High-resolution measurement of Neandertal tooth enamel thickness by micro-focal computed tomography

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THE BIOLOGICAL DISTINCTIVENESS OF Neandertals remains the focus of intense palaeoanthropological research and debate.[1] It has been claimed that Neandertals are characterized by having thin molar tooth enamel in comparison to penecontemporaneous humans from North Africa and the Levant and to recent people.[2–5]

Thin enamel has been related to evidence for an accelerated rate of crown formation in the Neandertals.[6–10] This, in turn, has been interpreted as signifying a 'major difference' from modern humans in the early stages of somatic development[2,3,5] and, more particularly, a notably shorter maturational period.[7,10] This developmental difference has been employed to support a specific distinction for *H. neanderthalensis*.[2,3,5,10] Other workers, however, have interpreted thin tooth enamel in Neandertals as a manifestation of their chronic 'suboptimal health'.[4] Like enamel hypoplasia, which has been reported to affect Neandertal teeth in high frequencies,[11–13] thin enamel has been viewed as a result of 'metabolic depressions which affect/arrest the development of mineralized tissue.'[4] If thin enamel is related solely to systemic stress in Neandertal populations, it does not speak to their rate of somatic development and is mute on the issue of their biological distinctiveness. However, a recent analysis of the incidence of linear enamel hypoplasia in a somewhat more representative sample of Neandertals concluded that they were no more stressed than present-day foragers such as the Alaskan Inuit.[14]

If enamel thickness is demonstrably thinner in Neandertals than in penecontemporaneous humans, this would be useful in the diagnosis of fossils (for example, the Tabun C2 mandible) whose attribution is otherwise debated.[15–17]

While enamel thickness in modern humans has been well-documented from physically prepared crown sections,[18–22] all studies of Neandertals to date have been based on lateral flat-plane radiographs.[2–5] This method, however, has been shown to yield inaccurate measurements of enamel thickness when compared to physical sections.[23] Thus, despite all that has been made of thin tooth enamel in Neandertals, it remains to be demonstrated whether, in fact, they actually differ from modern humans in this regard.

Micro-focal computed tomography (μ-CT) is a non-destructive method by which tooth enamel thickness can be measured accurately.[24] In order to quantify enamel thickness in a Neandertal non-destructively, the maxillary right third molar (M^3) of the Shanidar 3 specimen[25] was scanned using a Scanco μ-CT-20 machine (Scanco Medical, Switzerland). This produced 635 transversely-orientated slices at 36-μm intervals, in which the enamel–dentine junction could be seen clearly. From these data, we constructed a high-resolution virtual model of the tooth (Fig. 1a,b). This was virtually sectioned through the middle of the buccal and lingual convexities, approximating the transverse axis through the protocone and paracone (Fig. 1c).

The printed image of the μ-CT virtual cross section of the Shanidar 3 M^3 was measured by digitization using a Summa-Sketch III (CalComp, Inc.) tablet. Five measurements were recorded from this section in order to calculate an index of relative enamel thickness (Fig. 2). For comparison, homologous regions of enamel in equivalent planes of section were measured from photographs of whole crown cross sections for a large sample of human maxillary molars (n = 35), and a small sample of chimpanzee molars (n = 5). It has been shown from physical crown sections that chimpanzees

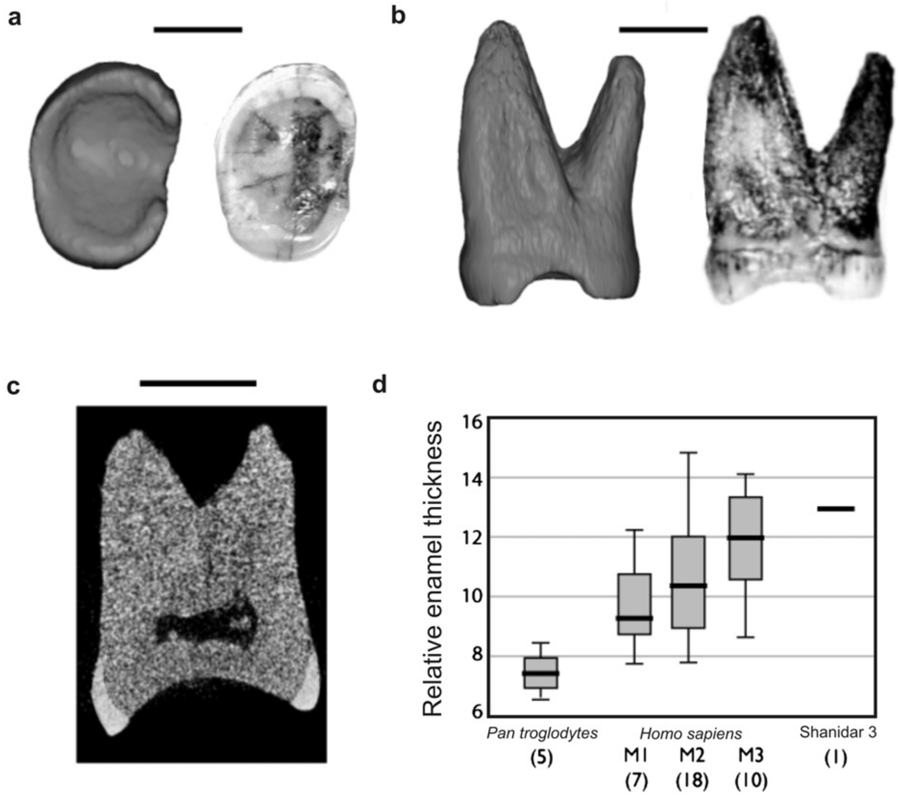

Fig. 1. Virtual models and photographs of the Shanidar 3 Neandertal M^3 in occlusal (**a**) and mesial (**b**) orientation (virtual models created using 3D-Slicer software; photographs courtesy of E. Trinkaus); scale bars = 5 mm. Figure **1c** shows the virtual cross section from which measurements were recorded; because the plane of section does not pass through the tips of the roots, they appear much shorter than in Fig. 1b; scale bar = 5 mm. The box-plot (**d**) shows the relative enamel thickness index for Shanidar 3 and the comparative samples (numbers in brackets denote sample sizes; thick horizontal bars are sample means; vertical lines are observed sample ranges; grey boxes represent 50% of the data). Figure 1d demonstrates the same trend exhibited by whole crown cross sections, in which chimpanzees have thinner enamel than humans, and relative enamel thickness tends to increase from M^1 to M^3 in recent humans. The enamel of Shanidar 3 is relatively thick, but it is accommodated within the modern human range.

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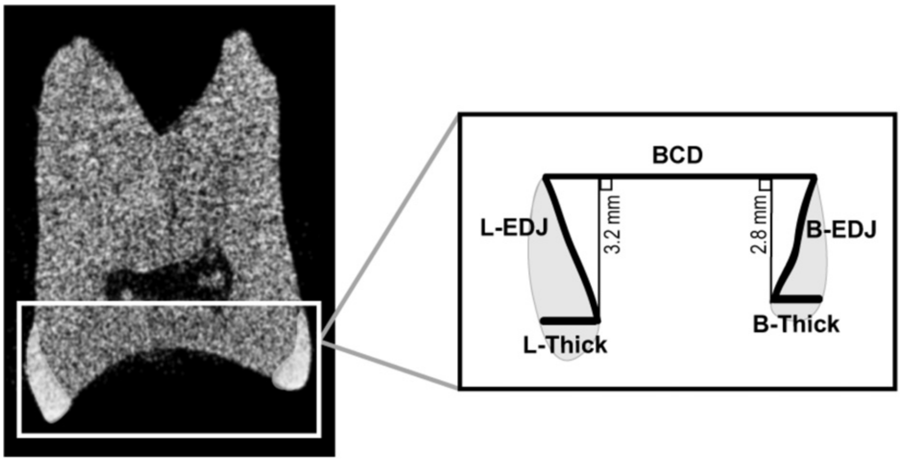

Fig. 2. μ-CT section of the Shanidar 3 molar showing the five measurements recorded for it and the comparative crown sections (buccal is to the right). 1) BCD, the bi-cervical diameter. 2) B-thick, the linear thickness of buccal enamel along a line parallel to BCD. This was measured at a point 2.8 mm from BCD, corresponding to the height of the buccal enamel rim on Shanidar 3. 3) B-EDJ, the length of the enamel–dentine junction on the buccal side, measured between the cervical margin and a point 2.8 mm from BCD. 4) L-thick, the linear thickness of lingual enamel along a line parallel to BCD. This was measured at a point 3.2 mm from BCD, corresponding to the height of the lingual enamel rim on Shanidar 3. 5) L-EDJ, the length of the enamel–dentine junction on the lingual side, measured between the cervical margin and a point 3.2 mm from BCD. An index of relative enamel thickness (RET) was calculated as: RET = 100 × {[(B-thick/B-EDJ) + (L-thick/L-EDJ)]/2}/BCD. The BCD has been shown to be a suitable size scalar for intra- and inter-specific enamel thickness comparisons;[20] in this case it acts to scale the average thickness of enamel by tooth size.

evince thin enamel compared to humans.[26]

The relative enamel thickness values calculated from these measurements correspond with those determined for the entire crown sections for the human and chimpanzee samples, and reveal the same tendency for relative enamel thickness to increase from M^1 to M^3 in modern humans[22] (Fig. 1d). The Shanidar 3 Neandertal molar has relatively thick enamel, surpassing the mean for the human M^3 sample. These results suggest that, contrary to previous reports,[2–5] Neandertal molars are not necessarily characterized by having relatively thin enamel. If the Shanidar 3 molar is typical for Neandertals, it would appear that they do not necessarily differ from modern humans in enamel thickness.

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Basil Schonland on the environment of science

Harwell has owed its success to the creation of an environment of freedom in which the pure scientist, the technologist, and even that rare bird, the inventor, can all feel at home.

Contact between the man who discovers the causes of things and the man who applies these discoveries to practical ends is widespread and has long been going on. It is commonplace in the large industries and is, or should be, the *raison d'être* of our national laboratories and research associations.

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It is easy to find out how much science the majority of Arts graduates know, for they know none. In the world of today this happy ignorance is tragic, for it inhibits proper public discussion of important issues. A knowledge of the meaning of a radio-isotope or a chromosome is at least as important as that of an irregular verb.

From the Stevenson Memorial Lecture delivered at Chatham House in London in November 1958, while Schonland was director of the Atomic Energy Research Establishment at Harwell.