



# The application of 3D geometric morphometrics and laser surface scanning to investigate the standardization of cranial vault modification in the Andes

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## ABSTRACT

Cranial vault modification and the social significance of permanent body modification have long been an important topic of interest in Andean archaeology. While previous studies have enriched our understanding of these practices among prehistoric Andean populations, the introduction of 3D surface scanners and geometric morphometric methods in archaeology enable us to examine head-shaping practices in novel ways. In this pilot study, we used a NextEngine 3D Laser Surface Scanner to generate high resolution models of artificially modified crania from four archaeological sites dating to the Archaic (2300–1600 BCE), Formative (500 CE), late Middle Horizon/early Late Intermediate period (LIP) (750–1100 CE) in Chile and late LIP crania (circa 1350 CE) from central, highland Peru. Landmarks were recorded on the 3D digital models of crania and these data were analyzed to assess variation in vault shape within and between the samples. Results of the PCA analysis showed graphical separation of the annular, tabular erect, and some tabular oblique types even when gross morphological assessments proved challenging. We documented marked variation within the general modification type traditionally identified as tabular oblique, which suggests more detailed classifications within this type are needed. We also investigated how standardized (i.e., similar) particular cranial modification types were at each site, and results show that the coastal sites of Morro 1 and Playa Miller 7, and the highlands Huari-Vegachayoc Moqo site show higher levels of standardization than the other four samples. This study highlights the utility of 3D imaging and geometric morphometric methods for straightforward, objective assessments of cranial modification and levels of standardization within sites and within particular modification types. This has implications for understanding the broader social and cultural significance of this practice, such as whether there were shared cultural norms about how a head should be modified, which could have led to highly uniform modification practices and head shapes in the Andes.

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## 1. Introduction

Ancient forms of body modification have received considerable attention in archaeology. For example, cranial vault modification (CVM), which originated independently around the world, appears to have been common among prehistoric populations throughout the Americas (Tiesler, 2014), and especially in the Andean highlands and coastal regions of South America (Dembo and Imbelloni, 1938; Dingwall, 1931; Gertszen, 1993; Gertszen and Gertszen, 1995; Tubbs et al., 2006). On

the South American continent, ancient cranial modification forms have been described and documented throughout Argentina (e.g., Perez, 2007), Brazil (e.g., Mendonça de Souza et al., 2008; Okumura, 2014), Chile (e.g., Boston, 2012; Gertszen, 1993; Manríquez et al., 2006; Rhode and Arriaza, 2006; Salazar et al., 2014; Torres-Rouff and Knudsen, 2007), Ecuador (e.g., Munizaga, 1976), and Peru (e.g., Blom et al., 1998; Hoshower et al., 1995; Pomeroy et al., 2010; Torres-Rouff, 2002; Verano et al., 1999). Some of the earliest examples of cranial modification in the Andes have been observed among the La Galgada highlanders of Peru (Grieder, 1988) and the Chinchorro of northern Chile (Munizaga, 1987) dating to around 5000 years BP. Cranial modification practices were eventually prohibited by the Toledan reforms of the sixteenth century, in large part because it was perceived as an idolatrous act in which the head shapes were meant to mimic the principal mountain deity of particular ethnic groups (Ulloa Mogollan, 1965[1586]).

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Although no written documentation is available for the prehistoric period in the Andes, Colonial chroniclers, el Inca Garcilaso de la Vega and Bernabé Cobo, offer some insights into the technique underlying this practice through their descriptions of head modification apparatuses that were applied to infants and young children (Cobo, 1979[1653]; Garcilaso de la Vega, 1966[1609] as cited in Torres-Rouff, 2003). The Spanish and Andean chroniclers also tried to explain the social meanings associated with this form of corporal modification, noting that different head forms were a way to discern village affiliation, linguistic group, and cultural groups more broadly. Using gross visual assessments, recent studies of CVM in the Andes have explored whether the practice was a corporal marker of gender, social, ethnic, or occupational identity (e.g., Blom, 2005; Blom et al., 1998; Lozada Cerna, 1998; Torres-Rouff, 2002), noting that ethnic or cultural affiliation (which could be tied to occupation) was a key factor in affecting which cranial modification style would be imposed upon an infant. Through this work, it has become clear that particular body modification practices, including cranial modification, were a powerful and permanent way to make and mark social identity in the ancient Andean world (Tung, 2007).

The use of new scientific techniques has enabled researchers to revisit Andean archaeological questions in a variety of ways, ranging from 3D analyses of artifacts and skeletal morphology, to ancient DNA analysis of nuclear DNA, to the use of drones and photogrammetry for mapping archaeological sites in 3D (e.g., Fehren-Schmitz et al., 2015; Kuzminsky, 2013; Poulson et al., 2013; Wernke et al., 2014). Among these, we will focus here on the application of 3D laser surface scanning technology and analyses that explore cranial morphological variation with a level of precision that moves beyond traditional assessments (e.g., Fehren-Schmitz et al., 2015; Kuzminsky, 2013). Building on previous research that has utilized gross visual assessments, linear measurements and angles obtained by calipers, and 2D approaches to the study of cranial vault modification, our study aims to utilize modern geometric morphometric techniques to explore variation in cranial modification forms between and within particular categories of cranial modification in the Andes. Although there are bioarchaeological standards using gross observations to classify crania into particular modification styles, the growing number of studies on cranial modification in the Andes is revealing a wider array of modification forms (e.g., Pomeroy et al. 2010; Torres-Rouff, 2002; Velasco, 2016), necessitating an improved methodology to more adequately document the differences within and between types.

We suggest that 3D scanning and morphometric analyses as described here will provide those clearer data, which will allow researchers to examine the diachronic and geographic uniformity of shape, or lack thereof, among artificially modified crania. Using 3D techniques, we document cranial modification forms and examine how similar (i.e., how standardized) particular modification types are at each site (e.g., how much variability is there within the tabular oblique type?). We also compare the differences between the samples to evaluate whether certain groups have more standardized norms and practices regarding head modification. Those insights may thus enable us to investigate broader questions about this Andean practice that were not documented by chroniclers, such as whether a specialist class with standardized techniques conducted the head modifications on infants. If specialists were tasked with this important job, there may be greater standardization within one type of cranial modification style (e.g., annular type). Standardized forms may also suggest that the notion of an ideal head shape was strongly reinforced and taught to mothers and caregivers to ensure community norms about how cranial modification was performed, whether through the use of cloth bindings around the head, boards strategically placed on the head, and/or pressure of the head against portable cribs, known as *kiraw*. In contrast, greater variability within a cranial modification type may suggest the absence of a specialized class responsible for modifying heads; instead, family members, or other non-specialists, may have modified the heads of infants, leading to greater variability within one modification type.

### 1.1. Cranial modification types

In the Andes, two general types of cranial modification are typically recognized: annular and tabular (Blom, 2005; Dembo and Imbelloni, 1938; Torres-Rouff, 2002). Annular modification uses cloth bindings and rope to elongate the skull posterior-superiorly with little to no lateral expansion of the parietal bosses, and the tabular form alters the head with boards and bindings, resulting in two major subcategories: tabular erect (flattened cranium from front to back with bulging parietals; the occipital bone is flattened, at a 90° angle with the basicranium) and tabular oblique which gives the head an elongated (posterior-superiorly) appearance by flattening the anterior and posterior aspects of the head, with an occipital bone that forms an obtuse angle with the basicranium (Fig. 1). Additional differences within the tabular form of modification include cases where only one aspect of the skull is flattened: frontal flattening, lambdoidal flattening, and occipital flattening, the latter of which can occur unintentionally when an infant is placed for extended periods on his/her back in a cradle board or on some other restrictive device with a solid surface.

## 2. Archaeological background

The modified crania come from four prehistoric sites in the Andes (Fig. 2): the sites of Morro 1, Playa Miller 7, and Azapa-140 in northern Chile and the site of Huari in central, highland Peru. The samples cover several millennia of prehistory, beginning with Archaic-period hunting, foraging, and fishing communities of the northern Chile coast, to increased sedentism, social complexity, and the introduction of irrigated farming, animal husbandry, and ceramic technology within Andean communities during the Formative period. The Late Intermediate period is difficult to generalize given the variety of local and regional changes that occurred along the coast of northern Chile and in the Ayacucho basin of Peru, but northern Chile is often characterized as a time of continued social change and economic specialization among sedentary agricultural societies who emphasized textile production, large-scale feasting, metallurgy, and ceramic production. These activities continued in the Ayacucho basin too, but the quality and quantity of textiles, metallurgy, and polychrome ceramics greatly decreased relative to preceding eras. Although there is clear evidence of violence during the Archaic period in northern Chile (e.g., Arriaza et al., 2008), bioarchaeological and archaeological data available for later periods, particularly the Late Intermediate period, indicates a time of increased warfare and other types of violence combined with social upheaval as evidenced by the emergence of defensive architectural structures in several areas of the central Andean highlands (see Arkush and Tung, 2013; Tung, 2014).

The Morro 1 site (2300–1600 BCE) in northern Chile is located in the modern city of Arica located a few kilometers south of the Peruvian border. Archaeological excavations conducted at Morro 1, combined with recent isotope studies, indicate that this hunter-gatherer-fisher group associated with the Chinchorro tradition, was likely sedentary or semi-sedentary, subsisting primarily on marine foods from the Pacific Ocean located approximately 0.5 km from the site (Arriaza et al., 2008; Poulson et al., 2013; Standen and Santoro, 2004; Sutter and Mertz, 2004). Perhaps the most intriguing and complex of these is the emergence of extensive mummification practices among the Archaic-period Chinchorro culture in northern Chile, who artificially mummified the bodies of adults and children and deposited them in simple, shallow burials (possibly familial units).

The site of Playa Miller 7 (1000 BCE–750 CE) is a Formative period site located approximately 0.5 km from the coast and represents some of the earliest forms of cultivation practices and sand-tempered pottery associated with this time sequence (Focacci, 1974; Sutter and Mertz, 2004; Watson et al., 2013). Recent research suggests that the individuals living at this site continued to exploit marine resources given their close proximity to the Pacific shoreline (Watson et al., 2010). The elaborate mummification practices of the Chinchorro during Archaic

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