterior planes of the frontal and occipital bones due to flat pads being bound to the skull over these bones. The temporal and parietal bones become shorter with compensatory expansion of the parietal bones laterally and to a lesser extent in the frontal region (Pomeroy et al. 2009). This results in the face, including the orbits, becoming broader compared to unmodified skulls. The cranial base and the foramen magnum are similarly affected (Anton, 1989; Cheverud et al., 1992). Other morphological changes are often seen in tabular form. The more severe degree of modification results in the bifid (or bilobed) form. This has a more significantly shortened vault and increased width with expansion of the parietals due to the pressure applied posteriorly (Fig. 4). Premature closure of the sagittal suture was also noted by White (1996) exacerbating this form of modification. These severe examples also reveal the effect of pressure on the skull produced by firm posterior pads with depressions present bilaterally in the parietal and occipital regions (Fig. 5).
Pathophysiology

The pathological effects of intentional cranial modification have been examined by Gertszen, (1993) studying a pre-Columbian population in Northern Chile. He found an increase in Wormian bones, evidence of occipital necrosis and premature closure of sutures. Wormian bones were also present in other cranial sutures which are not normally affected in unmodified skulls (Fig. 6). White (1996) found premature closure of the sagittal suture in modified Mayan crania which he suggested was due to an increase in fibrosis as a response to the tensile forces in the suture from the modifying process. Premature sutural fusion also occurs in treated hydrocephalus due to pressure on the cranial vault (Lekovic et al., 2007). The increase of Wormian bones (sutural ossicles) associated with intentionally modified crania has been confirmed by White (1996), Gottlieb (1978) and O’Loughlin (2004). These particularly occur in the lambdoid suture, related to the posterior fontanelle and probably caused by the increased dural strain and sutural width resulting from the mechanical stress due to the cranial modification process (Bellary et al, 2013). As well as the suture being broader there is increased complexity and convolution with additional interdigitation at sutural margins (Gottlieb, 1978). Anton et al., 1992 suggest that the coronal and lambda sutures are under greater tension particularly in the annular form of cranial modification resulting in greater sutural complexity.

Gertszen (1993) found that the cranial capacity of modified skulls was not altered, and thus concluded that neurological function was normal in such individuals. It has been assumed that if the practice of artificial cranial deformation had serious consequences for the individuals involved, particularly in childhood, it would not have continued (Gertszen, 1993). Enchev
(2010) also suggested that the survival of elderly people with modified skulls mitigated against significant neurological damage causing premature death or neurological impairment. He studied Proto-Bulgarian adult skulls and found no evidence of raised intracranial pressure on CT scans. It must be presumed that the intracranial pressure would be raised in children undergoing the modification process due to the external pressure placed on the cranium while brain and cranial vault expansion is also taking place. This is supported by the findings of O’Loughlin (1996) who found that cranial modification affected the shape and size of the sinuses in the endocranial vasculature. This was thought to be due to localised areas of increased pressure on these vessels.

Non-metric cranial traits are only minimally affected by cranial modification. Those which are genetically based and established prenatally are not affected. Only those close to areas of major alteration in growth or finish their development after birth may be altered (Del Papa and Perez, 2007; Gottlieb, 1978). These include Wormian bones. The changes are not sufficient to negate the use of cranial traits in population studies (Konigsberg et al., 1993).

The pressure of boards used to produce flattening of the occipital region could also affect the blood supply to this area resulting in necrosis in the underlying bone (Gertszen, 1993) (Fig. 7). Skin infections and infestation with lice leading to skin ulcers were additional problems encountered beneath bindings (Tubbs, 2006).

Figure 6. Modified Cranium with complex lambdoid suture with Wormian bones (Specimen 364)
Intentional cranial modification, body image and body modification.

The practice of intentional cranial modification may be understood within the context of other types of body modification and body image. Humans frequently make changes to their bodies to construct an alternate body image in order to distinguish themselves from others, conform to social trends or cultural styles, ascribe themselves to elite groups or provide themselves with a particular social identity. The modifications of their appearance take many forms, including differences in dress and jewelry, as well as tattoos, piercings, scarification, genital mutilation, foot binding, finger amputation and cranial modification, as well as dental avulsion, filing or drilling. All these forms of body modification alter an individual’s image and define how others perceive them (Lorentz, 2015). These changes may be simply regarded as aesthetic but are often of more significance as part of a multifaceted social identity which is created to emphasize the differences to individuals in similar populations (Torres -Rouff and Yablonsky, 2005).

The permanent forms of body modification are often associated with the ascription of a social identity or ethnicity enabling entrance to an elite group or status within a society. An individual may have been born into a particular ethnic group and therefore have no choice in the matter of their social identity; otherwise, the situation regarding entry being allowed or denied...
depends on their social, political and economic circumstances or the influence of a dominating group (Halsall, 2007). An individual’s social identity is therefore adaptable, determined by their social relationships and associated social boundaries and constructed as a form of social mobilization to reach their political goals (Zakrzewski, 2011). Barth (1998) emphasized the social boundaries which define ethnic groups, which may correspond to geographical boundaries. They may include many ethnic groups dominated by one group and include considerable cultural diversity with inherent advantages, such as monetary compensation as well as the enhanced reputation and status of the assimilating group or their leader (Barth, 1998).

The permanent forms of body modification used to construct social identities, involving the teeth and the skeleton recoverable for archaeological analyses, often enable the identification of distinct social groups. Below the practices of foot binding, dental modification and cranial modification are examined with respect to their roles in constructing social identities.

In China, from the 10th to the early 20th century, foot binding was practiced as a symbol of beauty and status, as women with bound feet were not needed for work. It began at the age of 5 to 7 years, when the bones were still flexible and the girls were considered old enough to understand the necessity of undergoing the procedure, which involved severe and protracted pain. It continued until the age of thirteen to fifteen years. The mothers constantly repeated that this was necessary in order to marry into a good family (Blake, 1994). Blake (1994) described foot-binding as an act of self-mutilation, creating a feminine mystique which defined the identity of those women and made them appear more sensual.

Dental modification has been a widespread method of altering body image and practiced particularly in Africa, Central and South America, the Philippines and Malaysia, with each continent having distinctive forms (Alt and Pichler, 1998). There were several methods used including dental inlays with jade, pyrite or gold, filing to reshape incisors, and dental avulsion, which was often associated with initiation rites (Mower, 1999). Williams and White (2006) described dental modification with the Maya which involved filing and inlays. There was no gender bias in the incidence of dental modification, but the actual type of modification was
different in males and females and was only found in high status burials. Dental modification was done at an age where consent was feasible although the practice was dictated by custom and associated with status as well as perceived as an aesthetic attribute.

Intentional cranial modification is a permanent and highly visible form of body modification (Fig. 8). It has been present in every continent spanning thousands of years and used to assign group affiliation, status within a tribe and also religious or aesthetic purposes. Tiesler (2014) describes regional differences in cranial modification in the classical period of Mayan culture. In the southern mountain region of the Mayan territory the erect type was common but in the lowlands in the north there was a wide range of styles broad and narrow, elongated and short. The forms which were most frequent were also seen in the representations of their gods. Blom (2005) investigated the Tiwanaku society in the Southern Andes from 500–1100 AD and their practice of intentional cranial modification. Regional differences were noted with the fronto-occipital type of modification predominant in the southwest on the coast whereas the annular type was used in the northeast on the eastern slopes of the Andes. It demonstrated that cranial modification was one of the signs of ethnic differentiation together with other indicators related to dress, language and life-style. First hand reports of cranial modification from this region are available from the Spaniards of the 16th century. From their observations, it was evident that the method of modification was group specific, but also related to status (Hoshower et al., 1995). Intentional cranial modification persisted in parts of Europe and particularly in France from the 14th to the 19th century (Dingwall, 1931). It was produced by bandages or tight-fitting caps and was said to encourage those parts of the brain associated with memory and intelligence but was also considered to enhance beauty.

These examples of changing body images resulting from permanent forms of body modification give some insight into the motivations associated with these customs. In all cases, the helped to define an individual’s social identity but often also ethnicity, group identity, status and social boundaries, as well as local customs and styles.
The Geographic and Temporal Distribution of Intentionally Modified Crania.

The phenomenon of intentional cranial modification spanned every continent and existed for over ten millennia. The widespread occurrence, both geographically and temporally, suggests that it was a spontaneous phenomenon with multiple independent origins. Geographically this included North and South America, the Pacific islands, Australia, South East Asia, China, India, North Africa and the Near East. Examples from all these areas were described by Dingwall in his 1931 text “Artificial Cranial Deformation; A contribution to the Study of Ethnic Mutilation”. In Europe the practice of intentional cranial modification extended from the Caucasus, Southern Russia and Eastern Europe reaching to the west as far as France. Kiszely (1978) provides an extensive catalogue in Eurasia of the geographic regions where modified crania have been found. The oldest confirmed examples of modified crania are from Australian terminal Pleistocene hunter-gatherer aboriginal populations at Kow Swamp and Coobool Creek in Northern Victoria which are carbon-dated at 11,000 BC (Brown, 1981). The crania were re-examined recently by Clark et al. (2007) and Durband (2008) confirming that the crania had been intentionally modified.

There is also evidence for this practice on the American continent. Cranial modification has been found throughout the length of the American continent extending from the Andes and west coast of South America, through Central America, the west coast of the United States to the north-west of Canada. The frequency of this practice in South America is demonstrated by large collections of crania often having more than 50 per cent with some form of modification (Rhode and Arriaza, 2006). The earliest modified skull comes from the early food producing period found in a cave in the Peruvian Andes and dated at 6000 – 7000 BC (Schijman, 2005). Africa has evidence of cranial modification involving Ethiopia, Algeria and Tunisia and particularly in Sub-Saharan regions of Nigeria, the Congo and Cameroon. In Ethiopia, an intentionally modified skull is believed to date from 8000 - 6000 BC (Kiszely, 1978). In some areas of Africa this practice has continued until recent times (Gertszen and Gertszen, 1995).

The only evidence of cranial modification in ancient Egypt is from the 18th dynasty during the 14th century BC. The skull believed to be that of Akhenaten appears to be intentionally (or
pathologically) modified and representations of Nefertiti and Akhenaten’s daughters also portray them with elongated crania suggesting artificial modification. There are portraits which depict subjects with elongated crania but no other examples of intentionally modified Egyptian skulls have been confirmed (Dingwall, 1931).

The first finds in the Near East were on the eastern Mediterranean coast and it is apparent that the practice had become widespread by the Neolithic Age (Kiszely, 1978). Many examples have been recovered from this region dating from the 9th to the 1st millennium BC. These included specimens from the Shanidar cave, 400 km north of Baghdad having carbon dating of 8650 BC (Solecki 1963, 1972). Examples from Ganj Darah Tepe, Iran, were dated at late 8th to early 6th century BC (Lambert 1979), Bouqas, Syria, ca. 6500 to 3500 BC, (Meiklejohn et al., 1992), Jericho, Palestine, 7th–6th millennium BC (Ferembach, 1985) and Khirokitia, Cyprus, from the 6th millennium (Angel, 1953) and Eridu, Iraq, which were dated at 4500–3500 BC, pre-dating the Sumerian culture (Kiszely, 1978). Most of these appeared to have been altered by encircling bandages. Ozbek (2001) reported a unique series of subadult remains with features of cranial deformation dated to the second half of the 5th millennium BC at Degirmentepe, Turkey, near the Euphrates River. In France modified skulls from the Neolithic period were found at Guiry–en–Vexin located in the north in the Ile–de–France region (Menard, 1977) and at Aveyron in the south of France (Baudouin, 1911). Modified crania were recovered from the Pacific coast of Southern Russia, at Promorye, dated to 5th–6th millennia BC, (Chikisheva and Shipkova, 1997, Shvedchikova, 2009). Several modified skulls dated to 2,000 BC have been found in Italy coming from the Neolithic Gaudo culture in the region of Campania (Kiszely, 1978).

During the Bronze Age (3000 - 1000 BC) cranial modification appeared in the Eurasian steppes of Southern Russia including Crimea and Southern Turkmenistan (Torres-Rouff and Yablonsky, 2005). Cranial modification in this area was first recorded by Zirchov (1940). They were not seen again in this area until the early Iron Age (700 - 500 BC) and appeared to have arisen spontaneously at these times (Torres-Rouff and Yablonsky 2005). Skulls recovered from Eastern Ukraine with fronto–occipital form of modification were dated at 450 – 500 AD (Arnold et al., 2008).
Many examples have been found on the north and east coast of the Black sea, the Crimea and Caucasus, particularly at sites around Kirsch and Tbilisi. Examples from Kirsch showed a marked form of modification produced by bandages encircled in a tight ring. Kiszely (1978) identified over 100 modified crania from the Crimea with a similar number from the Caucasus, including over 30 from the Samtavro/Mtskheta region dating from the 6th century BC to the 6th century AD. The skulls from Samtavro, Georgia, showed similar modifications to those from the Crimea but exhibited a greater degree of variation (Dingwall, 1931). Skulls which had been modified by the use of circular bandages excavated in the north Caucasus have been dated to the 12th to the 10th centuries BC (Field, 1953; Kiszely, 1978). Archaeological records have revealed modified crania from western Georgia dated at 3000 BC. References by Greek and Roman authors have confirmed their knowledge of this practice during the classical period in Europe. The region of the Caucasus was said to be inhabited by people known by names such as macrocephali which were recorded by Herodotus in the 5th century BC (ii. 104, vii. 78), Hippocrates, 4th century BC (2, Sect 14,207), Strabo, 1st century BC (XI, XI,8), and Pliny the younger in the 1st century AD (VI,4, vol 1,218). Artificial skull modification has been noted in Armenia in several sites in the north of that country dating from the 1st century BC to 3rd century AD produced by the techniques resembling those in the Caucasus (Khudaverdyan, 2011).

West of the Eurasian steppes, in the Carpathian basin, two skeletons with modified skulls were recovered from Bronze Age cemeteries near Budapest (Kiszely,1978) but large numbers occur in late Roman and early medieval sites in Eastern Europe, Romania and Hungary dating from the 2nd and 3rd centuries AD and are often associated with Roman forts and settlements. Gepids, who were originally from Eastern Germany, but by the 5th – 6th centuries were located in Danubian basin in the region of the Hungary, developed a tradition of skull modification (Fothi 2000). Bartucz (1936) was first to describe the techniques they had used to produce the antero-posterior form of alteration of the crania, which he believed they derived from the Huns, utilising two bandages from the frontal region to the occiput and from the dome of the skull to the chin. Modified skulls found in Bulgaria dating from the 4th to the 11th centuries were mainly located in the Black sea region, including a skull from a 4th– 6th century Christian burial (Enchev, 2010).
In Lower Austria and Moravia, in the Danube River basin, modified crania were present dating from the first half of the 5th century. The modified skull of a child aged 3–4 years from Lower Austria was found in a pit carved in a rock with radiocarbon dating of 380–440 AD. This was one of 19 artificially modified skulls found in Austria, all dating to the Migration Period, many occurring along river valleys (Pany and Wiltschke-Schrotta, 2008).

Further to the west in Bavaria, Bohemia, central Germany, the Rhine valley and southern France, Slovenia and Italy modified crania date from the second half of the 5th century and the first half of the 6th century. They are not as prevalent as those in the east and do not include any subadults have a large proportion of much of women (Hakenbeck, 2009).

The examples of skull modification described in Eurasia indicate the presence of this practice during the Neolithic period extending from Northern Africa to the east coast of Russia, the Caucasus, the Near East then as far west as northern France. In the Bronze-Age it was present in the Eurasian steppes, the Caucasus, the Carpathian basin, Northern Italy and possibly Egypt. From the late Iron Age to the early classical period the practice was common in Southern Russia and particularly around the north and east coast of the Black Sea as well as the Danube basin. During the later Roman and Early Medieval periods, it extended across Eastern Europe to the Rhine Valley, Italy and France.

Kiszely (1978) suggested that the cranial modification originated during the Neolithic period in Northern Africa, spreading to the Near East and Europe. Werner (1956) attributed the spread across Europe to the invasions across the Roman provinces by the Huns and subsequently by migrations of other nomadic tribes into these regions following the collapse of the Western Roman Empire.

This Study

This examination of the incidence of intentional cranial modification and its role in promoting social identity suggests that the practice was present in Eurasia since the Neolithic times, but it took on special significance during the Migration Period. This period coincides with the fall of the Western Roman Empire and the westward expansion of the Huns. Kiszely’s (1978) monograph, which was consistent with the findings of Dingwall (1931), revealed that the bulk
of the 260 locations containing modified skulls in Eurasia extended from Western Siberia and Central Asia, around the Caspian Sea, Caucasus, Ukraine and Crimea, Carpathian basin and Southern Austria and Moravia with the remaining 61 sites distributed to the west across Europe. It also indicates that, where dates have been recorded, most belong to the 2nd century BC to the 5th century AD and particularly from the Migration Period. Because of the prevalence of modified skulls in Europe during this period some authors have attributed it to the Huns as they moved from the Russian steppes to the East causing mass movements of the populations ahead of them (Werner, 1956, Nemeskéri, 1952). The evidence for the association of the Huns with the practice of intentional cranial modification in Europe has been speculative because the Huns left no written records or any other evidence to confirm this. Graves which can be definitely recognised as being Hunnic, by the nature of their grave assemblages, which include the remains of weapons such as the reflex bow, three-edged arrows, swords and weapon belts as well as horse harnesses, wooden saddles and belt and boot buckles are very rare, not only in Pannonia, but also in the Northern Black Sea region (Heather, 2009). The presence of intentional modified crania associated with these graves has not been recorded. This study has been undertaken to try to provide objective evidence as to the significance of the practice of intentional cranial modification in Europe during the migration period and the role of the Huns in its proliferation. Intentionally modified crania have been extensively studied in South America (Dembo and Imbelloni, 1938; Torres-Rouff, 2002; Blom, 2005; Tiesler, 2014) but this has not been the case in Europe.

In the past the assessment of cranial modification has been largely subjective based on visual inspection or linear measurements without being able to statistically analyse shape differences. By comparison this study aims to provide an objective, quantitative analysis of the shape of modified crania which can be interpreted to indicate regional, local and cultural differences including the relative incidences within each area, cultural systems within societies and migration patterns as well as the role of the Huns in propagating the practice in Europe. The study has its origins in Georgia, particularly the burial grounds at Samtavro and nearby regions, as these have been the subject of numerous investigations with a great deal of information regarding the practice of cranial modification able to be obtained and evaluated. My focus
then moves to the Carpathian basin, particularly relating to the European Migration period, as this was the time of a great expansion of the practice in this region with Hungary being central to this. It is then extended west to Austria, the Czech Republic and Bavaria. Contextual information regarding the historical and cultural background of Georgia and Europe at the time of the Migration Period in relative to the practice of intentional cranial modification is initially considered as a background to this study.

The historical and cultural background of Samtavro, Georgia

The period between the Classical Roman and the Early Medieval epochs, from the fourth to the seventh centuries CE, contemporary with the European Migration Period, is well represented in the burial ground at Samtavro. It covers over twenty hectares with tombs dating from the Bronze Age to the Early Medieval period (Sagona et al, 2010a). Samtavro lies on the northern border of Mtskheta, the former capital, a small town approximately 20km. from the present capital of the Republic of Georgia, Tbilisi. Mtskheta also had an elite burial ground on the right bank of the Kura River at Armaziskhevi. In the time period under consideration, the 4th–7th centuries AD, eastern Georgia was known as Iberia, then Kartli by the Georgians. Western Georgia was formerly Colchis, until late Roman times then Lazica and later Egrisi (Rapp, 2009). The regions of Colchis and Iberia were geographically separated by the Surami Massif which divides the country. This encouraged Colchis in the west to be orientated to the Black Sea and towards the Romans whereas Iberia in the east was orientated towards the Persians (Braund, 1994). The Caucasus Mountains forms a natural barrier to the north, but is divided by passes, most notably the Dariel Pass. Mtskheta lies at the junction between two rivers, the Kura, coming from the Anatolian highlands in the east and the Aragvi flowing from the Caucasus Mountains to the north. These were the principal riverine routes of Iberia. Mtskheta was therefore strategically placed to be the capital of Georgia until the 6th century when it was moved to Tbilisi.

In the 4th century the establishment of Constantinople as the capital of the Eastern Roman Empire made Colchis and Iberia even more important in maintaining the eastern border against attacks by the Sassanian Persians in the south as well as raids from the Scythians, Sarmatians
and Alans in the north and west (Braund, 1994). There are other references to the Alans and Sarmatians in Georgia and in the region of Mtskheta, as allies in strengthening the reign of Iberian rulers (Alemany, 2000; Gagoshidze, 2008).

After the 3rd century Iberia maintained its connections with Rome but still continued its alliance with the Persians. The establishment of Christianity in Rome and its acceptance in Iberia in the 4th century following a series of miracles culminated in the conversion of the Iberian king. This was advantageous to the Iberian state as it strengthened the alliance with Rome and enabled the Iberian kings to deal with the pagan priesthood who had acquired great wealth (Suny, 1994). Mtskheta became the centre of Christianity in Iberia which developed its own character incorporating pagan iconography, such as the bulls’ heads in the Svetitskhoveli Cathedral in Mtskheta and the cedar tree which is the “living pillar” supporting the church (Braund, 1994). Late in the 4th century the Romans abandoned Iberia, after their defeat at Adrianople by the barbarians in 378, leaving it under the control of the Persians (Maenchen-Helfen, 1973, Suny, 1994). During this period Christianity continued to have a strong following in Iberia together with Zoroastrianism (Braund, 1994). From the 5th century Persian control of Georgia was resisted by the Iberians mainly because of the suppression of Christianity and the establishment of Zoroastrianism (Braund, 1994). The opposition to Persia was intensified when Vakhtang Gorgasali became king c.449 AD. He moved the capital from Mtskheta to Tbilisi and shifted the allegiance of Iberia from Persia back to the Byzantium Empire (Braund, 1994). In spite of this Iberia continued its strong cultural and social orientation towards Persia and practiced a localised form of Zoroastrianism.

The history of Georgia during this era, contemporary with the European Migration Period, was thus marked by alternating alliances with Rome and Persia but the two cultures were not mutually exclusive (Rapp, 2009). The many styles of graves at the burial ground at Samtavro, on the outskirts of the ancient capital, Mtskheta (Fig. 8), reflect these varied and overlapping cultures with Roman paganism, Christianity and Persian Zoroastrianism (Mitchell, 2015).

The importance of the burial ground at Samtavro as a cultural reference for this region has seen numerous excavations at this ancient burial ground. These began with Bayern (1871–1878)...
then Vlasenkos and Kalandaze (1938–61), Apakidze (1976–86, 2000, 2002) and the most recent in 2008-2010 by the Georgian-Australian Investigations in Archaeology, a collaborative project by the Georgian National Museum (Lordkipanidze) and the University of Melbourne (Sagona). It covers twenty hectares with 4400 documented tombs (Sagona et al., 2017). Fifty-three tombs were investigated (Sagona et al., 2010a). Many contained the remains of multiple individuals. These excavations have recovered numerous intentionally modified crania.

Four types of tombs relating to the late antiquity period were recognised.

1. Stone cist tombs with the walls composed of large sandstone slabs with another three slabs providing the roof with a moveable smaller central capstone suggests that re-entry was a planned event possibly associated with some ritual. Many of these tombs contained the commingled remains of multiple individuals which were often disarticulated and incomplete as a result of secondary burials (Fig. 9). In many tombs the skulls were missing and twenty per cent did not contain any human remains at all. The skeletal elements were often scattered, with some appearing to have been rearranged in a specific pattern, usually with the long bones placed at the western end of the grave. Radiocarbon dates indicated that they were from the fourth to the sixth century (Tab.2).

2. Tile-lined tombs were composed of terracotta tiles on the sides and the floor. In these tombs the skeletons were largely intact with the individual in the supine position with the head towards the west suggesting Christian burials (Braund, 1994). They appeared to be generally undisturbed, containing only one or two individuals with the bones articulated and complete. The radiocarbon dates, indicate that they belonged to the late Roman, early Christian period (Tab.2).

3. Earthen pits were the simplest form of burial, covered with a stone or tile marker. Many of these contained only fragmentary skeletal remains. A radiocarbon date from a pit burial at Tsckantiskedi (in the vicinity of Samtavro) was 5th–6th CE (Tab.2).

4. A single clay sarcophagus with convex walls was present. It contained the remains of four individuals. A rope design decorated the exterior. Radiocarbon date for this tomb was 211–383 CE indicating it belonged to the Roman period (Sagona et al., 2010).
The modified crania from Samtavro analysed in this study had 35% cent from stone cist tombs, and 56% from pit tombs, both of these being dated later in time than the tile-lined tombs, which contained only 9% of the modified crania.

The material culture contained in the graves which associated with modified crania included tear-drop shaped bottles (unguentaria) which was a common Roman practice from 100 AD (Saginashvili, 2008), bronze mirrors originally produced by the Han Chinese and later copied by the Sarmatians north of the Black sea (Maenchen-Helfen, 1973) and trilobate arrow heads identical to those from the Eurasian steppes (Barbarunova, 1995), Females were often buried with jewelry, gold, silver and bronze finger rings, earrings and hair pins, as well as iron fibulae, buckles and bracelets and multiple beads of various materials including of gold, garnet, agate, glass and amber.

Table 2. Georgian radiocarbon assays (Sagona et al 2017)

<table>
<thead>
<tr>
<th>Tomb type</th>
<th>Number</th>
<th>Date range (C.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone cist</td>
<td>13</td>
<td>late 4th-mid 6th</td>
</tr>
<tr>
<td>Sarcophagus</td>
<td>5</td>
<td>2nd-6th</td>
</tr>
<tr>
<td>Tile lined</td>
<td>7</td>
<td>1st-late 4th</td>
</tr>
<tr>
<td>Pit</td>
<td>1</td>
<td>5th-6th</td>
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</table>
The historical and cultural background of Hungary in the Migration Period

The time extending from the Late Roman era to the Early Medieval Period was a turbulent time in the Roman province of Pannonia involving multiple changes in the ruling regime, mass migration and far-reaching ethnic and cultural impacts (Maenchen-Helfen, 1973; Sinor, 1990b; Kim, 2013; Maas, 2015) (Table 3). Pannonia, comprising the west of modern Hungary, was established by the Romans early in the 2nd century AD. The Danube formed the boundary to the northern and eastern boundaries of the Roman Empire. To the east is the Great Hungarian Plain which was known as the Barbaricum and occupied by the Sarmatians from the 2nd century and subsequently by Germanic groups (Bartosiewicz, 2004). The Goths, comprising many different Germanic tribes, migrated from the north in the 3rd century AD and defeated the Sarmatians, dominating the Northern Black Sea region from 300 AD. The advancing Huns eventually decimated the Sarmatians in 375 AD (Sinor, 1990a). The Alans, who were nomads of Iranian
origin and affiliated with the Sarmatians, lived east of the Goths on the River Don. Ammianus records that they were subsequently crushed by the Huns, advancing from the east with many Alans absorbed into their ranks (*Res Gestae* XXXI.3.1). The Huns attacked the Goths in 376 who fled to the west, amassing on the left bank of the Danube and sought refuge in Pannonia from the Romans, which was granted (Sinor, 1990b). Two years later a combined Gothic and Alan force attacked a Roman army, defeating them at Adrianople (Gerberding, 2005). The Romans then ceded control of Pannonia to the Goths (Mitchell, 2015). In 401 the Huns attacked the territory, defeated the Goths and established their base in western Pannonia in 420 (Heather, 2009). Atilla led the Huns for twenty years from 433. His empire included a mixture of Goths, Gepids and other Germanic tribes as well as Sarmatians and Alans. After his death in 453 the Hun Empire lost its dominance and was defeated by the Gepids at the battle of Nedao (Heather, 2009). The Lombards from Bohemia and the middle Elbe entered Pannonia and occupied the western half by the middle of the sixth century with the Gepids controlling the eastern regions. The Avars, a Turkic speaking, nomadic tribe from the Eurasian steppes defeated the Gepids in 568 and the Lombards, fearing annihilation withdrew to Italy leaving the Avars in command of the territory (Heather, 2009).

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<thead>
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<th>Column 1</th>
<th>Column 2</th>
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<th>Column 9</th>
<th>Column 10</th>
<th>Column 11</th>
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</thead>
<tbody>
<tr>
<td>Romans</td>
<td>Romans defeated by Goths at Adrianople in 378 AD</td>
<td>Romans ceded to Goths</td>
<td>Pannonia ceded to Goths</td>
<td>(Mitchell 2015)</td>
<td></td>
<td></td>
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<tr>
<td>Goths</td>
<td>Huns defeat Goths in 401 AD</td>
<td>Huns established as Hunnic base 420 AD</td>
<td>(Sinor 1990b)</td>
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<tr>
<td>Huns</td>
<td>Atilla dies 453 AD Hun defeated by Gepids and Ostrogoths in 455 AD</td>
<td>(Heather 2009)</td>
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<tr>
<td>Gepids</td>
<td>Gepids control eastern Pannonia</td>
<td>(Heather 2009)</td>
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<tr>
<td>Lombards</td>
<td>Lombards defeat Ostrogoths and control western Pannonia</td>
<td>(Heather 2009)</td>
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<tr>
<td>Avars</td>
<td>Avars/Lombards defeat Gepids</td>
<td>Lombards retreat to Italy</td>
<td>(Heather 2009)</td>
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<tr>
<td></td>
<td>Avars defeated after Siege of Constantinople</td>
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**Table 3. Timeline: Pannonia in Late Antiquity**

When Pannonia was ceded to the Goths only the Roman military and civilian elite departed but a large population of Romanised people remained and merged the culture of the Goths into their cultural practices (Muller, 2003a). The Goths were a conglomerate of several Germanic
groups with different cultures which were amalgamated into an East German style but with the arrival of the Huns with Sarmatians and Alans from the eastern steppes new styles were added. During the 5th century this combination of the Roman, Germanic and nomadic cultural styles produced the unique Danubian funerary style which was homogenous across Transdanubia and particularly associated with the multiethnic elite (Curta, 2005). The knives, cauldrons, fibulae, jewels in glassware, clasps, and pins with anthropomorphic heads reflect the steppic styles influencing European culture (Kim, 2013). In the middle third of the 5th century the aristocracy and their families, including the Huns, the Romanised population and the Barbarians who joined them, displayed their wealth, visible in their costume ornaments and the metal fittings of their weapons, made from gold and often inlaid with precious stones (Toth, 2003a). This is also reflected in the rich burials found from this period (Heather, 2009; Giumlia-Mair, 2013). The uniformity in grave goods does not allow for the identification of ethnicity (Ódor 2011; Bierbrauer 2011; Heather, 2009). This may be due to the preponderance of the Germanic style which was appropriated by the Huns and other nomadic tribes but may also result from the strong central authority of the Hunnic Empire bringing disparate tribes together (Kim, 2013). This effect was noted previously on the West Asian steppes (Istvánovits and Kulcsár, 2003). The burial ground at Keszthely-Fenékpuszta displays the culture of this period. It was a fortified site situated on a peninsula on the western side of Lake Balaton, covering fifteen hectares and surrounded by swamps adding to its defensive capability (Rizos, 2013). The type of construction, with round towers, dates it to the middle of the fourth century (Heinrich-Tamaska, 2011). It was one of a chain of fortified sites constructed by the Romans in Pannonia along the Danube (Rizos, 2013). Keszthely-Fenékpuszta was continually occupied in turn by the Romans, the Goths, the Huns, the Gepids, the Langobards and the Avars until the middle of the 8th century with over one thousand graves outside the old Roman fortifications and further graves at the site of the storehouse (horreum) and the early Christian Basilica (Daim, 2003).

The cemetery at the southern gate of the fortress contained thirty-one graves. The construction of the graves was partially or completely brick-lined as deep shafts and pits (Müller, 2003a). Papp (1983, 1984, 1985) examined crania from this cemetery establishing that 67.7% were intentionally modified.
Western Europe

The practice of Intentional cranial modification spread across to Western Europe during the Migration Period particularly following the Danubian basin from Hungary to Austria, Moravia in the Czech Republic and into Bavaria. Only rare examples are present in Austria although according to Tobias (2010) children with modified crania were recovered from burials dating to the first half of the fifth century but after that time only adults were found. The only Austrian modified crania in this study was from Vienna excavated by Matthias Much in 1897 in an ancient burial ground accidentally found in canal works. The grave was a simple pit with no evidence of a coffin. No grave goods were recorded.

Adults and children with modified crania have been recovered in Moravia. The two examples of adults which were suitable for this study which came from burial grounds in Raksice and Saratice but the modified skull of an infant was also present (see Fig.1).

The burial grounds in Bavaria at Altenerding and Straubing are extensive and have been almost completely excavated. They date from the mid-5th century to the mid-6th century. Altenerding has 1400 graves, many with grave goods. Females generally had dress ornaments and fibulae often from distant regions. The type of fibulae may not indicate the origins of individuals but does indicate their range of contacts. Males were generally accompanied by weapons (Hakenbeck, 2010). The changes in the material culture reflect the shift from the late Roman period to the Migration period and later Christian and Byzantine influences, particularly by the style of fibulae, which expressed an individual’s social identity (Hakenbeck, 2011). Straubing had 800 graves with a similar assemblage of grave goods. Both burial grounds had a small number of modified crania present, five were recovered from Altenerding and eleven from Straubing. Only one of these was associated with a male individual. Three of the females with modified crania had carbon isotope levels (obtained from rib collagen) outside the range of the local area indicating they had come from another region with a different diet (Hakenbeck, 2010). Another had a non-local strontium level indicating she was born elsewhere.
Chapter 2
Materials and Methods

Materials
Images of intentionally modified skulls from the Republic of Georgia and sites in Europe were taken for analysis using a Next Engine 3D laser scanner. This imaged the objects with multiple laser stripes with a resolution of 0.038 cm with 60 points per cm.

The crania were curated in repositories and had been previously visually selected as being modified. Only those crania in which the vault was intact were included in the study. In forty-eight per cent of the crania only the vault was present. The number was augmented by reconstructing our crania in which the base was absent crania. The method is detailed below.

Thirty-two modified crania were from Georgia, thirty-one from Hungary, thirteen from Bavaria, one from Crimea, one from Vienna and two from the Czech Republic. Details of the modified crania with their excavation sites are recorded below. The dates of the crania have been estimated by archaeological context and confirmed by radiocarbon analysis in Georgia (Sagona et al., 2017) and Hungary (Heinrich-Tasker and Schweissing, 2011).

The modified crania in Georgia and Hungary were initially identified by visual examination. It is hard to visually differentiate mildly modified crania from those regarded as unmodified. To avoid a bias in interpretation it was preferable to select a control group of unmodified crania from a recent population in which cranial modification was not practiced. Nineteen non-modified crania which were from modern populations curated in the Anatomy and Neuroscience Department, University of Melbourne, were therefore included for comparison. They were of worldwide origin but the exact provenance was unknown.

Details of Intentional Modified Crania studied

Republic of Georgia
Crania from Georgian sites were examined at the excavation site house at Mtskheta and at the Department of Ethnology, University of Tbilisi. The sample included material from a range of
dates within the European Migration Period (Table 1) and three sites from the region of Mtskheta (Fig.1)

Table 1. Catalogue of Georgian modified crania

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Sex</th>
<th>M</th>
<th>F</th>
</tr>
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<tbody>
<tr>
<td>Jinvali</td>
<td>4-8th c</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Nabagrebi</td>
<td>6-7th c</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Samtavro</td>
<td>1-3 c</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Samtavro</td>
<td>4-7th c</td>
<td>5</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 (29%)</td>
<td>22(71%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Map with sites of modified crania in Georgia
Hungary

Modified crania studied at the Museum of Natural History, Budapest are shown below (Table 2). Thirty crania from regions within Hungary were scanned. Their sites of origin are shown on the map (Fig. 10). Males and females were equal in number and 35% of the total were juveniles.

Table 2. Modified Crania from Hungary

<table>
<thead>
<tr>
<th>Site</th>
<th>sex</th>
<th>sex</th>
<th>adult</th>
<th>subadult</th>
<th>?</th>
<th>Date</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>&lt;18y</td>
<td>(3&lt;6y)</td>
<td>(1&gt; 6y)</td>
<td>(4&gt;12y)</td>
<td></td>
</tr>
<tr>
<td>Keszthely</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>1-7th C</td>
<td>10</td>
</tr>
<tr>
<td>Hajdunanas</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>0</td>
<td></td>
<td>3–5th C</td>
<td>9</td>
</tr>
<tr>
<td>Velem</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>5th C</td>
<td>1</td>
</tr>
<tr>
<td>Mohacs</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>5th C</td>
<td>1</td>
</tr>
<tr>
<td>Mozs</td>
<td>1</td>
<td>1</td>
<td>1(6+y)</td>
<td>1(16+y)</td>
<td></td>
<td>5th C</td>
<td>2</td>
</tr>
<tr>
<td>Rakoczi falva</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1(16+y)</td>
<td></td>
<td>3–5th C</td>
<td>3</td>
</tr>
<tr>
<td>Arad (Rumania)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5th C</td>
<td>2</td>
</tr>
<tr>
<td>Tiszavasvari</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8th C</td>
<td>2</td>
</tr>
<tr>
<td>Totals</td>
<td>9(50%)</td>
<td>9(50%)</td>
<td>18</td>
<td>10 (35%)</td>
<td>2</td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>
Central and Western European sites

Crania were studied at the Natural History Museum in Vienna, the State Collection for Anthropology, Munich and the Moravian Museum, Brno (Table 3). The sites of their origins are shown in Figure 2. The dates were provided by the curators as well as documented in published material (Wiltschke-Schrotta, 2010: Hakenbeck, 2009)

Table 3. Modified crania from other sites in Europe

<table>
<thead>
<tr>
<th>Site</th>
<th>Dates</th>
<th>Sex F/M</th>
<th>Adults</th>
<th>Juveniles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech R.</td>
<td>Saratice</td>
<td>5th c</td>
<td>F1/M0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Raksice</td>
<td>6th c</td>
<td>F1/M0</td>
<td>1</td>
</tr>
<tr>
<td>Austria</td>
<td>Vienna</td>
<td>5th c</td>
<td>F1/M0</td>
<td>1</td>
</tr>
<tr>
<td>Bavaria</td>
<td>Altenerding</td>
<td>5–6th c</td>
<td>F3/M0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Straubing</td>
<td>5–6th c</td>
<td>F9/M1</td>
<td>10</td>
</tr>
<tr>
<td>Crimea</td>
<td>Kerch</td>
<td>5–6th c</td>
<td>F1/M0</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td>F16/M1</td>
<td>17</td>
</tr>
</tbody>
</table>

Figure 2. Map of sites of European modified crania (modified from Map data © 2018 Google)
Sex determination

Significant sexual dimorphism is present because of the increased robusticity occurring in males, with a larger skull and more obvious muscle markings compared to many females who retain many of the pre-pubertal features such as small size and less obvious muscle attachments with some juvenile frontal and temporal bossing also present. These features enable sex to be allocated correctly by visual assessment in up to 96 per cent of documented skeletal individuals (Williams and Rogers, 2006). The relative difference in cranial dimensions between the sexes has also enabled metric analysis to be useful with correct allocation in up to 89 per cent of cases (Giles and Elliot, 1963). The changes present in modified crania would not be expected to affect these sex determinants. In order to obtain more consistent outcomes, a scoring system for some cranial features has been established. Five criteria have been used which demonstrate the differences in size, shape and robusticity between the sexes (Buikstra and Ubelaker, 1994).

The criteria are classified from one to five, from (definitely) female to (definitely) male as follows: 1 = female, 2 = probably female, 3 = neutral (indeterminate), 4 = probably male, 5 = male.

The nuchal crest (occipital protuberance) projects from the occipital bone and its size is representative of the musculature of the skull. In a gracile female it is smooth and scores 1, in a robust male it forms a massive hook and scores 5.

The mastoid process varies significantly in its size and is scored according to its volume rather than its length. Its size can be related to the external auditory meatus. If it is small it reaches only a small distance below the external auditory meatus (scoring 1), whereas if it is large it is several times longer and wider than the external auditory meatus (scoring 5).

The supraorbital margin, the upper border of the orbit, may be a sharp ridge in females (scoring 1) or thick and round in males (scoring 5).

The supraorbital ridge is a rounded elevation over the inner aspect of each orbit with a prominent eminence in the midline, the glabella. At the least they are smooth with little
prominence of the frontal area (scoring 1), but in males there may be a massive ridge in the midline and prominent supraorbital ridges laterally (scoring 5).

The mental eminence is rounded and comes to a point in females with little projection (scoring 1). In males it is square with a large projection (scoring 5).

In addition, the gonial angle of the mandible is a useful dimorphic feature as it provides an objective measurement. The angle is generally larger in females than males (Jensen and Palling, 1954). This has been quantified as being greater than 125 degrees in females and less than 125 degrees in males (Williams and Rogers, 2006). The angle is affected by changes to the muscles of mastication by the loss of molars, particularly if the loss is uneven or complete when it does not accurately indicate the sex (Oettle, 2009).

**Age at death determination**

The age of death determined by cranial elements is based on dental eruption and wear and the closure of cranial sutures. In my study of cranial modification, the main emphasis is to establish whether an individual has reached adulthood, assuming that the cranium has reached its permanent shape by that stage.

I used the eruption of the third molar as the indication of adult status when this was available. This indicates an age of approximately eighteen years but has a range of fifteen to twenty-one years (Hillson, 1996). The first and second molars erupt at approximately six years and twelve years respectively with considerable variation. The age can be further defined in subadults based on the stage of molar development (Hillson, 1996).

The age of adults can also be estimated based on dental wear although this is increasingly less accurate with advancing age and dietary variation (Miles, 1962).

The closure of cranial sutures has significant variation which limits its use in age estimation but was helpful when no other method was available (Buikstra, Ubelaker, 1994). The variation is increased when associated with intentional cranial modification because of premature closure of sutures. Gerszten (1993) found suture closure in undeformed skulls occurred from the age of 17 years but in deformed skulls this was apparent in most individuals from 10 years and
occurred particularly in the sutures underlying the area of external pressure. However, as the age of juveniles was determined by molar eruption in this study this was not an issue.

**Dating of crania**

The dates of excavations prior to the 1950’s were based on archaeological evidence. This includes the type of tomb and the arrangement of the human remains and the nature of grave goods. The dates of coins and the styles of pottery, jewelry and weapons can be used by comparison with examples from other sites with known dates (Odor, 2011; Straub, 2011, Furtwangler, 2008). This particularly applies to excavations with archaeological strata where sequences of styles of grave goods can be obtained. After the 1950’s, radiocarbon dating became available for investigating organic material enabling more accurate dates to be obtained. The accuracy depends on ensuring the sample analysed relates to the time and context of the subject being investigated. The result is calibrated to account for local and global effects (Bowman, 1990). Radiocarbon dates have been performed on material from Samtavro but in other regions I have relied on the dates given by the curator (based on archaeological data) and often those in published material (Odor, 2011; Straub, 2011; Sagona, 2010; Hakenbeck, 2009).

**Methods of Cranial Analysis**

**Incomplete Crania**

Crania in which the area to be analysed was incomplete, with the vault intact but the cranial base absent, were able to be included by reconstructing the skull using the trim function of the Next Engine scanner by attaching base of another skull from the same geographic region and of similar shape *(Figs. 3, 4, 5, 6)*. It involved four of the Samtavro crania. The landmark which was reconstituted in this way was the porion which was necessary in order to perform the outline analysis. The reconstruction was done in such a way as enable the analyses to be performed without affecting the outcome.
Figure 3. Cranial sections to be attached to reconstruct the cranium

Figure 4. Markers on corresponding landmarks of each cranial segment enabling alignment

Figure 5. Incomplete skull

Figure 6. Reconstructed skull

Two forms of analysis were performed, eigenshape analysis, based on cranial outlines and principal component analysis based on the cranial surfaces.
1. Eigenshape Analysis

This form of analysis was developed by MacLeod (2012a) to perform a quantitative analysis of shapes. In this study it was appropriate to use it to provide an objective analysis of the cranial outlines.

In the outline analyses, crania were positioned with the left lateral aspect exposed. A two-dimensional outline of the crania, delineated by the outline of the cranial vault superiorly and a line from the glabella through the upper margin of the porion inferiorly, defined the area used in the analyses (Fig.28). This segment was selected because it contains significant cranial shape variation which characterises the type of modification.

Digitalisation.

The outline of the cranium was digitalised using the tps Dig programme (Rohlf, 2004) using the method described by Schultz and Krieger (2007). This programme enables a statistical analysis of images to be performed from landmark data. In this study landmarks were placed commencing at the glabella followed by the occiput, lambda and bregma (Fig. 7). The tps Dig then generated the 200 equidistant semi-landmarks which were the X-Y coordinates used in the analyses. The techniques used in this analysis follow those described by Krieger and MacLeod (2008). The curves are partitioned between the landmarks ensuring that the segments correspond in each specimen representing biologically homologous structures. Interpolation then enters the same number of semi-landmarks (points) to the corresponding segments in each specimen. Those segments with a more complicated structure have a greater number of points. The total number of points around the outlines and the distance between the points in corresponding segments is the same for each specimen. This results in the outline of each specimen being the same size. The only differentiating feature is the shape. The X, Y coordinates around the curve are replaced by phi functions which are the changes in the angles between tangents from point to point (Zahn and Roskies, 1972). They are expressed in radians. The tps file for each cranium was then converted to a text file to be used for the eigenshape analysis.
The calculations for the outline analyses were performed using the internet-accessible Extended Eigenshape Morpho-tool (Krieger 2008), which implements the techniques described in MacLeod (2012a/b). This enables an eigenshape analysis to be performed from the tps Dig file.

In this analysis the derived from the digitalised cranial outlines are standardised by eliminating the size, position and rotation of the specimens leaving only the shape to be analysed. In order to do this the data was mean centred with the centroid, the mean distance from each landmark, moved to zero. The angle functions standardise the orientation of the specimens and together with the standardisation of size resulting from using the same number of equidistant semi-landmarks, the requirements of Procrustes superimposition (in which shape is the only variable) are fulfilled. The phi functions are used to create a data matrix of outlines and shape function coefficients. A singular value decomposition reduced the original two hundred coordinate points defining the cranial outline to forty-three eigenscores which accounted for one hundred percent of the outline shape variation. The first few eigenscores account for most of the shape variation. The eigenscores were then plotted to differentiate shapes in the modified crania.
2. Surface Analysis of modified crania

Surface analysis was used to define cranial vault morphology in the series of analyses comparing the shapes of adult and juvenile crania in Hungary and modified crania from Georgia with those from sites in Europe. This method was chosen as it potentially had more scope to demarcate the modified cranial surfaces.

Data acquisition

Evan Toolbox was used for the digitalisation and analyses of the cranial surfaces. The Evan Toolbox is a tool to enable morphometric analysis to be performed on 3D data which includes Procrustes Superimposition, principal component analysis and the visualisation of warped images (Weber and Bookstein, 2011). In this study the surfaces were digitalised using twelve landmarks (Table 4) and 251 semi-landmarks. The surface semi-landmarks were applied manually, approximately equidistant, to the template in concentric curves lateral to the sagittal curve (Fig. 8). The lines of semi-landmarks incorporated fixed landmarks where possible (See Gunz et al., 2005). The number of semi-landmarks used were deemed to be the minimum required to achieve the cover required to distinguish the shape differences and avoid redundancies which could make subsequent analyses more complicated and time consuming (MacLeod, 2014; Gunz et al., 2005). The semi-landmarks were then projected from the template to the target cranial surfaces to which homologous fixed landmarks had previously been applied. The semilandmarks were slid along tangents to the cranial surface to positions of maximal correspondence to the template bringing them into geometric correspondence with the homologous landmarks of the target specimens (Gunz et al., 2005). The information regarding the landmark configurations of the specimens was imported into a virtual programme network (vpn) in Evan Toolbox for Generalised Procrustes superimposition and Principal Component Analysis

Cranial landmarks used in the study of cranial surfaces

Sutural ossicles associated with cranial deformation do have the potential to affect the landmarking of the points associated with the coronal suture, (bregma) and the lambdoid
suture, (lambda and asterion). In this study the coronal suture was not significantly affected in the modified crania in this study so the bregma landmark was able to be placed at the junction of the coronal and sagittal sutures. However, the lambda suture was broader with greater complexity necessitating the position of the lambda and asterion landmarks to be modified. The lambda landmark was altered from the junction of the sagittal suture and the lambdoid suture to the point at the superior margin of the lambdoid bone aligned with the sagittal suture. The asterion landmark was changed from the junction of the temporo-parietal suture and the lambdoid suture to the point at the lateral margin of the lambdoid bone aligned with the temporo-parietal suture.

Table. 4. Cranial landmarks used in the study of cranial surfaces

Midline

Glabella: the most anterior midline point in the Frankfurt plane

Bregma: The point of intersection of the coronal and sagittal sutures

Lambda: The intersection of the sagittal and the superior margin of the lambdoid bone.

Inion: The point where the superior nuchal lines meet in the midline

Bilateral

Supraorbital notch: The point on the superior orbital margin lateral to the supraorbital notch

Ectoconchion: The point on the lateral margin of the orbit marking the greatest breadth

Stephanion: The point where the superior temporal line crosses the coronal suture

Asterion: The junction of the temporo-parietal suture with lateral margin of the lambdoid bone
Generalised Procrustes Superimposition

Generalised Procrustes Superimposition eliminated differences in the size, orientation and position. Position was standardised by centering the centroids of each landmark configuration to zero. The centroid of each configuration is the point at the mean values of the x, y, z coordinates of each of the landmarks. Orientation was standardised by rotating the landmark configurations to minimise the total distance between homologous landmarks. Size was standardised by scaling the centroid size of each landmark configuration to one. This left shape as the only parameter to be analysed (Zelditch et al, 2004).

Principal Component Analysis in cranial surface analysis

A principal component analysis was used to assess the relative shapes of the crania after the cranial shapes had been standardised with Procrustes superimposition Individual Principal Component (PC) axes accounted for the shape variation described by multiple landmarks, reducing the number of variables which needed to be to be assessed. The value of each PC was derived from a variance-covariance matrix (see Zelditch et al, 2004). The first principal component axis (PC1) accounted for a major percentage of the shape variance, with subsequent PC’s progressively less until 100% of the shape variance had been included. Plots of

Figure 8. Digitalised cranial surface
the first two PC’s were used to demonstrate the relationship of the crania from the various sites.

**Discriminant Analysis**

The crania were also analysed by discriminant analysis using XLSTAT software to further examine group separation using the eigenscores as the variables in the curve analysis and principal component scores as the variables in the surface analysis. These variables were imported into the XLStat statistical programme and a discriminant analysis performed to examine group separation. This is a multivariate method of analysis which assigns individual specimens to previously recognised groups. The number of variables was that which produced the best result in the confusion matrix for cross validation using the stepwise backward method.
Chapter 3

Intentionally modified crania at Samtavro

CONTEXT AND CONNECTION

Studies on the Archaeology of the Ancient Near East in Honour of Antonio Sagona

edited by

ATILLA BATMAZ, GIORGI BEDIANASHVILI, ALEKSANDRA MICHALEWICZ and ABBY ROBINSON
INTENTIONALLY MODIFIED CRANIA AT SAMTAVRO

Peter MAYALL

ABSTRACT

Excavations at the burial site at Samtavro, Georgia have recovered crania which have been intentionally modified resulting from head binding commencing soon after birth. These mostly date from the fourth to seventh centuries AD, corresponding to the appearance of modified crania in Eastern European burials. The practice in Europe has been attributed to the Huns who invaded the region from the Asian steppes in the fourth century. In Georgia, 24% of crania excavated have been modified, mostly involving women and few children. These findings suggest that the custom in Georgia was due to exogamy rather than directly related to Hunnic influence.

*  *  *

Georgian-Australian Investigations in Archaeology (GAIA), who in 2008–2010 excavated the Samtavro burial ground, recovered skeletal material that included crania which had been intentionally modified.1 Infant skulls had been bound soon after birth to produce a permanent alteration to their shape. The bindings would likely have remained in place until the skull bones had stabilised at three to four years of age. This practice has been noted in every continent, mainly appearing in Europe from the fourth century CE. Because this was also the era of the invasion of Europe by the Huns and the associated migrations from the Asian steppes, the Huns are believed to have been responsible.2 The picture is complicated by modified crania also being present at some sites prior to the arrival of the Huns.3 Though Samtavro has long been recognised as a European site where intentional cranial modification has been prevalent, particularly from the fourth century, there is no historical record of Hunnic presence in Georgia.4

In this study, modified and unmodified crania from the 2008–2010 excavations have been analysed, as well as modified crania recovered by previous expeditions at the site. Initially, this involved visual inspection but 3D laser scans of the skulls have also been taken to enable ongoing quantitative analyses to complement observations.

The modified skulls from Samtavro exhibit the annular (circular) form of modification. This is produced by the crania being encircled with one or more strips of cloth or similar material, from the frontal to the occipital region. This causes a flattening of the frontal bone and a transverse groove across that bone which continues laterally around the temporal regions on each side following the path of the binding. A second groove posterior to the coronal suture indicates another binding that extended from this region to the mandible.

1 Sagona et al. 2010.
3 Hakenbeck 2009.
4 Dingwall 1935, pp. 40–45.
The encircling of the cranial vault results in a narrowing of the skull beneath the binding, with a compensatory bulging above (Fig. 1). This also results in most facial measurements being narrower, and the height of the eye sockets is increased, compared with non-modified crania.\textsuperscript{5}

The 2008–2010 excavation at Samtavro has provided a cross-section of an unselected population, enabling the incidence of cranial modification to be estimated (\textbf{Table 1}). Almost one quarter of the crania that could undergo analysis had visual evidence of modification.

<table>
<thead>
<tr>
<th>Tombs excavated</th>
<th>53</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individuals</td>
<td>90</td>
</tr>
<tr>
<td>Skulls with assessable morphology</td>
<td>33</td>
</tr>
<tr>
<td>Modified crania identified</td>
<td>8</td>
</tr>
<tr>
<td>Subadults</td>
<td>1</td>
</tr>
<tr>
<td>Males</td>
<td>3</td>
</tr>
<tr>
<td>Females</td>
<td>4</td>
</tr>
<tr>
<td>Percentage of skulls modified</td>
<td>24.24%</td>
</tr>
</tbody>
</table>

\textbf{Table 1. Incidence of cranial modification in tombs excavated by GAIA.}

The incidence according to sex has been assessed from the total number of modified skulls recovered by the GAIA expedition, and is supplemented by modified crania from earlier excavations. This has revealed 71.43\% per cent of the adult modified skulls to be female (\textbf{Table 2}). The dates of the modified skulls, based on associated material culture, indicates that the majority are from the fourth to the seventh centuries CE, but some are from earlier periods. This is confirmed by the radiocarbon dating of the burials.

\textsuperscript{5} Anton 1989, pp. 253–257.
Table 2. Analysis of Samtavro modified skulls (including samples from previous excavations).

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Individuals</th>
<th>Males</th>
<th>Females</th>
<th>Subadults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samtavro</td>
<td>6th–4th century BCE</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samtavro</td>
<td>1st–3rd century CE</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Samtavro</td>
<td>4th–7th century CE</td>
<td>25</td>
<td>5</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Total (numerical)</td>
<td></td>
<td>32</td>
<td>8</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Total (per cent)</td>
<td></td>
<td>100.00%</td>
<td>25.00%</td>
<td>62.50%</td>
<td>12.50%</td>
</tr>
<tr>
<td>Total adults (numerical)</td>
<td></td>
<td>28</td>
<td>8</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Total adults (per cent)</td>
<td></td>
<td>100.00%</td>
<td>28.57%</td>
<td>71.43%</td>
<td></td>
</tr>
</tbody>
</table>

Where sex could be determined from the GAIA excavation, the male-to-female ratio was approximately equal in adults without cranial modification (Table 3). Furthermore, the results of the 2008–2010 excavations reveal that the number of subadults with modified skulls is smaller in the modified group (12.50%) as compared to the total population (over one quarter) (Tables 2 and 3).

Table 3. GAIA expedition: Sex of individuals.

<table>
<thead>
<tr>
<th>Subadults</th>
<th>17</th>
<th>27.42%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>23</td>
<td>37.10%</td>
</tr>
<tr>
<td>Females</td>
<td>22</td>
<td>35.48%</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Most of the modified skulls were found in the stone cist tombs and earthen pit burials which generally correspond to later dates. These are compared to tombs containing non-modified crania (Table 4).

Table 4. Incidence of tomb types containing modified crania (combined 1976 and 2008–2010 excavations).

<table>
<thead>
<tr>
<th>Stone cist</th>
<th>Tile-lined</th>
<th>Earthen pit</th>
<th>Sarcophagus</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>Unmodified</td>
<td>36</td>
<td>9</td>
<td>18</td>
<td>2</td>
</tr>
</tbody>
</table>

Comparison between the individuals with modified skulls and those from the unselected group of the 2008–2010 excavations suggests exogamous relationships in which the women came from a region with a high incidence of cranial modification. This occurrence has also been noted by Hakenbeck in western Europe during the migration period. The abnormally low incidence of subadults in the modified group also suggests that they did not belong to

5 Hakenbeck 2009.
the local population but were associated with a migrant population. The average age at death of the women is approximately equal in the two groups; many women died at an early age bringing the mean age of death to this low figure in both groups (Table 5).

<table>
<thead>
<tr>
<th>Women at Samtavro with modified crania</th>
<th>36 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women at Samtavro without modified crania</td>
<td>37 years</td>
</tr>
</tbody>
</table>

Table 5. Average age at death for females (combined 1976 and 2008–2010 excavations).

The tombs containing modified skulls are mostly from the 4th–7th centuries, corresponding to the migration period in Europe. This suggests that ancient Georgia was also influenced by the Hunnic invasion though there is no historical record of this. The evidence of modified crania in Samtavro prior to the Hunnic presence indicates that other events were also involved. Ongoing research including stable isotope studies and ancient DNA analysis will help to provide more evidence about intentional cranial modification.

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Peter MAYALL
University of Melbourne, Australia
Email: p.mayall@student.unimelb.edu.au
Chapter 4

Migrating Huns and modified heads: Eigenshape analysis comparing intentionally modified crania from Hungary and Georgia in the Migration Period of Europe

Migrating Huns and modified heads: Eigenshape analysis comparing intentionally modified crania from Hungary and Georgia in the Migration Period of Europe

Peter Mayall1‡, Varsha Pilbrow1‡*, Liana Bitadze2

1 The University of Melbourne, Parkville, Victoria, Australia, 2 Ivane Javakhishvili Institute of History and Ethnology, Tbilisi, Georgia

‡ PM and VP are joint senior authors on this work.
* vpilbrow@unimelb.edu.au

Abstract

An intentionally modified head is a visually distinctive sign of group identity. In the Migration Period of Europe (4th–7th century AD) the practice of intentional cranial modification was common among several nomadic groups, but was strongly associated with the Huns from the Carpathian Basin in Hungary, where modified crania are abundant in archaeological sites. The frequency of modified crania increased substantially in the Mtskheta region of Georgia in this time period, but there are no records that Huns settled here. We compare the Migration Period modified skulls from Georgia with those from Hungary to test the hypothesis that the Huns were responsible for cranial modification in Georgia. We use extended eigenshape analysis to quantify cranial outlines, enabling a discriminant analysis to assess group separation and identify morphological differences. Twenty-one intentionally modified skulls from Georgia are compared with sixteen from Hungary, using nineteen unmodified crania from a modern population as a comparative baseline. Results indicate that modified crania can be differentiated from modern unmodified crania with 100% accuracy. The Hungarian and Georgian crania show some overlap in shape, but can be classified with 81% accuracy. Shape gradations along the main eigenvectors indicate that the Hungarian crania show little variation in cranial shape, in accordance with a two-bandage binding technique, whereas the Georgian crania had a wider range of variation, fitting with a diversity of binding styles. As modification style is a strong signifier of social identity, our results indicate weak Hunnic influence on cranial modification in Georgia and are equivocal about the presence of Huns in Georgia. We suggest instead that other nomadic groups such as Alans and Sarmatians living in this region were responsible for modified crania in Georgia.

Introduction

Intentional cranial modification is a process whereby the head of an infant is purposefully moulded by applying external pressure to achieve a desired shape. Parents or carers start the
process as soon as an infant is born and continue it for the first three or four years of life while the cranial bones are still malleable. Once the bones have ossified the cranial vault assumes the intended shape and it is irreversibly modified. As a cultural practice intentional cranial modification was a worldwide phenomenon [1–3]. With independent occurrences spanning over ten millennia the motives for modification may have varied.

Whatever the motives, intentional cranial modification falls within the realm of body modifications along with tattoos, body piercings, and dental engravings that serve to denote affiliation with particular social or ideological groups. In as much as cranial modification is permanent and irreversible, yet not self-initiated, and in that it affects the most visible part of the body, the modified head serves as a strong physical signifier of conferred social identity and provides an excellent medium for studying human agency in promoting social identity [4, 5]. The social significance of cranial modification has been researched most intensively in South America and Mesoamerica, where cranial modification was ubiquitous for several thousand years [6–9]. The incidence and style of modification sheds light on social status, migration patterns, boundaries between social groups and changing social identity [6,7,10,11].

The purpose of this paper is to examine the social significance of intentional cranial modification in the Mtskheta region of the Republic of Georgia, where there was a dramatic increase in the practice of modification during the Migration Period paralleling that seen among Eurasian nomads under the influence of Huns. Roughly coinciding with the collapse of the Western Roman Empire, the Migration Period from the 4th century AD to the 7th century AD saw a large-scale movement of Germanic and Eurasian nomads into and around Roman territory [12]. The Huns based in Hungary are attributed with triggering the Migration movement, destabilising the Roman Empire and influencing the increased uptake of cranial modification in Europe [12–16]. Comparing modified skull shape in Georgia and Hungary will allow us to determine the presence of Huns in Georgia and understand their social influence.

The practice of cranial modification has been documented in Europe sporadically since the sixth millennium BC [2], well before the arrival of the Huns. Indo-Iranian nomadic-pastoralists such as the Scythians, Sarmatians, and Alans who lived in the region of the Eurasian Pontic steppes and the Caucasus had practised cranial modification since the fourth millennium BC [17–20]. The Scythians dominated the steppe region of the northern Black Sea (Fig 1) from the 7th - 3rd centuries BC until they were overthrown by the Sarmatians from the northern Caucasus [21]. By the 2nd century AD the Alans had overthrown the Sarmatians and occupied the territory from the Aral Sea to the Caspian Sea extending to the north of the Black Sea including the northern Caucasus (Fig 1). In the late third century AD the Huns displaced the Alans, who dispersed throughout Western Europe and North Africa, eventually settling in the northern Caucasus, in present-day Ossetia [22]. Several modified crania from Central Asia, the Trans-Ural region, and the Carpathian basin, dated prior to the arrival of the Huns, have been attributed to these groups [23–27].

The Huns were a heterogeneous band of nomadic warriors who had their origins in China and Inner Mongolia [17,28,29]. They arrived in Europe via Inner Asia incorporating several Central Asian Turkic and Scytho-Sarmatian groups within their ranks [17,28,30]. They had modified heads by the time they arrived in Europe, yet skeletal remains of the Chinese and Mongolian predecessors of the Huns show no signs of cranial modification [14,17,18,31,32]. It is believed that they picked up the practice in their journey towards Europe [2,14,18,31]. They settled for the most part in the Carpathian basin in Hungary, which has been described as the epicentre of Hunnic influence [18]. Their presence in Europe was short-lived, from about 370 AD to 460 AD, but they had an immense and lasting influence on the history and polity of the region. The incursions of the Huns on the Alans and Goths north of the Black Sea triggered the Migration Period and they were largely responsible for destabilising the Western Roman
Empire [12,16,18,30,33]. Their exploits, exaggerated to mythical proportions by the historians of the day, are strong indication that they wielded considerable regional power [12,18,28,29].

After the arrival of Huns, the incidence of modified crania rose sharply in burials in the Carpathian basin in Hungary, to around 50 to 80 per cent of crania [2,15,23,34–37]. At the same time modified crania start to appear in increased frequency in nomadic burials throughout Europe [2,15,23,37,38]. If we postulate that the Huns were influential and promoted the renewed practice of cranial modification in Europe [12–18, 30, 32,33], we can use cranial modification to examine the physical presence and social sphere of influence of Huns. One such area is the Republic of Georgia where modified crania have been noted sporadically since the Bronze Age. During the Migration Period, starting from about 4th century AD, however, modified skulls are far more frequently encountered in the region of Mtskheta, the capital of Iberian kingdom of Eastern Georgia, although there are no records that the Huns settled in Georgia during this period.

There are records that the Huns travelled across the Caucasus into Armenia through the Derbend Pass in 395 AD and returned to the Hungarian plain in the same way [17,18]. There are suggestions that Georgian noblemen sought the help of Huns to quell internal uprisings [18], but there are no firm records of Huns settling in Georgia. There are, however, ample references to the Alans and Sarmatians in Georgia and in the region of Mtskheta, as allies in strengthening the reign of Iberian rulers or rebels in carrying out raids on the Iberian kingdom [39,40]. It is known that the Huns had a close symbiotic relationship with the Alans and Sarmatians throughout the region of the Caucasus and Rome [22,38,40], subjugating them and including them within their ranks [16,19,21,29]. The question then is: can the modified heads in Georgia be attributed to Huns, or did they belong to another contemporaneous group practicing cranial modification? In this paper we compare the pattern of cranial modification in the Migration Period in Georgia with that in Hungary, to determine the likelihood and extent of Hunnic influence in Georgia. If the Georgian modified crania are Hunnic in origin, then they should be indistinguishable from Hungarian modified crania. Alternatively, if they were more diverse in origin they will only loosely resemble Hungarian Hunnic modified crania.
Materials and methods

Previous studies assessing patterns of cranial modification have variously used visual approaches [41,42], linear measurements [43], angles between landmarks [44], arc and chord measurements [45], and Elliptical Fourier Analysis [46], to study the shape of modified and unmodified crania. These approaches have progressively allowed for a more objective characterisation of modified crania, validating the ability of the naked eye in initially differentiating modified from unmodified crania. Our aim in this study is firstly to quantitatively separate modified crania from unmodified crania and secondly to differentiate modified crania from Georgia and Hungary. All the modified crania in our study were of the annular or circumferential type produced by the application of a circular bandage around the head, although there are variations, where a second vertical bandage is applied to the circular one. The annular form of modification is most commonly encountered in West Asia, Europe, the Caucasus, Trans-Ural and Siberian regions [2,13,15,23,47–50]. As with Perez [9], we use a geometric morphometric approach of Procrustes superimposition to remove differences related to orientation, translation and scale, so as to highlight differences in the annular modification style. We do not expect cranial shape to be ethnically or geographically relevant because the Georgian and Hungarian populations in the Migration Period were ethnically diverse, and overall cranial shape is a poor indicator of geographic origin [51]. Unlike Perez [9], we use extended eigenshape analysis [52–54], because this method allows us to divide the cranial outline into segments and study the difference between similarly modified Georgian and Hungarian crania more closely.

Sample

Our study is based on 21 modified crania from Georgia, 16 modified crania from Hungary and 19 unmodified crania from The University of Melbourne (Table 1). The Georgian crania came from the permanent osteological repositories of the Georgia National Museum in Mtskheta and the Ivane Javakhishvili Institute of History and Ethnology, University of Tbilisi. The Hungarian crania were studied at the permanent repository of the Hungarian Natural History Museum, Budapest. The sample localities are shown in Fig 1. We used dates provided by the museum or the original excavators to restrict our study to Migration Period sites (Table 1). The crania from Samtavro in Georgia and Keszthely-Fenékpuszta in Hungary have associated radiocarbon dates (Table 1). The unmodified crania from The University of Melbourne are part of a teaching collection of mixed worldwide provenance acquired after 1850 [55]. They were selected precisely because they have no history of intentional modification and permitted us an unbiased shape comparison with modified crania. All specimens are accessible in the specified repositories and teaching collection. The museums and university provided permission by electronic communication to undertake non-invasive scanning (no permit numbers provided).

In Hungary the modified cranial collection includes infants, juveniles, sub-adults and adults, with an equitable distribution of sexes. In Georgia 80% of the modified crania are adult female. There are no juveniles or sub-adults in the Migration Period sample in Georgia. To ensure an equal comparison we used only adult individuals in our study. We assessed adulthood through the eruption of the maxillary third molars and fusion of the cranial sutures. Sex was determined based on cranial characters such as prominence of glabella, sharpness of supraorbital margin, size of mastoid process, robusticity of nuchal crest and strength of mental eminence [61]. Because our study focused on the intact cranial vault, we were forced to exclude individuals with incomplete crania. Thus, our sample sizes and locality representations are reduced, and the sex breakdown deviated from the available sample, such that the Georgian
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1 Georgia National Museum.  
2 Hungarian Natural History Museum.

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sample included 76% females and the Hungarian sample 63% females. We did not focus on sex differences in our analyses, but pooled the sexes because Procrustes superimposition removes differences of scale.

Data acquisition

We used a Next Engine laser scanner to obtain three-dimensional (3D) images of the crania. It uses multiple laser stripes to image the object. In the wide view, which was used to image crania in this study, it has a resolution of 0.038 cm with 60 points per cm.

To acquire data for digitisation we marked the landmarks, bregma and lambda, on the 3D scans and positioned the scans in left lateral view such that a horizontal line extended from glabella to porion to the occipital region. We then converted the 3D scans into two dimensional (2D) images (Fig 2). We used the 2D outline of the cranial vault for analysis. Frieß and Baylac [46] have previously demonstrated that annular or circumferential modification results in shape changes to the face and the basioccipital region. However, in the absence of the face and cranial base, 2D outlines of the cranial vault preserve sufficient shape variation to characterise such modification. The cranial vault was the most suitable for the ancient crania in our study as in half of the available specimens the cranial base was missing or incomplete. We confined our study to crania in which the vault was intact. The horizontal line connecting glabella to porion and extending to the occipital region was used to demarcate the inferior margin of the cranium. Using the TPSDig program [62] we placed landmarks commencing at the occiput, continuing anti-clockwise to lambda, bregma and glabella, and obtained XY coordinates for these. We quantified the cranial outline with 200 points and acquired XY coordinates for these points (S1 File).

The advantage of using extended eigenshape analysis is that it allowed us to focus on parts of cranial outline that showed the greatest changes in curvature while excluding the inferior straight segment from glabella to occiput from the outline analysis as it contributed no

![Cranial outline showing bregma and lambda and straight line demarcating cranial base.](https://doi.org/10.1371/journal.pone.0171064.g002)
The landmarks and corresponding segments were selected so as to split the cranial outline into three curved segments and study differences in binding styles in each of the homologous segments: occiput to lambda (occipital), lambda to bregma (parietal), and bregma to glabella (frontal). In the case of four skulls from Samtavro where the base was deficient and porion was absent, we reconstructed this region using a base from a complete skull with the same glabella to occipital length. We placed a minimum of three corresponding points on the skull with the deficient base and the base of the substitute skull. We then used the align function of the Next Engine scanner software to align and unite the skulls. This allowed us to increase our sample size and take a complete outline for the tpsDig program, although we later excluded the base in the extended eigenshape analysis.

We conducted intraclass correlation studies [63,64] to determine the error rate in identifying landmarks on the cranial outline. Both intraobserver and interobserver error studies revealed high interclass correlations of 0.99 to 1.00 between two sets of measurements taken on a random sample of five specimens each from Georgia, Hungary and Melbourne. Having repeatedly identifiable landmarks and outlines ensured that each segment represented topologically homologous curves.

Eigenshape analysis

Extended Eigenshape analysis implements the techniques described in Krieger and MacLeod [65] and MacLeod [52–54] through the internet-accessible Extended Eigenshape Morpho-tool [66]. Although each specimen was marked with 200 points around the outline, segments with a more complicated structure were assigned a greater number of coordinate points (semi-landmarks). The maximum numbers of points encountered in individual segments were then interpolated to homologous segments across all specimens. Thus, individual segments across all specimens had the same number of equidistant points as the specimen with the most complex curvature. This ensured that fine details of shape change were captured and the outlines from each specimen had the same number of semi-landmarks. This procedure produced a single curve in the form of XY coordinates for each specimen. Procrustes superimposition using a Generalized Least Squares procedure helped to minimize the discrepancies in landmark configurations related to location and orientation and to resize each outline to unit centroid size to scale size differences. The XY coordinates were then converted to phi-functions [67], which are cumulative changes in the angle between tangents to the curve from point to point, expressed in radians. The phi functions effectively remove size, position and rotation from the outline data and align the data. A pairwise matrix of covariances between the phi functions was used to perform a singular value decomposition (similar to a principal component analysis), which re-configured and reduced the shape variation in the sample to a series of hierarchical eigenvectors or eigenshapes. The scores (eigenscores) of specimens on the eigenshapes were used to plot and visualize shape changes along the morphospace [66]. To further explore the discrimination between Georgian, Hungarian and modern crania we used the eigenshapes as variables in a discriminant analysis procedure. We used a step-wise procedure for the selection of eigenshapes, so that only those eigenshapes that were highly significant in discriminating groups were selected in an iterative manner to be included in the analysis (p<0.01 for F-value of variable to be entered, p<0.10 for F-value of variable to be removed). In each analysis no more than six eigenshapes contributed to maximum separation. The significance of F-values (p < 0.05) for the pairwise Mahalanobis distances helped determine the statistical difference between groups.

In the second stage of the analysis we studied the contribution of each of the landmarked segments in differentiating between the Georgian and Hungarian modified crania. The open curve procedure of extended eigenshape analysis allowed us to plot the eigenvectors showing
shape changes, and a discriminant analysis helped to study the contribution of each segment in differentiating the two groups. In circumferential modification, where a single or a double binding results in significant shape differences in the regions of the frontal, parietal and occipital, separate analyses allowed us to study the shape differences in greater detail.

**Results**

**Analysis of cranial outline**

The first two eigenshapes, ES1 and ES2, account for respectively, 26% and 9% of the variance in cranial shape. Each subsequent eigenshape captured a smaller proportion of variance, indicating substantial variation in modified cranial shape, forming a continuum with unmodified cranial shape. Fig 3 is a scatterplot of the cranial outlines on the first two eigenshapes with convex hulls demarcating each group. Also shown are the shape changes along the first two morphospaces and example crania demonstrating the variation in cranial shape. The example crania are oriented in the manner used for analysis. As the cranial outlines and example crania show, the first eigenshape plots the change from severely modified, tall and antero-posteriorly narrow cranial vaults to unmodified, shallow, antero-posteriorly wider vaults. The separation of the unmodified crania from the modified crania is seen along this axis. The second eigenshape separates, to some extent, the Georgian crania from the Hungarian ones. It plots the shape change from a mildly modified cranial vault with curved frontal, parietal and occipital

Fig 3. Eigenshape (ES) 1 and 2 showing scatter of cranial outlines with convex hulls demarcating each group, shape changes along the first and second morphospaces, and example crania demonstrating the variance.

doi:10.1371/journal.pone.0171064.g003
outlines to an oblique modification with supero-posteriorly oriented frontal and parietal, but rounded occipital outline. With the first two eigenshapes covering merely 35% of the variance in shape, the clusters in the scatterplot are not distinct. A ternary diagram (Fig 4) of the first three eigenshapes covering 43% of variance shows clear separation of the unmodified modern crania from the modified crania. High eigenscores on ES1 and ES2, with low eigenscores on ES3 cause the samples to cluster at the lower right corner, with some degree of separation of the Georgian and Hungarian crania along ES2 and ES3.

The Georgian crania display varying forms of modification from mild to extreme (Figs 5–7). In the extreme form the skull base is narrow and there is a compensatory bulge superiorly.

Fig 4. Ternary plot of the first three eigenshapes showing clustering pattern of crania.
doi:10.1371/journal.pone.0171064.g004

Fig 5. Georgian cranium used in this study demonstrating the effect of the annular form of modification, with several circular bandages resulting in a tall, vertical cranial profile. The orientation of the cranium is that used in the eigenshape analysis in this study.
doi:10.1371/journal.pone.0171064.g005
The frontal, squamous temporal, parietal and occipital bones are elongated and the superior parts of the parietal and occipital bones extend postero-superiorly. This is consistent with the use of a circular bandage secured in a ring-like manner from frontal to occipital. By positioning the bandages either high or low on the frontal and occipital and altering the tightness of the bandages the cranium is made to look tall, with vertical frontal and occipital profiles and bulging parietal profile (Fig 5), or low, with obliquely sloping frontal, occipital and parietal profiles (Fig 6). A milder form of modification is also seen, which restricts the height of the cranial vault and results in a bregmatic or postbregmatic depression along the vertical path of the bandage. This is consistent with adding vertical bandages to the circular ones, going from

![Fig 6. Georgian cranium used in this study demonstrating the annular form of modification, with several circular bandages resulting in an oblique cranial profile. The orientation of the cranium is that used in the eigenshape analysis in this study.](image)

doi:10.1371/journal.pone.0171064.g006

The frontal, squamous temporal, parietal and occipital bones are elongated and the superior parts of the parietal and occipital bones extend postero-superiorly. This is consistent with the use of a circular bandage secured in a ring-like manner from frontal to occipital. By positioning the bandages either high or low on the frontal and occipital and altering the tightness of the bandages the cranium is made to look tall, with vertical frontal and occipital profiles and bulging parietal profile (Fig 5), or low, with obliquely sloping frontal, occipital and parietal profiles (Fig 6). A milder form of modification is also seen, which restricts the height of the cranial vault and results in a bregmatic or postbregmatic depression along the vertical path of the bandage. This is consistent with adding vertical bandages to the circular ones, going from

![Fig 7. Hungarian cranium used in this study demonstrating the two bandage technique of annular modification. In addition to the circular bandages, a vertical bandage in the region of the bregma restricts cranial height and results in a bregmatic depression. The orientation of the cranium is that used in the eigenshape analysis in this study.](image)

doi:10.1371/journal.pone.0171064.g007
the crown of the head to the mandible (Fig 7). Our study indicates that both techniques of modification, along with variation in the first technique, were used in Georgia.

The Hungarian crania, by comparison, are constrained in their modification and do not display the tall, erect, oblique or shallow cranial vaults. This would suggest that they were modified using the second technique of two bandages, with one concentrically fitted bandage going from forehead to the nape of the neck across the temporal region, and another bandage going from the crown of the head to continue under the chin (Fig 7).

The Georgian crania have a wider scatter in all plots compared with the Hungarian and modern crania. Increased variation in cranial form in Georgia also becomes clear by examining the histograms and box-and-whisker plots showing the values for each group along the first two eigenshapes (Figs 8 and 9). The Georgian crania have greater variance in cranial shape, while the Hungarian crania, although distinct from the modern unmodified crania, are restricted in shape.

The step-wise discriminant function analysis used six eigenshapes to maximize discrimination; the pair-wise distinctions were statistically significant. Table 2 shows the accuracy of classification in the step-wise and cross-validation approaches. In the step-wise procedure the unmodified modern crania were discriminated with 100% accuracy. The Hungarian and modern crania were reciprocally 100% distinct; one Georgian cranium with a long and low cranial vault fell into the modern group (Fig 3). The Hungarian and Georgian crania, discriminated with 81% accuracy, had some overlap. The cross-validation procedure maintained the distinction of the Hungarian crania from the unmodified group, although one unmodified specimen fell into each of the Hungarian and Georgian groups. The Georgian crania had greater overlap with the unmodified modern sample in cross-validation, with three specimens classified as modern. The Hungarian and Georgian groups also showed overlap and reduced cross-validated classification accuracy.

Analysis of cranial segments

In the second part of the analysis we compared the frontal, parietal and occipital outlines to study the shape differences in modified crania from Georgia and Hungary. In analysis of the frontal segment, demarcated by the glabella and bregma, the first two eigenshapes accounted for a total of 47% of variance (Fig 10). The first eigenshape (31%) charts the change from a low, rounded frontal to a tall, vertical frontal, while the second one marks the change from the frontal being angular at the anterior end to being angular at the posterior end. The parietal outline (Fig 11), going from bregma to lambda, picks up 32% of variance on the first eigenshape and shows the transformation from a low, shallow outline, to a tall, peaked outline. The second eigenshape with 8% of variance shows the change from a symmetrically outlined parietal to an obliquely angled and asymmetrically outlined parietal. The occipital outline, which in this study goes from lambda to the point on the occipital that forms a straight line from glabella to porion, covers 24% of variance on the first eigenshape (Fig 12) and charts the change from a curved to a vertically oriented occipital outline. The second eigenshape covering 17% of variance shows the transition from an anteriorly angled occipital outline on the negative end of the axis to a posteriorly angled outline on the positive end of the axis.

There is considerable overlap between the Georgian and Hungarian crania on plots of the first two eigenshapes (Figs 10–12). It is worth noting, however, that, on the whole, the Georgian crania lie at the outer edges of scatter. As can be seen from the example crania included in the plots, the Georgian crania encompass a wide range of variation in modified cranial shape. These include low and rounded frontal, parietal and occipital outlines, obliquely angled frontal and occipital with asymmetrical parietal outlines and much more vertically oriented frontal
and occipital with tall, domed parietal outlines. The Hungarian modified crania fall within the range of cranial modification exhibited in Georgia, but in contrast with the Georgian crania they are constrained in showing gently sloping frontal, parietal and occipital outlines and do not show the extremes of low, high and oblique outline profiles seen in Georgia. The greater

Fig 8. Histograms depicting the eigenscores of Georgian, Hungarian and modern crania on ES1 and ES2.
doi:10.1371/journal.pone.0171064.g008
variance in the Georgian crania is also evident in the histograms and box-and-whisker plots depicting the scores of the crania on the eigenshapes. Fig 13 shows the frequency of scores for Georgian and Hungarian crania on ES1 for the frontal, parietal and occipital segments. Fig 14 shows the box-and-whisker plots for ES1. It is worth noting that in the region of the frontal and parietal the range around the mean is greater in Hungary even though the overall variance is greater in Georgia. Although not shown here, a similar pattern is repeated on all eigenshapes.

A discriminant function analysis using the eigenscores on all eigenshapes provides excellent and statistically significant separation of the Georgian and Hungarian crania (Table 3). On average the Georgian crania are classified at 78% accuracy and the Hungarian crania at 83% accuracy. Cross-validation does not reduce classification accuracy much. Georgian crania are still classified with an average of 78% accuracy and the Hungarian crania are classified with an average of 79% accuracy.

Discussion

Intentional cranial modification as a cultural practice has been noted in Georgia since the Bronze Age, but after about 400 AD the practice became far more common. As this coincides with the start of the Migration Period and the ascendancy of the Huns with their signature modified heads in the Carpathian basin in Europe, our study sought to compare modified cranial shape in Georgia and Hungary to determine whether the Huns or other contemporaneous groups were responsible for this cultural practice in Georgia.

Table 2. Classification accuracy from discriminant analysis of cranial outline.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Georgia (N)</th>
<th>Hungary (N)</th>
<th>Modern (N)</th>
<th>Percentage accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>17</td>
<td>3</td>
<td>1</td>
<td>81.0%</td>
</tr>
<tr>
<td>Hungary</td>
<td>3</td>
<td>13</td>
<td>0</td>
<td>81.3%</td>
</tr>
<tr>
<td>Modern</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>100%</td>
</tr>
</tbody>
</table>

Cross-validation

<table>
<thead>
<tr>
<th>Groups</th>
<th>Georgia (N)</th>
<th>Hungary (N)</th>
<th>Modern (N)</th>
<th>Percentage accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>52.4%</td>
</tr>
<tr>
<td>Hungary</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>68.8%</td>
</tr>
<tr>
<td>Modern</td>
<td>1</td>
<td>1</td>
<td>17</td>
<td>89.5%</td>
</tr>
</tbody>
</table>

doi:10.1371/journal.pone.0171064.t002
Fig 10. Eigenscores for the frontal outline plotted on ES1 and ES2 with convex hulls highlighting each group, also showing shape changes along the first and second morphospaces, and example crania demonstrating the variance.

doi:10.1371/journal.pone.0171064.g010

Fig 11. Eigenscores for the parietal outline plotted on ES1 and ES2 with convex hulls highlighting each group, also showing shape changes along the first and second morphospaces, and example crania demonstrating the variance.

doi:10.1371/journal.pone.0171064.g011
We found a distinct difference in the range of cranial shapes characterising Georgian and Hungarian crania. The Georgian crania showed greater variation in overall cranial outline and in the outline of individual cranial segments. The crania encompassed both shorter and taller varieties, ones that were highly compressed in the frontal and occipital regions and ones that were rounded and elongated from the frontal to occipital regions. In comparison, the Hungarian modified crania fell in the middle of the range of Georgian modified crania. They were characterised by relatively moderate frontal gradient, wide and shallow parietal outline and shallow occipital outline. This suggests that they were modified using the two bandage technique. This characteristic of Hungarian crania from the Migration Period has been recognized for some time. Pap [34–36] described the binding process at the site of Keszthely-Fenékpuszta as having one concentrically fitted bandage going from forehead to the nape of the neck across the temporal, and another bandage going from the crown of the head to continue under the chin. The second bandage caused a bregmatic depression around the coronal suture reducing cranial height while also reducing the height of the mandibular ramus and symphysis, and flattening the ramus. The greater variation in the range of curvature in the frontal and parietal segments as seen in the box-and-whisker plots in our study (Fig 14) suggests that the placement of the vertical bandage may have varied from prebregmatic to postbregmatic. Pap [36] suggested that the second bandage would not have hindered opening the mouth for food intake, but would have tightened the bandage to make it more effective.

**Fig 12. Eigenscores for the occipital outline plotted on ES1 and ES2 with convex hulls highlighting each group, also showing shape changes along the first and second morphospaces, and example crania demonstrating the variance.**

doi:10.1371/journal.pone.0171064.g012
It is significant that the two-bandage method restricting cranial height became widespread in the Transdanubian region between 4th–7th century AD following the period of Hunnic occupation, although multitudes of nomadic people in this region were engaged in the practice of intentional cranial modification prior to this time [2,13,15,20,31,58]. This attests to the strong influence of the Huns on the region and suggests that they promoted their identity by

Fig 13. Histogram depicting the frequency of eigenscores on ES1 for the Georgian and Hungarian crania on frontal, parietal and occipital segments.

doi:10.1371/journal.pone.0171064.g013
Fig 14. Box-and-whisker plots showing ES1 scores for the Georgian and Hungarian crania in frontal, parietal and occipital segments.

doi:10.1371/journal.pone.0171064.g014
adopting a variation on an existing cultural custom. Where membership to the Hunnic community was inclusive without regard to genetic and ethnic background, this would suggest that the Huns were ingeniously able to differentiate themselves from other contemporary groups by standardising the technique of modification as a membership marker. Extensive literature on social identity theory suggests that diverse ethnic groups that are in close contact highlight differences by way of marking boundaries so as to strengthen their self-identity [68,69]. This could certainly apply to the Migration Period where several groups, described as nomads, barbarians or Germanic tribes, were in close proximity, yet often in conflict [70]. The heightened uptake of cranial modification in Migration Period Europe and variation in the style of modification could be interpreted as a way for the nomadic groups to define distinct social identities.

The skewed representation of predominantly adult females and the absence of juveniles with modified crania in the region of Mtskheta in Georgia suggests that the practice of cranial modification was not of local origin. This contrasts with the situation in Hungary where a complete demographic profile from juveniles to adults with intentionally modified crania exists. The situation in Mtskheta is similar to that in Germany, where Hakenbeck [15] suggested that the practice of female exogamy resulted in non-local females migrating from their place of birth and abandoning the custom of intentional cranial modification in their new community.

If the ubiquitous presence of modified crania with low cranial vault is considered to be a signifier of Hunnic identity, it may be surmised that Hunnic dominion and influence over Georgia from 4th–7th century AD was weak at best. The varied styles of annular modification encountered in the Mtskheta region suggest that there were multiple groups practising cranial modification during this time. Who then were these groups? It is difficult to answer this question with certainty but there is clear evidence that the Alans were present in the region of Mtskheta both prior to and during the time period under consideration. They are described in the Georgian historical chronicles as allies in strengthening the reign of Parnavaz and his son Saurmag (299–159 BC), in combating Armenian rulers, Artasan (72 AD) and Amazasp II.

![Table 3. Classification accuracy from discriminant analysis of frontal, parietal and occipital outlines.](https://doi.org/10.1371/journal.pone.0171064.t003)

<table>
<thead>
<tr>
<th></th>
<th>Georgia (N)</th>
<th>Hungary (N)</th>
<th>Percentage accuracy</th>
</tr>
</thead>
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<td><strong>Frontal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
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</tr>
<tr>
<td>Hungary</td>
<td>3</td>
<td>13</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Cross validation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>16</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Hungary</td>
<td>3</td>
<td>13</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Parietal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>16</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Hungary</td>
<td>2</td>
<td>14</td>
<td>88%</td>
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<tr>
<td><strong>Cross validation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>16</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Hungary</td>
<td>3</td>
<td>13</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Occipital</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>17</td>
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<td>81%</td>
</tr>
<tr>
<td>Hungary</td>
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<td>13</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Cross validation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>17</td>
<td>4</td>
<td>81%</td>
</tr>
<tr>
<td>Hungary</td>
<td>4</td>
<td>12</td>
<td>75%</td>
</tr>
</tbody>
</table>

doi:10.1371/journal.pone.0171064.t003
(185–189 AD), in carrying out raids on the Georgian kingdom of Kartli during the reigns of Mirian (284–361 AD) and Vakhtang Gorgasali (447–552 AD), and in forming marital alliances with the Georgians [39]. The Alans had been practising cranial modification before the Huns arrived in Europe [18], which strengthens the possibility that some of the modified crania in Mtskheta belong to the Alans. The Georgian chronicles and classical historians such as Strabo and Pliny also describe the Sarmatians, who maintained strong connections with the Iberian kings of Georgia and helped them in their wars against Rome and Armenia [40]. These historical references, combined with deviations in the techniques of modification identified here, suggest that nomadic groups such as the Alans and Sarmatians in Mtskheta intensified the practice of intentional cranial modification as a way of differentiating themselves from the Huns and maintaining their social identity.

Conclusion

The practice of intentional cranial modification was prevalent among the Indo-Iranian nomads such as the Scythians, Sarmatians, Alans and Gepids in the region of the Hungarian Plains, Eurasian Steppes and the Caucasus, prior to the arrival of Huns in Europe. After the arrival of Huns and with the start of the Migration Period the practice became far more common across Europe. Given the strong influence of the Huns on the events of the Migration Period, it is often assumed that modified skulls in Migration Period Europe signify the presence or the cultural influence of the Huns. Using extended eigenshape analysis in this study we found differences between the annular styles of modification utilized in Hungary and Georgia. The Hungarian modified crania were uniform in their pattern of modification and appear to have been modified using two bandages, which served to reduce cranial height. This strengthens our hypothesis that cranial shape was standardised in the Pontic steppe, which was the epicentre of Hunnic domination, so as to establish Hunnic identity. This was not the case in Georgia where modified crania in this study encompassed a range of variation from mild to extreme. This fits with the understanding that varied cultural influences distinct from those in Hungary operated simultaneously in Georgia. Our study finds little evidence for Huns or direct Hunnic influence in Georgia, but we suggest that existing nomadic groups such as the Alans and Sarmatians were responsible for the modified crania here. This conclusion also fits with the absence of textual references for Huns settling in Georgia, but can be accounted for by ample textual references for the presence of Alans and Sarmatians in the region. The Alans and Sarmatians were not immune to the influence of Huns, however. The Huns subjugated many, but not all, of them in the Hungarian plain. If there was any Hunnic influence in Georgia it was in the heightened uptake of the existing social custom of cranial modification in the Georgian nomadic groups.

Supporting information

S1 File. Georgia Hungary Modern.tps. Landmark data for each specimen. (TPS)

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**Author contributions**

- **Conceptualization:** PM VP.
- **Formal analysis:** PM VP.
- **Investigation:** PM.
- **Methodology:** PM VP LB.
- **Project administration:** VP.
- **Resources:** PM LB.
- **Supervision:** VP.
- **Validation:** PM VP.
- **Visualization:** PM VP.
- **Writing – original draft:** PM.
- **Writing – review & editing:** PM VP LB.

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Chapter 5

Generalized Procrustes analysis of an ontogenetic series of modified crania: Evaluating the technique of modification in the Migration Period of Europe (4th–7th century AD)

Generalized Procrustes analysis of an ontogenetic series of modified crania: Evaluating the technique of modification in the Migration Period of Europe (4th–7th century AD)

Peter Mayall | Varsha Pilbrow

Department of Anatomy and Neuroscience, University of Melbourne, Parkville, Victoria 3000, Australia

Correspondence
Varsha Pilbrow, Department of Anatomy and Neuroscience, The University of Melbourne, Parkville, Victoria, Australia, 2000.
Email: vpilbrow@unimelb.edu.au

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Abstract

Objectives: The arrival of the Huns into Europe in the fourth century AD increased the occurrence of intentional cranial modification among European nomads. It has been postulated that the Huns used a two-bandage cranial binding technique to differentiate themselves from surrounding nomadic groups, including those from Georgia. This study examines this hypothesis by comparing Migration Period (4th to 7th century AD) juvenile crania, which retain strong impressions of bindings, with adult modified crania from Hungary and Georgia.

Materials and Methods: Twelve surface landmarks and 251 semi-landmarks were used to study ontogenetic trajectories in 9 juvenile and 16 adult modified skulls from 8 Hungarian sites and 21 adult skulls from two Georgian sites. Generalized Procrustes analysis, linear regression of Procrutes distance on dental age and log centroid size, and warping the principal components (PCs) in shape space helped to identify cranial shape changes.

Results: The PCs provide significant separation of the juvenile and adult groups from Georgia and Hungary. Variation in modified cranial shape was limited in Hungary compared to Georgia. There was stronger correlation between juvenile and adult modified cranial shape in Hungary than in Georgia. Warping along the first axis reveals the trajectory from marked flattening of the frontal and occipital regions in juveniles to diminished flattening in the same regions in adult crania, corresponding with one binding. Another depression extending from the post-bregmatic region to the temporal region, similarly strong in juveniles but diminishing in adults, marks the second binding.

Discussion: Hungarian crania were modified with two bindings with limited shape variation, whereas the Georgian crania had greater variation in shape being also modified with antero-posterior bindings. The findings from this study alongside contemporary historical sources help to understand the role of intentional cranial modification as a mark of social identity among nomads in the Migration Period of Europe.

KEYWORDS
Georgia, Hungary, intentional cranial modification, ontogenetic allometry, procrustes superimposition

1 INTRODUCTION

Intentional cranial modification is a cultural practice where members of a social group mold the soft cranial bones of an infant into desired shape by applying tight bandages. Once the cranial bones ossify the modified head serves as a visible mark of affinity with a social group (Tiesler, 2014). Evidence for the practice of intentional cranial modification in the Mtskheta region of the Republic of Georgia exists from the third millennium BC, but it became far more prevalent after the fourth century AD corresponding to the Migration Period (4–7 AD) in Europe (Dingwall, 1931; Kiszely, 1978). This is the period following the collapse of the Western Roman Empire when there was large-scale migration of
Germanic and Eurasian nomadic groups around Roman territory (Halsall, 2007). The proliferation of the practice during this period is associated with the Huns, nomadic warriors from Central Asia, who settled in the Carpathian basin around Hungary and Romania in the fourth century AD (Sinor, 1990), and practiced cranial modification as a unique marker of their social identity (Werner, 1956). The Huns are largely credited with destabilizing the Western Roman Empire and setting in motion the great migrations (Halsall, 2007; Kim, 2013; Sinor, 1990; Vaissière, 2015). They were so influential in European history that modified crania from archaeological sites in the Migration Period are attributed to the Huns (Anke, 1998; Huck, 2007; Maenchen-Helfen, 1973; Schmidt, 1987; Werner, 1956), even in regions where historic records do not mention the presence of Huns and despite evidence for the practice prior to the arrival of Huns in Europe. This is the case in the Mtskheta region of Georgia. From 2008 to 2011, the University of Melbourne and the Georgian National Museum carried out joint excavations at the 1500 BC to 600 AD burial site of Samtavro and found that roughly 24% of the excavated crania from burials dated to the Migration Period were intentionally modified. Combined with the finding of bronze mirrors, which Werner (1956) suggested are Hunic cultural artifacts, we postulated a Hunic link to the region (Sagona et al., 2010). To test the hypothesis that Huns were present in Georgia we subsequently used eigenshape analysis to compare adult modified crania from the Mtskheta region of Georgia with modified crania from the Carpathian basin around Hungary, where Hunic presence was unambiguous (Mayall, Pilbrow, & Bitadze, 2017). From two-dimensional analysis of the sagittal outline of the cranium, we found that the Hungarian crania were far more constrained in shape during the Migration Period, whereas modified crania from Georgia from the same time-period displayed a variety of shapes. We postulated that the technique of modification in Hungary was under strong social control and involved the use of two bindings, one circular and another vertical, whereas in Georgia, either single or double circumferential bindings resulted in a diversity of modified shapes. Based on this we suggested that other nomadic groups were involved in the practice of intentional cranial modification in Georgia, but Huns had little influence on the practice there.

Juveniles make up 36% of the sample with modified crania from Hungary and they preserve strong signs of the bindings placed in early childhood. In contrast, we do not find juveniles with modified crania in the Mtskheta region of Georgia, although juveniles make up 22% of the skeletal sample in the region (Sagona et al., 2010). The juvenile modified crania from Hungary thus provide a unique means to test the hypothesis that people from the Hunic region of the Carpathian Basin in the Migration Period used a specific two-binding technique, which differed from that in Georgia.

The process of modifying the child’s skull to achieve a desired shape begins at birth. The cranial vault is 25% of adult size at this time (Vinicius, 2005) and the bones are soft and malleable to allow passage through the birth canal. In annular or circumferential binding, caregivers wrap the bandages around the frontal, parietal, and squamous portions of the temporal and occipital bones. These bones are intramembranous in ossification, with most of their growth occurring during the first and part of the second year, when sutures take up the mechanical stress from the growth of the brain, while sutural margins provide sites of bone growth through apposition (Rice, 2008). Caregivers maintain the bindings for the first few years of life while the bones are malleable and sutures unfused (Tiesler, 2014). The pressure from the bindings initiates premature closure of the sutures and changes the normal direction of cranial growth, with compensatory growth occurring perpendicular to the closure (Gerszten, 1993; Gerszten & Gerszten, 1995; Hukki, Saarinen, & Kangasniemi, 2008; Rice, 2008; Tiesler, 2014). Compression in the anterior–posterior and medio-lateral directions in annular or circumferential binding forces growth in a superior direction, resulting in a tall, domed skull. We see such skulls in Georgia during the Migration Period. Modified skulls from Hungary from the same time-period show compression not only in the anterior–posterior and medio-lateral directions, but also in the coronal direction. Thus, they do not have a domed shape. Instead, they show bulging in the region of the parietal squama, suggesting that the adult carers placed a vertical bandage in the region of anterior fontanelle perpendicular to the circular bandages. The juvenile skulls from Hungary display clear depressions in the pathway of the bandages and provide an ideal means to study the technique of modification in the Carpathian basin in contrast with Georgia.

In this study, we use the Evan Toolbox software (http://www.evan-society.org) to quantify cranial shape and study the pathway of the bindings in three dimensions in order to get a fuller understanding of the binding styles. We use Procrustes superimposition to compare the shape of juvenile crania from Hungary with adult crania from Hungary and Georgia. By tracing cranial shape change in an ontogenetic series and studying the correlation between the juveniles and adults in principal components (PCs) defining shape we are able to gain insight into the techniques used in the modification of Hungarian and Georgian adult crania. Generalized Procrustes analysis allows us to exclude differences in the size, orientation, and position of the cranial landmark configurations, and include males, females, and juveniles in the sample, leaving shape as the only remaining variable to be analyzed.

2 | MATERIALS AND METHODS

2.1 | Sample

We studied 25 intentionally modified crania from the Natural History Museum, Budapest derived from eight burial sites (see Map, Figure 1). These included seven juvenile crania and three adult crania from southern Hungary (Keszthely, Mözs, and Mohacs), one juvenile and thirteen adult crania from the north (Velem-Szentvid, Rakoczifalva, Tiszavasvari, Hajdúnánás), and a juvenile cranium from Arad-Gáj (Romania). All samples come from the main regions of Hunic settlements in Hungary and Romania (Sinor, 1990). The individual from Arad-Gáj was placed with the Hungarian samples in Budapest and comes from Transylvania, which was ceded from Hungary to Romania in 1947. We describe these samples as Hungarian based on their current repository.

We focused our analysis on the cranial vault as this is the region of the skull subject to bindings. In order to place landmarks and semilandmarks for Procrustes analysis, the main criterion for sample

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inclusion was a sufficiently intact cranial vault. This allowed us to include several specimens where the cranial base was absent. However, several samples where the cranial vault was incomplete were deemed unsuitable for the study. Thus, of 21 individuals with modified skulls from Keszthely-Fenékpuszta (Pap, 1985), 14 were available to be imaged but only eight were suitable to be included in this study. Mőzs had over 40 modified skulls (Óodor, 2011), of which three were available, but one juvenile was suitable for study. Only single individuals were available to study from Mohacs, Tiszavasvári, Velem-Szentvid, and Arad-Gáj. These sites therefore permit as complete a representation of samples as was possible. Small sample sizes and poor subsampling across sites and age classes are universally acknowledged limitations in studying ontogenetic allometry in archaeological and paleontological contexts, and are likely to produce results with lower statistical power (Brown & Vavrek, 2015). At the same time, ontogenetic series of modified crania provide a unique perspective for studying cultural modification as juvenile crania retain impressions of bindings placed in early childhood. Few previous studies have included such samples. We bear in mind the sampling limitations when interpreting our results and hope that additional studies with augmented samples may help to verify our findings.

We included 21 modified adult crania from Georgia (Figure 2). The Georgian crania came from the region of Mtskheta, studied at the Georgian National Museum’s osteological repository and the History and Ethnographic Institute of Tbilisi. Table 1 provides details on the sites, dental age, sex distribution, and dating information for the samples.

For all juveniles, we estimated age-at-death by the sequence of dental eruption (Buikstra & Ubelaker, 1994). The age of adults was estimated based on the degree of closure of ektocranial sutures (Meindl & Lovejoy, 1985). We assigned the following developmental stages to the dental eruption state: M0: first molars are unerupted, thus individuals below the age of 6; M1: first molars are in full occlusion, but second molars unerupted, thus individuals between the ages of 6 and 12; M2:
## TABLE 1  Materials used in the study

<table>
<thead>
<tr>
<th>Sites</th>
<th>Specimen numbers</th>
<th>Dental age</th>
<th>Dates</th>
<th>M/F</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samtavro</td>
<td>1593, 1594, 1596, 1613, 1618, 1619, 1621, 1632, 1635, 1638, 1880, 1881, 1958, 1964, 2166, 2167, 1973</td>
<td>M3\textsuperscript{a}</td>
<td>4–6 c AD\textsuperscript{b}</td>
<td>5/13</td>
<td>18</td>
</tr>
<tr>
<td>Jinvali</td>
<td>2383, 2020, 2402</td>
<td>M3</td>
<td>4–6 c AD\textsuperscript{c}</td>
<td>0/3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hajdúnás-Furjhalom</td>
<td>151229, 162250, 190280, 273396, 290415, 337493, 355515, 8221072, 8221073</td>
<td>M3</td>
<td>3–5 c AD\textsuperscript{d}</td>
<td>5/4</td>
<td>9</td>
</tr>
<tr>
<td>Keszthely-Fenékpuszta</td>
<td>20092614, 20092612</td>
<td>M3</td>
<td>4–7 c AD\textsuperscript{e}</td>
<td>1/1</td>
<td>2</td>
</tr>
<tr>
<td>Mohacs</td>
<td>5258</td>
<td>M3</td>
<td>5–6 c AD\textsuperscript{f}</td>
<td>0/1</td>
<td>1</td>
</tr>
<tr>
<td>Tiszavasvari</td>
<td>10970</td>
<td>M3</td>
<td>5 c AD\textsuperscript{d}</td>
<td>0/1</td>
<td>1</td>
</tr>
<tr>
<td>Rakoczifalva</td>
<td>200711, 200717</td>
<td>M3</td>
<td>5–6 c AD\textsuperscript{g}</td>
<td>1/1</td>
<td>2</td>
</tr>
<tr>
<td>Velem-Szentvid</td>
<td>5111</td>
<td>M3</td>
<td>5 c AD\textsuperscript{d}</td>
<td>1/0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>8/8</td>
<td>16</td>
</tr>
<tr>
<td>Hungary Juveniles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mözs</td>
<td>11885</td>
<td>M1</td>
<td>5 c AD\textsuperscript{h}</td>
<td>undetermined</td>
<td>1</td>
</tr>
<tr>
<td>Arad-Gáj</td>
<td>110</td>
<td>M2\textsuperscript{a}</td>
<td>5 c AD\textsuperscript{d}</td>
<td>undetermined</td>
<td>1</td>
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<tr>
<td>Rakoczifalva</td>
<td>200713</td>
<td>M0</td>
<td>3–5 c AD\textsuperscript{h}</td>
<td>undetermined</td>
<td>1</td>
</tr>
<tr>
<td>Keszthely</td>
<td>2009265</td>
<td>M2</td>
<td>4–5 c AD\textsuperscript{e}</td>
<td>undetermined</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20092625</td>
<td>M1\textsuperscript{a}</td>
<td>4–5 c AD</td>
<td>undetermined</td>
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</tr>
<tr>
<td></td>
<td>20092627</td>
<td>M1</td>
<td>4–5 c AD</td>
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<td>1</td>
</tr>
<tr>
<td></td>
<td>20092613</td>
<td>M2</td>
<td>4–5 c AD</td>
<td>undetermined</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20092610</td>
<td>M0\textsuperscript{a}</td>
<td>4–5 c AD</td>
<td>undetermined</td>
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<tr>
<td></td>
<td>20092626</td>
<td>M2</td>
<td>4–5 c AD</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>undetermined</td>
<td>9</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Dental age key: M0 (0–6 years); M1 (6–12 years); M2 (12–18 years); M3 (18+ years).

\textsuperscript{b}Sagona et al., 2010.

\textsuperscript{c}Georgia National Museum.

\textsuperscript{d}Hungarian Natural History Museum.

\textsuperscript{e}Heinrich-Tamaska and Schweissing (2011).

\textsuperscript{f}Müller (2011).

\textsuperscript{g}Tóth (2015).

\textsuperscript{h}Odor (1984).

## TABLE 2  Cranial landmarks used in this study

<table>
<thead>
<tr>
<th>Midline</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glabella</td>
<td>The most anterior midline point in the Frankfurt-Horizontal plane</td>
</tr>
<tr>
<td>Bregma</td>
<td>The point of intersection of the coronal and sagittal sutures</td>
</tr>
<tr>
<td>Lambda</td>
<td>The point where the superior nuchal lines meet in the midline</td>
</tr>
<tr>
<td>Inion</td>
<td></td>
</tr>
<tr>
<td>Bilateral</td>
<td></td>
</tr>
<tr>
<td>Supraorbital notch</td>
<td>The point on the superior orbital margin lateral to the supraorbital notch</td>
</tr>
<tr>
<td>Ectoconchion</td>
<td>The point on the lateral margin of the orbit marking the greatest breadth</td>
</tr>
<tr>
<td>Stephanion</td>
<td>The point where the superior temporal line crosses the coronal suture</td>
</tr>
<tr>
<td>Asterion</td>
<td>The junction of the temperoparietal with the lambdoid suture</td>
</tr>
</tbody>
</table>
second molars are in full occlusion, but third molars are unerupted and cranial sutures are unfused, thus individuals between the ages of 12 and 18; M3: third molars are in full occlusion, thus individuals above the age of 18. When the third molars were absent, we assigned individuals to the M3 stage based on cranial suture closure. We estimated sex from features of cranial robusticity (Ascadi & Nemeskeri, 1970). Georgia has a predominance of females with modified heads (76% in our sample), but there is equal representation of males and females in Hungary. Our rationale for including variably represented samples in our study is explained below. The implications of the difference between Georgia and Hungary in age and sex representation of modified crania are addressed in the Discussion. We took the dates for the specimens from museum records based on archaeological contexts, or from radiocarbon dates, as stated in Table 1. We selected specimens specific to the 4th to 7th c AD.

2.2 | Data acquisition

We obtained cranial images using a NextEngine three-dimensional laser scanner, which uses multiple laser stripes to image the object. We used the wide view, which has a resolution of 0.038 cm with 60 points per cm. The surfaces of the specimens were digitalized using 12 landmarks and 251 semi-landmarks (Figure 3). We placed four landmarks in the midline and four bilaterally, making sure we captured locations in the sagittal, coronal, and transverse planes (Table 2). We applied surface semi-landmarks manually to the template, approximately equidistant in concentric curves lateral to the sagittal curve. The lines of semi-landmarks incorporated fixed landmarks where possible (see Gunz, Mitteroecker, & Bookstein, 2005). The number of semi-landmarks used were the minimum required to cover the cranial vault and decipher the shape differences while avoiding redundancies which could make subsequent analyses more complicated and time consuming (Gunz et al., 2005; MacLeod, 2014). We then projected the semi-landmarks onto the target cranial surfaces to which we had previously applied homologous fixed landmarks. We slid the semi-landmarks along tangents to the cranial surface to positions of maximal correspondence to the template bringing them into geometric correspondence with the homologous landmarks of the target specimens (Gunz et al., 2005). When cranial portions were missing, a thin plate spline interpolation was computed from the landmarks and semi-landmarks of the template and the incomplete specimen and mapped onto the incomplete specimen using the sliding step to minimize bending energy between the two (Gunz & Mitteroecker, 2013). We then imported the information regarding the landmark configurations of the specimens into a virtual program network (vprn) in Evan Toolbox for Generalized Procrustes superimposition and visualization of the shape changes in the modified specimens by warping exemplar specimens along the principal axes of variation.

2.3 | Shape analysis

After the cranial shapes had been standardized with Procrustes superimposition to eliminate differences in the size, orientation, and position, we used a principal components analysis to assess the relative shapes of the Georgian and Hungarian adult and the Hungarian juvenile specimens. The centroid of each configuration was calculated as the point at the mean values of the x, y, z co-ordinates of all the landmarks. The centroid size was determined as the square root of the summed squared distances of each landmark to the centroid. Position was standardized by centering the centroids of each landmark configuration at zero. Orientation was standardized by rotating the landmark configurations to minimize the total distance between homologous landmarks. Size was standardized by scaling the centroid size of each landmark configuration to one. This left shape as the only parameter to be analyzed (Zelditch, Swiderski, Sheets, & Fink, 2004). This procedure of standardizing position, orientation, and size allowed us to include samples encompassing a range of cranial sizes and degrees of robusticity, thus individuals covering ontogenetic stages from juveniles to senile adult males and females. Individual PC axes accounted for the shape variation described by multiple landmarks, reducing the number of variables to be assessed. The Evan Toolbox program derives the value of each PC from a variance-covariance matrix (see Zelditch et al., 2004). The first PC axis (PC1) accounted for a major percentage of the shape variance, with subsequent PCs progressively less. until 100% of the shape variance had been included. We used plots of the first two PCs to demonstrate the relationship of the adult and juvenile crania from Hungary and those from Georgia.

To further examine group separation and get a quantitative assessment of the degree of crossover between the Georgian and Hungarian adult crania and between these and the Hungarian juvenile crania, we subjected the PCs to a discriminant function analysis. We used a step-wise procedure to select the PCs that produced the best discrimination so that only variables that were highly significant in discriminating groups were selected in an iterative manner (p < .01 for F-value of variable to be entered, p < .10 for F-value of a variable to be removed). No more than six PCs covering 56% of the total variance were used in the analysis.

We used regression analysis to explore the ontogenetic correlation between juvenile Hungarian cranial shape and adult Hungarian and Georgian cranial shape. To assess the fraction of shape variance explained by growth and development, we regressed Procrustes...
distance (PD) against centroid size (as a measure of cranial growth), and dental age (as a measure of age), quantified by the $R^2$ value (Zelditch et al., 2004). PD provides a measure of shape variation for each specimen and is the sum of the distances between homologous landmarks between each specimen and the reference specimen, after Procrustes superimposition. The reference specimen used was the one with the lowest value for the independent variable being assessed. PD was the dependent variable with centroid size and age serving as independent variables. The logarithm of centroid size was used because most of the variation in shape was seen in the smaller values of centroid size (Zelditch et al., 2004).

The cranial shapes were then visualized in Evan Toolbox by warping the individual landmark configurations onto a template (Weber & Bookstein, 2012). Moving the cursor along a PC in the graph plotter progressively warps the underlying landmark configurations and generates a surface in the viewer, giving a clear picture of the shape variation described by each PC.

### 3 | RESULTS

#### 3.1 | PC analysis

Forty-six PCs capture the differences in cranial shape in the Hungarian and Georgian adult and Hungarian juvenile crania. The first two PCs account for 29% and 15% of the shape variation, respectively. Figure 4 plots the crania on the first two PCs. Convex hulls display the cut-off points between the groups. Example crania show the extent of shape variation. The scatter diagram shows wide variation in shape of the Georgian crania compared with the Hungarian adult and juvenile crania. The Georgian crania vary from long and low at the negative end of the

**TABLE 3** Discriminant analysis classification accuracy with cross-validation

<table>
<thead>
<tr>
<th>Group</th>
<th>Hungary juveniles</th>
<th>Hungary adults</th>
<th>Georgia adults</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hungary juveniles</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>88.9</td>
</tr>
<tr>
<td>Hungary adults</td>
<td>0</td>
<td>15</td>
<td>1</td>
<td>16</td>
<td>93.8</td>
</tr>
<tr>
<td>Georgia adults</td>
<td>0</td>
<td>1</td>
<td>20</td>
<td>21</td>
<td>95.2</td>
</tr>
</tbody>
</table>

Cross-validation

<table>
<thead>
<tr>
<th>Group</th>
<th>Hungary juveniles</th>
<th>Hungary adults</th>
<th>Georgia adults</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hungary juveniles</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>88.9</td>
</tr>
<tr>
<td>Hungary adults</td>
<td>0</td>
<td>14</td>
<td>2</td>
<td>16</td>
<td>87.5</td>
</tr>
<tr>
<td>Georgia adults</td>
<td>1</td>
<td>1</td>
<td>19</td>
<td>21</td>
<td>90.5</td>
</tr>
</tbody>
</table>
first PC to narrow and tall at the positive end. The adult Hungarian crania have a relatively small range of shape variation. In spite of the small number of juvenile Hungarian crania the variation in shape is quite extensive. The Hungarian adult and juvenile crania cluster around PC2 and are characterized by post-coronal flattening and bulging parietals. Several Georgian crania also fall into this morphospace.

### 3.2 Discriminant analysis

A step-wise discriminant analysis selected six PCs to provide the best separation with cross-validation (Table 3). When three groups, Hungarian juveniles, Hungarian adults, and Georgian adults, were used in the analysis overall accuracy of classification was 93.5% (89.1% in cross-validation). When the procedure was repeated in an attempt to classify the Hungarian juveniles in a post hoc manner based on the discriminant functions of the Hungarian and Georgian adults, six (67%) of the Hungarian juveniles were attributed to Hungarian adults despite greater shape variation and sample size of the Georgian adults (Table 4). This shows similarity in cranial shape between the Hungarian juveniles and adults.

### 3.3 Ontogenetic allometry

An analysis of variance (ANOVA) showed significant correlation \( (p < .05) \) between PD, as consensus shape, cranial growth characterized by the natural logarithm of the centroid size (lnCS), and dental age, as a proxy for development (Table 5). In a regression of cranial shape against cranial growth there was stronger linear relationship between Hungarian juvenile and adult crania, with an \( R^2 \) value of 0.352, than between Hungarian juvenile and Georgian adult crania, with an \( R^2 \) of 0.269. Figure 5 shows the scatter plot of PD against lnCS for Hungarian juveniles of dental ages M0–M2, Hungarian adults of M3 dental age (Figure 5a), and Georgian adults of M3 dental age (Figure 5b). The Hungarian juveniles and Georgian adults have strong variation in lnCS, but not so the Hungarian adults. Dental age provides a stronger variable than lnCS for simulating ontogenetic trajectory (Simons & Frost, 2016) and returned a stronger \( R^2 \) correlation of 0.467 for the Hungarian juvenile and adult crania, than the Hungarian juvenile and Georgian

### Table 4

Discriminant analysis classification accuracy, with Hungarian juveniles classified post hoc

<table>
<thead>
<tr>
<th>Group</th>
<th>Hungary adults</th>
<th>Georgia adults</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
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<td>Hungary adults</td>
<td>14</td>
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<td>16</td>
<td>87.5</td>
</tr>
<tr>
<td>Georgia adults</td>
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<td>20</td>
<td>21</td>
<td>95.2</td>
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<tr>
<td>Hungarian juveniles</td>
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<td>3</td>
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<table>
<thead>
<tr>
<th>Group</th>
<th>Hungary adults</th>
<th>Georgia adults</th>
<th>Number</th>
<th>Percentage</th>
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<tbody>
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<td>Hungary adults</td>
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<td>2</td>
<td>16</td>
<td>87.5</td>
</tr>
<tr>
<td>Georgia adults</td>
<td>2</td>
<td>19</td>
<td>21</td>
<td>90.5</td>
</tr>
</tbody>
</table>

### Table 5

Correlation between Procrustes distance as dependant variable and proxies for ontogenetic trajectories as independent variables

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Hungarian juveniles and Hungarian adults</th>
<th>Hungarian juveniles and Georgian adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( F )-statistic</td>
<td>( p )-value</td>
</tr>
<tr>
<td>Natural log centroid size</td>
<td>12.47</td>
<td>.002</td>
</tr>
<tr>
<td>Dental Age</td>
<td>20.19</td>
<td>.00</td>
</tr>
<tr>
<td>Dental age with natural log of centroid size as covariate</td>
<td>10.80</td>
<td>.04</td>
</tr>
</tbody>
</table>

**Figure 5**

Regression of PD by natural log of centroid size. (5A) Hungarian juveniles and Hungarian adults. (5B) Hungarian juveniles and Georgian adults
adult crania, which returned an $R^2$ of 0.363 (Table 5). A correlation of PD and dental age with lnCS as a covariate increased the correlation to $R^2$ of 0.684 for the Hungarian juvenile and adult crania and $R^2$ of 0.61 for the Hungarian juvenile and Georgian adult crania. A plot of dental age against estimated marginal means of PD demonstrated that most shape change occurred during the period of rapid cranial growth, during the M0–M1 dental age period (0–6 years), with further change occurring up to M2 (6–12 years), after which there was little change leading to M3 (above 18 years) (Figure 6). Although the Georgian adults have a higher range and standard deviation in PD values (Figure 7), the mean PD values do not differ significantly between the Georgian and Hungarian adults. Our results of stronger correlation between the Hungarian juveniles and adults in analyses of ontogenetic allometry should nevertheless be treated with caution given our relatively small sample of juveniles.

3.4 | Warping in Evan Toolbox

The shape differences in modified crania are revealed with Evan Toolbox by warping along the PC axes. The three-dimensional landmark configurations at each point are applied to a template which then displays the modified shape as denoted by PC1 and PC2 at that point. Warping along PC1 from +0.1 to −0.1 demonstrates the transition in shape from a simulated juvenile to a simulated adult cranium along that axis (Figure 8). The sagittal view shows that the frontal and occipital regions of Hungarian juvenile crania have a steep angle as a result of the anteroposterior binding. These areas become less steep and more rounded in the adult cranium after the age when the binding has ceased. The axial view reveals the biparietal diameter to be wide in the juvenile crania as a result of the second vertical binding producing compensatory expansion in the parietal regions but this is reduced in the adult cranium. Similarly, an expansion of the postorbital region due to the vertical binding is noted in the juvenile crania causing a reduction in the postorbital constriction in these as compared to the adult crania. While the warping is visualized on a template in Evan Toolbox, the ontogenetic shape changes can also be appreciated by comparing photographs of actual Hungarian juvenile and adult crania, as shown in Figure 9.

The depressions on the cranial bones allow us to interpret how the bindings were applied to produce the modified shapes. We selected four crania from Georgia and four from Hungary to depict the variety of modified cranial shapes (Figure 10). Georgian crania such as 1880 and 2383 appear to be modified by one or two encircling bindings extending from the frontal to the occipital regions. Grooves from the bandages are visible on the frontal, parietal, and occipital bones. This form of modification, termed the annular type (Dembo & Imbelloni, 1938; Zhirov, 1940) is maintained by placing tight bandages high or low on the frontal and occipital regions, which results in the head appearing tall and domed or low and sloping. Specimen 1958 in Figure 4 also demonstrates this modification. Most of these crania are visually striking. There is marked compensatory expansion superiorly or obliquely posteriorly allowing the brain to grow toward the uncompressed regions of the skull (Tiesler, 2014). Other crania from Georgia, such as 1618 and 2402 (Figure 10) are flattened in the region of bregma, suggesting the presence of a second binding. The obliquely oriented frontal and vertically oriented occipital in 1618 may have been produced by stiff compression boards or bandages, which may be described as coronal-occipital (Zhirov, 1940) or tabular modification (Dembo & Imbelloni, 1938). A post-coronal bandage ensures that the
head is not too tall. The Georgian crania flattened in the region of bregma are similar to those from Hungary (Figure 10, 11885, 20092613, 337493, 355515). These are modified with two bindings, the first placed antero-posteriorly and the second extending from the post-coronal region over the temporal bones bilaterally to the angle of the mandible. This produced flattening of the frontal bone with a fairly steep gradient, flattening of the occipital region, as well as post-coronal flattening and depressions of the temporal bones laterally with bilateral compensatory expansion of the parietal bones in the line of the binding. Crania such as 20092613 and 337493 show the typical uniform shape for the Hungarian crania (see other examples in Figure 4). There are, however, some severely modified crania in this group. The juvenile cranium 118855 has strong impressions of annular and coronal bindings resulting in a bilobed appearance and bulging parietales. The adult specimen 35515 similarly has a bilobed appearance, albeit less severe. This individual also displays an oblique frontal and vertical occipital region and deep marks from pressure pads on the parietal bosses. The groove from the post-bregmatic binding is also clearly visible. Figure 11 shows these crania in superior view.

Our study demonstrates the utility of a geometric morphometric approach in detecting shape differences in intentionally modified crania from Georgia and Hungary and between juvenile and adult Hungarian crania. Using surface landmarks and semi-landmarks from three dimensions, we were able to show that crania from Hungary during the Migration Period were modified in a uniform manner compared with modified crania from Georgia. This result reinforced our previous findings from two-dimensional outline analysis (Mayall et al., 2017).

Warping the mean cranial shape along the PC axes revealed the transformation from the juvenile to adult modified crania associated
with anterior–posterior and superior–inferior bindings resulting in a bilateral expansion in the region of the parietals (Figure 8). The bindings in the juveniles leave exaggerated depressions in the pathway of the bandages (Figures 9–11). This is because the cranial bones in juveniles are soft and unilaminar and the bones are not completely mineralized. The trabecular structure with the diploe in between the outer tables is not visible until the fourth year (Lieberman, 2011; Rice, 2008; Standing, 2008). As a result, juvenile cranial bones have greater plasticity and are susceptible to alteration from compression. The pathway of the bandages as seen in sagittal and superior views supports our previous hypothesis (Mayall et al., 2017) that cranial modification in Hungary during the Migration Period was predominantly done using two bandages. Pap (1984, 1985) has previously described this type of modification for the crania from Hungary.

The regression analyses of the Hungarian adult and juvenile modified crania confirmed that the period of greatest cranial shape variation corresponds to the early period of life during the time of rapid cranial growth. This is also the period in which bindings are applied to the crania. Tiesler (2014) states that cranial modification is possible only during the period of active cranial growth, principally during the first two years of life as after this time growth of the cranial vault occurring at the sutures ceases. By incorporating ontogenetic series of modified crania into our study, we find, however, that we are able to offer a slightly different perspective. Limited cranial shape variation across several Hungarian sites and age classes, and over a long period of time suggests that we are observing a consistent pattern. Although larger sample sizes for each age group and site are needed to substantiate our findings, we see rapid shape changes to the cranial vault from birth to the eruption of first molars at six years (Figure 6). Following this, there are slight shape changes until the eruption of the second molar at about 12 years, and then further changes take place until the eruption of third molars in adulthood. Our observations fit the growth trajectory of the cranial vault paralleling the growth of the brain (Lieberman, 2011). By the time of the eruption of the first molar at around six years, 95 percent of brain growth is complete, followed by slower growth of the vault during the juvenile period until the eruption of the second molar and more rapid growth until the eruption of the third molar in adolescence (Lieberman, 2011). Ross and Williams (2010) found small changes in cranial vault dimensions from the age of 14 to 20, but significant vault changes in the 25- to 40-year range. Previous studies also found considerable variation in the pattern and degree of cranial suture closure at the endocranial and ectocranial surfaces, with sutures sometimes remaining patent even into the third and fourth decades of life (Aiello, & Molleson, 1994; Albert, Ricanek, & Patterson, 2007; Baer, 1956; Kendrick & Risinger, 1967; Key, Aiello & Molleson, 1994; Perizonius, 1984; Thompson & Kendrick, 1964; Vijaya Kumar, Agarwal, Bastia, Shivaramu, & Honnunagar, 2012). There is also evidence that the biological process of bone absorption and deposition remodel the cranial bones and change the thickness and shape of the cranial vault well into the sixth decade of life (Albert et al., 2007;
of Turkic and Scytho-Sarmatian groups (Czeglédy, 1983) around 370 AD from the East and were themselves a conglomeration of Romanized populations, as well as the Huns, who arrived in Hungary in the Migration Period of Europe. This is seen in the stylistic homogeneity in cranial modification in Hungary. The correlation we found between juvenile and adult modified cranial shape is unlikely to be due to genetic affiliation because diverse socio-cultural groups were present in Hungary during the Migration Period. Historical sources mention the presence of Germanic groups, including Goths, Gepids, Langobards, Indo-Iranian nomadic tribes such as Sarmatians and Alans, pre-existing Romanized populations, as well as the Huns, who arrived in Hungary around 370 AD from the East and were themselves a conglomeration of Turkic and Scytho-Sarmatian groups (Czeglédy, 1983; Hancock, 2013; Kelly, 2015; Kim, 2013; Sinor, 1990; Vaissière, 2015).

Putting together the historical references and archaeological evidence it is reasonable to assume that the Huns promulgated the practice of cranial modification in the region at this time. Their arrival in the Carpathian basin marks a dramatic and definitive turning point in the history of Hungary, the Roman Empire, and Europe (Kim, 2013; Sinor, 1990), setting in the motion the great migrations of the Germanic and Eurasian nomads and ultimately destabilizing the Roman Empire (Halsall, 2005, 2007; Heather, 2015). While historians are unclear on whether the Huns picked up the practice on their journey to Europe from other groups such as the Alans, or carried the practice from their roots in Mongolia and Inner Asia, it is certain that they had modified heads by the time they arrived in the Pontic steppe (Czeglédy, 1983; Maenchen-Helfen, 1958, 1973; Sinor, 1990). Upon their arrival, the practice became extremely prevalent in Hungary, modified crania making up to 80 percent of the crania in grave sites during the Migration Period (Fóthi, 2000; Hakenbeck, 2009; Kiszely, 1978; Pap, 1984, 1985; Torres-Rouff & Yablonsky, 2005). Although the political dominion of the Huns in Hungary was fairly short-lived, from about the 370s to the 460s (Kim, 2013; Vaissière, 2015), the practice of cranial modification in Hungary continued at least until the 7th c AD under the political sway of other nomadic groups such as the Goths, Gepids, Langobards, and Avars (Molnár, János, Szucs, & Szathmáry, 2014). The practice was widely adopted and maintained within the local community in Hungary as is evident from the incidence of modified crania from all age groups, neonates to senile adults, and an equal representation of males and females. It appears that several social groups in the region shared a social identity by following the same style of cranial modification over nearly three centuries despite political turnover. This attests to the influence of the Huns in consolidating this identity. The influence of the Huns long after their official political power had declined can best be appreciated if we consider that Western and Byzantine chroniclers anachronistically attributed several later events in the history of Europe and Hungary to the Huns (Czeglédy, 1983; Sinor, 1990).

Cranial modification in the Mtskheta region of Georgia in the Migration Period provides a counterpoint to the practice in Hungary. There are examples of modified heads in the Bronze Age, but these are sporadic and isolated compared with the proliferation after the 4th c AD, when modified crania make up about 24% of the crania from grave sites in Mtskheta. The increase in incidence can reasonably be associated with the Migration Period, but the diversity in modified cranial shape compared with Hungary suggests that a distinct set of social influences were operating in Georgia at this time. Indeed, historical references are equivocal about the presence of Huns in Georgia, but the presence of Alans and Sarmatians is consistently recorded (Alemany, 2000; Furtwängler, Gagoshidze, Lühr, & Ludwig, 2008; Rapp, 2003; reviewed in Mayall et al., 2017). Alans and Sarmatians were assimilated into the Hunnic ranks in Hungary (Hancock, 2013; Sinor 1990), but in Georgia the variation in modified cranial shape may suggest that they were forging a distinct social identity. The Alans eventually formed the kingdom of Alania (present-day Ossetia) in northern Georgia (Borjian, 2006). Different styles of modification among groups in close proximity highlight the value of ethnicity as “a social construct used to amplify cultural distinctions that are overlaid on biologically similar populations” (Torres-Rouff & Yablonsky, 2005, p 3). The presence of predominantly adult females with modified heads and the absence of modified heads in the large sample of juveniles is difficult to interpret, but suggests that cranial modification was a non-local practice in Mtskheta and the females were migrants who did not extend the practice of cranial modification to the next generation. Hakenbeck (2009) similarly postulated the practice of female exogamy for Migration Period sites in Germany, where there is predominance of females and absence of juveniles with modified heads. Further studies involving cultural artifacts, genetic material, and strontium and oxygen isotope ratios may help to determine the original location of these individuals.

The social significance of cranial modification in the Migration Period of Europe is similar to that in South America and Mesoamerica, where cranial modification was practiced for several thousand years (Tiesler, 2012). Researchers were able to identify temporal changes in modification styles, evidence for solidarity in tight regional groups where there was little variation in cranial shapes, and the presence of mixed urban groups where diverse modification styles provided fluid boundaries between groups (Blom, 2005; Perez, 2007; Torres-Rouff, 2002).

5 | CONCLUSIONS

The Migration Period is acknowledged to be a formative period in the history of Eurasia. Historians have largely relied on contemporary historical and linguistic sources to reconstruct this time-period with little reference to the archaeological record (Frachetti, 2011; Goffart, 2006). The bioarchaeological evidence as portrayed by the distinctive skeletal mark of modified crania adds a new dimension to understanding social interactions during this time-period (Anke, 1998; Hakenbeck, 2009; Huck, 2007; Kiszely, 1978). In this study, surface analysis helped to provide a more comprehensive assessment of the cranial shape...
differences between regions, which confirmed that Georgian and Hungarian crania were modified using different methods. By incorporating juvenile crania in the study, we demonstrated that the Hungarian crania were modified using a uniform technique of two bandages, which constricted cranial shape, whereas Georgian crania were bound using several techniques, which resulted in a variety of cranial shapes. Regression analyses confirmed that the major shape alteration occurred during the first few years of life, during the period of rapid cranial growth but there was some reversal to the unmodified shape in adulthood after the bindings had been removed. Intentional cranial modification was widespread in Europe during the 4th to 7th centuries and was used as a permanent and highly visible form of social identity.

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ORCID

V. Pilbrow  http://orcid.org/0000-0002-6677-9390

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Chapter 6

A review of the practice of intentional cranial modification in Eurasia during the Migration Period (4th – 7th c AD)

The practice of intentional cranial modification was known in Eurasia since the Bronze Age. It intensified during the Migration Period (4th – 7th c AD) coinciding with the arrival of Huns in the Carpathian basin. The resurgence in the practice has been attributed to the Huns even in regions removed from the Huns in geography and time. As highly visual symbol, cranial modification clearly played an important role in negotiating social identity during the movement of nomadic tribes in the Migration Period. The purpose of this paper is to compare styles of modification in regions across Eurasia to determine the role of cranial modification in conveying different identities. Three-dimensional landmark coordinates were used in a geometric morphometric analysis to compare the shape of 23 modified crania from The Republic of Georgia, 17 from Hungary, 13 from Germany, two from The Czech Republic, one from Austria and one from Crimea. A generalized Procrustes analysis was used to standardize size differences and reveal shape differences. Results from principal components and discriminant analysis reveal significant differences in the style and shape of cranial modification among Georgia, Hungary and Germany. A review of the tomb types, burial assemblages and historical records brings up a complex pattern of multiple nomadic groups involved in the practice of cranial modification in each region. In Hungary the style of modification was homogeneous and the practice was local in origin. In Georgia and Germany individuals with modified crania were migrant and did not perpetuate the practice in their new homeland. We suggest that the resurgence of the practice during the Migration Period was initiated by the Huns as a means to maintain central control using a visual form of social identity. This was emulated by other nomadic groups acknowledging the importance of the practice for conveying social identity at boundaries.
A review of the practice of intentional cranial modification in Eurasia during the Migration Period (4th – 7th c AD)

P. Mayall¹, V. Pilbrow¹

University of Melbourne, Parkville, Victoria, Australia, 3000.

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Corresponding author:

Varsha Pilbrow, The University of Melbourne, Parkville, Victoria, Australia, 3000

Phone: +61383445775

Fax: +61393475219

Email: vpilbrow@unimelb.edu.au

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Abstract

The practice of intentional cranial modification was known in Eurasia since the Bronze Age. It intensified during the Migration Period (4th – 7th c AD) coinciding with the arrival of Huns in the Carpathian basin. The resurgence in the practice has been attributed to the Huns even in regions removed from the Huns in geography and time. As highly visual symbol, cranial modification clearly played an important role in negotiating social identity during the movement of nomadic tribes in the Migration Period. The purpose of this paper is to compare styles of modification in regions across Eurasia to determine the role of cranial modification in conveying different identities.

Three-dimensional landmark coordinates were used in a geometric morphometric analysis to compare the shape of 23 modified crania from The Republic of Georgia, 17 from Hungary, 13 from Germany, two from The Czech Republic, one from Austria and one from Crimea. A generalized Procrustes analysis was used to standardize size differences and reveal shape differences. Results from principal components and discriminant analysis reveal significant differences in the style and shape of cranial modification among Georgia, Hungary and Germany.

A review of the tomb types, burial assemblages and historical records brings up a complex pattern of multiple nomadic groups involved in the practice of cranial modification in each region. In Hungary the style of modification was homogeneous and the practice was local in origin. In Georgia and Germany individuals with modified crania were migrant and did not perpetuate the practice in their new homeland. We suggest that the resurgence of the practice during the Migration Period was initiated by the Huns as a means to maintain central control using a visual form of social identity. This was emulated by other nomadic groups acknowledging the importance of the practice for conveying social identity at boundaries.
**Introduction**

Cranial modification is a unique way of conveying social identity because the modified head provides a powerful visual symbol, but the individual is not consulted in the practice, as parents or care givers modify the infant’s head into a desired shape within the first few years of life when the bones are soft and undergoing rapid growth. The practice has been recorded in all parts of the world over several millennia (Dingwall, 1931; Kiszely, 1978; Brown, 1981). It has a long history across the Eurasian steppes extending from the Bronze Age (3000 – 1000 BC) to the Medieval Period (5th – 15th c AD) and covering Western Asia to the Carpathian Basin, including the northern and southern Caucasus. Torres-Rouff and Yablonsky (2005) provide references to modified crania in Bronze Age sites associated with the Catacomb culture (2000 – 1000 BC) in the Eurasian steppes and southern Turkmenistan. Field (1953) investigated modified crania from Nalchik in the Northern Caucasus dated from the 11th to 12th c BC. Ginsburg (1968) mentions occurrences in the Volga and Kuban areas of the Soviet Union. Kiszely (1978) describes modified crania from Bronze Age sites in Hungary. In our investigation, we encountered intentionally modified crania from Bronze Age sites in Georgia. It is unclear if the practice arose sporadically and independently in each of these regions, but Kiszely (1978), who surveyed the practice in Eurasia from 6000 BC to 700 AD, suggested that it originated in Southwest Asia. Indeed, there are earlier and higher incidences of the practice in Palestine, Lebanon, Syria, Iraq, and Iran in the Bronze Age (Kiszely, 1978; Meiklejohn et al., 1992; Özbek, 2001).

In each of these regions, after the initial appearance of modified crania in the Bronze Age, the practice disappeared for over a half a millennium to reappear during the Iron Age (700 – 500 BC). Evidence is found in Kazakhstan, 700 – 500 BC, Kyrgyzstan, 600 – 300BC, Uzbekistan, 300BC – 500 AD, and later in the Volga region north of the Black sea, 100BC – 400AD (Papp, 1985; Shvedchikova, 2009; Torres-Rouff and Yablonsky, 2005). During this time the practice is associated with the Scythians, Sarmatians and Alans (Ginsburg, 1968; Melyukova and Julia, 2008; Torres-Rouff and Yablonsky, 2005). The Scythians established their dominion over the steppe regions from the 7th to the 3rd centuries BC (Melyukova and Julia, 2008). The Sarmatians were Iranian nomadic tribes, related to the Scythians, who formed from the Sauromatae in the foothills of the Urals and from the 3rd c BC moved to the Volga and North Black sea regions and south into the Northern Caucasus (Sinor, 1990). In Hungary, a small number of modified crania have been recovered from first century Sarmatian burials along the Tisza river in Hungary and on the right bank of the Danube (Hakenbeck, 2011). Later, from the 2nd – 3rd centuries AD, kurgan burials found in the north Caucasus containing modified skulls have been attributed to the Alans, a later branch
of the Sarmatians, who dominated the region from the first century AD (Sinor, 1990; Abramova, 1995). As occurred in Central Asia, we found modified crania reappearing in Georgia in the 6th c BC after a lapse of about 600 years. These fit with historical records of the role of Sarmatians and Alans in assisting rulers of the Iberian Kingdom in Georgia (Alemany, 2000; Fürtwangler et al., 2008).

During the Migration Period of Europe (4th to 7th c AD) the practice of cranial modification increased greatly in prevalence. This was a time of great political, religious, population and economic change in Europe (Kim, 2013) and is marked by mass migrations of nomadic tribes into and around Roman territory (Halsall, 2007). The Romans withdrew from the eastern provinces in the 4th c AD ahead of the collapse of the Western Roman Empire allowing the Goths to control Pannonia (Heather, 2009). The Huns, who originated from Mongolia arrived in the province by the mid-fourth century and established their base in the Hungarian plain and eastern Romania after crushing the Goths, Sarmatians and Alans (Kim, 2013; Vaissière, 2015). The displaced Goths and many of the Alans fought for entry into Roman territory at the battle of Adrianople, which marks the start of the Migration Period (Halsall, 2007; Heather, 2015). Following this, there was a surge of people from north of the Danube and the Eurasian steppes into eastern and central Europe (Heather, 2009). A sharp rise in the incidence of modified crania in Europe during this time, particularly in the Carpathian Basin, which was the administrative base of the Huns, coupled with the immense influence of the Huns on the political events of Europe led to the belief that cranial modification in Migration Period Europe was primarily a Hunnic cultural practice. This belief was further fueled by the perception that burials with modified crania held Hunnic grave goods, such as broken bronze mirrors (Werner, 1956; Kiszely, 1978; Pap, 1983, 1984; Föthi, 2000; Torres-Rouff and Yablonsky, 2005; Hakenbeck, 2009). Closer scrutiny reveals that the exclusive association of intentional cranial modification with the Huns during the Migration Period is not straightforward. The practice was prevalent in the Eurasian steppes prior to the arrival of the Huns, as documented, and modified crania are evident throughout Europe during the Migration Period, even in regions where the presence of the Huns is not known.

In the Mstkheta region of Georgia there was significant increase in the number of modified crania after the 4th c AD, although historical records do not document the presence of Huns in Georgia. As the particular shape of the cranial vault signifies social identity, we previously compared the outline of the modified cranial vault in Georgia with that in Hungary, the administrative center for the Huns, to test for the presence or cultural influence of Huns in Georgia (Mayall, Pilbrow and Bitadze, 2017). We found limited variation in shape of cranial outline in Hungary, but greater variation in Georgia. Using juvenile
cricia from Hungary that clearly preserve the impressions of the tight bindings placed while the bones are still soft, we further verified that the limited variation in shape in Hungary was achieved using two perpendicular bindings in an annular style of modification, while in Georgia there was additional use of concentric annular bindings leading to greater variation in adult cranial shape (Mayall and Pilbrow, 2018). Thus, these studies do not support the presence of the Huns in Georgia during the Migration Period. Nonetheless, the sporadic rise in the incidence of modified crania in Europe even in regions removed from the presence of the Huns highlights that the practice served an important function in negotiating social identity among nomadic groups during the turbulent times of population movement. The importance of the practice as cultural currency for promoting social identity, conveying aesthetic values and determining social boundaries among diverse groups is previously attested (Gerszten, 1993; Torres-Rouff, 2002; Tiesler, 2012, 2014; Blom, 2005). In Central and South America, where cranial modification was ubiquitous for several thousand years (Tiesler, 2012), an assessment of modification styles helped to identify temporal changes in styles, evidence for solidarity in tight regional groups, and the presence of mixed urban groups where diverse modification styles provided fluid boundaries between groups. The situation with cranial modification in the Europe and the Eurasian steppes in the Migration Period is similar to that in the Americas, but with the added social impetus of maintaining social identity while migrating and encountering other nomadic groups. There has been significant research into the practice in Europe (Werner, 1956; Maenchen-Helfen, 1958; Kiszely, 1978; Pap, 1983, 1984, 1985; Fóthi, 2000; Torres-Rouff and Yablonsky, 2005; Pany and Wiltschke-Schrotta, 2008; Hakenbeck, 2009); however, a comparative analysis of the shape of the cranial vault in defining social identity has not been undertaken. Our purpose in this paper is to compare the shape of the cranial vault in modified adult crania from several European sites including Germany, Austria, the Czech Republic, Crimea, Georgia and Hungary to determine similarities and differences in modified crania in the Migration Period. This may help us understand why the practice grew in prominence during this time and how variations on the same cultural practice were used to convey different identities. We use 3D surface analysis as it provide a more effective means to study the cranial vault in multiple orientations.

Materials and methods

Materials

A total of fifty-seven adult modified skulls from Georgia, Hungary, Germany, Austria, Crimea, and the Czech Republic were examined for this analysis (Fig 1., Table 1). Based on sexually dimorphic characters of the cranium (Ascadi and Nemeskeri, 1970), 70% of the crania from Georgia were identified as female,
and 59% of crania from Hungary were female. In Bavaria the sample was almost entirely female (92%). The small samples from the Czech Republic, Crimea and Austria were also identified as female. The sex distribution is partly a sampling bias where crania suitable for study were female, but Georgia and Bavaria also exhibit an inherent bias towards females in their sample of modified crania, which has been attributed to female exogamy (Hakenbeck, 2009; Mayall and Pilbrow, 2018). We address this further in the Discussion. The sites were dated by radiocarbon dates or archaeological context (Müller, 2003a, b; Tóth, 2003a, b; Sagona et al., 2010; Hakenbeck, 2011; Heinrich-Tamáska and Schweissing, 2011; Ódor, 2011).

Figure 1. Map of Europe showing location of sites for modified crania in this study

Twenty-three Georgian crania from three localities in Mtskheta, Samtavro, Nabagrebi, and Jinvali were studied at the permanent osteological repositories of the Georgian National Museum in Mtskhe and the Ivane Javakhishvili Institute of History and Ethnology, University of Tbilisi. They all come from the Migration Period, when there was a surge in the practice of cranial modification and 24% of the skulls from Mtskheta were found to be modified. Most were recovered from stone cist and earthen pit burials.
Cist burials were built from roughly hewn sandstone, while earthen pit burials were capped with sandstone or tile markers (Sagona et al., 2010). These were the most common burial types in Mtskheta after the 3rd c AD. Most of these tombs contained the remains of multiple individuals, although individuals with modified crania were also found buried alone. One individual came from a tile-lined plinth burial. This burial type was common during the period of the Roman influence in Georgia, from 2nd to 4th c AD, but uncommon after the 4th c AD (Sagona et al., 2010).

Seventeen Hungarian modified crania derived from the permanent repository of the Natural History Museum in Budapest came from the sites of Keszthely-Fenékpuszta, Hajdúnánás-Furjhalom, Mohacs, Mözs, Rakoczifalva, and Velem-Szentvid. The ancient burial ground at Keszthely Fenékpuszta, outside the south wall of a former fortified Roman settlement is typical of those in Hungary. It had thirty-one graves of which seventy-seven per cent of the individuals had intentional cranial modification (Papp 1983, 1984). The graves were either deep shafts or pits with a niche on one side (Muller, 2003). The 5th century cemetery at Mözs had ninety-six graves of which three were pits with a side niche, ten were brick structures and the remainder, rectangular shafts. Forty-two per cent of the Mözs’ skeletons had intentionally modified skulls including both men and women (Ódor, 2011).

The Altenerding and Straubing burial sites in Bavaria dated from the 5th to the 6th c AD (Hakenbeck, 2011) yielded thirteen modified crania for this study. These were studied at the Natural History Museum in Munich. The remains come from row grave cemeteries, which were common in Germany during the Migration Period (Effros, 2003). The Altenerding and Straubing sites are extensive and almost completely excavated. Modified crania are rare. Altenerding has 1400 graves with only five individuals having modified crania. In Straubing there are 800 graves from which eleven modified crania were recovered (Hakenbeck et al., 2010).

Isolated crania from other sites, two from the Natural History Museum in Vienna, one from Crimea and two from the Natural History museum in Brno (Czech Republic) were also included. Little contextual information on sites or burial types is available for the skulls from Crimea and Brno, but the cranium from Vienna came from an earthen pit burial identified as a Longobard cemetery of Wien-Mariahilfer Gürtel (Tobias et al., 2010).

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<td></td>
<td></td>
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<td>Vienna</td>
<td>8686</td>
<td>5 – 6 c AD</td>
<td>1</td>
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</table>
Methods

The crania were scanned using a NextEngine 3D laser scanner (http://www.nextengine.com/). It uses 60 scan points per centimeter to generate a dense cloud of points, which is then rendered into a 3D model using the in-built software package ScanStudio. The scans were imported into Evan Toolbox (http://www.evan-society.org) and the surfaces of the specimens were digitized using twelve landmarks and 251 semi-landmarks (Fig. 2). The landmarks, as defined by Steele and Bramblett (1998), include: glabella, bregma, lambda, inion, supraorbital notch, ectoconchion, stephanion, and asterion. The first four were placed in the mid-sagittal plane and the next four were placed bilaterally. Equidistant surface semi-landmarks were then applied to a template in concentric curves lateral to the sagittal curve including fixed landmarks where possible (Gunz et al., 2005). This ensured that the shape of the modified cranium was analyzed in three dimensions. The template was then used to project the semi-landmarks to the other cranial surfaces to which homologous landmarks had been applied. The semi-landmarks were slid along tangents to the cranial surface to positions of maximal correspondence to the semi-landmarks of the template and then projected back to the cranial surface to bring them into geometric correspondence with the homologous landmarks (Gunz et al, 2005). When a small portion of the cranium was missing, thin-plate spine interpolation was used to impute missing landmarks, which were then mapped onto the incomplete specimen using the sliding step to minimize distortion (Gunz and Mitteroecker, 2013).

Figure 2. Example cranium showing landmarks and semi-landmarks used in this study

<table>
<thead>
<tr>
<th>Czech Republic</th>
<th></th>
<th></th>
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<td>Saratice</td>
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<td>Kerch</td>
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<td></td>
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<td>15</td>
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</table>

Table 1. Materials used in study

Figure 2. Example cranium showing landmarks and semi-landmarks used in this study
The x, y and z landmark configurations were subjected to Generalized Procrustes Analysis to standardize the shape of the specimens, eliminating differences in the size, orientation and position of the crania, leaving shape as the only parameter to be analyzed. The standardized landmark configurations were then loaded into a virtual program network (vpn) in Evan Toolbox and a Principal Components Analysis (PCA) was performed, with the value of each PC being derived from a variance-covariance matrix (Zelditch et al., 2004). The first principal component axis (PC1) accounts for the majority of the shape variance, with subsequent PCs progressively less variance until 100% of the shape variance has been included. The principal component scores were then used in a discriminant analysis to determine whether the regional difference in modified cranial shape were significant enough to accurately classify the crania from Georgia, Hungary and Germany. We used cross-validation to evaluate the accuracy of the discriminant analysis, whereby one case was left out in deriving a discriminant function, and this function was then used to classify the case. A match between the classification and cross-validation results helped us determine the number of PCs to be used in the discriminant analysis. The crania from Austria, Crimea and the Czech Republic being far fewer were left unassigned to a group, but the discriminant scores from the other regions were used to determine their closest affinity in a post-hoc analysis. This methodology is the same as was used in our previous paper (Mayall and Pilbrow, 2018). It has the advantage of analyzing cranial shape in three dimensions and the warping feature of Evan Toolbox allows us to view changes in the standardized cranial shape and verify the style of bandaging.

Results

The PCA revealed high variance in the sample, with 20 PCs needed to cover 95% of the variance. The first three PCs account for more than 50% of the variance. A bivariate scatter plot of PC1, which accounted for 27% of the shape variation and PC2 which accounted for 17%, indicated that there is considerable cross-over between the shape of German crania and those from Georgia and Hungary (Fig. 3). The Georgian crania exhibit the greatest variance in modified cranial shape seen both at the negative end of PC1 with crania displaying a low cranial vault (1645) and at the positive end of PC1 with crania having a high vertical vault (1880). The negative end of PC2 is also occupied by Georgian crania with an obliquely sloping vault (2383). In addition, marked by the green polygon, several Georgian crania fall in the zone of non-overlap with the Hungarian and German crania. The German and Hungarian crania, in contrast, fall towards the centre of the plot and are more tightly clustered. They are characterized by a uniform cranial height, although there are some examples of tall frontal regions (20092616, 35515). The crania from Germany have some overlap with Hungarian crania, but more so with Georgian crania,
although some fall outside of the range of both groups. The cranium from Kerch in Crimea lies in the range of overlap of the three main regions, but crania from Moravia in the Czech Republic and Vienna in Austria are outliers. One cranium from Moravia (168447) is like the German crania, while the other one (24359) is an outlier with a tall cranial vault similar to the cranium from Vienna (8686) and Georgia (1880). Figure 4, which plots PC2 against PC3, accounting for 27% of overall variance, shows a clearer separation of Hungary, Georgia and Germany.

Figure 3. Scatter plot of principal components one and two and examples of modified crania

Figure 4. Scatter plot of principal components two and three
To clarify regional differences, we performed linear discriminant analysis using scores for six PCs which accounted for 71% of the shape variation (Table 2). This number of PCs gave the best result in cross-validation. There were two discriminant functions given three groups. The overall classification accuracy was 60% (57% cross-validated) demonstrating that each region has some level of distinction in cranial shape, but also some overlap (Fig. 5). The Georgian crania had the greatest classification accuracy and greatest range of the three groups. On the scores for discriminant function one they differed significantly from the other two regions (p = 0.00, Fig. 6). The German and Hungarian crania overlapped with one another and differed significantly only on the scores for function two (p = 0.04). In the post-hoc analysis the cranium from Crimea was assigned to Georgia; the ones from the Czech Republic were assigned to Georgia and Germany, although both fell within the zone for Hungary. The cranium from Austria fell with Hungary.

Figure 5. Scatter plot showing results of classification of crania on discriminant function analysis, and specimen numbers of crania that fall closest to the centroid in each region.
<table>
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<th>Georgia</th>
<th>Germany</th>
<th>Sample size</th>
<th>Percentage</th>
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<td>4</td>
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<td></td>
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<td>15</td>
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<td>8</td>
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<tr>
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<td>53.8%</td>
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</table>

Table 2. Classification Accuracy of Hungarian, Georgian and German crania, with crania from Crimea, Czech Republic, Austria classified post-hoc

Figure 6. Discriminant scores for function 1, p values for statistical difference between groups, examples of crania nearest to the mean and outliers
Crania that fell closest to the centroid (162250, 1964, 310 of Figs. 5 and 6) exemplify the styles of modification in each region. When viewed in sagittal and axial orientation they show depressions from the bandaging and verify the use of annular style of modification (Fig 7). The Hungarian crania appear to have fronto-occipital annular and post-coronal vertical bandages. This causes antero-posterior shortening and bi-parietal expansion of the cranium. The German crania suggest the usage of a wide circular bandage from the forehead to the nape of the neck, leaving the occipital area intact. The crania are shortened in length, but do not display the parietal width of the Hungarian crania. Two depressions in the frontal region of Georgian crania fit the presence of concentric circular bandages compressing the forehead and proceeding to the post-inion region. The severe bandaging causes the forehead to be obliquely sloping, with the skull being long and narrow in axial view. The styles of bandaging are not exclusive to each region, however; there are variations and outliers in each region. The crania from Georgia, in particular, encompass all styles.

Figure 7. Hungarian, German and Georgian crania that lie closest to the centroids show regional characteristics

Crania that are mis-classified and classified post-hoc provide further understanding of regional differences (Fig. 8). Specimen number 513 from Germany and 6398 from Crimea were classified with Georgia and show the features of a tall and domed cranial vault and long, narrow skull, whereas 328
from Germany, mis-classified with Hungary, shows the typical Hungarian features of reduced length, flattened crown and expanded parietals.

Fig. 8. Bavarian and Crimean crania assigned to the Georgian shape and Bavarian cranium assigned to Hungarian shape

Discussion

There are differences in the style of cranial modification in Georgia, Hungary and Germany during the Migration Period. The crania from Georgia are most variable, and in discriminant scores they are significantly different from the Hungarian and German crania. The Hungarian and German crania, in contrast, are similar in shape, yet differ from each other statistically in the scores for the second discriminant function indicating some differences. Not much can be said about the isolated crania from the Czech Republic, Austria and Crimea, but they fall on the periphery of the range of shape variation of the three main groups, which suggest some distinctions. Based on this diversity of modified cranial shapes we surmise that there were diverse cultural influences operating throughout Eurasia in maintaining the practice of cranial modification during the Migration Period. Our study does not find support for the direct presence of Huns in Bavaria, Mtskheta, Brno, Vienna and Kerch, or for the
assumption that the practice was primarily Hunnic in Eurasia (Werner, 1956; Kiszely, 1978; Pap, 1983, 1984; Föthi, 2000; Torres-Rouff and Yablonsky, 2005; Hakenbeck, 2009).

Considering the demographic profile of individuals with modified crania, we note differences between Hungary, on the one hand, and Georgia and Germany on the other. From around the 4th c AD and continuing to the 7th c AD, intentional cranial modification became highly popular as a cultural practice in Hungary. More than 50% of crania in grave sites from this time are reported to be modified (Kiszely, 1978; Pap, 1983, 1984, 1985; Fóthi, 2000; Torres-Rouff and Yablonsky, 2005). Individuals with modified crania show an equal proportion of males, females, and subadults aged from neonates to adolescents (Mayall and Pilbrow, 2018). This suggests that the practice was local in Hungary. In Georgia and Germany, however, we do not find juveniles with modified crania. It is likely that the individuals with modified heads were migrants who did not continue the practice of modifying their infant’s heads in their new homeland. There is a higher proportion of females with modified heads in these regions (92% in Bavaria and more than 70% in Georgia), suggesting a female-biased migration (Hakenbeck, 2009). Isotopic records provide some evidence for non-local dietary signals in Germany and Hungary (Hakenbeck et al. 2010, 2017). As the shape of the modified head rules out the likelihood that the migrants were Huns from Hungary, it opens the question as to who were these people and where were they migrating from?

The burial sites and grave goods do not throw much light on this question. The archaeological findings from the excavation at Samtavro, the largest burial ground in Mtskheta, Georgia indicate changing burial practices during the Migration period. Tile-lined tombs were common in the late Roman period and contained the remains of one or two individuals with articulated and complete bones. The grave goods included tear-drop shaped bottles, ceramic vessels and silver and gold jewelry (Sagona et al., 2010). The grave findings, together with the radiocarbon dates (Sagona et al., 2010) indicate that they belonged to the late Roman, early Christian era. Stone cists, the most common tombs during the following period, with radiocarbon dates from the fourth to the sixth century (Sagona et al., 2010) contained the remains of multiple commingled individuals. Intentionally modified crania were rarely present in tile-lined graves, but most were found in stone cist and earthen pit burials. Examples of grave goods included glass bottles, glass plates, goblets, iron nails, broken bronze mirrors and iron trilobate arrow heads (Davis-Kimball, 1995). The arrowheads were like the iron arrowheads commonly found in burials across the Eurasian steppes, including those of the Sarmatians, north of the Black Sea (Moshkova, 1995). Bronze mirrors which had been deliberately broken were found associated with females, one with a
modified head (Sagona et al., 2010). These were common in grave assemblages in the Eurasian steppes and the Caucasus. They were associated with the Huns as they had not been seen in Eastern Europe prior to the Hunnic advance in the fourth century AD (Maenchen-Helfen, 1958). However, they did exist with the Sarmatians in the Eurasian steppes from the third century (Maenchen-Helfen, 1973). The presence of the broken bronze mirrors and iron arrowheads indicates the contacts of Georgia with the Asian steppes whereas the tear drop bottles which originated in Northern Italy among the grave assemblages indicate even wider trade links (Fürtwangler et al., 2008). Thus, there were competing influences in Georgia during this time making it difficult to identify the migrants with modified heads. The Georgian historical chronicles provide references to the Alans and Sarmatians as allies of the Georgian kings or as brigands carrying raids on the borders of the Iberian kingdom (Alemany, 2000; Fürtwangler et al., 2008). These groups practiced cranial modification and were based in the northern Caucasus; thus, it is possible that these groups are represented in Mtskheta. Future research would benefit from comparing the modified crania from Mtskheta with those from Alanic burials.

The Altenerding and Straubing row-grave burial sites in Bavaria, Germany reflect the shift from the late Roman period to the Migration period and later, Christian and Byzantine influences. The grave goods showed a diversity of cultural influences (Giesler, 1998). Most female graves contained glass beads, belt buckles and knives. The funerary dress and ornaments such as brooches suggest links to distant regions and have been described as Frankish/Alamannic, Ostrogothic, Langobardic and Thuringian (Hakenbeck, 2007). The position and style of fibulae enabled female clothing to be reconstructed and show conformity to local custom (Hakenbeck, 2009). Some females with modified heads were buried with foreign brooches yet their funerary dresses were typical of the local area of the late 5th early 6th centuries (Hakenbeck, 2009). The only male with cranial modification was accompanied by grave goods including a long sword, a silver buckle, bronze tweezers, and knife. Three of the females with modified crania had carbon isotope levels outside the range of the local area indicating they had come from another region with a different diet (Hakenbeck et al. 2010). Another had a non-local strontium level indicating she also was born elsewhere (Hakenbeck et al., 2010). The burial goods and funerary dress do not shed light on the origin of individuals with modified crania but show conflicting identities and the attempts of nonlocals to fit in in the region.

Even in Hungary where the practice of cranial modification was indigenous, there were multiple changes in the ruling regime during the Migration Period. The Goths and Alans were already in the region when the Huns arrived and even when Pannonia, the west of modern Hungary, was ceded by the Romans to
the Goths prior to the arrival of the Huns, a large population of Romanised people remained and merged the culture of the Goths into their own cultural practices (Müller, 2003a). Other Germanic tribes including Gepids and Langobards made cultural contributions in the 6th century (Müller, 2003c, Tóth, 2003b). Intentional cranial modification was a cultural practice in the region prior to the arrival of the Huns. It became common after the arrival of the Huns and persisted until the eighth century (Hajdu et al., 2009) long after the Huns lost power in the mid-5th century. In terms of grave goods, the arrival of the Huns together with Sarmatians and Alans from the eastern steppes brought new features to add to the mix producing the unique Danubian funerary style which was homogenous across Transdanubia involving gold and silver jewelry, weapons and other personal accoutrement (Heather, 2009). It is believed that this Danubian style was particularly associated with the multiethnic elite who controlled the Hunnic Empire and cannot be identified with any specific ethnic groups (Curta, 2005). Graves identified as definitely Hunnic are very rare, not only in Pannonia, but also in the Northern Black Sea region (Heather, 2009). Some of these contain animal bones, bronze belt buckles, metal artefacts with ankle clasps, boot straps and harnesses (Ódor, 2011; Müller, 2003b; Nagy, 2010).

The review of the historical and archaeological evidence associated with cranial modification illustrates a complex and contrasting pattern between clear regional differences in styles of cranial modification and several nomadic tribes engaged in the practice co-existing with local populations in each region. It appears that the same nomadic groups lived in regions where modification styles differed. The Alans are known from Georgia and Hungary, and the Langobards are known from Hungary and appear to have been present in Germany. This makes it difficult to suggest that regional differences in modification styles were aligned with specific nomadic groups.

On the other hand, the practice of modification requires a long-term commitment as it is undertaken in the first few years of an infant’s life. Parents or care-givers from diverse nomadic groups would assign a life-long identity to their infants by using a specific bandage technique. This suggests a nested hierarchy of identities, where tribal or ethnic identity was superseded by regional group identity. In the case of the Huns, it appears that loyalty and commitment was easily achieved. The Huns generated a great deal of wealth through military conquests and tributes from the Romans (Wolfram, 1985), and shared it with the nomadic tribes, who were sworn as vassals (Heather, 2009). The style of cranial modification would have served as a token of allegiance to create a unique and permanent shared identity consolidating Hunnic power. This may explain why the practice grew in prevalence during Hunnic times. Although this model for Hunnic dominance has not been proposed before, historians have suggested that Huns had a
The continuation of the practice with the same zeal after the Hunnic period and the resurgence of the practice in other parts of Eurasia in the Migration Period indicates that the custom was emulated and its value for maintaining social identity was acknowledged. As the nomadic groups were on the move, different styles of modification would have helped to highlight their social identity at boundaries through contrast and juxtaposition. The greater diversity of modification styles in Georgia suggest that identities here were fluid and not as regularized. As the individuals with modified heads appear to be migrants, both here and in Germany, it is possible that more than one nomadic group is represented in these regions.

**Conclusions**

The origin of cranial modification in Eurasia is not easily explained but the spread of the practice during the Migration Period is related to the arrival of the Huns in the Hungarian plain. This study suggests that the practice of cranial modification was associated with social change, in particular, the dominance of the Huns in the Carpathian Basin. In this region the form of modification was homogenous, consistent with some form of central control creating a highly visible social identity. In peripheral areas such as Georgia and Bavaria Hunnic influence is not as apparent, there was greater variation in the type of modification in Georgia and it was related to migration in Georgia and Germany. The migrants with modified crania were generally well assimilated into their final destination judging from their burial assemblages although the absence of juveniles with modified crania suggests that they did not continue the practice of cranial modification.
References


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Chapter 7

Discussion and conclusions

This bioarchaeological study revealed distinct differences in the practice of intentional cranial modification in Georgia, Hungary and Bavaria which were related to the temporal occurrence, the demography, the incidence, the associated material culture and the morphology. The investigation of these features has given an insight into the unique character of the custom in each of these regions and their underlying formative influences.

Temporal occurrence

The majority of modified crania from all three sites date to the 4th–7th c AD corresponding with the European Migration Period. As shown in the present study, Georgia has examples dating back to 3000 BC but most date from the 4th to the 7th centuries. In Hungary the practice is almost exclusively associated with the Migration Period (Papp, 1983, 1984, 1985) with rare examples prior to that time whereas in Bavaria, all the modified crania recovered, date to the late 5th century and the first half of the 6th century (Hakenbeck, 2009).

Incidence

Burial sites in Hungary indicate that the practice was almost universal with up to eighty per cent of individuals having modified crania (Papp, 1983, 1984, 1985; Ódor, 2011). It was also common in Georgia with over twenty per cent of crania modified but rare in Bavaria with only fourteen modified crania in over two thousand graves (Hakenbeck, 2009).

Demography

The analysis of the Hungarian crania in this study indicated that intentional cranial modification was indigenous in this region by the presence of large numbers of juveniles with modified crania together with adult males and females. In Georgia both sexes were involved but very rarely involved juveniles indicating the practice was not indigenous but associated with migration. This was also the case in Bavaria, but here it almost exclusively involved females.
suggesting it was an exogamous migration pattern. Part of the spread of the practice into peripheral regions was due to the mass migration which, included many individuals with modified crania, fleeing ahead of the Huns as they moved into Europe and also those moving from Hunnic controlled regions after the collapse of the Huns’ power in the mid-5th century (Heather, 2009; Mitchell, 2015). This would appear to have been the situation in Georgia and Bavaria where the practice was not indigenous but associated with migrants. The establishment of the practice of intentional cranial modification within a community requires extensive planning in order to achieve the desired result, including the organisation of individuals with the expertise to carry out this procedure and the patience to continue the process for several years (Lorentz, 2015; Hakenbeck, 2009).

**Material culture**

Previous studies have indicated that there was no significant difference in the grave goods within any of these three sites to enable ethnic differentiation or suggest differences in ethnicity particularly between the individuals with or without modified crania. The grave goods from the excavation at Samtavro, the largest burial ground in Mtskheta, Georgia included tear-drop shaped bottles, ceramic vessels and silver and gold jewelry (Sagona et al., 2010). The grave findings, together with the radiocarbon dates (Sagona et al., 2010) indicate that they belonged to the late Roman, early Christian era.

Despite the multiethnicity of this society the grave goods do not reveal any significant cultural traits over this period (Sagona et al., 2013). The examination of the grave assemblages in Hungary such as those at Mősz by Óodor (2011) and Keszthely by Straub (2011) indicated that homogeneity in material culture was particularly evident in this region being derived from an amalgam of Eastern German, pre-existing Roman and nomadic styles with this uniformity in grave goods not allowing for the identification of ethnicity (Bierbrauer, 2011; Heather, 2009). Similarly, Hakenbeck (2007) studying grave assemblages in 6th century Bavarian graves found no relationship between grave goods and ethnicity. However, this may not reflect the actual circumstances in the society as burial displays are influenced by factors such as social stress and power struggles within the community which limit value in determining ethnicity, status, wealth
or religion (Jones, 1997). Halsall (2007) suggests a family with established wealth had no reason to demonstrate this with a burial ritual. Religious symbols may also have been obtained by trade and purely worn for decoration or as amulets (Daim, 2003). Rizos (2013) notes that this applied to individuals buried close to the basilica at Keszthely who had jewelry and attire indicating that they were Christians, but there is no way of knowing how or why they obtained these items.

**Morphology**

Quantitative shape analysis of the modified crania in this research has demonstrated that those from Hungary were well differentiated from the Georgian crania based on their morphology. In Georgia there was a wide range in cranial shape but the majority had the annular form produced by a encircling binding from the frontal to the occipital region. This produced a groove in the line of the binding with a compensatory expansion superiorly. This type of modification was also present with ancient Georgian crania dating back to 1200 BC. The most common type of modification in Eastern Europe and on the Eurasian steppes was also the annular form (Torres-Rouff, Yablonsky, 2005). It was also present in the northern Caucasus from the 12thc BC (Field, 1953) and then from Central Asia, the Eurasian steppes, the Aral Sea to the Black sea from 500BC (Sharapova and Razhev, 2011). Many of the Alans in the Northern Caucasus moved to the south, particularly to South Ossetia, with the arrival of the Huns into the region in the 4th century which probably accounts for the presence of the modified crania in Georgia.

In contrast to the situation in Georgia, intentionally modified crania were rare in Hungary until the 4th century which coincided with the arrival of the Huns (Maenchen-Helfen, 1958; Hakenbeck, 2009; Heather, 2015). The Huns had passed from Central Asia and the Eurasian steppes through regions in which the annular form of cranial modification had been indigenous (Czegledy, 1983; Sinor, 1990; Ginsburg, 1968). They had also absorbed warriors from the nomadic tribes, particularly the Alans who had practiced this form of cranial modification (Hancock, 2004). After their arrival in the Carpathian basin the practice proliferated in that region with over 50% of crania found to be modified in many burial grounds from the 5th
century (Ódor, 2011; Papp, 1983, 1984, 1985). This included males, females and juveniles indicating that it was indigenous to this region. However, the shape analyses of cranial outlines in this study confirmed that Hungarian crania had a form which was different to those from Georgia. Georgian modified crania were varied in form but predominately with a single fronto-occipital binding. Those from Hungary had been modified with two bindings, the first fronto-occipital, as with the annular form, with an additional binding from the post-coronal region to the mandible producing flattening of the parietal superiorly and producing a compensatory expansion laterally. Surface analysis comparing juvenile and adult modified crania in this study confirmed the methods and results of this form of modification and also revealed that there was a great deal of homogeneity in the type of cranial modification in Hungary.

The practice of cranial modification extended to Western Europe with the examples from burial grounds in Bavaria revealing modified crania of various shapes. Sixty-one percent were not assigned to either Hungary or Georgia suggesting that these individuals had originated from other regions where cranial modification was practiced.

This analysis comparing intentional cranial modification in Georgia, Hungary and Bavaria has revealed significant differences which provides some suggestions on the origins of the practice in these sites, the associated migration patterns, the ethnical and cultural implications and the influence of the Huns in the manifestation of the custom in each of these regions.

**The Role of the Huns in the practice of Intentional cranial modification Europe.**

There is no doubt that the Huns had a pivotal role in the spread and intensification of intentional cranial modification in Europe as this custom corresponded with their arrival in this region in the 4th century and their associated tribes, the Alans and Sarmations, into Pannonia (Kiszely, 1978; Pap, 1983, 1984, 1985; Torres-Rouff and Yablonsky, 2005; Hakenbeck, 2009; Kim, 2013).

There are several questions in relation to this which need to be addressed.

1. The Huns had not practiced cranial migration prior to coming to Central Asia so what was their purpose of introducing intentional cranial modification into Hungary?
2. Why was cranial modification accepted by the majority of such an ethnically diverse population?

3. The type of cranial modification on the steppes was the single binding annular form but why was this changed to the double binding method in Hungary and why was this method uniform throughout this province?

4. Why did this form of modification persist long after the Hunnic power ceased in the mid-fifth century?

These are the speculative answers to these questions.

1. Having a settled base on the Great Hungarian plane was a cultural change for the Huns, no longer did they have the advantages of a highly mobile nomadic force which could attack isolated settlements and then quickly disappear into the wilderness (Kelly, 2005). Prior to arriving in Europe, the Huns had lived in the Eurasian steppes for over a century among people who had a long history of Intentional cranial modification. Initially this was used as a form of social differentiation by the nomads in the steppes (Torres-Rouff, Yablonsky, 2005). The practice was then continued by the Sarmatians and the Alans who having been conquered by the Huns were then incorporated into the Hunnic ranks bringing the custom with them as a permanent and highly visible form of social identity.

2. The Huns had a well-developed centralized authority prior to settling on the Hungarian Plain (Kim, 2013). This enabled them to maintain their dominance in spite of the poly-ethnic society, initially by fear, but soon by virtue of the massive wealth introduced into the region by tributes paid in gold by the Romans (Wolfram, 1985; Heather 2009). The gold was shared with Germanic leaders within the Hunnic regime who were sworn to serve the Huns as vassals, greatly enhancing Hunnic military power (Heather, 2009). Societies such as this were able to establish a common culture which depended on them exhibiting a particular objective trait (Barth, 1998). In the case of the Huns this was cranial modification. Extrapolating from the work of Barth (1998) this established their social identity in which they were able to show allegiance to a shared culture and conform to the requirements of that culture including the maintenance of cultural boundaries relating to social relations. Cranial modification was a permanent and highly
visible symbol not only for its superficial appearance but because it embodied many the other features unique to that society. When the parents or elders intentionally modified the cranium of an infant, they were ascribing that child with a particular social identity (Blom, 2005). This may have been a voluntary decision to gain advantages by adapting to the new social and political circumstances brought about by the Hunnic dominance (Torres-Rouff, Yablonsky, 2005). Certainly, an individual recognised as being a Hun was given an increase in rights and a special status (Heather, 2009). Dingwall (1931) has described the rituals associated with custom in many different societies. It was a complicated process which was highly regulated (Hakenbeck, 2009). As well as skill and patience this would have required a large number of trained birth attendants to institutionalise this practice in Hungary during the Migration Period.

3. As this quantitative analysis confirmed there was a distinct difference in the shape of the modified crania in Hungary as compared with those in Georgia and also in the Eurasian steppes it seems likely that the Huns introduced intentional cranial modification in Hungary as a strategy for sociocultural change in their emergence as a sedentary population. This may have been as a method of cultural differentiation from the steppe nomads who practiced the annular type of modification. Regional differences in forms of cranial modification have been described by Tiesler (2014) in the classical period of Mayan culture and Blom (2005) in the Southern Andean Tiwanaku society from 500‒1100 AD demonstrating that cranial modification was used for ethnic differentiation. From first hand reports of cranial modification from the Spaniards of the 16th century it was evident that the method of modification was group specific, but also related to status (Hoshower et al., 1995). In Hungary during the Migration Period cranial modification was ubiquitous which suggests it was not related to status and also largely uniform in shape with no evidence of group or ethnic differentiation. However, although the material culture within this region appears to have been uniform this does not exclude the presence of other identities or divisions of status within that community (Heather, 2009).
4. Intentional cranial modification persisted in Hungary until the seventh century long after the end of the Hunnic power in the mid-fifth century (Hajdu, 2009). Tiesler (2014) has described a similar situation in Mesoamerica where cranial modification persisted for many generations in spite of cultural changes. It appears to have been the result of a family tradition associated with the perception of proper child rearing as well as continuing a constructed social identity.

Conclusions

The history of European migration has been well documented previously. This has included work by ancient authors including Ammianus (Rolfe, 1939) in the fourth century, Priscus (Blockley, 1983) in the fifth century and Jordanes (Mierow, 1915) in the sixth century which in spite of their shortcomings have provided the background for studies by modern authors. The Huns left no written records to chronicle their passage from the Eurasian steppes into Europe in the fourth century. The archaeological findings do provide some details such as the cauldrons along their route (Erdy, 1995) and ‘Hunnic burials” containing grave goods including weapons and equipment and skeletal material related to horses (Heather, 2009; Muller, 2011). However, these are rare and therefore of limited value in investigating the Huns. Fortunately, another feature of burial assemblages from the European Migration Period which has been associated with the Huns were intentionally modified crania. These were rare in Europe prior to the arrival of the Huns but after their appearance became very common along the Carpathian basin. My study has therefore concentrated on investigating these crania.

My research has been based in the Republic of Georgia as a known region where intentionally modified were frequently recovered. The origins of the individuals with modified crania in this region is not certain although presumed to be Alans with many settling in South Ossetia to escape the Huns (Brzezinski and Mielczarek, 2002). The Ossetian language still has traces of the language of the Huns which establishes their presence in that region (Alemany, 2000).

In order to proceed further with the investigation of modified crania my focus expanded to include Hungary, because of the ubiquitous nature of modified crania in that country and then to Bavaria, the Czech Republic and Austria to gain further knowledge regarding the spread of
modified crania and the role of the Huns in propagating the practice in these areas. I noted that modified crania in both Georgia and Bavaria were largely associated with females with an absence of juveniles but in Hungary equal numbers of men and women were involved and also many juveniles. This would suggest that cranial modification in Georgia and Bavaria was associated with migration but it was indigenous in Hungary.

I used geometric morphometric techniques to enable a quantitative statistical analysis to be performed to compare modified cranial shapes from different regions. These techniques are non-destructive but provide objective evidence from which the aims of this study could be achieved. A 3D scan provided the images for the analyses. The initial study compared sagittal outlines from modified and unmodified crania. This was successful in differentiating these indicating that the method could be employed for the comparison of the modified crania from the various regions. Landmarks around the cranial outlines provided the variables for Eigenshape analyses which indicated that crania from Georgia were different in shape to those from Hungary because of a different binding technique, the former being bound mostly in an antero-posterior direction whereas those from Hungary also included a vertical binding. It also showed that the Hungarian crania were fairly homogeneous in their modified shape compared with the greater variation in shape of the Georgian crania. The next study, using surface landmarks, compared Hungarian juveniles with adults. A regression analysis confirmed the association between the juvenile and adult crania. Because the evidence of modification was prominent on the juvenile crania, clearly showing the path of the bindings, this confirmed the technique which had been used in the modification procedure. The investigation then moved to other sites in Europe including crania from the Crimea, Austria, the Czech Republic and Bavaria. These were compared with modified crania from Georgia and Hungary. A surface analysis was performed which confirmed the differences between the Georgian and Hungarian crania in the outline analysis but also indicated that the crania from the peripheral regions, displaying some of the features of the Georgian and Hungarian crania also had considerable shape variation. These findings would suggest that the Huns had a direct role in encouraging intentional cranial modification in Hungary during the Migration Period as a form of social identity to indicate their affinity to the Huns and differentiate themselves from populations.
beyond their borders. The peripheral regions such as Georgia and Bavaria were only indirectly affected by the Huns as a result of the populations migrating to escape the Hunnic pressure from areas in which cranial modification had been practiced.

This research must still be regarded as preliminary due to the relatively small sample sizes. Future work could include specimens from other neighbouring countries such as Armenia and Azerbaijan and larger samples from the areas which were studied where larger numbers were not available at this time.

Further analysis of Alan burials in the northern Caucasus and the Eurasian steppes would help to establish the connection of the Alans in those regions with the individuals who are presumed to have been Alans and came to Georgia during the Migration Period. It would also be advantageous to include a much greater emphasis on the cultural context of the modified crania in Georgia, which would assist in establishing the migrants’ origins.

In this investigation of the morphology, in particular the deep grooves in the line of the bindings, the flattened surfaces anteriorly and posteriorly and the areas of compensatory expansion were used to study the type of bindings used to produce the differing shapes. An alternative method of determining where the bindings were applying pressure to the crania would be to use CAT scanning. This would help to study the points of pressure inducing thinning of the cranium due to loss of the diploe at these points as Crubézy (1990) has demonstrated.
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## Appendix

### Georgian Modified Crania

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Total individuals with sex determined 2008–2010 45
Males 23
Females 22
Subadults 17

Czech Republic modified Crania

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Non-modified Samtavro crania

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### Austrian Modified Crania

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### Hungary modified crania

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| 9000 | Csongrad | 1–5th C | ?  | 16 | cranial vault |
| 5258 | Mohacs   | 5th C   | F  | 40+| complete      |
| 20092613 | Keszthely  | 4–5th C | ? | 10 | complete      |
| 2009264 | Keszthely | 4–5th C | F  | 40+| Cranial vault |
| 20092616 | Keszthely | 4–5th C | ? | 16+| complete      |
| 20092612 | Keszthely | 4–5th C | F  | 50+| complete      |
| 20092610 | Keszthely | 4–5th C | ? | 10–12| incomplete |
| 20092614 | Keszthely | 4–5th C | F  | 14+| Cranial vault |
| 20092620 | Keszthely | 4–5th C | F  | 18+| Cranial vault |
| 20092621 | Keszthely | 4–5th C | M  | mature | complete |
| 11641 | Mozs     | 5th C   | ?  | 16+| complete      |
| 6810911 | ?        | ?      | M  | mature | complete |
| 20092626 | Keszthely | 4–5th C | ? | 14+| Cranial vault |
| 20092623 | Keszthely | 4–5th C | ? | 6+| incomplete    |

Germany modified Crania

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Crimean Cranium

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Mayall, Peter Ronald

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