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Brief Communication

Artificial deformation versus normal variation: re-examination of artificially deformed crania in ancient Korean populations

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Abstract The purpose of this investigation was to examine cranial deformation versus normal cranial variation in ancient Korean populations from the 1st century B.C. to the 7th century A.D. by means of geometric morphometrics and multivariate statistical methods. The samples of human crania in this study were 7 male and 11 female individuals from the Yean-ri site, 4 males and 6 females from the Nukdo site, and 6 males and 4 females from the Imdang site. Of the 38 adult individuals, 2 females (Ye085 and Ye099) from the Yean-ri site were reported to have artificially deformed crania in a previous study. In the present study, two-dimensional geometric morphometric methodology was employed to evaluate cranial shape variation. Deformed crania were characterized as an anteroposterior modification based on Antón's classification system. Deformed crania showed relatively flatter frontal and occipital bones and superoposteriorly developed parietal bones from a lateral view, which may reflect compensatory development due to pressure from an anterior to posterior direction. Moreover, Im095 (female) and Nu051 (male) had relatively flatter frontal bones and were similar to the deformed group; however, the convexity in the occipital bone was too pronounced to allocate these individuals to the deformed group.

Key words: Cranial shape, artificial deformation, Yean-ri, Imdang, Nukdo

Introduction

It is well known through Chinese documents (e.g. *Samgukji*) that artificial cranial deformation was practiced by some populations in ancient Korea. According to the Chinese historical record, when a baby was born in ancient Korea, the parents would intentionally press the baby's anterior head with a stone to make it more angular. The pressure influenced cranial morphological development during childhood, resulting in vault compression along the sagittal plane, with expansion along the mediolateral dimensions. According to *Samgukji*, all individuals of the Jinhan population had deformed crania. Jinhan is one of the three Han states (Mahan, Jinhan, and Byunhan) that existed in the central and southern regions of the Korean peninsula during Three Kingdoms Period (300–668 A.D.) until the advent of highly stratified states. Although it is not clear that intentional deformation was widely practiced in the three Han states, the only cases of artificially deformed crania in Korea have been reported in the Yean-ri population of the 'Gaya' region. 'Gaya' was a confederacy consisting of various political organizations located in the southeastern part of the central region in South Korea from approximately the 1st to 6th centuries A.D. (Shin, 2000; Barnes, 2004). The Yean-ri site is located northeast of Gimhae, South Korea and dates from the 4th to early 7th centuries A.D. Previous studies of artificial cranial deformation from the Yean-ri site analyzed skulls by means of visual and traditional morphometrics (Ogata et al., 1988; Mine, 1999), with little attention to the possibility that this practice might have occurred in other communities.

The purpose of this investigation was to examine cranial deformation and normal cranial variation in several populations of ancient Korea by means of geometric morphometrics and multivariate statistical methods. We analyzed deformed cases from the Yean-ri site, along with crania from Nukdo and Imdang sites dating from the 1st century B.C. to the 7th century A.D. Specifically, our research was focused on: (a) re-examining cranial deformation cases from the Yean-ri site using geometric morphometrics to better understand culturally modified vault morphology; and (b) identifying other artificial deformation cases in ancient populations of Korea using multivariate statistical methods.

Materials and Methods

The samples of human crania included were generally complete adult individuals from the Yean-ri, Nukdo, and Imdang sites. Due to the condition of skeletal preservation, we analyzed 38 individuals: 7 males and 11 females from the Yean-ri site, 4 males and 6 females from the Nukdo site, and

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Table 1. Skeletal samples used in this study

Site	Period	*N* (total)	Males	Females
Yean-ri	4th–7th C AD	18	7	11
Nukdo	1st C BC–1st C AD	10	4	6
Imdang	4th–7th C AD	10	6	4

6 males and 4 females from the Imdang site (Table 1). Of the 38 individuals, 2 female individuals (Ye085 and Ye099) from the Yean-ri site have been previously identified to have artificially deformed crania with frontal flattening and parietal bulging (Mine, 1999). The Yean-ri and the Nukdo sites were excavated between 1976 and 1980 and between 1985 and 1986, respectively. The Imdang site was excavated in 1982 (Pusan National University Museum, 1985, 2004; Yeungnam University Museum, 2015). The Yean-ri and Nukdo sites are located near the Nakdong River basin of southern Korea, although the Nukdo site is on an island. The Imdang site is located in a more northern region than the other two sites (Figure 1). The Imdang burials included mounted tombs for the elite class, while the Yean-ri and Nukdo burials included wood and stone-cist coffins in large cemeteries for the non-elite community.

In order to evaluate cranial shape variation, we analyzed normal and artificially deformed crania using a two-dimensional geometric morphometric method. First, each cranium was placed in combination instruments consisting of a Mollison craniophor No. 209 and Auricular head spanner No. 201 (GPM Anthropological Instruments of DKSH, Switzerland) that were set to the Frankfurt horizontal (FH)

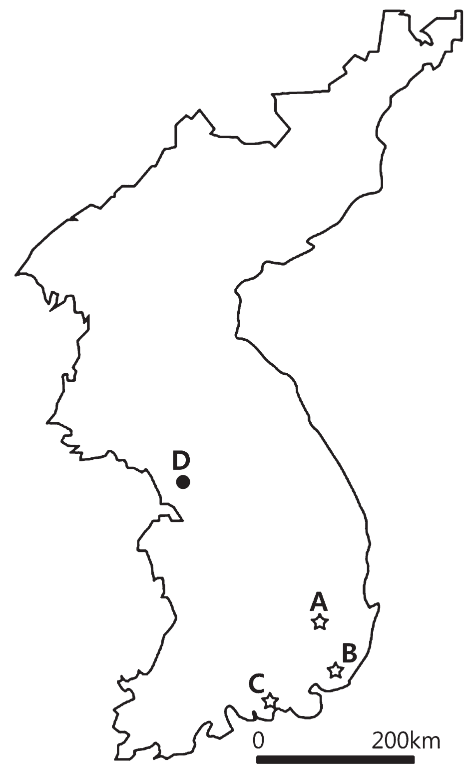

Figure 1. Geographical distribution of sites: (A) Imdang, (B) Yean-ri, (C) Nukdo, (D) Seoul.

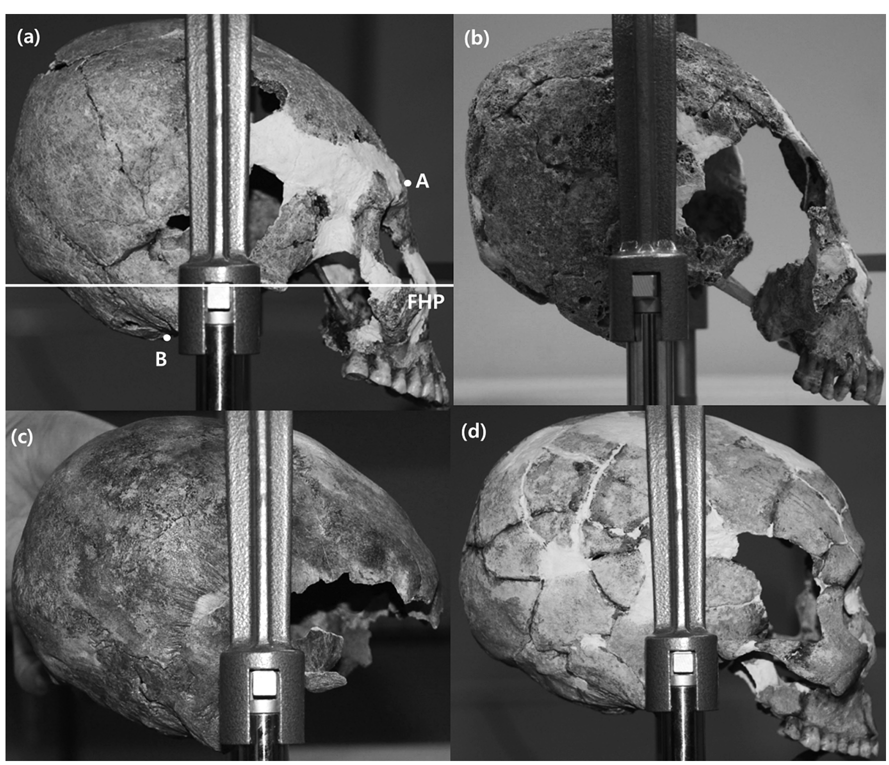

Figure 2. Right side of Ye085, Ye099, Im095, and Nu051 placed in the combination instruments set to the Frankfurt horizontal plane: (a) Ye085, (b) Ye099, (c) Im095, (d) Nu051. A, glabella; B, opisthion; FHP, Frankfurt horizontal plane.

plane. The center point of the combination instruments where the porion is located was set in the center of the frame (Figure 2). Second, the right side of the cranium was photographed using a Nikon digital camera with an AF-S Micro Nikkor 105 mm lens (Nikon, Japan). The picture was taken with the camera at 90° to the sagittal plane. Third, 74 semi-landmarks were digitized between the glabella and the opisthion using the MakeFan7 program (Sheets, 2009). Fourth, Procrustes superimposition was performed to evaluate any shape variation in the samples by scaling the centroid sizes to 1, altering centroids to the same coordinate points, and rotating landmarks with least-squares superimposition (Zeldithch et al., 2012). The rotation is iterated by generalized Procrustes analysis (GPA) until the distances between landmarks were minimized to bring all samples into a common coordinate system. The GPA superimposition was performed using Morphologika2 v. 2.4 (O'Higgins and Jones, 2006). The shape differences were presented based on the Procrustes distances between them. Moreover, the curves of the semi-landmark sets were slid along tangent lines with least-squares calculation, which was limited by a set of semi-landmarks of the reference set to maintain homology (Zeldithch et al., 2012).

Principal component (PC) analysis was conducted with Morphologika2 v. 2.4 to explore subtle patterns of cranial shape variation. The type of artificial cranial deformation was identified based on Antón's classification system (Antón, 1989). Discriminant function analysis was conducted with Morpho J 1.05e (Klingenberg, 2011) to examine statistical differentiation between the deformed and normal cranial groups using 10000 rounds of permutation testing.

Results

Of the total variance, 75.25% was cumulatively explained by using the first three PC scores: 38.34%, 20.73%, and 16.18%. These three PCs contributed most strongly to the evaluation of cranial shape variation. For those three PCs, there was no distinct shape variation to differentiate the three groups by site and sex. On the first PC axis, the two female specimens previously identified as having artificially deformed crania (Ye085 and Ye099) (Ogata et al., 1988; Mine, 1999) were located close to the end of the positive points (Figure 3). They had flatter frontal and occipital bones and superoposteriorly developed parietal bones from a lateral view. It seemed the bregma was shifted backward and the lambda was located more superiorly in the deformed group than in the normal group. On the first axis, the two specimens' crania exhibited a more rounded shape as they were located more towards the negative points. The normal frontal bones were vertical and the normal occipital bones were more convex relative to those of the deformed crania. The second PC shows the relationship between cranial length and height (Figure 3). On the second PC axis, the two artificially deformed crania were located near the zero point. Thus, the relationship between cranial length and height of the deformed cranium was similar to that of the normal group. On the third PC axis, the shape of frontal and occipi-

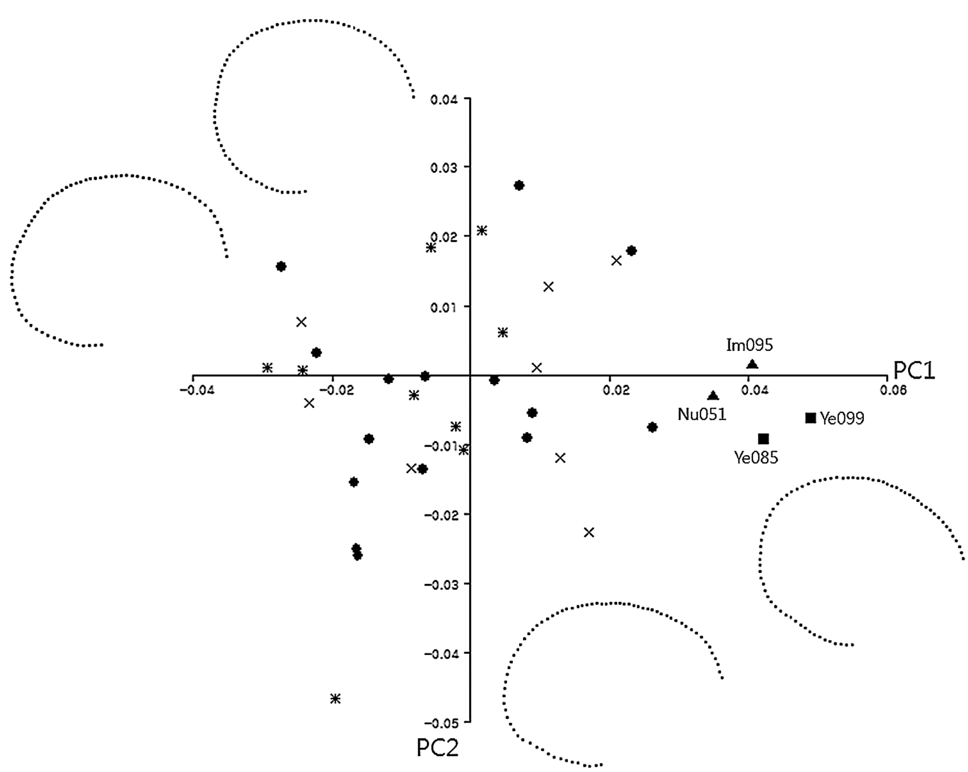

Figure 3. Coordinate plane with first and second principal components axes. Yean-ri site: black circle; Imdang site: cross; Nukdo site: black star. Two artificially deformed crania (Ye085 and Ye099) are in the black rectangle. Im095 and Nu051 are in the black triangle. Two artificially deformed crania show flatter frontal and occipital bones and superoposteriorly developed parietal bones from a lateral view.

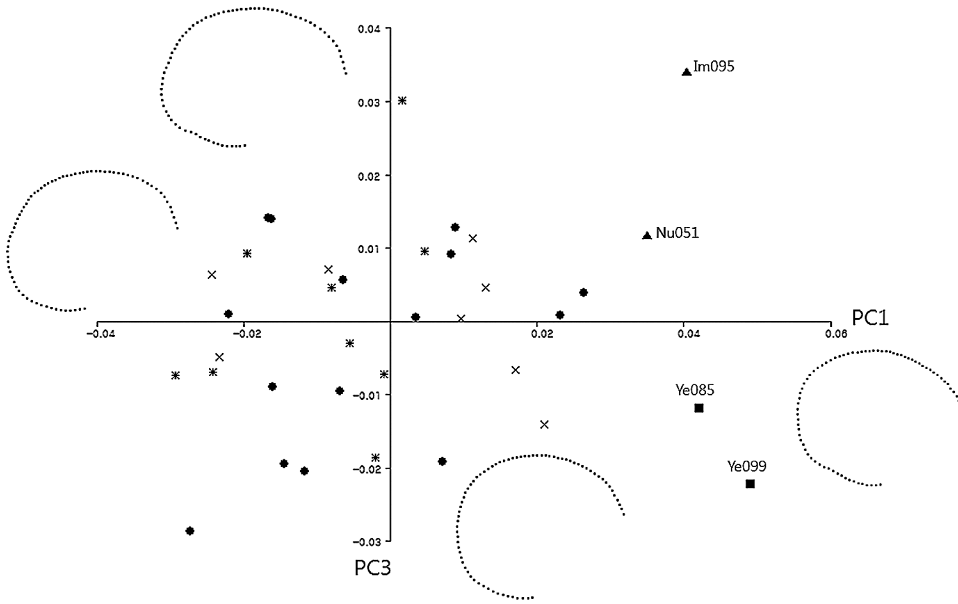

Figure 4. Coordinate plane with first and third principal components axes. Yean-ri site: black circle; Imdang site: cross; Nukdo site: black star. Two artificially deformed crania (Ye085 and Ye099) are in the black rectangle. Im095 and Nu051 are in the black triangle. Two of the artificially deformed crania show relatively flatter frontal and occipital bones in addition to superoposteriorly developed parietal bones. Im095 and Nu051 are located closer to two of the artificially deformed crania on the first principal component axis, while they are relatively farther away on the third principal component axis.

tal bones became flatter as the third PC decreased (Figure 4). As the third PC increased, the frontal bone became more vertical and the occipital bone became more convex. On a coordinate plane with the first and third PC axes, the two artificially deformed crania (Ye085 and Ye099) were located in the right and inferior corner. This reflected their relatively flatter frontal and occipital bones in addition to the superoposteriorly bulging shape of parietal bones from the lateral view (Figure 4). Based on these results, the coordinate plane of PC1 and PC3 identified the cranial regions that can be applied to diagnose deformed crania in this study.

On the first PC axis, two crania from the Imdang (Im095; female) and Nukdo (Nu051; male) sites were located close to the two artificially deformed crania (Figure 3, Figure 4). On first PC axis, Im095 and Nu051 have relatively flatter frontal and occipital bones and superoposteriorly compensatory development in the parietal bones. However, Im095 and Nu051 were located relatively farther on the third PC axis than the deformed crania (Figure 4). These two samples showed relatively less flat frontal and more convex occipital bones than the two with deformed crania. The occipital bone convexity of Im095 was the most pronounced in this study.

Meanwhile, the differences between the deformed and normal groups were statistically significant in the discriminant function analysis based on 10000 rounds of permutation testing ($P = 0.001$). However, cross-validation tests discriminated one deformed cranium as the normal group and one normal cranium as the deformed group (Table 2).

Table 2. Result of cross-validation test with the leave-one-out method (%)

	Deformed cranium classification (*n*)	Normal cranium classification (*n*)
Deformed cranium	50 (1/2)	2.7 (1/36)
Normal cranium	50 (1/2)	97.3 (35/36)

Discussion and Conclusions

Artificial cranial deformation occurred throughout the Old and New Worlds as a cultural phenomenon, and studies have largely focused on the effect of deformation on skull growth and form (Antón, 1989; Cheverud et al., 1992; Meiklejohn et al., 1992; Kohn et al., 1993; O'Brien and Stanley, 2013). Artificial cranial deformation has been considered 'nature's experiment,' allowing the examination of the association of cranial parts and cranial development by dividing the cranium into vault, face, and basicranium (Antón, 1989; Cheverud et al., 1992; Meiklejohn et al., 1992; Kohn et al., 1993; Lieberman, 2011; O'Brien and Stanley, 2013). It was hypothesized that vault modification affected both the basicranium and the face as they share several functions such as accommodation and protection of the brain. Therefore, artificial deformation can result in compensatory development as the parts respond to cranial reshaping because the overall size remains the same after cranial deformation.

In general, artificial cranial deformation was performed shortly after birth and the process continued during the first two years of life (Dingwall, 1931). Following Antón's classification (Antón, 1989), deformed crania include (1) crania with anteroposterior modification that are restricted with boards, stones, or pads on the forehead for anteroposterior shortening, allowing the cranium to grow laterally and superiorly; and (2) crania that are circumferentially restricted by encircling the vault with textiles or other soft material while allowing compensatory growth posteriorly and superiorly

(Antón, 1989). According to Antón, the two deformed crania in the present study can be designated as the anteroposterior modification type. This classification is consistent with the study on Yean-ri crania by Mine (1999). The deformed crania in the present study showed relatively flatter frontal and occipital bones and superoposteriorly developed parietal bones in lateral view, which may reflect compensatory development due to pressure from the anterior to posterior direction. The anteroposterior modification type was practiced by the Ancon (Peru), the Makapuan (Hawaii), and the Songish (Pacific Northwest coast; Antón, 1989; Kohn et al., 1993), and produces less convexity in the frontal and occipital bones.

In the present study, the cranial reshaping differentiated the deformed and normal crania on the PC1 and PC3 axes (Figure 3, Figure 4). Our results correspond with previous studies (Antón, 1989; Kohn et al., 1993; O'Brien and Stanley, 2013) that reported shorter cranial length and broader cranial breadth in the anteroposterior cranial modification group than in the normal group. In this regard, the two deformed crania from Yean-ri in this study can be allocated to the anteroposterior cranial modification type based on the flatter frontal and occipital bones and superoposteriorly developed parietal bones.

In discriminant function analysis, the cranial shape of Ye085 and Ye099 showed statistically significant differences from the normal groups ($P = 0.001$). However, cross-validation tests using the leave-one-out method allocated one normal specimen as the deformed group and one deformed cranium was assigned to the normal group (Table 2). However, the results may be due to the very small sample size of the deformed group ($n = 2$) in the present study. Im095 may have been allocated to the deformed group because the specimen was most closely located to the deformed group on the first PC axis. Similarly, Ye085 on the first PC axis may be allocated to the normal group in a cross-validation test with leave-one-out. Thus, leaving out Ye085 or Ye099 from the cross-validation test may lower the classification rate. Focusing only on the flat frontal bone of Im095 and Nu051, it can be postulated that the Im095 and Nu051 crania might have been modified by a different method than the deformed specimens from Yean-ri. However, the cranium of Im095 was relatively less flat in the frontal and more convex in occipital bones compared to the deformed crania. In particular, the convexity of occipital bone of Im095 was the most pronounced among the specimens in this study and may not reflect intentional modification. Moreover, Antón (1989) reported that occipital convexity was different between the normal and deformed groups. In this context, Im095 and Nu051 crania should be regarded as a normal variation rather than as artificial deformation.

In conclusion, the results of this study showed that the geometric morphometric method can be an efficient way to capture subtle shape differences between deformed and normal crania using a lateral view. A flat frontal bone and flat occipital bone along with superoposteriorly developed parietal bones need to be observed from a lateral view to diagnose an anteroposterior cranial modification type. According to these criteria, other probable cases of deformed crania were not found in other specimens from the Yean-ri, Imdang, and Nukdo sites. Although the relatively flatter frontal bones of Im095 and Nu051 were similar to the morphology of the deformed group, the convexity in the occipital bone was too pronounced to allocate these specimens to the deformed group.

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