

High Resolution Computed Tomography of a Chinchorro Mummy

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Abstract The use of advanced medical imaging technology in the study of mummified bodies is becoming increasingly common, as it offers the possibility of obtaining a large quantity of information without affecting the conservation of the ancient remains. In March 2013, the mummy of a Chinchorro infant was examined at the National Institute of Radiological Sciences in Japan, using high-resolution computed tomography with a 16×0.5 mm detector configuration. The study was conducted while the mummy was on loan to the National Museum of Nature and Science in Tokyo for a special exhibition, and sought to gather information on the mortuary technique employed and state of conservation of the mummified body. A whole-body scan was performed with a slice thickness of 1 mm and a peak voltage of 120 kVp. The data obtained was processed using different software programs and enabled the research team to better understand the mummification technique employed, as well as to identify anatomical structures of the face and neck that were hidden by a mask but were important for determining bioanthropological parameters such as age. Considering the complete absence in the reported literature of imaging studies of Chinchorro bodies using high resolution computed tomography, this work offers some initial results and will serve as a reference for future studies that employ this technique on mummified bodies in a fragile state of conservation.

Introduction

The application of x-rays to the study of mummified human remains took place just months after Wilhelm Roentgen's discovery of those rays in 1895 (Fiori and Nunzi 1995; Rühli *et al.* 2004). Later, with the advent of computed tomography in the 1970s, this imaging technique became the preferred method for assessing mummified remains, as it provided information about the soft tissues and body cavities in a non-destructive manner, and with better contrast and spatial resolution. It also provided the opportunity to virtually remove from the images of body

cavities, layers of material from the embalming process as well as anatomical structures (Harwood-Nash D 1979; Hoffman *et al.* 2002; Hawass and Saleem 2016). More recently, the use of state-of-the-art multidetector computed tomography has given investigators a more in-depth understanding of the processes involved in mummification and allowed them to identify pathological conditions not visible to the naked eye (Gupta *et al.* 2008; Wade *et al.* 2012).

In the Americas, the use of artificial mummification to preserve human remains predates artificial mummification in the Old World (Guillen 2004). The earliest artificial mummification process was developed on the Pacific coast of South America by a group of maritime and terrestrial



Fig. 1. Map of northern Chile and southern Peru showing the area inhabited by the Chinchorro's.



Fig. 2. The mummified Chinchorro infant examined in this study.

fishing, hunting and gathering people—the so-called Chinchorro culture, whose members inhabited a vast territory extending from what is now Southern Peru to present-day Antofagasta, Chile (Figure 1) between 9000 and 3500 BP

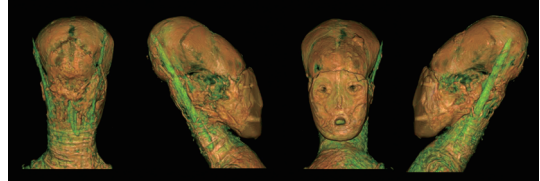


Fig. 3. 3D reconstructions of the head from different angles.

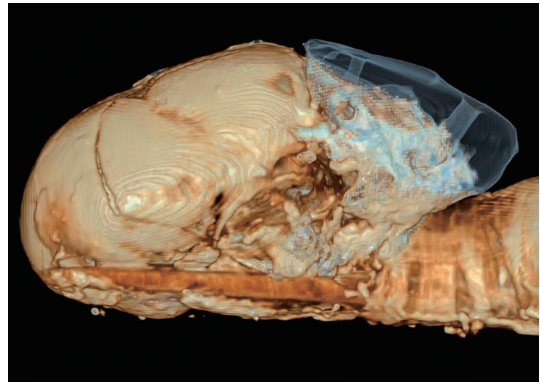


Fig. 4. Mask covering the mummy's face virtually removed.

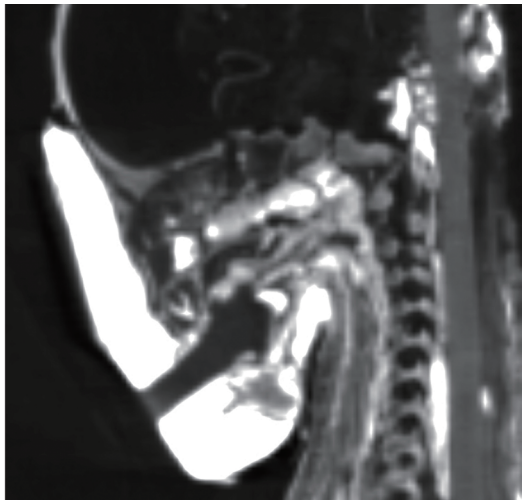
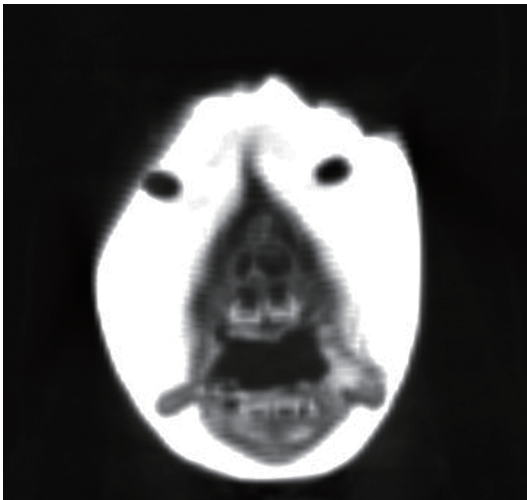


Fig. 5. CT section showing dental development.

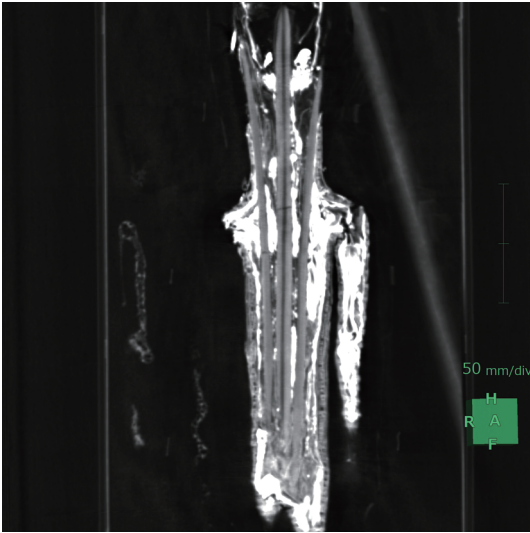


Fig. 6. Three wooden rods alongside the spinal column.

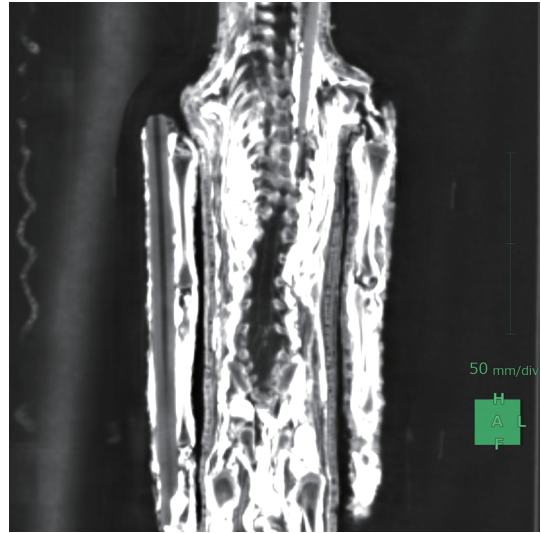


Fig. 8. A wooden rod running in right arm.

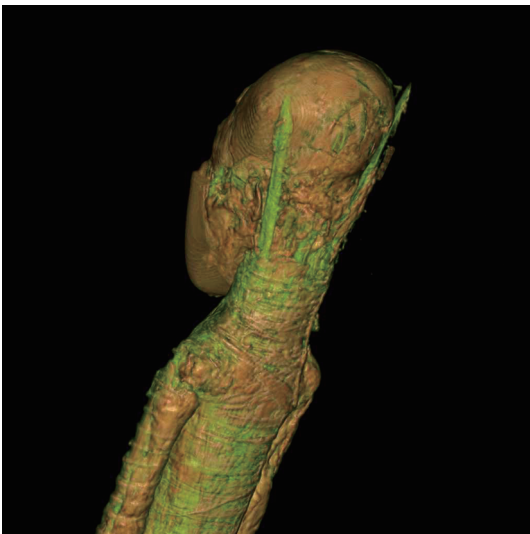


Fig. 7. 3D reconstruction of the trunk showing wooden rods for structural support of the head and limbs.



Fig. 9. CT reconstruction showing dense metaphyseal bands in lower limb bones.

(Arriaza 1995a; Arriaza *et al.* 2008; Shady 2014; Standen & Arriaza 2014). The Chinchorros are considered to have been the earliest human settlers on the Atacama Desert coast. For almost 4000 years they employed complex mortuary practices to preserve the remains of all deceased

individuals in their society, regardless of age, sex or social status. These practices evolved over time and geographic location, with different types of mummification techniques arising from complex, well-planned funerary rites (Arriaza &

Standen 2014).

Although there are several typologies for artificially mummified Chinchorro mummies (Uhle 1919; Allison *et al.* 1984; Arriaza 1995a, b; Arriaza *et al.* 2005), in this paper we follow Arriaza's classification which defines four different types, namely black, red, bandaged and mud-coated mummies (Arriaza 1995a; Llagostera 2003; Arriaza & Standen 2014). The most complex of all were the "black" mummies; in this type, the embalming process considered defleshing the corpse (the bones cleansed and wrapped), a reconstruction with white clay and a final painting with black manganese paint. In "red" mummies there was partial disarticulation and in most cases the skin was not removed completely. Additionally, the head received a more elaborate treatment and the body was painted with bright red ochre paint. The "bandaged" mummies are considered a variation of the red style where the body was defleshed, reconstructed, and wrapped in either animal or human skin and then painted red, while the "mud-coated" bodies were first smoked and then covered with mud (Arriaza 1995a; Llagostera 2003; Guillen 2004; Arriaza and Standen 2014).

Since the Chinchorro mummies were first discovered, several investigations have identified the characteristics and evolution of the mummification processes developed by the Chinchorro culture; however, imaging studies of the bodies are almost non-existent, with only one published report on the use of computed tomography to examine six "statuettes" mummies (Arriaza *et al.* 2003). A few other studies have mentioned the use of computed tomography to examine Chinchorro bodies but the results of those investigations have never been published (Arriaza 2005). This paper reports the findings in a "red" Chinchorro mummy (4800–4000 BP) examined using high-resolution computed tomography in which bioanthropological, paleopathological and mummification parameters were analyzed.

Materials and Methods

In 2013, the Museo de Historia Natural in Valparaíso, Chile loaned a "red" Chinchorro mummy corresponding to an infant (Figure 2) to National Museum of Nature and Science, Tokyo for the exhibition entitled "The Great Journey, The Odyssey of Humankind." The mummy was transported to Tokyo to be exhibited for a three-month period. During its time in Japan, the body was examined using high-resolution computed tomography (CT) in order to obtain bioarcheological, paleopathological and conservation information as well as to analyze the embalming technique employed. This paper reports on the findings of those analyses.

The mummy

According to the records of the Museo de Historia Natural in Valparaíso, the mummy became part of the collection in 1915, along with three other mummified bodies from the same provenance. The bodies were deemed to have come from archeological excavations conducted by German archeologist Max Uhle, considered the discoverer of the Chinchorro culture (Vera 1981). However, after an exhaustive review of the historic information available regarding the time-frame of Max Uhle's investigations in Northern Chile (Rowe 1954), we estimate that these mummies, which were found in the city of Arica, were recovered prior to Uhle's excavations and sent to Valparaíso on the way to their intended final destination in Santiago. Based on the mummification technique employed, the mummy evaluated in this study has been assigned to the so-called "red" mummy type (Standen 1995a), and as such dated to between 4800 and 4000 BP (Arriaza and Standen 2014).

During the mummy's time in Tokyo, National Museum of Nature and Science, Tokyo arranged for a radiological assessment of the body using high-resolution computed tomography. The mummy was transported to Japan's National Institute of Radiological Sciences, where an anthropological and conservation investigation

was conducted at the New Particle-Therapy Research Facilities using a TOSHIBA Aquilion/LB helical scanner. During scanning, the mummy remained wrapped in its museum storage box, while a complete scan of the body was performed. The images were acquired at 64 mAs and 120 kVp, and axial images at 1 mm intervals were obtained and later interpreted by a team of expert medical radiologists at the Autopsy Imaging Information Center (Ai Center). The images, based on two-dimensional transversal, coronal, oblique and sagittal sections, as well as 3D volumetric images, were interpreted at the workstation provided by the scanner manufacturer. The 3D images were rendered using AZE Virtual-Place (AZE, Tokyo, Japan) and Vincent (Fujifilm, Tokyo, Japan) software.

Results

Head. Figure 3 shows 3D reconstructions of the head from different angles. The images reveal an extremely elongated cranium, which suggests the practice of artificial cranial deformation. This interpretation is supported by the wide angle observed between the longitudinal axis of the cranial vault and the longitudinal axis of the face when the mask covering the mummy's face is virtually removed (Figure 4). The anterior (or bregmatic) fontanelle is not closed but the other fontanelles are completely obliterated, while the frontal (metopic) suture is partially closed, all pointing to the young age of the infant. Two exterior lateral wooden rods can be observed at the nuchal region (one on each side of the neck), while a third central rod passes through the foramen magnum and enters the endocranium after running posterior to the vertebral column. The three rods are intended to provide support to the head relative to the body. There is a gap at the atlantooccipital joint though the cervical vertebrae are articulated. This means the mummification process included disarticulation but not decapitation. On the posterior right side of the head there is material that looks like a piece of thread that seems to have been added at a later

time. The cranial cavity is eviscerated with some clay residue.

The face is covered by a finely polished clay mask with eyeholes, nostrils and a mouth opening. These orifices extend from the surface into the cavities themselves. Thus, this mask recreates the face during lifetime. The mask covers approximately from the superciliary arch to the lower edge of the jaw, and under it, all of the facial bones are preserved in their correct anatomical position. The lips and alveolar gingivae can also be observed under the mask's mouth opening. On the CT sections, Four dental crowns of the upper deciduous incisors and lower deciduous incisors can be identified (Figure 5). Judging by the degree of dental eruption, the infant would have been before one year of age (Ubelaker 1999). The scan also showed that both auricles (pinnae) had been preserved and the external acoustic meatus had been filled with clay.

Trunk. The bones of the trunk remain articulated. Apparently, during the mummification process, the embalmers left the ligaments necessary to keep the joints articulated, while removing the soft tissue. As with the head, a flat, narrow wooden rod has been placed alongside the spinal column, extending from the endocranium to the pelvic floor (Figure 6). There are also two lateral rods running parallel to the central one, that appear on either side of the neck, extending from the lower limbs to the parietal-occipital region. The thoracic vertebrae display lateral deviation, the cause of which cannot be determined, i.e. scoliosis or post-mortem deformation, while the lower ribs appear fractured but maintain their structure. The trunk is also wrapped in cord, over which a thin layer of mud is applied (Figure 7).

Limbs. The upper limbs also have internal wooden rods that extend from the shoulder to the hand (Figure 8). As with the rest of the body, the lower limbs remain articulated, although there is some clay present at the joints. The ligaments of both knee joints are severely deteriorated, but the cruciate ligaments can still be identified. The right foot is in very poor condition. Both the femoral and tibial epiphyses display dense bands that

could indicate nutritional problems or poisoning from heavy metal consumption (Figure 9).

Discussion

The use of high-resolution computed tomography provided insights into the mummification process employed by the Chinchorros and enabled the identification of bioarcheological characteristics of the body through the computerized removal of the mask overlaying the infant's face. This in turn allowed a more precise determination of the age of the child based on the degree of tooth eruption and the measurement of the long bones.

To date, most of our understanding of the mummification techniques employed by the Chinchorros has come from the study of damaged mummies in which structural elements and the materials used in the embalming process could be directly observed. As mentioned before, the Chinchorro mummy assessed in this study is classified as a "red" mummy according to the embalming technique used to preserve the body (Vera 1981; Arriaza 1995). Arriaza and Standen (2014) note that in this type of mummification the embalmers worked directly upon the body, making incisions on the abdomen, shoulders, inguinal region, the knees and ankles, removing most of the viscera and some of the musculature, and then inserting long wooden rods under the skin of the limbs and spinal column to support the body. In this process, the eviscerated cavities were also filled in with organic material and the incisions sutured. The results of the CT scan confirm this description, as it shows the incisions and sutures on the anterior surface of the thorax and abdomen. They include a diagonal incision that extends from the left axillary region to the right flank, a second parallel incision that begins on the left flank and extends to the right iliac fossa and a third incision made perpendicular to the previous ones that extends from the right hypochondrium to the left flank. Sutures attaching the lower limbs to the trunk can also be observed, as can the eviscerated cavities (cra-

nium, thorax, abdomen and pelvis). Regarding supports, the CT scan confirms the presence of supporting rods in the limbs and trunk; these rods are internal, only exiting from the body at the nuchal region, while another rod that joins the head to the trunk extends internally from the pelvis to the endocranium.

The cranium lacks two characteristic features of "red" mummies: it has no wig placed upon it and neither the head is wrapped in cloth (Arriaza 1995a). However, there is evidence of an intentional oblique annular deformation of the skull, which does correlate closely with "red" mummies, as this cultural innovation appeared during the same period in which the "red" mummy technique emerged as a mortuary practice (Arriaza 1995b; Shady 2014).

Regarding the presence of dense bands at the epiphyses of the long bones of the lower limbs, these may be a normal variation or may indicate chronic heavy metal toxicity (from lead, arsenic, bismuth or phosphorus) or an infectious disease (Resnick 1981; Raber 1999; Vahter 2008; Dähnert 2011). Dense transverse bands on long bone metaphyses is within the normal range of variation among infants and could offer an explanation in this case (Resnick 1981; Dähnert 2011). However, different studies have demonstrated that at least some Chinchorro groups suffered from chronic arsenic intoxication (Figueroa *et al.* 1988; Byrne *et al.* 2010; Arriaza *et al.* 2010, 2018) owing to the fact that many freshwater sources in Northern Chile, including the Arica area, display high arsenic concentrations (Hopenhayn-Rich *et al.* 2000; Figueroa 2001). Lead is another heavy metal that has been reported in bodies discovered at some Chinchorro sites, with water again suggested as a potential source of contamination due to geochemical processes (Bartkus *et al.* 2011). It is therefore not possible to rule out heavy metal toxicity as a cause of the dense bone bands, regardless of the fact that the infant may well have been breastfeeding, and may have been protected to some degree from the effects of arsenic poisoning by a diet based primarily on mother's milk (Concha *et al.* 1998;

Islam *et al.* 2014). Nevertheless, it has also been shown that prenatal exposure to arsenic significantly increases an infant's mortality risk, especially from infectious disease, during the first year of life (Vahter 2008). It seems, then, that the presence of dense metaphyseal bands could be due to a series of factors rather than a single cause.

Conclusion

High-resolution computed tomography confirmed descriptions found in macroscopic studies of the materials and techniques employed by the Chinchorros in their mummification processes; it also expanded our bioanthropological knowledge of the body studied by allowing artifacts from the mortuary process such as the face mask to be eliminated virtually. This in turn allowed a more accurate determination of the infant's age. Additional data obtained includes the presence of dense metaphyseal bands, which could be a normal variation, or the result of a pathological condition.

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