8. HRXCT analysis of hominoid molars: A quantitative volumetric analysis and 3D reconstruction of coronal enamel and dentin

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Keywords: 3D reconstruction; HRXCT; enamel thickness; enamel and dentin volumes; hominoids

Abstract

The significance of enamel thickness in hominoid evolution has been plagued by the absence of nondestructive quantitative analysis. The aim of this investigation was to use a nondestructive method of analysis to document the volume of enamel and dentin, thereby providing a quantitative method for comparing both extant and extinct hominoid dentition. High-resolution X-ray computer tomography (HRXCT) is a nondestructive technique for visualizing and quantifying the interior of objects such as bone, teeth and minerals. HRXCT is also capable of obtaining digital information on their 3D geometries and volumetric properties. HRXCT differs from conventional medical CT-scanning in its ability to resolve details as small as a few microns in size, even when imaging objects made of high density materials like enamel and dentin. HRXCT also differs from micro-CT in its ability to examine large specimens up to 1.5 meters, with higher energy sources (typically 125–450 keV) that make the instrument capable of penetrating much denser objects including teeth and very heavily mineralized fossils. HRXCT offers several advantages over both the medical and micro-CT systems. Hominoid teeth used in this study consisted of a collection of extant hominoids as well as a number of fossil hominoids (*Proconsul and Sivapithecus*). HRXCT was used to obtain a data set of serially sectioned digitized images at a slice thickness of

S.E. Bailey and J.-J. Hublin (Eds.), Dental Perspectives on Human Evolution, 117–136.

approximately 50 micrometers per section. The digital images were analyzed, and 3D reconstructions allowed for the collection of volumetric data for coronal enamel and dentin. HRXCT provides researchers with capabilities not found in other CT systems, which allows for a wider range of specimens sizes, with customizable scanning parameters unique to each specimen type. Our results demonstrate that HRXCT is an effective means by which volumetric data and 3D reconstruction of dental hard tissues are obtained from both extant and extinct hominoid dentitions.

Introduction

The importance of enamel thickness in hominoids was first demonstrated by Gantt and colleagues (1976, 1977; Molnar and Gantt, 1977). Its significance and phyletic relationship in both extant and extinct hominoids have since been studied by a number of investigators over the past thirty years (Martin, 1983, 1985, 1986; Ward and Pilbeam, 1983; Beynon, 1984; Martin and Boyde, 1984; Beynon and Wood, 1986; Gantt, 1986, 1998; Grine and Martin, 1988; Beynon et al., 1991; Macho and Thackeray, 1992; Molnar et al., 1993; Ramirez Rozzi, 1993; Smith and Zilberman, 1994; Bromage et al., 1995; Macho, 1995, Schwartz et al., 1995, 1998, 2003; Cameron, 1997, Macho, 1994; Schwartz, 1997, 2000a; Strait et al., 1997; Gantt and Rafter, 1998; Reid et al., 1998; Risnes, 1998; Schwartz and Dean, 2000; Andrews and Alpagut, 2001; Bonis and Koufos, 2001; Grine et al., 2001; Grine, 2002; Martin et al., 2003; Smith et al., 2003, 2004, 2005). These investigators documented that humans have thick enamel, while in *Gorilla* and *Pan* the enamel is thin in comparison. Additionally, many of these investigators consider the differences in enamel thickness, especially between extant and extinct hominoids, to be a significant phyletic character and a means by which isolated teeth may be assigned to specific taxa (Gantt, 1981, 1982, 1986, 1998; Martin, 1983, 1985, 1986; Grine and Martin, 1988; Ramirez Rozzi, 1993; Schwartz, 1997, 2000a; Schwartz et al., 2003; Smith et al., 2003). Some have attempted to describe the range of enamel thickness, its pattern of distribution and its functional significance (Gantt, 1977, 1986; Macho and Berner, 1993, 1994; Spears and Macho, 1995, 1998; Schwartz, 1997, 2000a, b; Gantt and Rafter, 1998; Macho and Spears, 1999; Schwartz et al., 2003).

These endeavors, however, have led to continued controversy as to the significance of enamel thickness, the methods and procedures of analysis (see Grine, 2002, for a discussion of scaling of tooth enamel thickness and molar crown size), and criticism of using destructive techniques in order to produce sectioned teeth or thin sections, especially in extinct hominoids (Macho and Berner, 1993; Dumont, 1995). Thickness data have primarily been obtained from thin sectional and/or tooth section analysis (Gantt, 1977; Martin, 1983; Shellis, 1984, 1998; Beynon et al., 1991) and information obtained in the course of determining crown formation times (Shellis, 1984, 1998; Risnes, 1986; Beynon and Dean, 1987, 1988; Dean, 1988, 1998; Dean et al., 1993, 2001; Ramirez Rozzi, 1993; Beynon et al., 1997; Ramirez Rozzi et al., 1997; Schwartz, 1997, 2000a; Reid et al., 1998; Smith et al., 2005; Reid and Dean, 2006; Reid and Ferrell, 2006). These methods necessitate the destruction of the tooth or part of it, and thus limit the specimen's availability for use in studies of morphometry, enamel distribution, or in obtaining volumetric data.

The development of nondestructive methods for studying dental hard tissues has long been a goal of dental anthropologists and paleoanthropologists. Most researchers are hesitant to allow destructive techniques to be used on their material, especially hominoid finds. Specimens that have been sectioned have not been generally available