# Trepanation in South-Central Peru During the Early Late Intermediate Period (ca. AD 1000–1250)

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*KEY WORDS* cranial surgery; trauma; Andes; innovation; collapse

*ABSTRACT* This study evaluates trepanations from five well-contextualized prehistoric sites in the south-central highlands of Andahuaylas, Peru. The emergence of trepanation in this region coincides with the collapse of the Wari Empire, ca. AD 1000. Thirty-two individuals from Andahuaylas, AMS radiocarbon dated to the early Late Intermediate Period (ca. AD 1000–1250), were found to have 45 total trepanations. Various surgical techniques were being employed concurrently throughout the region. Scraping trepanations evinced the highest survival rate; circular grooving, drilling and boring, and linear cutting were far less successful. Evidence of perioperative procedures like hair shaving, poultice application, and possible cranioplasty use aimed to ensure the survival of a trepanation recipient. Postmortem trepanations, also present in Andahuaylas, were likely executed on corpses as a means of better understanding cranial anatomy and improving techniques. Similarities in trepanation patterns throughout the region attest to common motivations to engage in surgery. Although moderate physical head trauma seems to be the impetus for intervention in many cases of trepanation, other motivations included physiological and possibly psychosomatic factors. Nevertheless, treatment was not for everyone. In Andahuaylas, trepanations were withheld from subadults, females, and those individuals who practiced cranial modification. Am J Phys Anthropol 152:484–494, 2013. 

Trepanation is a surgical procedure involving the intentional penetration and removal of a part of the cranial vault. The largest studied samples of trepanations are those that derive from prehistoric Peru. In the south-central Andean highlands, trepanations first appeared during the Early Intermediate Period (ca. AD 200–600) (Verano, 2003; Verano and Finger, 2010), but the procedure was not universally adopted at that time (Andrushko, 2007). Nevertheless, cranial surgery was a viable form of intervention until at least the early 16th century when the Spanish apparently put an end to the practice. But how did this trepanation emerge in the first place?

Scholars have long debated the factors that may have spurred this type of surgery. The primary motivation posited for trepanations was to alleviate intracranial pressure and remove bone fragments in instances of blunt force trauma (BFT) (Verano, 2003). In one study, Andrushko and Verano (2008) found that trepanations were placed over or alongside depressed or radiating fractures in 29 of 66 (44%) cases. Rates of trauma may actually be higher but are unobservable because trepanation incisions may obscure the original fracture. However, BFT may not be the only or even the primary cause for cranial surgery. Ethnohistoric data suggest that trepanations may have also been used to alleviate pain or distress caused by a number of factors including scalp injuries and infections, neurological disorders, and psychosomatic illnesses (Verano, 2003; Andrushko and Verano, 2008; Verano and Andrushko, 2010; Verano and Finger, 2010). Although penetrating the skull for these reasons may seem risky, the perceived benefits of trepanation may have outweighed other concerns. For the practitioner, the proliferation of patients with potentially deadly or disfiguring injuries and diseases provide a chance to innovate and improve upon techniques for treatment (Baker and Ausink, 1996; Hughes, 2008).

## Violence and deprivation in late prehispanic Peru

If trepanation is indeed a surgical mechanism intended to cope with a wide variety of physical and psychosomatic trauma, then eras that witness violence, stress, and deprivation should also demonstrate increased rates of trepanation. Perhaps no epoch in Peruvian prehistory evinced higher levels of conflict and hardship as the early Late Intermediate Period ([LIP], ca. AD 1000–1250) (Covey, 2008; Tung, 2008; Arkush and Tung, 2013). This era followed the collapse of the Wari Empire (ca. AD 600–1000) in the south-central Peruvian Andes and was characterized by a worsening drought. Among those imperial provinces most impacted by Wari incursion and eventual disintegration was Andahuaylas, a crucial near-hinterland territory located about a day-and-a-half walk from the imperial capital city of Huari (Fig. 1).

As in other regions (Schreiber, 1992; Tung, 2012), Wari's strategy of statecraft in Andahuaylas involved managing local people via colonial outposts as well as

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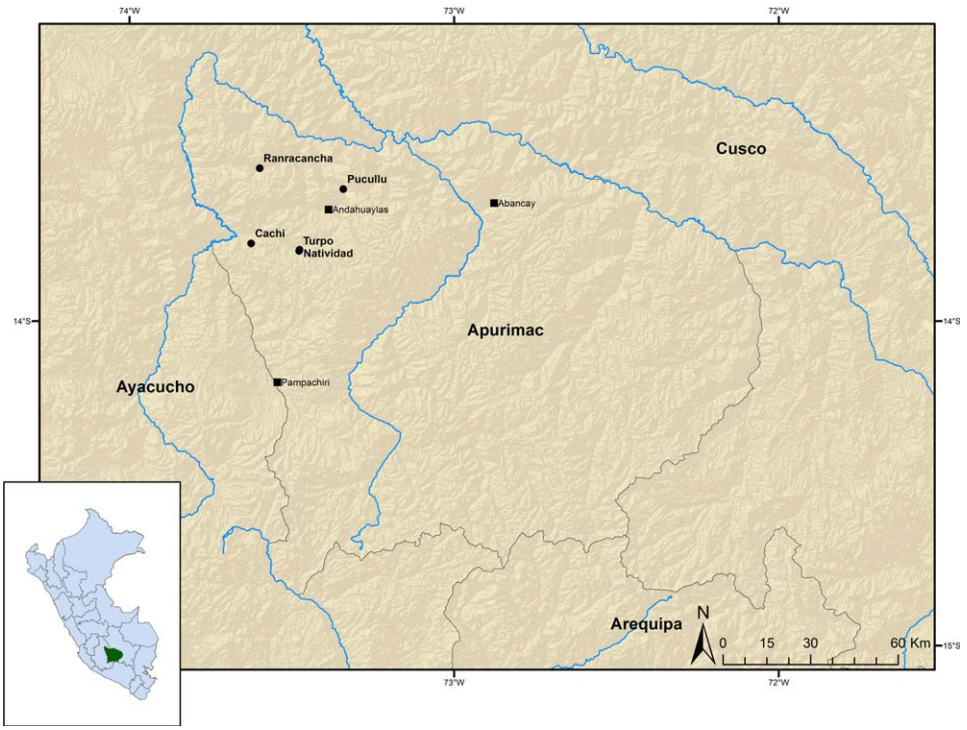


**Fig. 1.** Map of the Andahuaylas region in south-central Peru. The skeletal samples derive from Turpo, Natividad, Ranracancha, Cachi, and Pucullu. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

co-opting local leaders. One of Wari's most successful tactics throughout its vast empire was the performance of violence, reified through the use of trophy heads, sanguine iconography, and physical trauma (Tung, 2012). However, in Andahuaylas, violence was uncommon during Wari times. Only 2 of 28 (7%) crania dated to the later Wari era (AD 880–900 [2σ]) have evidence of trauma, and all observed wounds were sublethal (Kurin, 2012). Although trepanation was practiced during the Wari era in the south-central highlands, instances of cranial surgery are rare in Middle Horizon Andahuaylas (Verano, 2003; Meddens and Branch, 2010).

Wari's presence in Andahuaylas varied, but its retraction beginning ca. AD 1000 seems to have been uniformly tumultuous. Village hamlets and old imperial outposts were abandoned between cal. AD 1000 and 1100, as populations moved to high altitude ridge and hilltop settlements, located between 3500 and 4000 masl (Bauer and Kellett, 2010; Meddens and Branch, 2010). These densely populated, permanently occupied hillforts often lacked nearby freshwater sources, and have defensive features like walls, ditches, precipices on three sides, and lookouts (Gómez, 2009). The consequences of agglutinated, unsanitary living conditions may account for the dramatic increase in rates of pathological lesions (e.g., porotic hyperostosis) indicative of compromised health and disease throughout Andahuaylas (Kurin, 2012).

Moreover, Wari's fragmentation appears to have created a political vacuum which provoked significant social instability and civil unrest throughout much of Peru (La Lone, 2000; McEwan, 2005; Conlee and Schreiber, 2006; Tung, 2008; Arkush and Tung, 2013). Such was also the case in Andahuaylas, where violence rates skyrocketed during the LIP: 56.7% (138/243) of the late adolescent and adult males and females suffered cranial trauma (Kurin, 2012:156). However, violence was not experienced equally by everyone. Individuals who practiced cranial modification, a signifier of social or ethnic identity (Torres Rouff, 2002; Blom, 2005) were victims of sublethal and lethal trauma at significantly higher rates than their unmodified counterparts (Kurin, 2012). Thus, although violence in postimperial Andahauylas was widespread and pervasive, it seems to have largely targeted specific social groupings, and not the entire population.

Violent physical conflict, overcrowded living conditions, resource scarcity, and increasing rates of poor health appear to have characterized populations in Andahuaylas following Wari collapse. Yet high frequencies of violent injuries and diseases have often accelerated medicocultural advances such as surgical techniques and technology (e.g., prosthetics) (Hughes, 2008). Those innovations emerge as a response to novel challenges during troubled times (Baker and Ausink, 1996). The tumultuous milieu of early LIP Andahuaylas may have provided a crucible that fomented the development of novel surgical techniques, trepanation being most prominent.

## MATERIALS AND METHODS

### Recovery of human remains

Human remains assessed in this study were excavated from five sites in modern Andahuaylas and Chincherros Provinces (Apurimac Department), in highland Peru (Fig. 1). Excavations recovered mostly commingled cranial and postcranial remains (MNI = 477) from one tomb and 17 cave ossuaries; however, this article only reports on crania. Both the tomb and the cave ossuaries contained the remains of males, females, and subadults. At

*TABLE 1. Trepanation by site*

| Site | No. of tombs/ caves excavated | Temporal association | Cranial MNI | No. individuals with trepanation | No. of trepanations | Trepanation prevalence (%) |
|---|---|---|---|---|---|---|
| Turpo | 1 | MH | 28 | 0 | 0 | 0 |
| Cachi | 13 | LIP | 162 | 14 | 14 | 8.6 |
| Ranracancha | 1 | LIP | 39 | 6 | 8 | 15.4 |
| Pucullu | 1 | LIP | 31 | 5 | 10 | 16.1 |
| Natividad | 1 | LIP | 24 | 7 | 12 | 29.1 |
| *Total* | 17 | MH-LIP | 284 | 32 | 45 | 11.3 |

the Wari-era site of Turpo, 28 crania were recovered from a large circular, semi-subterranean, stone-lined tomb. This style of group burial is regularly encountered among Wari hinterland populations (Ochatoma, 2007; Tung, 2007). During the LIP, the use of cave ossuaries (called *machays*) became common in Andahuaylas. These collective internments were likely used to inhume members of the same lineage (Kurin, 2012). In total, 256 crania were examined from the sites of Cachi, Ranracancha, Natividad, and Pucullu. Although somewhat commingled, directly dated crania within the caves confirm individuals were interred between ca. AD 1080 and 1280 (AMS, $2\sigma$).

### Evaluating trepanation

All recovered crania were inventoried and examined for evidence of trauma, pathological lesions, and trepanations. Sex was determined based on dimorphic characteristics, while age categories (young adult ([YA], 20–34 years), middle adult ([MA], 35–49 years), and old adult ([OA], 50+ years)) were assigned based on endocranial and basicranial suture closure, dental development, and dental wear (Buikstra and Ubelaker, 1994). Data were also collected on cranial modification, as this boundary-marking practice likely denoted specific social or ethnic groupings within this region of ancient Peru (Torres-Rouff, 2002; Kurin, 2012). In this case, the age and sex profiles of distinct cave ossuaries and sites were remarkably consistent, as were rates of trauma, disease, and cranial modification. Given these broad similarities, crania from Ranracancha, Cachi, Natividad, and Pucullu were collapsed into a single sample for analytic purposes.

Following other trepanation studies in the Andes (Verano, 2003; Andushko and Verano, 2008), only those crania with at least four vault bones (i.e., frontal, parietals, and occipital), were observed for evidence of trepanation. Data were collected on trepanation presence, type, size, location, and degree of healing. Concomitant head wounds or pathologies were also recorded.

The type, size, and shape of a trepanation is largely contingent on the technique used. Correspondingly, each form of trepanation necessitates its own unique tool and manner of incision. For example, scraping involves the repeated abrasion of the ectocranial surface, creating an irregular, beveled area of bone; this technique usually impacts the largest surface area of the cranium (Andrushko and Verano, 2008). Circular grooving and cutting is identified by the presence of a circular furrow, which results in the creation of a round bone plug that is pried out of the cranium. Boring and drilling uses a bit to abrade the cranium repeatedly, forming a ring of small circular bore holes with overlapping borders. Finally, linear cutting employs a sawing motion to create a cross-hatched square of bone that can be excised.

Trepanation apertures were categorized as either "complete," which perforated the internal table, or "attempted" trepanations which only pierced the external table. When possible, the number of individual bore holes or cut marks which comprised a single trepanation were also tallied. Trepanation location was recorded to discern whether certain regions of the skull were preferred for surgery, and a caliper was used to measure the size of the perforation. Trepanations were also categorized as either healing (if the borders showed signs of active remodeling) or unhealed (if the margins were "crisp"), as this data informs on whether a patient survived the surgery. Cases of concomitant traumatic injury or pathological lesions were also recorded in order to determine whether any meaningful associations existed (Andrushko and Verano, 2008). Crania that lacked evidence of trepanation were also examined following Verano (2003) to serve as a comparison for sex, age, cranial modification, and trauma rates within the general population. Finally, statistical tests of significance were employed to assess data patterns.

## RESULTS

Two-hundred eighty-four crania were examined of cranial surgery. Of these, 32 (11.3%) crania had at least one attempted or complete trepanation. For many individuals in Andahuaylas, trepanation was not a singular event. Among the 32 affected individuals, there were 45 total trepanations. Twenty-eight percent (9/32) had more than one perforation.

### Trepanation following Wari collapse

Trepanation was not performed on any of the 28 crania from the local Wari-era site of Turpo. During the Late Intermediate Period, trepanation frequencies are significantly higher: 12.5% (32/256) (Fisher's exact, $P = 0.0293$; $N = 284$) show evidence of surgery. While knowledge concerning cranial surgery was certainly present in areas under Wari rule during the Middle Horizon (Verano, 2003), apparently it was not implemented in Andahuaylas. Trepanation rates were similar between LIP sites, and at each site, multiple trepanation techniques were being used. Stratigraphic and radiometric results confirm that populations in early Andahuaylas were employing four highly distinct methods of trepanation concurrently (Table 1): scraping, circular grooving and cutting, boring and drilling, and linear cutting (Verano, 2003).

*TABLE 2. Trepanation types*

| Site | No. of scraped trepanations | No. of circular grooving trepanations | No. of boring and drilling trepanations | No. of linear cutting trepanations | Total trepanations |
|---|---|---|---|---|---|
| Turpo | 0 | 0 | 0 | 0 | 0 |
| Cachi | 6 | 5 | 2 | 1 | 14 |
| Ranracancha | 6 | 2 | 0 | 0 | 8 |
| Pucullu | 6 | 2 | 2 | 0 | 10 |
| Natividad | 8 | 0 | 7 | 0 | 12 |
| *Total* | 26 | 9 | 11 | 1 | 45 |

## Variability in trepanation size and location

In Andahuaylas (Table 2), the most common type of trepanation technique in Andahuaylas was scraping: 58% (26/45) trepanations used this technique. Circular grooving was observed in 20% (9/45) of cases, while boring and drilling was implemented in 24% (11/45) of cases. Linear cutting was only observed in one instance (2%).

Of note, the boring and drilling trepanation technique creates uniform bore holes which are isometric to the drill bit employed. Thus, the size and shape of discrete holes informs on tool kit standardization (Tung, 2012). When bore hole diameters were compared within and between sites in Andahuaylas, only slight differences emerged. At the site of Pucullu, average drill hole size was 5.987 mm (SD = 0.506 mm; $n = 15$ holes); at site of Natividad, the average bore hole size was 6.105 mm (SD = 0.829 mm; $n = 143$ holes); at site of Cachi, bore holes averaged 4.335 mm (SD = 0.449 mm; $n = 60$ holes). Drilling and boring trepanations were not observed at Ranracancha.

The location of trepanations on the cranium can inform on whether certain regions were favored for surgery over others. In Andahuaylas, trepanations were significantly directed to the left parietal boss region, relative to other sides of the cranium ($\chi^2 = 32.733$, $P = 0.0001$; df = 5; $N = 45$). Thirty-five percent (13/45) of all trepanations are on this area of the head, notable for its lack of veins, musculature, sinus cavities, and sutures. Yet these anatomical bodies did not evade impact entirely. Overall, 10 of 45 (22.2%) trepanations on 10 individuals impacted sutures, while 18/45 (40%) trepanations on 13 individuals likely impacted either facial or temporal musculature. In three cases (3/45 = 6.7%), trepanations were placed over the frontal sinus cavities.

## Healing and survivability

Among the 45 trepanations on the 32 affected individuals, 30 (66.6%) trepanations demonstrated either short-term or long-term healing. Yet despite high survival rates overall, some trepanation methods were more successful than others. Scraped trepanations were universally successful. One hundred percent (26/26) of the scraping trepanations had at least some healing. Other methods had significantly lower healing rates. Linear cutting was never successful (0/1). Circular grooving was successful in 5/9 (55.6%) cases, while drilling and boring was highly unsuccessful: of 11 drilling/boring trepanations (made from at least 218 separate perforations) only one—composed of a single perforation—showed some evidence of short-term healing. Overall, trepanation by scraping method was significantly more successful than both circular grooving (Fisher's exact, $P = 0.0031$; $N = 45$) and boring and drilling (Fisher's exact, $P < 0.0001$; $N = 45$).

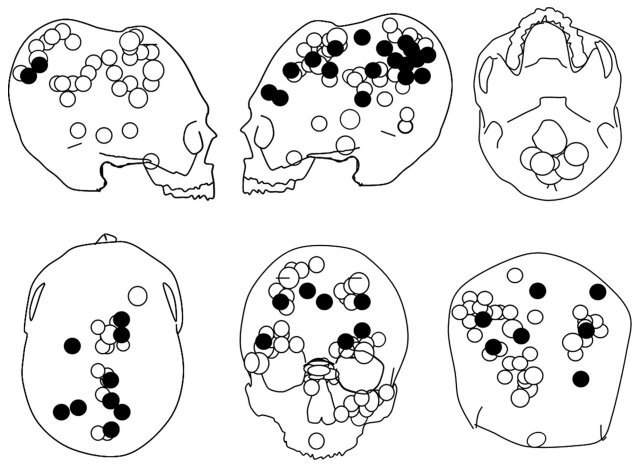

**Fig. 2.** Cranial trauma (white dots) and trepanations (black dots) on the entire Andahuaylas population.

When multiple trepanations are present, the technique and success of an earlier trepanation seems to structure subsequent interventions. For instance, of the five multi-trepanned individuals with boring and drilling perforations, four (80%) also have scraped trepanations. While the scraped trepanations were all well healed, the drilling and boring trepanations were not healed. The bore holes were made well after the scraped trepanations, and they were all drilled around (or just after) the time of death.

## Motivations for trepanation: blunt force trauma and osteitis

In over half of observable cases (18/31 = 58.1%), trepanned individuals had trauma located on or adjacent to a fracture, or on another part of the injured cranial vault or face (Fig. 2). However, only three of 31 (9.7%) individuals had a trepanation placed directly on a fracture; 4/31 (12.9%) had a trepanation placed adjacent to the trauma, and 11/31 had a trepanation present on the cranium, but not directly over or alongside a head wound.

Data also suggests that not all manners of traumatic injury merited intervention. For instance, among the seven individuals where trepanations were on or adjacent to head trauma, all wounds were either linear or depressed fractures. Linear fractures are fissures that occur at the point of impact and follow a path of least

resistance as a result of the bones' failure to rebound from generalized force. Depression fractures, on the other hand, occur as a result of direct, localized impact (Lovell, 1997). Depending on the force of impact and location of injury, the resulting fracture pattern varies from a relatively mild hinged, shallow, "pond" shape, to a lethal web of concentric rings that radiate across the vault (Novak, 1999). The latter class of severe trauma, common in Andahuaylas, is not associated with trepanations. Unsurprisingly, facial wounds (e.g., broken nasal bones), although frequent, were not associated with trepanations either.

While there appears to be some association between cranial fractures and trepanations, head trauma was not the only impetus for surgery in Andahuaylas. In at least three cases (3/31 = 6.7%), individuals had trepanations placed over areas of inflammatory, porotic bone that had undergone significant remodeling. Despite long-term healing, trepanations were still warranted. However, none of the three patients survived the operation.

## Sex, age at death, and cranial modification use among trepanation recipients

In Andahuaylas, only adults over around 20 years old evince trepanations (Table 3). Among 52 subadults examined, none show signs of cranial surgery. Trepanation also appears to have been significantly directed towards males. Of those 32 individuals in Andahuaylas with trepanations, 25 are males, three are females, and four are unsexed adults. Trepanned males are significantly overrepresented relative to the general population (Fisher's exact, $P < 0.0001$; $N = 184$). Of 90 male crania observed, 27% ($n = 25$) evince trepanation, while only 3.1% ($n = 3$) of 94 females demonstrate surgical perforations.

Finally, trepanation rates were compared between those with and without cranial modification, a prominent signifier of ethnic or social affiliation in Andahuaylas (Kurin, 2012). Twenty-seven of 187 (14.4%) modified crania had evidence of trepanation, while 8.2% (5/51) of unmodified individuals had trepanation. This difference is not significant (Fisher's exact, $P = 0.4913$; $N = 249$).

## Perioperative procedures

For those deemed fit for surgery, trepanations may have been executed along with other ancillary practices. The surgical perforation of the skull represents just one step in a lengthier operation. In Andahuaylas, there is evidence that patients were "prepped" for surgery and attended to after the operation concluded.

For instance, the well-preserved, mummified head of a long-haired young adult male from Natividad, catalogued as Hry.23, demonstrates two distinct trepanations, each associated with a different perioperative procedure (Fig. 3). First, the scalp tissue surrounding a healing scraped trepanation on the posterior section of the right parietal is conspicuously devoid of long hair. At 60× magnification, the hair on the scalp immediately surrounding the trepanation appeared sharp and cleanly cut, very similar to microscopic images of modern shaved hair; follicle tips around the trepanation did not have a "buffed down" appearance of hair which has sloughed off due to decomposition and postdepositional activity. Given the difficulty of realizing a successful surgery, hair around trepanations may have been kept very short in case further intervention was required.

This same individual also has a small bore hole on the forehead, over the sagittal sinus vein and angular artery. These veins and arteries are associated with trauma-induced migraine pain (Shevel, 2007; Pathak et al., 2009). The lack of healing around the bore hole on Hry.23 suggests that it was drilled around (or after) the time of death and may represent a failed attempt to alleviate venal pressure. Over the wound, there is a smudge of a dark substance—with finger print ridges still preserved—characteristic of an herbal poultice (Fig. 3, inset).

Another type of perioperative procedure is a cranioplasty (Fig. 4), a repair made to a cranial defect. In Andahuaylas, there is one possible case of a cranioplasty—a metal plaque—associated with a trepanation. The affected cranium, Son.02.02.12, was directly AMS radiocarbon dated to AD 1160–1260 (2σ). A scraped trepanation spans the left frontal and parietal bones. The perforation shows signs of long-term healing, with smooth, dendritic bone growth forming an undulating, roughly circular margin.

Cranium Son.02.02.12 was found lying on its left side; the thin (0.47 mm) metal plaque was immediately below the trepanation, suggesting a very close, if not direct association. At 214 $mm^2$, it conforms almost precisely in size and shape with the trepanation aperture, and there is no evidence of a hole or metal process, which would have suggested that it was a *tupu* pin that was used for pinning women's shawls together. The absence of hammered relief work suggests it was not used as an armband, breastplate, or similarly fashioned ornament. There were no signs of metal transfer on the bone around the trepanation aperture. This indicates that the plaque was not placed directly on the bony vault (but could have been secured to the scalp prior to death) (Duday, 2009). Given the paucity of other examples of metal cranioplasties, the therapeutic attribution of the plaque remains circumstantial.

## Postmortem trepanations

Trepanations in Andahuaylas show evidence of technical refinement as practitioners presumably worked to ensure that their iatric interventions did not cause the death of the patient. Trial-and-error experimentation may be evinced in the bioarchaeological record through repeated attempts which are continued until success is achieved. Unfortunately, most methods of trepanation surgery cannot speak directly to technical acumen. Both scraping and circular cutting and grooving, for instance, are reductive practices, and with every repetitive abrasion, the previous indenture is erased. However, changes in discrete penetrations caused by boring and drilling are amenable to such analysis. This section will present evidence of trepanations from Andahuaylas which show clear, unambiguous signs of experimentation.

First, Son.02.02.100 is a 628 $mm^2$ piece of an adult left parietal bone (Fig. 5). The highly brittle fragment has two clear, sharp v-shaped incisions, which form a right angle and a square plug of bone 32 $mm^2$. Importantly, the incision was made on the *endocranial* surface of the parietal; the incisions do not penetrate the external table. Due to its location, the only way this trepanation could have been attempted was if an individual was already dead, and their cranium was not intact (i.e., broken or fragmentary).

*TABLE 3. Individuals in Andahuaylas with trepanation*

| Cat. No. | Era | Site | Sex | Age category | Modification[a] | Concomitant trauma | Concomitant pathology | Sensitive areas impacted | No. of trep events | Minimum number of perforations | Trep methods[b] | Healing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RCC.01.01.03 | LIP | Ranracancha | M | YA | 1 | 0 | 0 | 0 | 1 | 1 | C | 0 |
| RCC.01.01.04 | LIP | Ranracancha | M | YA | 1 | 0 | 0 | 1 | 1 | 1 | C | 1 |
| RCC.01.01.05 | LIP | Ranracancha | F | YA | 1 | 1 | 0 | 1 | 2 | 2 | S, S | 1,1 |
| RCC.01.01.02 | LIP | Ranracancha | M | MA | 1 | 0 | 0 | 0 | 2 | 2 | S, S | 1,1 |
| RCC.01.01.32 | LIP | Ranracancha | M | OA | 1 | 0 | 0 | 0 | 1 | 1 | S | 1 |
| RCC.01.01.40 | LIP | Ranracancha | U | A | 1 | 0 | 0 | 0 | 1 | 1 | S | 1 |
| PCU.01.01.26 | LIP | Pucullu | M | YA | 1 | 1 | 1 | 0 | 4 | 15 | D, D, D, D | 0,0,0,0 |
| PCU.01.01.16 | LIP | Pucullu | M | YA | 1 | 0 | 0 | 0 | 3 | 3 | S, C, D | 1,1,1 |
| PCU.01.01.08 | LIP | Pucullu | M | OA | 1 | 1 | 0 | 1 | 1 | 1 | S | 1 |
| PCU.01.01.12 | LIP | Pucullu | M | MA | 1 | 1 | 0 | 1 | 1 | 1 | S | 1 |
| PCU.01.01.13 | LIP | Pucullu | U | YA | 1 | 0 | 0 | 1 | 1 | 1 | S | 1 |
| HRY.11 | LIP | Natividad | M | YA | 1 | 0 | 0 | 1 | 3 | 43 | S, D, D | 1,0,0 |
| HRY.23 | LIP | Natividad | M | MA | 1 | 1 | 0 | 1 | 2 | 2 | S, S | 1,1 |
| HRY.02 | LIP | Natividad | M | MA | 0 | 0 | 0 | 1 | 2 | 45 | S, D | 1,0 |
| HRY.31 | LIP | Natividad | M | YA | 1 | 0 | 0 | 1 | 2 | 2 | S, D | 1,0 |
| HRY.01 | LIP | Natividad | M | MA | 1 | 1 | 0 | 1 | 2 | 53 | S, D | 1,0 |
| HRY.06 | LIP | Natividad | M | YA | 1 | 0 | 0 | 1 | 1 | 1 | S | 1 |
| HRY.09 | LIP | Natividad | M | MA | 1 | 0 | 0 | 1 | 1 | 1 | S | 1 |
| SON.07.01.05 | LIP | Cachi | M | MA | 1 | 0 | 0 | 1 | 1 | 1 | C | 1 |
| SON.02.03.32 | LIP | Cachi | F | MA | 1 | 1 | 0 | 0 | 1 | 1 | C | 1 |
| SON.02.03.27 | LIP | Cachi | M | A | 1 | 1 | 0 | 1 | 1 | 1 | C | 0 |
| SON.02.03.18 | LIP | Cachi | M | YA | 1 | 0 | 1 | 0 | 1 | 1 | C | 0 |
| SON.02.03.100 | LIP | Cachi | U | A | 1 | 9 | 0 | 0 | 1 | 1 | L | 0 |
| SON.02.03.33 | LIP | Cachi | U | MA | 1 | 0 | 0 | 0 | 1 | 1 | S | 1 |
| SON.02.02.12 | LIP | Cachi | M | OA | 1 | 0 | 0 | 1 | 1 | 1 | S | 1 |
| SON.02.02.03 | LIP | Cachi | M | MA | 1 | 1 | 0 | 1 | 1 | 1 | S | 1 |
| MSM.07.01.01 | LIP | Cachi | U | A | 0 | 0 | 1 | 1 | 1 | 1 | C | 0 |
| MPM.01.16 | LIP | Cachi | M | YA | 0 | 0 | 0 | 1 | 1 | 24 | D | 0 |
| MPM.01.12 | LIP | Cachi | M? | YA | 0 | 0 | 0 | 0 | 1 | 36 | D | 0 |
| MPM.01.01 | LIP | Cachi | M? | MA | 0 | 0 | 0 | 1 | 1 | 1 | S | 1 |
| MPM.01.15 | LIP | Cachi | F | OA | 1 | 0 | 0 | 0 | 1 | 1 | S | 1 |
| MPM.01.14 | LIP | Cachi | M | YA | 1 | 1 | 0 | 0 | 1 | 1 | S | 1 |

[a] 0 = no; 1 = yes; 9 = unobservable.
[b] S = scraping; C = circular cutting and grooving; D = drilling and boring; L = linear cutting.

**Fig. 3.** Mummified young adult male skull with shaved hair (left) and possible poultice use over an unhealed bore hole (right). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

**Fig. 4.** Old adult male with healing scraped trepanation and metal cranioplasty (inset). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

**Fig. 5.** Detail of linear cutting marks on the endocranium (inset is the entire parietal fragment). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Other probable cases of postmortem trepanations are present in Andahuaylas. For instance, cranium Hry.01, from Natividad, is an adult male recipient of at least three operations (Fig. 6). The individual has a scraped trepanation on the right parietal-occipital region which shows signs of long-term healing. Also present are 63 discrete bore holes on the squamous portion of the right occipital; none show signs of healing. Long sequences of overlapping bit indentations form parabolic and oval shapes. Some of these shapes overlap, and only 17 (27%) bore holes actually penetrated the internal table, the rest just pierced the external surface.

Bore hole diameters were measured and indicate that at least two different drill bits were used. Initially, a smaller bit was used in three trepanation events. A complete trepanation consisting of 13 bore holes produced cavities with an average diameter of 5.06 mm each. Just lateral to this complete trepanation is an attempted trepanation consisting of 12 bore holes with an average

**Fig. 6.** Possible postmortem experimentation with differently sized drill bits on the left occiput (inset is posterior view of the cranium). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

**Fig. 7.** Possible postmortem experimentation featuring bore holes of increasing depth. Upper inset is healed scraped trepanation on the left temporal squama; lower inset is anterior view of the cranium. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

diameter of 4.55 mm. An attempted parabolic-shaped trepanation made from at least 28 bore holes covers an area of 161.6 $mm^2$. Sometime later, a drill bit twice as large (7.01 mm) was used to make three complete bore holes. One of the bore holes was made directly over the parabolic trepanation. Color differences around the margins of the three large bore holes indicate they were drilled postmortem. Finally, bone polishing on the occipital and basicranium suggests considerable handling well after the time of death.

Strong evidence for perimortem experimentation is also present on cranium Hry.11, a middle adult male also from Natividad (Fig. 7). This individual has a well-healed scraped trepanation which spans the left parietal and temporal bones. This individual also has a complete trepanation made from 74 bore holes covering 571.7 $mm^2$ on the right frontal and parietal bones. An additional 19 discrete bore holes only penetrated the external table. These attempted perforations form a parabolic shape whose placement follows the medial and posterior edge of the complete trepanation. Notably, the parabola of attempted bore holes all display consecutively deeper perforations. The shallowest perforation measures 3.4 mm, but holes increase in depth by about 0.2 mm as one moves posteriorly. Bore hole size and color continuity suggest that all the perforations were received in a single event after death.

## DISCUSSION

### Trepanation, experimentation, and unwell bodies

Trepanation in Andahuaylas was an innovative practice. Its emergence coincides with a time of increasing violence and deprivation. Like other innovations, trepanations were quickly and widely adopted, but not highly standardized. Basic precepts like where to place an incision, as well as the profile of suitable patient, seem to have been shared across Andahuaylas. A mosaic of perioperative practices suggests practitioners were trying different approaches to ensure the survival of patients. Signs of postmortem experimentation suggest that cranial surgery was viewed as a practical skill which called for increasing standardization and proven methods (Graham, 2003).

Compared to other Andean regions, trepanation appears relatively late in Andahuaylas (Verano, 2003). Radiocarbon dates confirm that the practice emerged only after Wari's collapse in the 11th century. However, within a few generations, trepanation was relatively widely adopted in the region. By the early 12th century, at least four distinct surgical techniques were being practiced contemporaneously: scraping, circular grooving, boring and drilling, and linear cutting.

### Diverse motivations for trepanation

Previous scholarship on trepanations in the Andes convincingly demonstrate that they were often made to alleviate intracranial pressure brought about by acute traumatic injury (Verano, 2003; Andrushko, 2007; Andrushko and Verano, 2008; Verano and Finger, 2010). Indeed, results from Andahuaylas suggest some association between trauma and cranial surgery.

Eighteen out of 31 (58%) trepanned individuals also evince head wounds. For seven of those 31 individuals (22%), trepanations were placed on or alongside an existing fracture. Rates of trauma and trepanation in Andahuaylas are somewhat higher than Verano's (2003) observation of other populations from Peru's southern highlands (where 11.8% of 86 trepanned crania also had concomitant fractures) but is similar to frequencies observed in the central highlands (Verano and Finger, 2010). The association of trauma and trepanation in Andahuaylas may actually be much stronger but remains unobservable because trepanation apertures can obliterate signs of fracture (Verano, 2003). Furthermore, not all types of trauma are associated with surgery. High impact, perimortem, "lost-cause" wounds that were too serious to warrant surgical intervention are not associated with trepanations; broken bones on the face apparently did not merit surgery either.

Yet blunt force trauma was not the only motivation for trepanation. The presence of unhealed trepanations over areas of healing inflamed bone in 3/32 (9.4%) individuals shows that trepanations were not exclusively reserved

for urgent intervention on acute, traumatic injuries but may have been also used to treat the swelling and pain associated with longer-term infections of the scalp, epicranial aponeurosis, or the ectocranial surface itself.

Several lines of ethnohistoric and ethnographic data inform on possible underlying motivations for trepanation use in the protohistoric past. Accounts from Peru (Cobó, 1964; Bastien, 1985; Salomon and Uroiste, 1991) suggest that the physiological impacts of head wounds are not the sole impetus for medical intervention. Rather, trepanations may have been used to treat psychosomatic and neurological disorders which emerged as a consequence of both physical and emotional trauma. This class of illness is sometimes termed *sonqonanay* [animus pain] (Villagomez, 1919; Burneo, 2003; Betanzos, 2004; Pomata and Campos, 2008). According to traditional Andean beliefs, any sort of physical or emotional trauma is always potentially dangerous primarily because it can lead to fatal *susto* [fright sickness/animus loss] (Greenway, 1998). It is this potentially lethal "fear" which requires medicocultural intervention and not necessarily the proximate pathology. As an underlying cause for medical intervention, *susto* can emerge in any stressful situation or in any unwell individual.

Today, healers alleviate *susto* by blowing forcefully on the anterior fontanelle in a procedure known as *qayapa* (Gómez Choque, 2009; Kurin, 2012). Like trepanations, fontanelles conform to a class of anatomy known in Quechua as *ñupu* [something that is soft and sinks to the touch] (Holguin, 1952). Healers gauge the vitality of infants affected by *susto* by observing how the fontanelle pulsates. For stricken adults, trepanation would have been a process where artificial *ñupus* were permanently incised into the skull. The surgery itself may have been known by some iteration of the word *sircca* (Holguín, 1952). In its noun form, *sircca* means "a swollen vein or a lancet." As a verb, *sircca* means "to pulsate or beat, to bleed out, bloodlet, or pierce."

In sum, a couple of different factors may account for the extensive and pervasive dispersal of a new surgical technique like trepanation. As a practical skill, the circumstances that predicated the need for trepanation (e.g., violent trauma, other stressful or fear-inducing circumstances) may not have been present during the Wari imperial era in the Andahuaylan hinterlands. However, once Wari collapsed, a milieu emerged wherein the proximal causes which motivated surgery became prevalent and widespread. The physiological and psychosocial stressors which necessitated therapeutic trepanations (i.e., infections and *susto*) may have been heightened due to endemic violence and a decreased quality of life, evinced by high rates of cranial trauma and increasing signs of disease. Because trepanation patterns were largely shared across the region, the proximate and underlying factors which motivated this procedure were most likely well-established and far-flung.

## Development of surgical procedures

Practitioners in Andahuaylas developed fairly standardized surgical techniques and toolkits to deal with these stressors. For instance, bore hole dimensions show that distinct LIP sites were using drill bits of different gauges (sizes) but similar shapes. Bore hole diameters suggest one bit was used on two different crania at Cachi, a different bit used on one cranium at Pucullu, and at least two distinctly sized bits were used on four crania from Natividad (Fig. 6).

Furthermore, as in other areas of the Andes, trepanations in Andahuaylas are most commonly found on the left side of the head (Verano, 2003; Verano and Finger, 2010), possibly due to traumatic assault by mostly right-handed opponents (Stewart, 1958). However, surgical techniques were more nuanced than simply intervening at the point of violent impact. In Andahauylas, trepanations overwhelmingly directed to the left parietal are not associated with increased injury to that region of the skull. Because crania do not evince correspondingly high concentrations of head wounds on the left parietal, the decision to trepan in that area was probably not predicated on the location of acute injury. Rather, practitioners likely took into account that surgical intervention on areas like the parietal bosses was less risky than other regions. Correspondingly, incisions were placed on predetermined regions of the vault. Nevertheless, in some cases, the motivation for surgery apparently outweighed the risk of impacting delicate areas of the cranium. Trepanations which encroached on meningeal arteries or dural sinuses could have led to epidural hematomas, infections, and death. Their presence in these sensitive regions (see Table 3) may thus reflect a sense of urgency (Kurin, 2012).

## Biosocial attributes of trepanation recipients

While proximate causes which merited surgical intervention included both physical injury and osteitis, biosocial factors appear to have constrained its use within the injured and ailing population. Cranial surgery in Andahuaylas was significantly structured by sex and age. Male to female trepanation rates are 8:1. Other studies in the Andes show less of a skew in adult sex ratios — trepanned males tend to outnumber females by only about 2:1 (Verano, 2003; Andrushko, 2007, Table 2). This trend becomes even more striking given that adult males and females in early LIP Andahuaylas were the recipients of trauma at nearly identical rates (males trauma rate = 70/113 (61.9%), female trauma rate = 64/102 (62.7%)) (Kurin, 2012). If surgeries were reserved solely for victims of traumatic cranial injury, then males and females would be expected to show similar trepanation rates. These data suggest that the procedure was either mediated by gender or highly correlated to sex-specific activities which could predicate the need for surgery (Larme, 1998).

Similar to females, the absence of subadults among the trepanned population is distinct from other regions in the Andes, where juveniles make up between 6% and 8% of trepanned individuals (Finger and Fernando, 2001; Verano, 2003, Table 2; Andrushko, 2007). Even though subadults in LIP Andahuaylas were impacted by violence and suffered from diseases at a considerable rate (Kurin, 2012), trepanation does not appear to have been a viable form of intervention for the younger members of that society. In sum, the absence of trepanned subadults and the underrepresentation of females implies that these members of society were not viewed as appropriate patients for trepanation.

Also noteworthy, individuals with cranial modification are not undergoing trepanation at a significantly higher rate than unmodified individuals. This trend is important given that people with cranial modification experience significantly higher rates of violence than unmodified

individuals. Moreover, although individuals with cranial modification are being wounded more often, they are not receiving proportionally more surgeries, as inferred by trepanation presence. If trepanations were reactively employed in all cases of traumatic injury, the subpopulation with cranial modification should exhibit proportionally more trepanations because they have substantially higher rates of injury and stress, yet this is not the case.

All told, these results suggest that trepanation may have been withheld as a viable intervention in cases of trauma towards members of Andahuaylan society with cranial modification. Curtailing "necessary" medical treatments within a subpopulation group is a sign of deep social inequality and fits into the model of selective violence that appears to have characterized ethnically marked populations during the early LIP in Andahuaylas (Kurin, 2012).

Finally, medical histories appear to have been important as well; individuals who were "fit" enough to survive one intervention were perhaps deemed appropriate patients for subsequent (ultimately unsuccessful) surgeries or postmortem experimentation. This is evinced by the prevalence of individuals with both healing scraped trepanations and unhealed drilling and boring trepanations. After death, people who had been trepanned were interred collectively with individuals who lacked the surgery; they did not get specialized mortuary treatment.

In sum, trepanations in Andahuaylas are not just about a therapeutic intervention targeting those who have been victims of traumatic cranial injury. Rather, interventions were directed toward a certain *kind* of unwell body. Before an incision was ever attempted, there appear to have been certain factors which structured the rules regarding who could receive treatment.

### Perioperative procedures and experimentation

Practitioners in Andahuaylas engaged in several mechanisms to ensure the survival of patients including head shaving, poultice use, and possible cranioplasties on living patients. Poultices may have been especially common in the late prehispanic Andes (see Verano and Andrushko). For instance, colonial chronicler Cieza de Leon (1996) wrote that locals living in the Andahuaylas region used poultices derived from, "a yellow flower," to cure sickness. My ethnographic research in the region suggests that this flower may be *Oenothera Rosea*, locally known as *Yahuar Sua* [blood thief, trans. Quechua]. Informants have reported that this "blood thief" is still used today to treat head and scalp wounds (and even modern craniotomies) because of its prized analgesic, anti-inflammatory, and antiseptic properties (Kurin, 2012).

In contrast, repairs to the cranial vault, like that associated with Son.02.02.12, are rare in the Andean highlands (Andrushko, 2007; Verano and Andrushko, 2010), and previous reports of metal cranioplasties, specifically, have proven unreliable (Tello, 1913). In Cuzco, Verano and Andrushko (2010) report that an excised bone was secured back in place following a trepanation, but evidence of cranioplasty use in Andahuaylas remains circumstantial. Nevertheless, Andahuaylans understood that patients required intervention beyond simply drilling a hole into the head; ephemeral therapeutic poultices were employed temporarily, while possible cranioplasty use signals attempts to cope with trepanations in the long term.

Most significantly, postmortem trepanations appear to confirm that practitioners were experimenting on corpses. Crania were abraded with different drill bits, intentionally corroded into prodigious shapes, and polished by frequent handling. Unambiguous cases of postmortem intervention as well as the concurrence of several different trepanation types suggest that Andahuaylans were engaging in different experimental techniques as a means of improving operating procedures and increasing knowledge concerning cranial anatomy in a society where no such template existed previously.

## CONCLUSION

### Coping with novel challenges using innovative practices

Trepanation emerged in LIP Andahuaylas following the collapse of the Wari Empire ca. AD 1000. Procedures were pragmatic, problem specific, and praxis oriented. Ubiquity in technique suggests that practitioners throughout Andahuaylas shared a common understanding of how and where to perform cranial surgery, and likely employed roughly similar toolkits. While trepanation by scraping was overwhelmingly successful and directly associated with cranial trauma, the boring and drilling method was almost universally unsuccessful. Instead, this type of trepanation may have been intentionally practiced on corpses as a means of better understanding cranial anatomy and improving techniques.

Given that trepanation patterns are similar between sites, the social and/or biophysical factors that motivated individuals to remove a portion of the cranial vault may have been present throughout the region. Although physical trauma seems to be the impetus for intervention in many cases of trepanation, other motivations may have included physiological or psychosomatic factors. Surgical intervention in Andahuaylas was also mediated by age, gender, and ethnicity. Despite the fact that stress and violence impacted much of the LIP population, trepanations were primarily reserved for adult men; surgery was proportionally withheld from women, youths, and groups who practiced cranial modification. All told, these results signal innovative technical developments in the aftermath of the Wari Empire and speak to the maturation of distinct (though not intractable), culturally informed understandings of how to heal an unwell body in the ancient past.

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