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Exploring hominin and non-hominin primate dental fossil remains with neutron microtomography

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Abstract

Fossil dental remains are an archive of unique information for paleobiological studies. Computed microtomography based on X-ray microfocus sources (X-µCT) and Synchrotron Radiation (SR-µCT) allow subtle quantification at the micron and sub-micron scale of the meso- and microstructural signature imprinted in the mineralized tissues, such as enamel and dentine, through high-resolution "virtual histology". Nonetheless, depending on the degree of alterations undergone during fossilization, X-ray analyses of tooth tissues do not always provide distinct imaging contrasts, thus preventing the extraction of essential morphological and anatomical details. We illustrate here by three examples the successful application of neutron microtomography (n-µCT) in cases where X-rays have previously failed to deliver contrasts between dental tissues of fossilized specimen.

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Keywords: Neutron Radiography; Neutron Imaging; Neutron Computed Tomography; CCD Camera; Paleontology

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1. Introduction

Fossil dental remains represent the most common evidence testifying the life of extinct taxa in a given region at a given time. In parallel with results from research on developmental biology and genetics, advances in comparative structural morphology of fossil and living primate dental remains show that a significant amount of valuable biological information is preserved in the internal structure of tooth crowns and roots (rev. in Macchiarelli et al., 2013). Since the first discovery of X-rays by Röntgen in 1895, paleontology was among the first scientific fields to use radiography to study human fossil remains (Walkhoff, 1903; Gorjanović-Kramberger, 1906). These early applications already discovered substantial differences between the Neanderthal and modern human dental structure. In response to the potentially conflicting requirements of preservation vs. scientific fruition/exploitation of the fossil record, the available computed microtomography technologies based on X-ray microfocus sources (X-µCT) and Synchrotron Radiation (SR-µCT) allow nowadays the quantification at the micron and sub-micron scale of the meso-/microstructure of the mineralized biological tissues through high-contrast and high-resolution "virtual histology" (Macchiarelli et al., 2008; Smith and Tafforeau, 2008). Nonetheless, depending on the degree of alterations undergone during fossilization, X-ray analyses of dental tissues do not always provide a distinct structural signal (Fig. 1), thus preventing the extraction of essential paleobiological evidence (e.g., Schwarz et al., 2005; Smith et al., 2009; Zanolli et al., 2015).

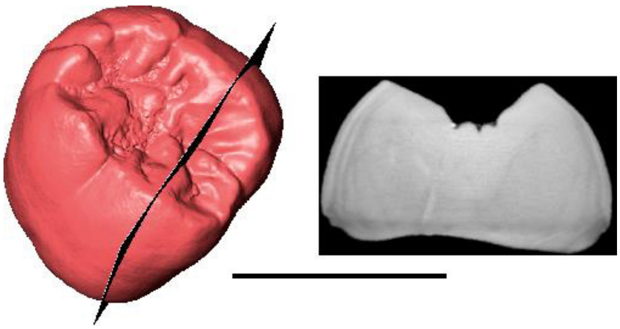

Fig. 1. X-ray analyses of many fossil hominid teeth from Indonesia exhibit no contrast between the enamel and the dentine (Zanolli, 2011).

Besides phase-contrast SR-µCT, a new complementary tool was recently developed to investigate the internal structure of dense materials: neutron microtomography (n-µCT). Even if neutron were discovered in 1932, their use in 3D imaging was developed only recently, when high quality neutron sources and detector systems became available (Tremsin et al., 2011). Neutrons have an absorption profile (interaction mechanism of neutrons with matter) that differs from X-rays (Kardjilov et al., 2003; Winkler, 2006; Sutton, 2008; Tremsin et al., 2015). Because of their unique ability to penetrate materials opaque to X-rays, neutron-based analytical techniques such as neutron radiography and n-µCT represent an effective investigative tool for imaging the fossil material with a better contrast resolution despite the variably hazy appearance of the inner structural signal (Zanolli et al., 2013). We illustrate here the formidable potential of applying n-µCT to the fossil record, and in particular to heavily mineralised remains such as teeth.

2. Material and methods

2.1. Fossil material

The extent of such problems and the investigative limitations in signal retrieving are illustrated here by a few examples of paleontological dental remains from distinct chrono-geographic contexts: a highly mineralized jaw fragment attributed to *Homo erectus* (Sangiran 1b) from Java, Indonesia, a fossil orangutan molar (SMF-8889) from Indonesia and a cercopithecoid upper jaw (STS 1039) from the Sterkfontein Cave, South Africa, still embedded in a