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ORIGINAL PAPER

Earliest-known intentionally deformed human cranium from Asia

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Abstract
Hereditary hierarchy is one of the major features of complex societies. Without a written record, prehistoric evidence for hereditary hierarchy is rare. Intentional cranial deformation (ICD) is a ritualized and cross-generational cultural practice that embodies social identity and cultural beliefs in adults through the behavior of permanently and immutably altering infant head shape. Therefore, ICD is usually regarded as an archeological clue for the occurrence of hereditary hierarchy. With a calibrated radiocarbon age of 11,245–11,200 years BP, a fossil skull of an adult male discovered in Northeastern China is among the oldest-known ICD in the world. The fossil demonstrates the oldest application of the more sophisticated tabular deformation methodology that requires securing hard flat surfaces to the forehead and back of the skull of infants, differing from the other earliest-known records of ICD that used other processes. Along with the other earliest global occurrences of ICD, this discovery points to the early initiation of complex societies among the non-agricultural local societies in Northeastern Asia in the early Holocene. A population increase among previously more isolated terminal Pleistocene/early Holocene hunter-gatherer groups likely increased their interactions, possibly fueling the formation of the first complex societies.

Keywords Intentional cranial deformation · Complex society · Cross-generational cultural practice · Hereditary hierarchy

Introduction

Human societies are thought to have become more complex since the beginning of the Holocene (about 11 ka) (Johnson and Earle 2000; Marcus 2008; Sheehan et al. 2018) after the end of the last major glacial interval. Hereditary hierarchy is generally regarded as one of the essential characteristics of complex societies. The origins of hereditary inequality, or the replacement of egalitarian societies with ascribed hereditary hierarchy, represents the major transition from a lower to a higher level of social complexity (Marcus 2008). Without written records, prehistoric evidence for this crucial transition in human cultural evolution is rare. However, intentional cranial deformation (ICD), also known as artificial cranial modification, generally is regarded as a definitive archeological signal for hereditary rank (Goodrich and Tutino 2001; Marcus 2008; Marcus and Flannery 2004).

The human head is widely regarded as the carrier of the soul, identity, personhood, ancestry, and ethnicity (Bonogofsku 2011; Duncan and Hofling 2011). Past and present societies and cultures have treated the heads of living and deceased individuals in very diverse ways, including their decoration, deformation, trephination, and even decapitation (Bonogofsku 2011). Within that diversity, ICD is an intriguing cultural practice that is a deliberate, significant, and permanent modification to the shape of the human skull, produced by compressing an infant's head with hands, binding the head with hard, flat surfaces, or by tightly wrapping the head in

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cloth. ICD is a ritualized and cross-generational cultural practice that results in an easily recognizable flat, elongated, or a conical vault shape in adulthood. The practice of ICD and its associated meme are regarded as a significant way to symbolize social identity and embody cultural beliefs, with the results signifying group affiliation, or demonstrating social status (Duncan and Hofling 2011; Tiesler 2014).

ICD has a rich historic and prehistoric record in cultures around the world (Dingwall 1931; Enchev et al. 2010; Jung and Woo 2017; Kiszely 1978; Ricci et al. 2008; Tiesler 2014) that probably continues today (Childress and Foerster 2012). Although the practice of ICD has been suspected in the Neanderthals (Trinkaus 1982) and a latest Pleistocene human from the Upper Cave of the Zhoukoudian locality in China (Weidenreich 1939), these suggestions have been seriously challenged (at least they were not intentionally deformed) (Clark et al. 2007; Thorne et al. 1999; Tiesler 2014). The earliest-known preserved skulls that undoubtedly exhibit ICD are from the early Holocene (about 10,000–12,000 years ago) in the central Murray River region of southeastern Australia and the Proto-Neolithic deposits in Shanidar Cave in Iraq (Brown 2010; Meiklejohn et al. 1992; Solecki et al. 2004) (see Supporting Text).

Recently, the skull of the 2011DHAIIIM45 skeleton, which was excavated from the single burial of the Houtaomuga Site Phase I period, was suggested as the earliest-known ICD evidence in Asia (Zhang et al. 2019). Originally, the calibrated radiocarbon dating directly on the skeleton is 11,235–11,145 BP (Zhang et al. 2017), but was re-dated as 12,027–11,747 BP by the team who declare the skeleton presenting the oldest-known evidence of ICD practice (Zhang et al. 2019). The 2011DHAIIIM45 skull is dolichocephalic, but does not show typical ICD flattening, elongation, or conical shape. Detailed analysis on the cranial metric variables and non-metric traits indicated that the 2011DHAIIIM45 skull falls in the variation range of the East Asian population (Xiao 2014).

Material and methods

The fossil was discovered from the Dadingzi Hill underwater sand mining site in the Songhuajiang River about 20 km east to the Harbin City, Heilongjiang Province, Northeastern China. Sedimentation in this area belongs to the late Pleistocene to early Holocene Guxiangtun Formation, which is mainly a set of fluvial deposits formed during the Last Glacial Period. Thousands of mammalian fossil fragments, including dozens of fossil human remains, were discovered from this sand mining site and nearby areas. Radiocarbon dating on the mammal and human fossils indicated an age span about 10–40 ka. Supporting Text provides full information about CT scanning, radiocarbon dating, and trophic position (stable isotope) analysis.

Results

The new fossil clearly exhibiting ICD (Songhuajiang Man I, IVPP PA1683, Fig. 1) reported here was collected at an underwater sand mining site in the Songhuajiang River near Harbin, Heilongjiang Province, Northeastern China. Direct AMS radiocarbon dating of the cranium reveals a calibrated date of 11,245–11,200 years BP (see Supporting Text). The age places the Songhuajiang ICD record roughly as old as the previously oldest-known ICD records from Australia (calibrated AMS ^{14}C date of 11,440 ± 160 years BP, the most securely dated age) (Brown 2010) and older than the records from the Middle East (calibrated ^{14}C date of 10,600 ± 300 years BP) (Meiklejohn et al. 1992; Solecki et al. 2004).

The Songhuajiang ICD cranium is lightly built, showing modern aspects that resemble the Proto-Neolithic crania from Shanidar Cave and Jericho (Meiklejohn et al. 1992; Solecki et al. 2004), but differing from the heavily built crania from southeastern Australia (Brown 2010). The facial cranial part of the skull is missing, but the neurocranial portion of the skull is nearly complete. Only the sphenoid and the condyles of the occipital are damaged. The individual has a prominent supraorbital ridge, blunt supraorbital margin, strong temporal line, and a long and large mastoid process, suggesting that the cranium probably belongs to a male (Buikstra and Ubelaker 1994; Rogers 2005). The preserved cranial sutures show early stages of fusion. The coronal and sagittal sutures exhibit minimal to marked degree of closure, while the other sutures, such as lambda and sphenotemporal, are almost unfused. Based on the composite scores reflecting the degree of the ectocranial suture closure (Meindl and Lovejoy 1985), the age at death is estimated as young adult (20–34 years). The assessment of its ethnicity is difficult, given the missing facial cranial region and its antiquity, but the moderately wide interorbital space, large mastoid process, shallow infraglabellar notch, and rounded and sloping supralateral margin of the orbits commonly are present in Asian people, particularly in the modern Chinese population (Liu et al. 2006a; Liu et al. 2006b; Rhine 1990). Despite the strong deformation of the parietal region, the skull shows a clear obelionic depression near the parietal foramen. The frequency of occurrence of this feature is very high in the modern Chinese population (Liu et al. 2006a; Liu et al. 2006b). Overall, these non-metric cranial characteristics mentioned above are more consistent with the morphology of a young male Asian individual.

The oldest-known ICD records from Australia exhibit a very mild change to cranial shape, likely resulting from pressing hands onto the newborn's forehead (Anton 1989; Brown 2010). The oldest-known, undoubted ICD records from the Middle East were generated by circumferential restriction to skull growth by wrapping the infant's head with one or more pieces of cloth. By contrast, the Songhuajiang Man I exhibits typical tabular deformation, which clearly is a more

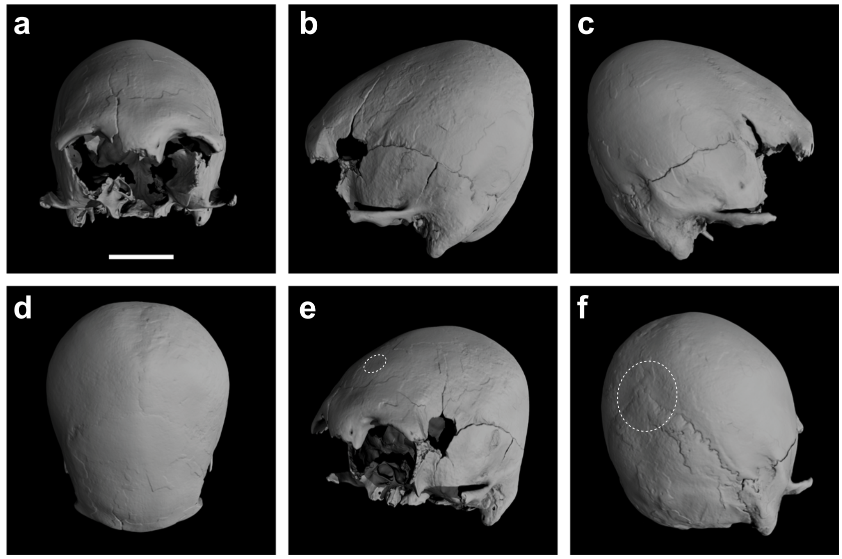

Fig. 1 Songhuajiang Man I intentionally deformed cranium fossil (IVPP PA1683). **a** anterior view; **b** left lateral view; **c** right lateral view; **d** superior view; **e** anterior-left lateral view; **f** posterior-right lateral view. White dashed circles in **e** and **f** indicate the flat areas that likely were secured against a hard surface during infancy/early childhood. White scale bar indicates 5 cm

complicated and sophisticated ICD methodology than the manual molding or annular type of deformation. This version of ICD results in a cranial vault, as seen in the Songhuajiang Man I fossil, that has a core-like shape, with a very flat and superior-posteriorly sloping forehead, and a nearly vertical, flat occiput. The forehead does not exhibit a circular depression that would have formed as the result of the restriction by bandages (as in annular deformation). The squama of the frontal bone is flat with a very low frontal eminence. The frontal curvature index (a measure of the flatness calculated as the ratio of the subtense height relative to the chord length) is 14.1, much lower than in undeformed skulls (Brown 2010) (Table 1). There is a small flat area between the two frontal eminences, and displaced slightly to the left side (Fig. 1e). This flat region probably is the result of binding a hard flat plate or board, possibly a so-called anterior pillow (Kiszely 1978). on to the frontal region for a prolonged time during the growth of the immature skull. The parietal is anteroposteriorly shortened, but superior-posteriorly elongated. The parietal curvature index is 27.6, much higher than that of undeformed skulls (Brown 2010). As in other tabularly deformed crania, the parietal eminence bulges significantly laterally and has a large curvature. In superior view, the posterior part of the skull is much wider than the anterior part, and clearly differs from the cylindrically shaped cranium produced by annular deformation. There is a disk-like flat region around the lambda (Fig. 1f), which must be the result of the area being secured against a hard flat surface during infancy/early childhood. The squama of the occipital region also is flat. The occipital curvature index is 18.6, much lower than in undeformed skulls (Brown 2010). The external occipital protuberance and external occipital crest are weak.

Cranial deformation affects the frequency of wormian bones (suture ossicles) (Anton et al. 1992; O'Loughlin 2004; Van Arsdale and Clark 2012; White 1996) and also alters the endocranial structures such as brain shape and blood vessel patterns (Dean 1995; Grupe 1984; O'Loughlin 1996). The Songhuajiang Man I has a small piece of wormian bone along the parietal-mastoid suture, and a tiny piece on the occipital-mastoid suture on the right side of the skull. Although the wormian bones on the lambda suture commonly are present in modern African and European populations, they have a lower frequency in the extant Asian population (Liu et al. 2011).

Table 1 Linear dimensions and subtenses in the Songhuajiang Man I. Measure definition as in reference (Brown 2010)

Variables	Measurements
Frontal chord (n-b)	126.07 mm
Frontal sub h	17.78 mm
Frontal curvature index	14.1
Frontal angle	19.84
Parietal chord	96.28 mm
Parietal sub h	26.61 mm
Parietal curvature index	27.6
Parietal angle	25.6
Occipital chord	110.59 mm
Occipital sub h	20.55 mm
Occipital curvature index	18.6
Occipital angle	18.09
Basion-bregma	154.45 mm
Max biparietal br	141.68 mm
Min frontal br	92.5 mm
Nasion-opisthocranion	169.84 mm
Minimum vault thickness at glabella	16.48 mm
Minimum vault thickness at bregma	7.46 mm
Minimum vault thickness at inion	13.23 mm

The virtual endocast of the Songhuajiang Man I (Fig. 2) is anterior-posteriorly shorter than an undeformed endocast. The frontal and occipital regions are flatter, while the parietal region is more superiorly projecting. In lateral and posterior view, the occipital transverse sulcus and lunate sulcus are broad and deep. In undeformed endocranial casts, these two sulci are usually invisible or quite shallow (Connolly 1950). On the left side, the anterior branch of the middle meningeal vessel is deep and thick and has many crenulated terminal branches. The posterior branch of the middle meningeal vessel is shallower, thinner and has fewer branches. As it is commonly seen in other deformed crania, the posterior part of the posterior branch angles superiorly and extends to the top of the parietal lobe. On the right side, the anterior branch of the middle meningeal vessel is as deep and complicated as that on the left side. The entire posterior branch alters its direction by extending posterior-superiorly, almost parallel to the anterior branch. The anterior and posterior branches are similarly deep, but the posterior branch has fewer branches. In the undeformed endocast, the anterior and posterior branches of the middle meningeal vessel are equally thick, moderately deep, lack the convoluted terminal branches, and do not exhibit the altered direction (Dean 1995; Grupe 1984; O'Loughlin 1996). The impression of the sagittal sinus of the Songhuajiang Man I is quite deep and does not display compression or flattening, different from most other deformed crania. The drainage predominantly goes to the right transverse sinus. In undeformed crania, the sagittal sinus usually drains to the right transverse sinus, while in deformed crania, it has a higher frequency of traveling to the left side (Dean 1995; O'Loughlin 1996).

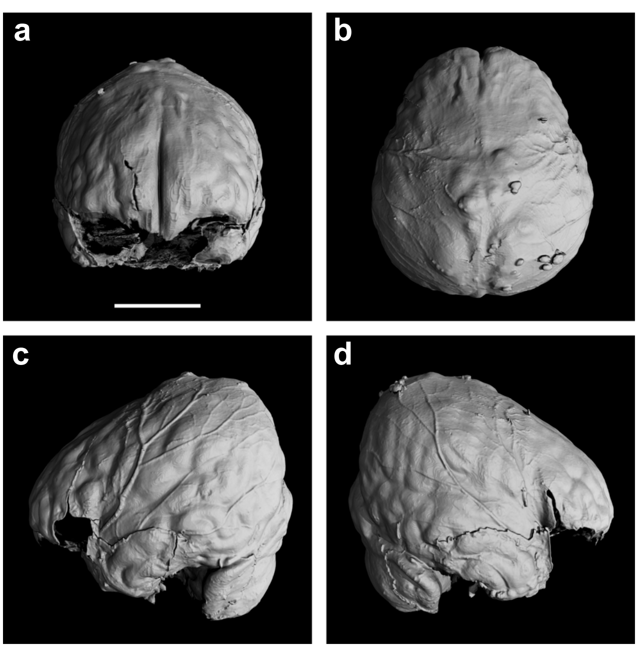

Fig. 2 Virtual endocast of the Songhuajiang Man I (IVPP PA1683). **a** anterior view; **b** superior view; **c** left lateral view; **d** right lateral view. White scale bar indicates 5 cm

It is widely assumed that the variation among individual people in the isotopic composition ($\delta^{13}C$-$\delta^{15}N$) of their bone collagen reflects differences in their diets (Katzenberg 2008; Keegan 1989). The $\delta^{13}C$ of Songhuajiang Man I is −20.8‰, and the $\delta^{15}N$ is 11.4‰. The low carbon isotope value indicates that this man had a diet mainly consisting of C_3 foods. Nitrogen stable isotope ratios are low among terrestrial herbivores, but high in fishes (Katzenberg 1999; Katzenberg 2008). The relatively high nitrogen isotope value in the bone collagen of Songhuajiang Man I not only suggests his dietary protein originated from high trophic levels but also indicates that the animal protein probably derived from sources in lakes and rivers. The isotopic composition of $\delta^{13}C$ and $\delta^{15}N$ in Songhuajiang Man I is very close to the values found among the early and middle Neolithic people from the Angara River and Upper Lena River in Siberia (Katzenberg 1999), who were hunter-fisher-gatherers.

In Australia, the Middle East, and now the Songhuajiang area, ICD crania make up only a small proportion of the known human specimens (see Supporting Text). The low frequency likely is the result of only select individuals in these populations (maybe the elite children) being involved in the practice and application of ICD.

Discussion

Various ritualized and costly actions, such as firewalking, ritual scarification, and subincision, are theorized as credibility enhancing displays that could promote group solidarity and intragroup cooperation, and they reflect a deep level of commitment to group ideologies and religious beliefs (Henrich 2009). The practice of ICD is such a ritualized and costly action that results in highly visible and permanent life-long body modification that even extends beyond an individual's lifespan (Lorentz 2010; Rorabaugh and Shantry 2017; Tiesler 2014). Differing from other typical body treatments, ICD is performed by the parental generation and applied to the descendant generation (a cross-generational action). Through this practice, a highly visible and permanent icon for specific social identity and cultural beliefs is embodied from one generation to the next generation. The continuation of this cultural tradition requires much forethought and planning to achieve the desired result in adults of the next generation. Individuals with their appearance, as the result of ICD, obtained an ascribed status that was enhanced by an easily recognizable, highly visible, and immutable physical trait. The practice symbolized in ICD is not only accepted and understood by the clan/group who performed this activity on their descendants, it also should be understood and recognized by other groups who have interaction with the ICD expressing groups, including those who do not perform this practice.

There are tremendous archeological and ethnographic literatures on the practices of ICD in the historical period, and there is a huge variety in the ICD methods and believes embedded in the practices (see Supporting Text). Given its long history and wide distribution, the motives for the creation and continued practices of ICD cannot be satisfactorily explained with a single theory. They obviously involve the kinship, status, ethnicity, social identity, sex, or a combination of some of these reasons.

It is widely suggested that there are two most common motives for the practice of ICD: esthetics reason and social differentiation (Duncan and Hofling 2011; Marcus 2008; Marcus and Flannery 2004; Tiesler 2014). When the ICD head shape is regarded as a sign of beauty, such as in some Sunda Island populations, where the practice of ICD was purely out of an esthetic reason (Blackwood and Danby 1955; Mally 2017a; Mally 2017b), the practice of ICD always involves the majority of the population. When the practice of ICD is out of the ranking reason, the practice is always a selective behavior (Duncan and Hofling 2011; Marcus 2008; Marcus and Flannery 2004; Tiesler 2014). Historically, Fray Juan de Torquemada (1615) probably is the first to suggest that ICD was associated with nobility and reflected social status (Juan de Torquemada 1995 [1615]). There are some evidences showing a direct link between social ranks and ICD. For example, at the San José Mogote site (about 3100 BP), the signs of hereditary differences in rank appeared. Only the elite of the population lived in multi-structure residences, wore sumptuary goods of jade, magnetite, and mother-of-pearl, and practiced ICD as a sign of nobility (Marcus and Flannery 2004).

The low frequency of ICD in Australia, the Middle East, and the Songhuajiang area suggests that ICD was a very selective behavior, and probably also a ritual action, before it became a meme widely distributed across different time periods and cultures. This selectivity is highly suggestive of the presence of social and/or cultural differentiation within the populations or cultures (Duncan and Hofling 2011; Marcus 2008; Marcus and Flannery 2004; Tiesler 2014).

These earliest ICD records show that different geographically distant, early cultures around the world spread this cultural practice from one generation to the next outside of an agricultural setting. The association of ICD with agricultural practice appears to have occurred later in the Holocene. As in Australia and the Middle East, the practice of ICD in the Songhuajiang area occurred in hunter-gatherer populations. The isotopic composition of $\delta^{13}C$-$\delta^{15}N$ of the bone collagen of Songhuajiang Man I indicates that the man had a diet mainly consisting of C_3 foods and ingested protein that originated from sources in lakes and rivers. It is generally believed that hunter-gatherers tend to have an egalitarian social ethos. However, by reinforcing the ascribed status of a social entity via such a sophisticated and ritualized way as the practice of ICD, the people in these areas signified their intragroup affiliation and delimited intergroup social boundaries. Multiple clans, with and without the practice of ICD, must have had frequent interactions, and probably formed a kind of larger tribe or community. Relatively stable, but complex and likely socially stratified tribes or communities formed by different hunter-gatherer clans likely were present in the Middle East, Australia, and East Asia during the Pleistocene-Holocene transition.

The natural and social factors that led to the practice of ICD, and the intertwined enhanced ascribed social status resulting from this practice are critical for understanding the

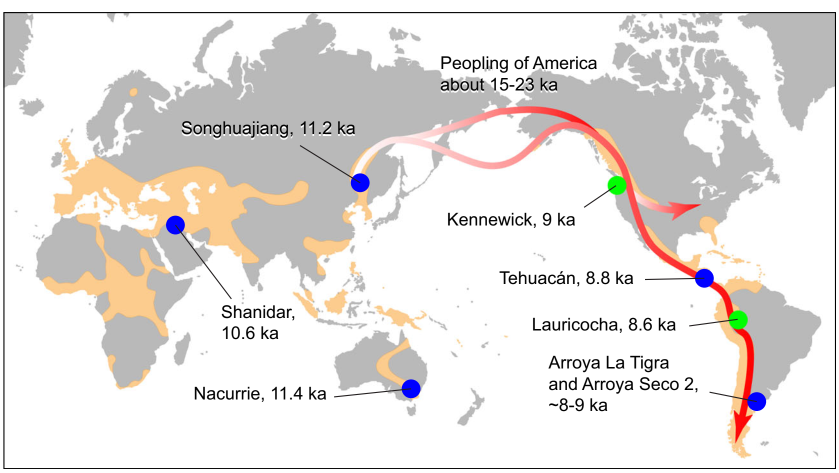

Fig. 3 Worldwide distribution of the practice of intentional cranial deformation (ICD) in archeological records. The areas in pale orange indicate the distribution. Blue dots indicate sites with undoubted ICD. The green dots indicate places with dolichocephalic crania, which are elongated heads that may not be ICD. Data from references (Brown 2010; Dingwall 1931; Enchev et al. 2010; Jung and Woo 2017; Kiszely 1978; Meiklejohn et al. 1992; Munizaga 1987; Ricci et al. 2008; Solecki et al. 2004; Tiesler 2014). The date for peopling of Americas is inferred from analyses of genomic data from reference (Nielsen et al. 2017). The global map is modified from https://upload.wikimedia.org/wikipedia/commons/c/c2/Blank_Map_Pacific_World.svg (under the Creative Commons Share Alike license: https://creativecommons.org/licenses/by-sa/3.0/deed.en)

early evolution of human social complexity. Even though it is widely suggested that the development of intensive resource use, such as the shifts from foraging to agriculture, is relevant to the (origin and) evolution of social complexity, recent anthropological research suggests that intensification of resource use or acquisition and sociopolitical hierarchy are broadly reciprocal, probably as a feedback loop that also may have involved population growth (Sheehan et al. 2018).

The terminal Pleistocene-early Holocene transition is marked by a major period of significant climate change, forming an ecological threshold for humans. A penecontemporaneous dramatic increase in the human population occurred independently in different parts of the world, presumably when humans adapted to a more sedentary lifestyle (Bellwood and Oxenham 2008; Bocquet-Appel and Bar-Yosef 2008), and this increase is widely considered as the result of the agricultural revolution. However, sudden increases in human and artifact remains in areas without evidence of agriculture, such as Siberia, Northeast China, and Australia, suggest that the spurt of demographic growth also was present at the same time in areas with predominantly hunter-gatherer groups (Pitul'ko 2001; Tankersley and Kuzmin 1998). The population increase among these hunter-gatherer populations may have increased the home ranges of various clans and propelled their dispersal. This change consequently increased the likelihood of interactions and communication among previously more isolated hunter-gatherer groups. The practice of ICD for enhancing social identity in these areas likely reflects their social complexity, as well as inequality or disparity among individuals (i.e., stratification). It is generally accepted that social inequality and complexity are correlated with the degree of social stratification (Grusky 2011). A socially stratified group or tribe is more organized and efficient in a variety of endeavors including hunting, gathering, and agricultural production. The cross-generational nature of ICD (and its associated meme) actually may have functioned to reinforce that social stratification or to increase cultural cohesion continuing the social complexity or hierarchy over time, in particular during the transition to more sedentary and agriculturally oriented societies in the early Holocene.

Given the current archeological record, the oldest-known evidence for the practice of ICD is spread over less than a thousand years across a very large geographic area (Middle East, East Asia, and Australia, Fig. 3) close in time to the Pleistocene-Holocene transition (~ 11.7 ka) (Brown 2010; Meiklejohn et al. 1992; Solecki et al. 2004). Despite that narrow temporal window, the methods for deforming a neonate's cranium differed among those three populations. While it cannot be totally rejected that the people from about 11,000 years ago in Australia, Northeast Asia, and the Middle East shared a deep social belief or identity related to ICD expression, it is more likely that the people from these three widely separated areas faced a similar incentive that drove them to make similar cultural responses. However, the later prevalence of ICD among native populations and cultures of the Americas may have a different interpretation. Genetic studies have revealed unquestionable Asian origins of the natives in the New World, and the archeological records in Siberia and Beringia suggest that the initial dispersal of modern humans to North America probably occurred after 15 ka (Graf and Buvit 2017; Nielsen et al. 2017). Given those close genetic and cultural connections, the widespread native practice of ICD in the New World may derive from a continuation of this potentially ancestral cross-generational meme in northeastern Asia.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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