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New radiological approach for analysis and identification of foreign objects in ancient and historic mummies

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ABSTRACT

Traditional x-ray images of mummies may reveal foreign objects lodged within the body or its wrappings, but can only give a vague idea of the material of which these objects consist. More precise information may be obtained by means of computed tomography which delivers not only a three-dimensional reconstruction of the object's shape, but also a measurement of radiodensity and a representation of the radiological structure.

While the density values and structures of body tissues and substances are well documented in radiological publications, little data exist of material not usually found in the human body. The aim of this study is to analyse the radiological density and structure of a series of test objects, so that these may serve as a reference for comparison with potential foreign objects found in mummified remains. Value and limitations of this method are discussed and the practical application is demonstrated through four examples.

1. Introduction

As a result of the technical advances in the field of radiodiagnostics, radiological examinations are being used to study ancient and historic mummified remains more and more frequently. Apart from the high information gain offered by this form of study, such analyses have the additional advantage of being non-invasive, therefore avoiding any damage to valuable archaeological finds, museum exhibits or other testaments of ancient cultures.

Conventional x-ray imaging (Harris and Wente, 1980; Ikram and Dodson, 1998) and computed tomography (CT) (Lynnerup, 2007, 2010; Alt and Rühli, 2010; Rühli et al., 2004) are the most commonly applied techniques. Most studies focus on issues such as potential disease, trauma, kinship, age at death, cause of death and embalming technique (Jackowski et al., 2008; Hawass et al., 2009, 2010; Pernter et al., 2007; Tchapla et al., 2004; Wade et al., 2011; zur Nedden et al., 1994).

Such examinations occasionally reveal foreign objects, located either within the wrapping material or in the body interior and are thus not visible from the outside (Harris and Wente, 1980; Ikram and Dodson, 1998). Apart from the general detection of such objects, it is also important to determine their form and composition. In some cases, the question arises whether these objects may be linked to the cause of death or whether they have a religious or cult significance and were placed on/in the body in the course of funerary preparations. A 3-dimensional reconstruction of the CT data, constituting a figural representation, may yield decisive answers. For a more precise historical placement, however, the material type must also be determined. This is not only the case for adornments or cult objects, but also for weapon fragments such as arrow- or lance-heads (Gostner and Egarter Vigl, 2002).

Computed tomography offers a means of determining the material composition, firstly by depicting the form and structure, secondly by measuring the radiological density. This physical quantity is measured in Hounsfield units (HU). Whilst the typical density and structures of body tissues and substances are well documented in current literature (Kalender, 2011), no such compilation exists for material types not found in the human body. The aim of this study, therefore, is to determine the HU-values and the radiological structure of a large variety of materials and to evaluate the applicability of the results. Additionally, four case

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studies are described so as to demonstrate the methodological approach and the value of CT analyses for the differentiation between organic, mineral and metallic materials in mummies.

2. Materials and methods

2.1. Selection of test material

The selected materials are to cover a broad range of substances, which might potentially be found in mummies, so as to allow a swift and simple comparison with findings from other case studies. From the metal group, gold, silver, copper, bronze and iron were selected, the gemstone/mineral group comprised emerald, ruby, sapphire, aquamarine, lapis lazuli, chrysocolla, malachite, turquoise, pyrite, haematite, calcite, chalcedony, quartz, desert glass, aventurine, rock crystal, tiger's eye, carnelian, agate, onyx, amethyst, obsidian, flint, chert, amazonite, moonstone, topaz, tourmaline, serpentine, garnet, jade, opal and Andean opal. In addition, tree resin, bitumen, amber, African ivory, mammoth ivory, antler, horn, bone, mollusc shell, nacre, pearl, coral, clay pottery and wood.

2.2. Method of study

Computed tomography was selected as the method of study, using a Philips CT scanner, model Brilliance CT 16-slice. The specifications of this device are: 16 detector rows, detector row thickness 0.75 mm, transaxial spatial resolution 24 Lp/cm (corresponding to about 0.4 mm), rotation time 0.5 s. It is installed in the division for nuclear medicine of the hospital of Bolzano, together with a positron emission tomography scanner.

The precision and reliability of the equipment are periodically monitored and correspond to the international technical standards (e.g. EUR 16262 EN). In particular the CT number, was verified with respect to mean value of reference materials (air, water, bone etc.), linearity, spatial uniformity and noise (expressed as standard deviation).

The exposition parameters were as follows: Voltage 120 kV, current 200 mAs/rotation, slice thickness 6 mm, collimation 4×6 mm, image matrix 512×512 pixel, reconstruction filter D (standard filter).

This examination technique measures the degree by which x-rays are attenuated when penetrating tissue and materials. Slice images are generated by a rotation of the x-ray tube and the oppositely situated detector around the object of study. These images consist of 512×512 pixels. Each pixel represents a small volume within the body or object, known as a voxel. The pixel number denotes the x-ray attenuation in that particular voxel, expressed by the coefficient μ. To standardise the image representations, the radiological density is (universally in the medical field) defined as CT numbers, which are expressed through the following formula:

$$\text{CT number} = \frac{\mu_{\text{tissue}} - \mu_{\text{water}}}{\mu_{\text{water}}} \cdot 1000[\text{HU}]$$

Whereby the factor 1000 serves to change specific values (from $-1{,}024$ to $3{,}071$) into whole numbers (from -1024 to 3071) and to allocate the value -1000 to air. As can be seen in the formula, the CT numbers relate to the attenuation of water: They are depicted on a scale in which water has the value 0 and air has the value -1000. This scale is referred to as the Hounsfield scale after its inventor and the determined values are known as Hounsfield Units (HU) (Fig. 1).

Medical scanners are usually limited to a range of -1024 HU to $+3071$ HU. The scanner used for this study has a slightly lower maximal value of $+2978$ HU and a minimal value of -1024 HU. Since CT numbers are universal defined for all CT instruments, they may be compared with reference data. The accuracy of the mean CT number of water is normally <4 HU, over the entire HU range $<5\%$; the spatial uniformity is <8 HU; the noise of a uniform material image, reconstructed with a standard "convolution kernel", <5 HU.

CT numbers together with other data, such as form and structure, may be used to identify the material. In the course of our study, 52 test objects were scanned, each with 4 CT slice images with a slice thickness of 6 mm. In each of these 4 slice images, a ROI (region of interest) was defined, for which the mean HU value and the standard deviation (SD) were determined (Fig. 2a and b). The average was calculated from these 4 values and listed in Table 1.

An inhomogeneous material composition for a given object leads to pixel value fluctuations within a ROI. The square average of the fluctuations yields the standard deviation (SD).

All test objects were examined for radiologically verifiable structures, the results were documented (work station: EBW Brilliance, Philips).

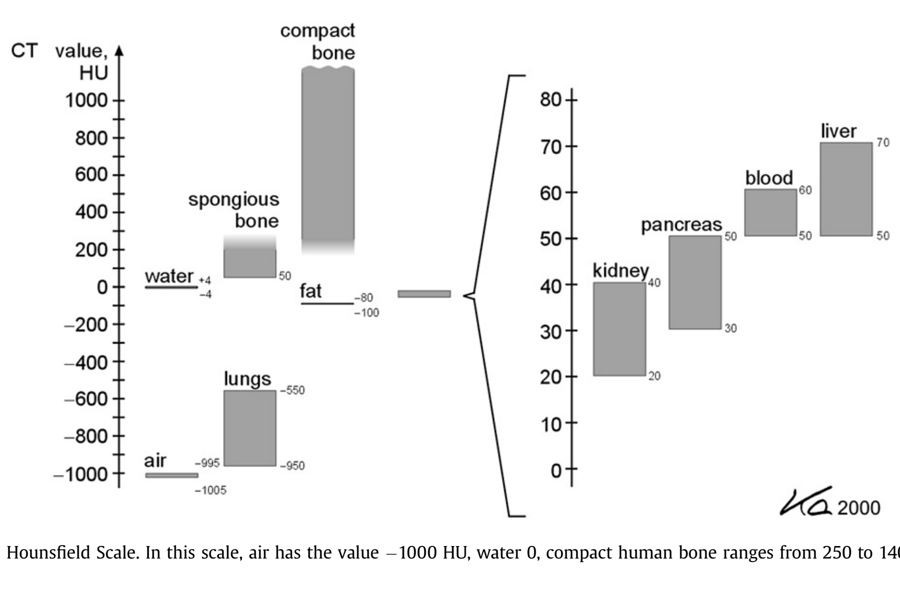

Fig. 1. Hounsfield Scale. In this scale, air has the value −1000 HU, water 0, compact human bone ranges from 250 to 1400 [8].