Supplementary Information

Title:

Two Methods of Intentional Cranial Modification from Early Holocene Songhuajiang in Northeast China

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Supplementary Text S1. Basis for specimen classification and treatment of unclassified material

Specimens assigned to the annular modification group are classified a priori based on well-established morphological criteria. The three Peruvian Bone Clones specimens (BC115, BC200, and BC201) can be confidently classified as annularly modified crania, as they show clear circular banding impressions on both the frontal and occipital regions, lack localized frontal or occipital flattening, and exhibit pronounced antero-posterior elongation, resulting in a characteristic cylindrical vault shape. These traits are consistent with the widely accepted criteria for annular modification observed across Andean regions. The same pattern applies to specimens CO314, CO361, and CO365, which also exhibit distinct circular banding marks on the frontal and occipital bones. Their cranial vaults are cylindrical rather than conical, supporting attribution to annular modification. Therefore, these six specimens are treated as annular modified specimens.

The classification of PA1616 and PA1683 is based on following studies: (Ni et al., 2020; Yin et al., 2022).

Specimen AN2375 represents a modification type restricted to the occipital region from the Dawenkou Culture (Zhao et al., 2017). Specimen CO316 shows extreme occipital flattening and bilateral expansion of the parietals, while the frontal bone shows no evidence of modification. This pattern differs from tabular deformation, which involves compression on both frontal and occipital regions, and is more similar to AN2375.

To further support these classifications, scanned images of the crania are provided as **Figure S1**.

Supplementary Text S2. FTIR Analysis

FTIR (Fourier Transform Infrared Spectrometer) analysis was performed on three of our samples using FTIR spectroscopy at the Institute of Geology, Chinese Academy of Geological Sciences with a HYPERION 2000 microscope coupled with a Bruker Vertex 70V spectrometer.

The phosphate-crystallinity index (PCI) of modern human bone typically ranges from 2.9 to 3.1, whereas values of approximately 3.5 are reported for ancient human bones (Wright,Schwarcz, 1996). The B-carbonate on Phosphate Index (BPI) of modern bone apatite is reported to range from 0.29–0.96, while values for ancient human bone typically fall between 0.26–0.70; the mineral carbonate/phosphate (C/P) ratio is generally close to 0.14–0.42 in modern bone and 0.12–0.37 in ancient bone (France et al., 2020). The specific FTIR-derived indicators for the three analyzed specimens are presented in Table S5.

Supplementary Tables

Number	Landmark names	Position
1	nasion	frontal
2	glabella	frontal
3,4	sphenion	frontal
5	bregma	frontal
6,7	dakryon	frontal
8,9	frontomalare orbitale	frontal
10,11	frontomalare temporale	frontal
12,13	frontomalare	frontal

Number	Landmark names	Position
1	bregma	parietal
2	lambda	parietal
3,4	asterion-anterior	parietal
5	asterion-posterior	parietal
6	sphenion-anterior	parietal
7	sphenion- posterior	parietal
8	lambda	parietal

Number	Landmark names	Position
1	lambda	occipital
2,3	asterion-posterior	occipital
4,5	mastoid-occipital point	occipital
6	opisthion	occipital

7,8	occipital condyle	occipital
9	occipital protuberance	occipital
10	middle nuchal line	occipital

Table S2. List of anatomical landmarks on frontal, parietal, and occipital bones.

Number	Curve names	Position	Numbers of semilandmarks
1,2	orbital margin	frontal	9 each
3	along the coronal suture	frontal	34
4	coronal suture-right	parietal	13
5	sagittal suture (from b to l)	parietal	13
6	lambdoid suture	parietal	13
7	squamous suture	parietal	13
8,9	lambdoid suture	occipital	10 each
10,11	mastoid border	occipital	6 each
12	occipital condyle	occipital	7
13	superior nuchal line	occipital	17

Table S3. List of curves.

Number	Patch names	Position	Numbers of semilandmarks
1	the superior part of the frontal bone	frontal	116
2	right parietal bone	parietal	169
3	occipital bone	occipital	100

Table S4. List of patches.

Specimen	Annular	Type III	Tabular	undeformed
AN624	0.970823	6.95E-12	4.49E-03	0.024684
SHJ001	0.088308	9.92E-10	0.908751	2.94E-03
SHJ002	0.400728	4.52E-04	5.72E-08	0.598820

Specimen	Annular	Type III	Tabular	undeformed
AN624	2.08E-04	0.079925	2.34E-3	0.917531
PA1688	0.499119	0.035986	0.463781	1.11E-03
SHJ001	0.657343	0.040386	0.301452	8.19E04

Specimen	Annular	Type III	Tabular	undeformed
AN624	0.022648	2.62E-9	1.76E-05	0.977334

Table S5. Posterior probabilities from the LDA analyses of the first 20 PCs of frontal, parietal, and occipital bone landmark configurations.

Specimen	PCI (Phosphate Crystallinity Index)	BPI (B-carbonate on Phosphate Index)	C/P (Mineral Carbonate/Phosphate)
PA1616	3.165472	0.678015	0.294289
PA1683	3.036124	0.712437	0.394651
PA1688	2.844108	0.759300	0.460093

Table S6. FTIR-based bone mineral preservation indicators for Songhuajiang specimens.

Supplementary Figures

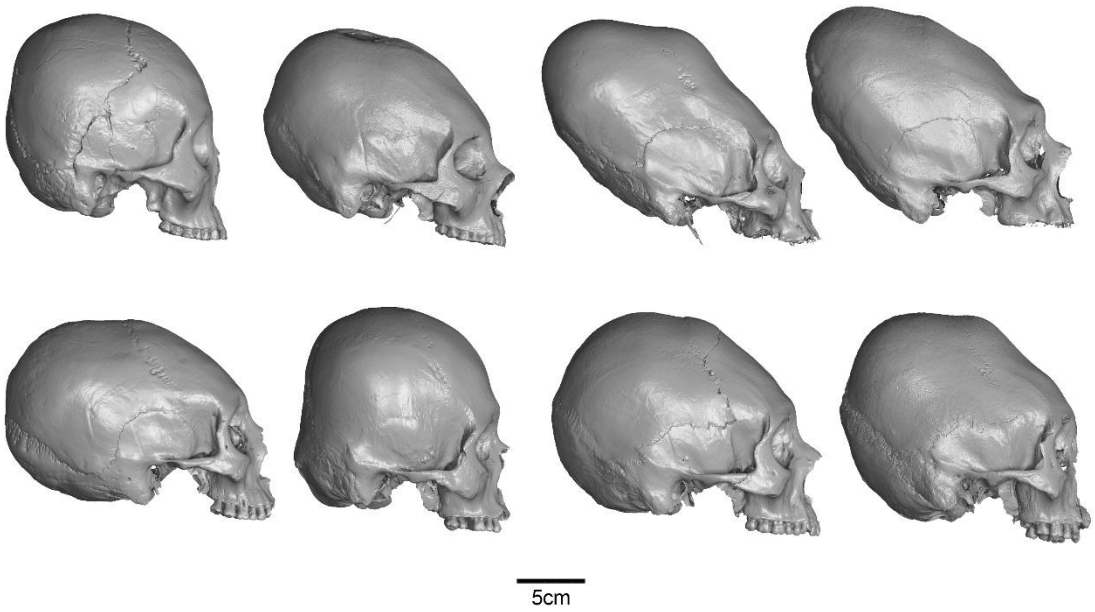
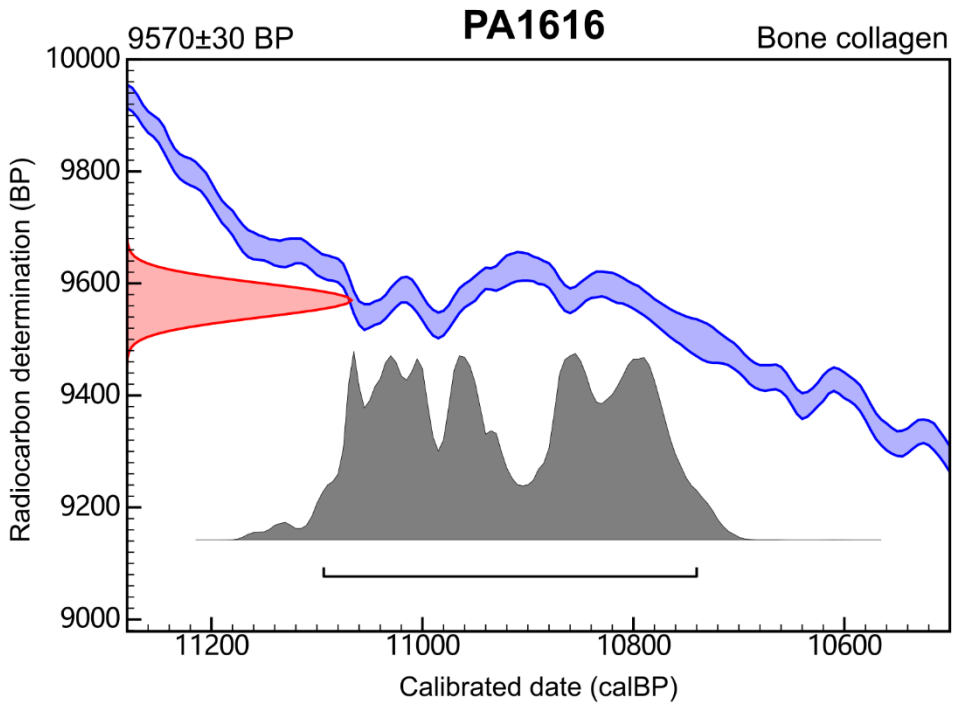
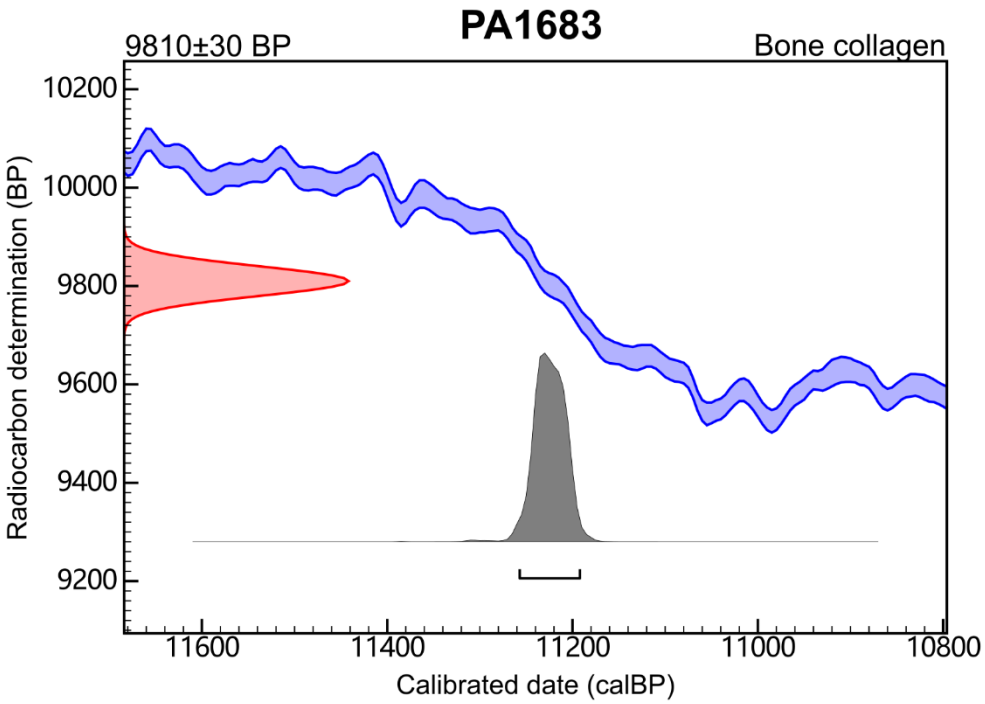
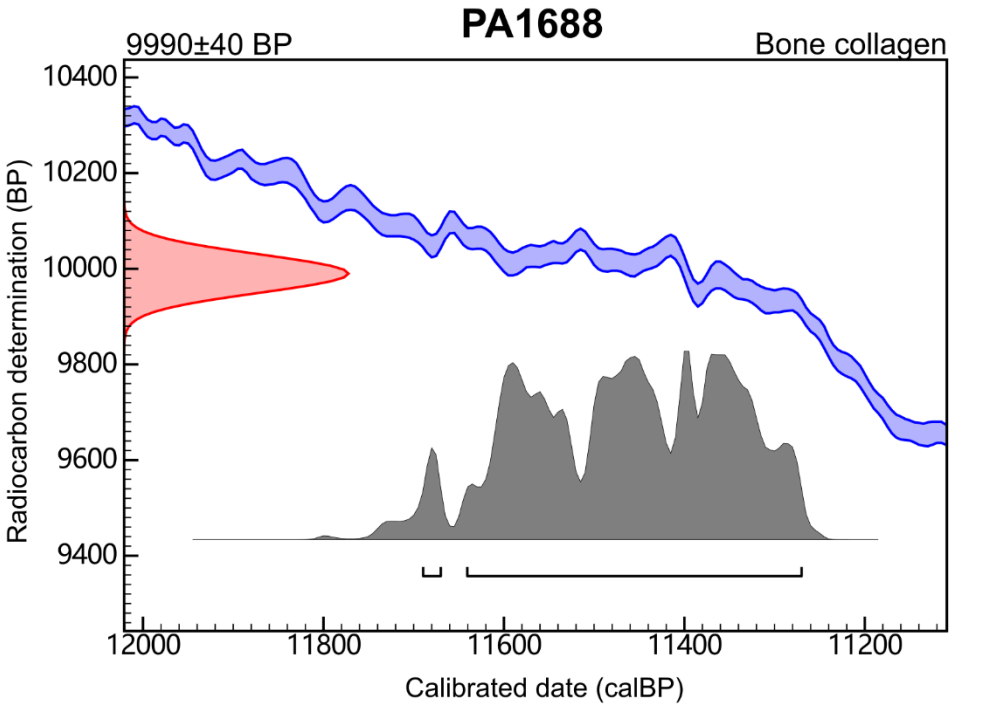


Figure S1. 3D surface models of the comparative crania included in this study. Top, from left to right: AN2375, BC115, BC200, BC201; bottom, from left to right: CO314, CO316, CO361, CO365.




PA1683
9810±30 BP
Bone collagen
Radiocarbon determination (BP)
10200
10000
9800
9600
9400
9200
11600
11400
11200
11000
10800
Calibrated date (calBP)


PA1688
9990±40 BP
Bone collagen
Radiocarbon determination (BP)
10400
10200
10000
9800
9600
9400
12000
11800
11600
11400
11200
Calibrated date (calBP)

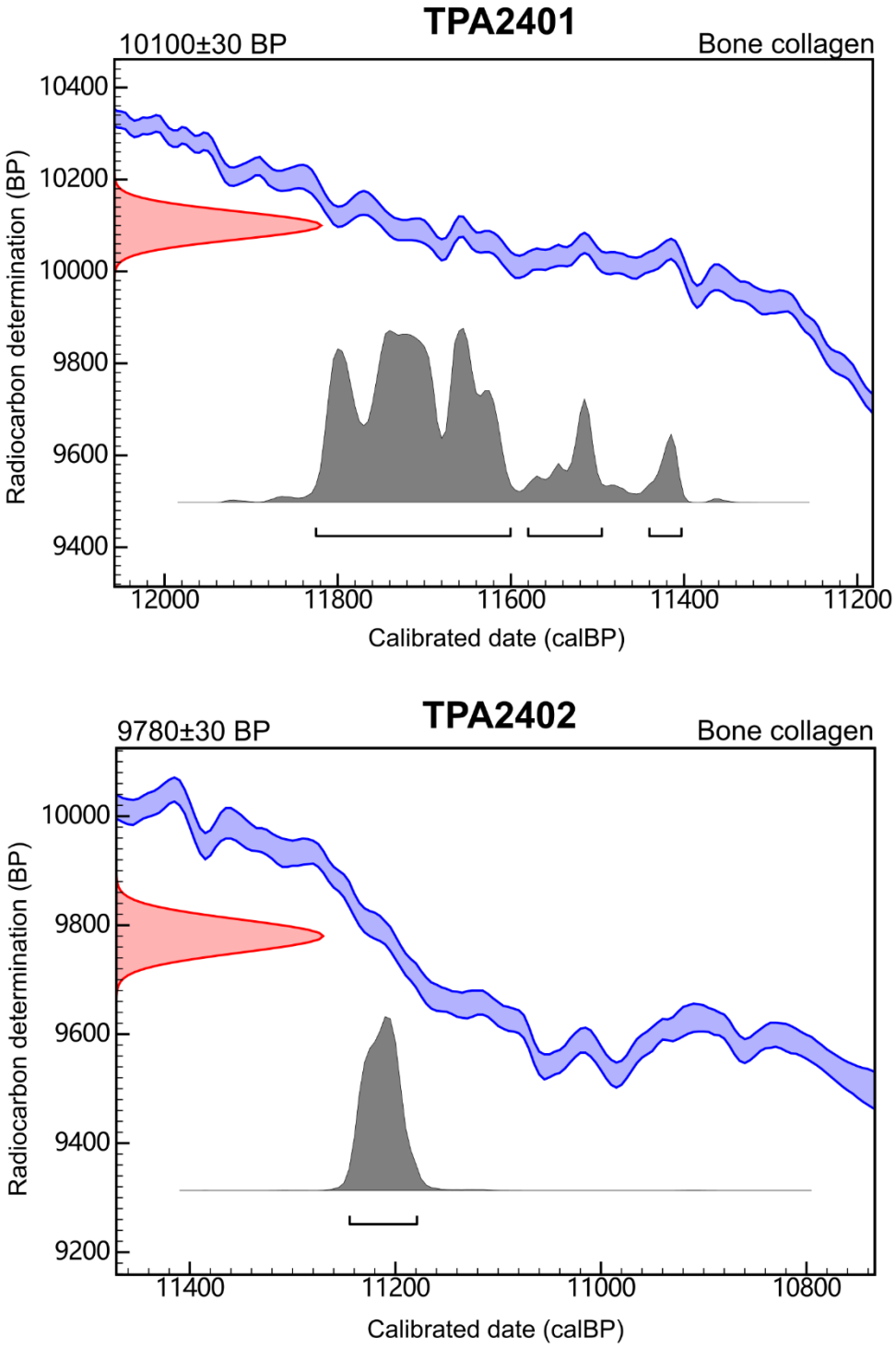


Figure S2. Posterior probability distributions of individual radiocarbon dates. From top to bottom: PA1616, PA1683, PA1688, TPA2401, and TPA2402.

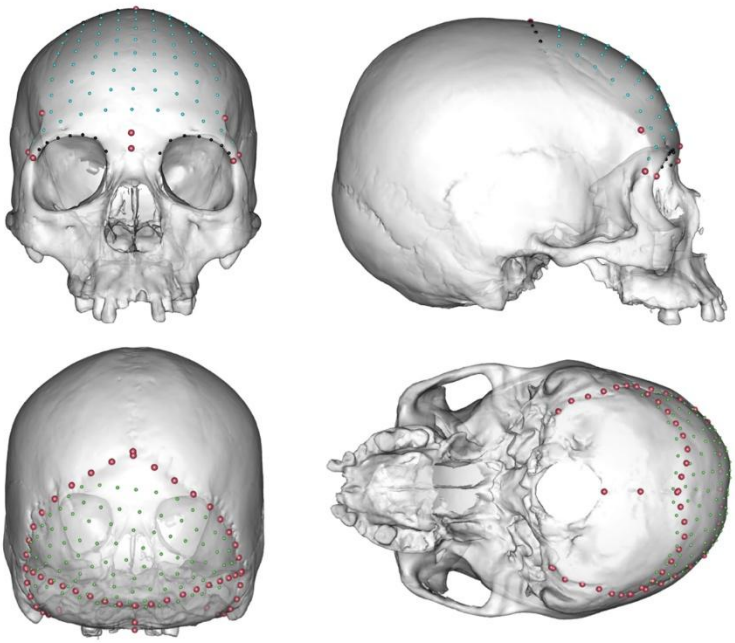
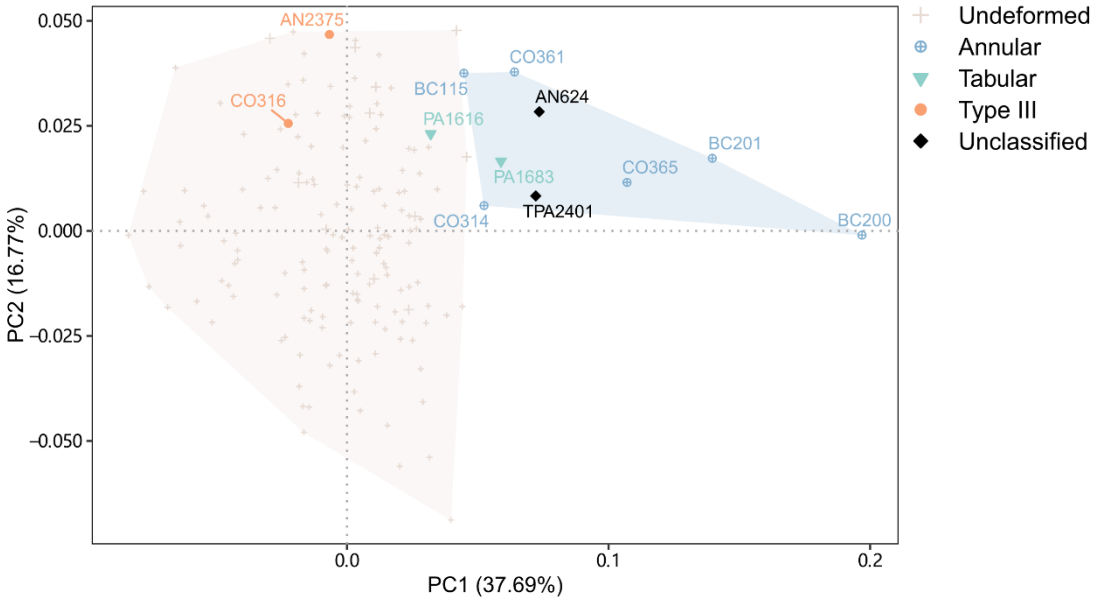


Figure S3. Landmark Settings for GM analysis. Red dots indicate fixed landmarks considering only the preserved regions, black dots indicate landmarks on curves, and blue dots indicate landmarks on surfaces. Top: Frontal landmarks; bottom: Occipital landmarks.



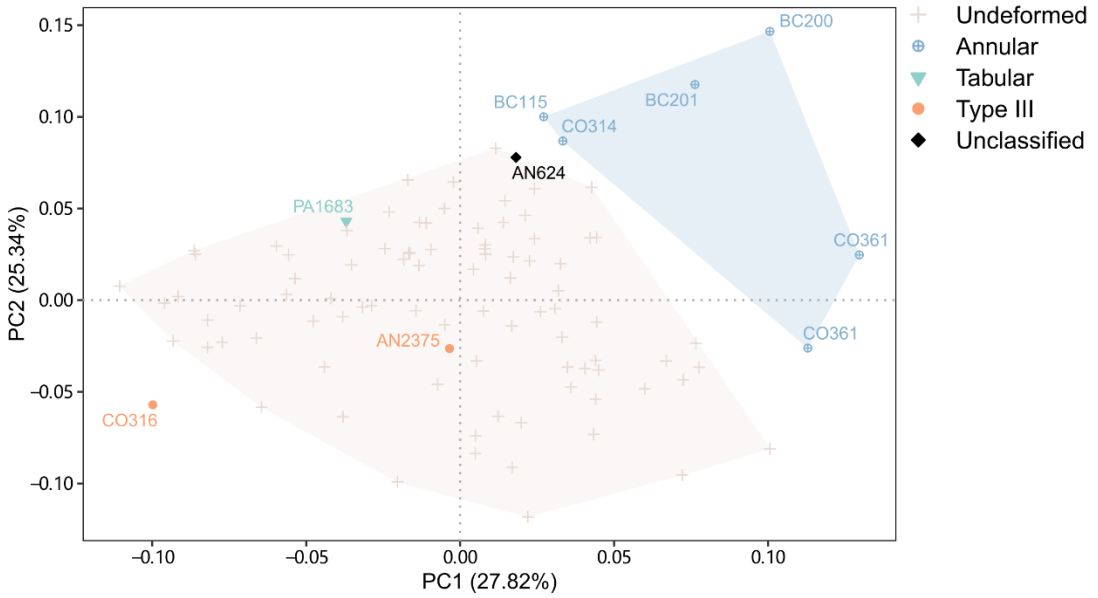


Figure S4. PCA plot on the frontal (top) and Occipital (bottom) morphology of intentionally modified and unmodified human craniums considering only the preserved regions.

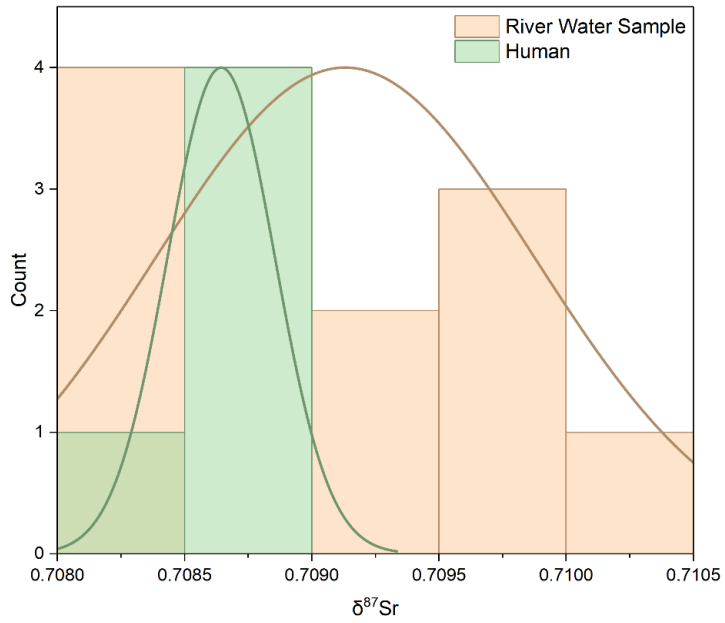


Figure S5. Density plot of strontium isotope values for human and environmental samples, adapted from (Wang,Tang, 2020).

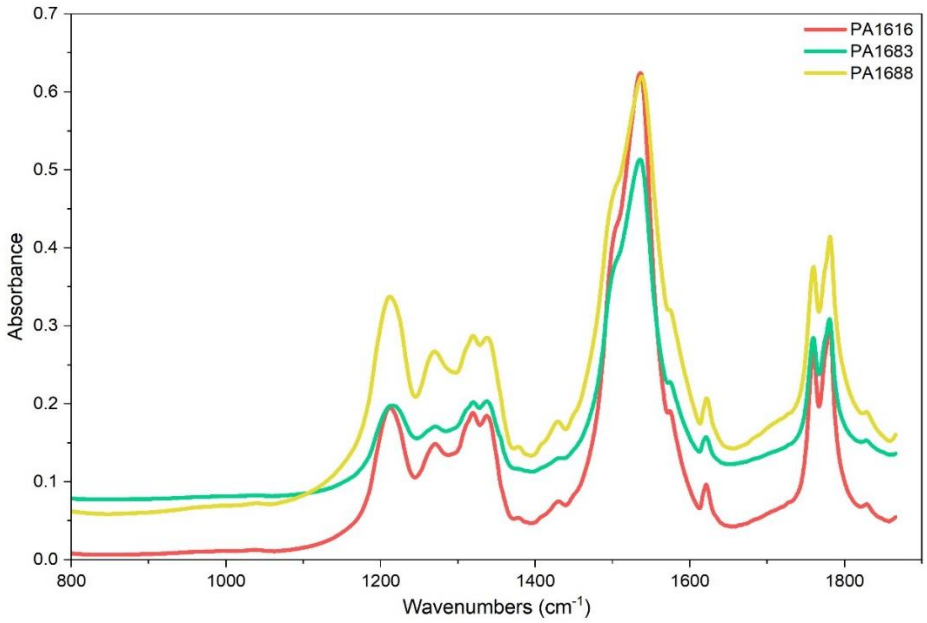


Figure S6. FTIR plot for specimens PA1616, PA1683 and PA1688.

Reference

France CAM, Sugiyama N, Aguayo E (2020) Establishing a preservation index for bone, dentin, and enamel bioapatite mineral using ATR-FTIR. Journal of Archaeological Science: Reports 33: 102551. https://doi.org/10.1016/j.jasrep.2020.102551

Ni X, Li Q, Stidham TA, et al (2020) Earliest-known intentionally deformed human cranium from Asia. Archaeol Anthropol Sci 12: 93. 10.1007/s12520-020-01045-x

Wang X, Tang Z (2020) The first large-scale bioavailable Sr isotope map of China and its implication for provenance studies. Earth-Sci Rev 210: 103353. https://doi.org/10.1016/j.earscirev.2020.103353

Wright LE, Schwarcz HP (1996) Infrared and Isotopic Evidence for Diagenesis of Bone Apatite at Dos Pilas, Guatemala: Palaeodietary Implications. J Archaeol Sci 23: 933-944. https://doi.org/10.1006/jasc.1996.0087

Yin Q, Li Q, Zhang H, et al (2022) A 10 ka intentionally deformed human skull from Northeast Asia. Int J Osteoarchaeol 32: 932-937. https://doi.org/10.1002/oa.3104

Zhao Y, Zeng W, Wei C, et al (2017) Study of Occipital Deformation in the Dawenkou Culture. Southeast Culture: 9.