Histopathological Study of a Mummified Eye and Optic Nerve from a Strangled Peruvian Mummy

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Established Facts

- Mummified individuals are very difficult to study from a forensic and histopathological point of view due to tissue degradation.
- Ocular structures are easily damaged and rarely found in mummies.

Novel Insights

- Rehydration allows the histopathological study of mummified tissues, and eye structures such as eyelids, sclera, the optic nerve, and periorbital fat can be recognized after the mummification process.
- Optic nerve hemorrhage can help to establish strangulation as the cause of death in mummified subjects.

Key Words

Paleopathology · Mummy · Eye · Optic nerve hemorrhage · Strangulation

Abstract

We present the histopathological findings of a naturally mummified eye from the Peruvian Lambayeque culture (900–1,200 AD), in which rehydration, light microscopy, and scanning electron microscopy allowed a detailed analysis of several eye tissues including the eyelids, sclera, and optic

nerve, the latter showing evidence of hemorrhage likely related to the documented strangulation as the cause of death. We conclude that histopathological analysis of rehydrated mummified tissues can provide valuable information from fragile eye structures including the optic nerve, and these findings can be useful from a forensic point of view.

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Introduction

In spite of the relative preservation in more than 90% of natural mummies, very few studies have described the histology of mummified eyes [1]. Analysis of this organ could provide not only interesting information about the mummification process and ocular diseases in antiquity but also forensic clues regarding the cause of death.

Given the scarcity of reports on this organ, we decided to describe our histopathological findings in a mummified eye from a 35- to 38-year-old sacrificed woman belonging to the Peruvian Lambayeque culture (between 900 and 1,200 AD) from the northern coast of Peru, which showed very good preservation of soft tissues, including the seldom found optic nerve, as well as pathological signs consistent with strangulation.

Case Report

The specimen consisted of soft parts detached from the anterior aspect of the left orbit and malar region of a female individual (registry No. G2.6/91, burial No. 7/91) from the 1991 excavation of Huaca Cao Viejo [2, 3]. The sample included recognizable closed eyelids and skin on the anterior aspect (fig. 1). The posterior aspect of the specimen was very irregular, but a 10-mm beveled cord-like structure was found to protrude close to the center (fig. 1 inset) and was interpreted as a possible optic nerve with a thickness that varied from 4 to 1.5 mm at the terminal part. The peripheral part of the specimen showed a harder consistency suggestive of thin bone. In toto immersion in Sandison's solution [4] for 2 h and fixation in formalin for 24 h were followed by serial transverse sectioning of the whole wet specimen. The putative optic nerve was also sectioned transversally. Sections thus obtained were subjected to routine histopathological processing through paraffin embedding and microtome sectioning. Hematoxylin-eosin staining was performed on 3- to 4- μ m sections. A 3 $\times$ 3 $\times$ 2 mm sample of the nerve was also submitted for scanning microscopy. The rehydrated and formalin-fixed fragment was allowed to dry for 7 days and examined uncoated using a low vacuum electron microscope (ESEM-Quanta 200; FEI).

Soft parts of the specimen from the face showed good preservation macroscopically, including the left ocular area which was histopathologically analyzed.

The eyelids had a well-preserved structure in which the tarsal dermis, striated muscle, and palpebral glands were easily recognized (fig. 2a, b).

The eyeball showed good preservation of the sclera, which had a maximum thickness of approximately 430 μ m (fig. 2c). In the inner third of this structure, a brown pigment consistent with choroidal melanin was easily observed (arrow in fig. 2d). Neither the lens nor the retinal epithelium could be recognized. Contrarily, the histology of both the transversal sections of the putative optic nerve and some of the sections crossing the full specimen at approximately the center was consistent with the former. Indeed, parallel compartments separated by a thick wall were interpreted

Fig. 1. The specimen analyzed consisted of soft parts from the anterior left-malar area which included a closed eye. The posterior aspect of the specimen showed a 10-mm beveled cord-like structure consistent with the optic nerve (inset) which measured 1.5–4 mm in diameter.

as nerve fascicles which surrounded elongated hollow structures most likely corresponding to central retinal vessels (fig. 2e). Interestingly, abundant extravasated erythrocytes were found in some areas of the nerve, consistent with hemorrhage (fig. 2f). The average thickness of the nerve, including the meningeal cover, was 3 mm after histological processing. Scanning electron microscopy showed meningeal covers around the end of the structure (fig. 2g) and longitudinal structures on the surface, consistent with nerve fibers (fig. 2h). Other orbital tissues such as fragments of bone and adipose tissue (fig. 2i) were easily recognized.

Discussion

The Lambayeque culture, also known as Sican, developed on the northern coast of Peru in the Andes cultural area. Several Lambayeque burials are documented in Huaca Cao Viejo of the El Brujo complex belonging to the era of main extension and territorial influence (900–1,200 AD) [2]. Like other Andean cultures, the Lambayeque seem to have practiced ritual sacrifices of both male and female subjects who were close to important individuals, thus continuing their links after death [2, 3]. This is also the case for cultures such as the Inca, Moche, Nasca, and Wari, with different rituals, including the transformation of heads into trophies, and goals such as worshiping the

Fig. 2. **a** Low-power view of the eyelid. **b** Muscle bundles (solid arrow) and palpebral glands (dotted arrow) can be recognized. **c** Sclera. Histology shows a thick structure composed of parallel membranous layers measuring more than 400 μm . **d** Melanin-containing cell in the inner aspect of the sclera. **e** Longitudinal section of the optic nerve showing parallel structures consistent with nerve

fibers and central vessels (arrows). **f** Infiltration of nerve fibers by erythrocytes indicating optic nerve hemorrhage. **g** Scanning electron microscopy of the optic nerve showing laminar structures (arrow) around the nerve fibers consistent with meningeal covers. **h** Scanning electron microscopy showing longitudinal structures of the optic nerve. **i** Adipose tissue surrounding the globe.

mountains, marking significant political events or providing a powerful status [5–10]. This knowledge has helped to provide a better understanding of the motivations behind sacrificial rituals and social practices in the ancient populations of the Andes. The Lambayeque subject de-

scribed here was strangled with a cotton noose that was still in place when the subject was studied, and she might correspond to a concubine of a subject of high status.

There are rare histological descriptions of mummified eyes, with those of optic nerves being even less frequent.

Previous reports of ocular structures include some pathological findings with potential historical consequences. For instance, Salo et al. [11] identified *Mycobacterium tuberculosis* in the eye of a 1,000-year-old Peruvian mummy, providing convincing evidence of the preexistence of tuberculosis in the New World prior to the arrival of Christopher Columbus. Other descriptions of infectious conditions include Chagas' disease in mummies from the Atacama Desert [12]. On histological analysis of ocular tissues from mummified Eskimo children from Qilakitsoq, other authors were able to identify eyelid, sclera, lens and pigment, but not the optic nerve [13]. Holz et al. [14] recently reported their findings in 2 mummified eyes from the Atacama Desert with very good preservation of the sclera, lens, uvea, and folded segments of pigment epithelia. Contrary to expectations, Egyptian mummies rarely provide well-preserved eyes for histopathological analysis, since embalmers usually made no attempt to preserve them and often replaced the eyes with materials such as linen, shells, artificial eyes, or even onions (!) [15, 16].

Our study provides detailed histological features of some of the structures of an Andean pre-Columbian mummified eye, including the elusive optic nerve, as well

as some technical approaches such as scanning electron microscopy which we consider useful for the processing and study of this organ. Of special interest are the signs of hemorrhage that we found in the optic nerve, which are consistent with strangulation as the cause of sudden intracranial hypertension and subsequent venous stasis with rupture of the central retinal vein or its tiny collaterals on the pia of the optic nerve [17, 18]. This is, to our knowledge, the first time that such a finding has been reported in ancient mummified tissue and, together with our previous study of a 3,000-year-old brain [19], it shows that histological analysis can be performed on fragile naturally mummified nervous tissues after adequate rehydration. We also believe that the findings and methods presented here could help in the evaluation of modern cases of potential strangulations by careful analysis of ocular structures.

We conclude that the procedures described here allow morphological and forensic studies which can help to better understand the mummification process as well as detect ancient pathological findings or forensic clues in rarely preserved organs such as the eye, in which several structures are often amenable to macro- and microscopic evaluation.

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