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Hair surface and mechanical properties of Copt mummies from Antinopolis

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ABSTRACT

In the late nineteenth century, excavations were conducted in the necropolis of the site of Antinopolis, a city founded in 130 CE. Over sixty Copt mummies, out of the thousands of graves excavated, were brought to France in the early twentieth century. Unlike mummies of the Pharaonic era, no specific study has been conducted on the mummies of the Christian era. To identify these techniques of mummification and their state of preservation, the Louvre museum has conducted a multidisciplinary study on thirty-nine mummies located throughout France.

In this work, we studied the surface topography and the mechanical properties of the hair from eleven mummies.

To qualify the hair wear, 3D topography of their surface has been measured with an interferometer of vertical resolution 2 nm and an analysed surface of 20 × 84 μm. The results show that, for most of the hair samples, the cuticle has completely disappeared and the cortex appears very porous. However, for a few of the hair samples, the scales are perfectly regular like those of healthy hair, which is probably due to the mummification techniques used.

The mechanical properties of the hair were determined using a three-point bending mechanical test.

The results show that the mechanical hair properties are not correlated with the surface morphology of the cuticle.

1. Introduction

Antinoe is located on the eastern side of the Nile River Nil, some 286 km south of Cairo. This town was founded on October the 30th, 130 BCE, by the Roman Emperor Hadrian to honour Antinous who drowned in the Nile near there. The city was then named "Antinopolis". The city was very rich, thanks to its geographical position, and during the 3rd century CE, it was also the headquarters of a diocese.

The ruins of this Roman city can be found in the plain next to the village of Cheykh Abadeh. The first drawings of the sites were made by the scholars in the expedition to Egypt led by Bonaparte at the end of the 18th century. Twenty years later, those relics were destroyed to build moderns towns, but the remains of the Christian city are still visible: we can see the traces of a church and of many tombs.

Between 1895 and 1910, some archaeological excavations were carried out in the cemetery site by the French archaeologist Albert Gayet (Gayet, 1987; Hoskins, 2004). Of the thousands of tombs excavated, more than sixty mummies were brought to France at the beginning of the 20th century.

Even though the processes changed over time, the mummification process was applied from the Pharaonic period into the Christian era. Many studies about different kinds of mummies and mummification processes have been realised using nondestructive methods including radiography, CT-scanning, endoscopic techniques, as well as minimally-destructive methods as chemical, physical, and biological methods (Klys et al. 1999; Edwards et al. 2002; Previgliano et al. 2003; Lynnerup, 2007; Papageorgopoulou et al. 2009; Cersoy et al. 2012).

However, no study has been conducted on the conservation mode for Copt Egyptian mummies in the first Christian era, whereas there are many studies on the mummies of the Pharaonic age (Lucejko et al. 2012; Isidro et al. 2006; Cotte et al. 2005; Manialawi et al. 1978).

In 2010, a programme to study 38 Coptic mummies was created by the Louvre museum (department in charge of long-terms loans)

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to address two issues. The first one concerns identification of Christian mummification methods for funerals and the second one concerns carrying out an assessment of the conservation status of the mummies.

Contrary to the skin and the other organs, the mummies' hair is the best-conserved part of the body and the most generous: we can take a sample without altering the body. Microscopic observation of the hair of the 38 mummies shows differences for hair density. Some mummies are completely bald and the surface of the skulls appears, others retained some hair longer than 20 cm. Although this hair apparently seems "normal", as soon as it is manipulated, some of it presents a brittle behaviour (Fig. 1).

To study the differences in the treatment of the mummies and assess their present conservation status, this paper purposes to analyse the surface morphology and the mechanical properties of the hair sample.

2. Experimental method

2.1. Hair samples

Hair samples were taken from 11 mummies out of 38. The mummies come from different museums and they are identified using the name of the town where the museum is located, followed by a number or a letter, if there are several from the same museum: Dunkerque, Châteauroux, Versailles, Lyon (2980, 2430), Montpellier (A, C, F), Paris (23735, 27310, 27317). To ensure the conservation of the mummies, only 4 to 5 hair samples of 1–5 cm were removed. The samples were taken from areas located on the top of the head and not covered by any kind of fabric. The samples were stored in a glass tube and put in a desiccator.

2.2. Morphological analysis of the hair surface

2.2.1. Scanning Electron Microscope (SEM) analysis

The surface of the hair was first observed with an optical microscope and then with an SEM with a charge of 10 kV and two amplification factors (×500 and ×2000 magnifications).

2.2.2. Optical interferometry

This optical interferometry method used for the surface hair analysis has previously been described in the literature (Fougère et al. 2009). The interferometer (Veeco Instruments™, Wyko, UK) is an optical device designed to measure the topography of surfaces. A white light source is split into two separate beams, of which one is reflected on the surface studied before touching the charge coupled device (CCD) detector and the other is reflected from the reference mirror to the CCD detector. When recombined, the two beams create a series of white and dark bands called fringes that make up an interferogramme. These fringes can be associated with, and translated to, lines on a topographic map. The microscope is connected to a piezo-electric transducer to increase the measurement amplitude, with displacements controlled by a microcalculator. Data collected by this method consists of point coordinates in the *x*, *y* and *z* axes, which when reconstructed create a three-dimensional representation of the surface. A vertical scanning interferometry (VSI) mode is used when imaging hair. A ×75 magnification was used to obtain an 20 × 84 μm image with a resolution of 2 nm. For each hair sample, three measurements were carried out.

2.2.3. Fractal dimension (FD) (Mamdelbrot, 1961; Falconer, 2003)

The surfaces of the mummies' hair are very complex. Their characteristics depend on age, individual variability, external treatments and state of conservation. They are characterised by some morphological transformations linked to the mummification technics used and the effect of the passage of time. A simple characterisation of the hair surface with the classical parameters of roughness is not sufficient (Fougère et al. 2009). An intrinsic characterisation method, based on the calculation of the fractal dimension (Gagnepin and Roques-Carmes, 1986; Zahouani et al. 1998a,1998b), has been chosen for this paper to analyse the mummies' hair topography. By using a contemporary Caucasian reference hair (Seshadri and Bhushan, 2008; Kajiura et al. 2006; Takahashi et al. 2006), this method enables us to evaluate a fractal degradation degree of the mummies' hair surface.

2.3. Measurement of the mechanical properties of the hair

It should be noted that the number of hairs available is very limited. This is the reason the three-point bending strength test has been performed to estimate the mechanical behaviour of the mummies' hair, because this method does not require many and long hairs.

To perform the measurement, a specific sample holder was devised. The sample holder has a U-shape and it is created in order to

Fig. 1. Examples of three different types of mummies' hair. (a) Hair is of medium length and visually seems not damaged (Ref. Paris 23735). (b) Hair is of medium length and visually appears damaged (Ref. Lyon 2430). (c) Hair is of medium length and appears highly damaged (Ref. Versailles).