7. Micro-computed tomography of primate molars: Methodological aspects of three-dimensional data collection

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Abstract

Phylogenetic, paleodietary, and developmental studies of hominoid primates frequently make use of the post-canine dentition, in particular molar teeth. To study the thickness and shape of molar enamel and dentine, internal dental structures must be revealed (e.g., the location of dentine horn apices), typically necessitating the production of physical sections through teeth. The partially destructive nature of such studies limits sample sizes and access to valuable fossil specimens, which has led scholars to apply several methods of radiographic visualization to the study of teeth. Radiographic methods aimed at visualizing internal dental structures include lateral flat-plane X-rays, ultrasound, terra-hertz imaging, and computed tomography. Each of these techniques has resolution limitations rendering them inadequate for accurately reconstructing both the enamel-dentine junction and the outer enamel surface; the majority of studies are thus performed using physical sections of teeth. A comparatively new imaging technique, micro-computed tomography (mCT), accurately portrays the enamel-dentine junction of primate molars, and provides accurate measurements of enamel cap thickness and morphology. The research presented here describes methodological parameters pertinent to mCT studies of molars (slice thickness and pixel resolution), and the observable impact on measurement accuracy when these parameters

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are altered. Measurements taken on a small, taxonomically diverse sample of primate molars indicate that slice thickness should be conservatively set at approximately 3.45 % of specimen length, and image resolution should be maximized (ideally, greater than or equal to 2048 × 2048 pixels per image) in order to ensure measurement accuracy. After discussing this base-line protocol for future mCT studies of the primate dentition, illustrative applications of this imaging technology are presented.

Introduction

Background

Internal dental structures viewed by radiographic means have been employed in taxonomic, phylogenetic, and functional studies of primate and human evolution for nearly 100 years (Miller, 1915). The scientific value of studies of internal dental morphology is evident from even a cursory review of the scientific literature pertaining to human evolution, and is only briefly recounted here. The thickness of molar enamel, for instance, is one of the most widely-cited morphological characters relevant to hominoid and hominin evolution (e.g., Gantt, 1977; Martin 1985; Grine and Martin, 1988; Andrews and Martin, 1991; Andrews, 1992; White et al., 1994; Senut et al., 2001; Brunet et al., 2002; Martin et al., 2003; Grine, 2004; Smith et al., 2005). Measurement of enamel thickness necessitates clearly portraying the enamel-dentine junction, so that internal structures of the tooth are revealed. It has further been demonstrated that controlled planes of section are necessary to accurately describe the thickness of enamel, especially in inter-species comparisons (Martin, 1983). In order to achieve uniform planes of section from which to record enamel thickness measurements, physical sections through teeth are often produced, which partially destroy the tooth.

Another fruitful line of investigation, the quantification of enamel-dentine junction (EDJ) morphology, also involves destroying dental material in order to view and measure internal surfaces. Korenhof (1960, 1961, 1978, 1982), Corruccini (1987), and Olejniczak et al. (2004) each employed destructive or semi-destructive techniques in order to study the morphology of the coronal dentine surface. Although EDJ morphology is well suited to studying taxonomic affiliation and mechanisms of dental development, partial destruction of dental tissues is necessary in order to view this surface. Sample sizes in these studies have been limited, despite the promising results produced thus far.

Techniques that involve full or partial destruction of a tooth in order to accurately visualize the EDJ and measure the thickness of enamel limit access to museum samples, and preclude the study of important fossil specimens. In order to acquire large samples of teeth (including fossil material), several non-destructive techniques have been employed, including ultrasound imaging (Yang, 1991) and tera-hertz pulse imaging (Crawley et al., 2003). Despite a long history of innovation, few radiographic methods have proven to accurately measure internal dental structures, and some methods are subject to high degrees of measurement error (e.g., lateral flat-plane X-rays (Grine et al., 2001) and medical CT (Grine, 1991; Spoor et al., 1993).

A relatively new radiographic technique, micro-computed tomography (mCT), has recently been applied to the study of the primate dentition (e.g., Chaimanee et al., 2003; Kono, 2004; Olejniczak and Grine, 2005, 2006). We have reported elsewhere that the measurement accuracy of mCT cross-sections is within 3% of equivalent measurements taken on physically prepared tooth sections, when linear and area measurements are considered (Olejniczak and Grine, 2006). Thus, mCT is capable of providing non-destructive high-resolution measurably accurate visualizations of primate teeth