# On Dental Wear, Dental Work, and Oral Health in the Type Specimen (LB1) of *Homo floresiensis*

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*ABSTRACT* The claim that the lower left first mandibular molar of LB1, the type specimen of *Homo floresiensis*, displays endodontic work, and a filling is assessed by digital radiography and micro-CT scanning. The $M_1$ tooth crown is heavily worn and exhibits extensive dentine exposure that is stained white, but there is no trace of endodontic treatment or a dental filling in this Indonesian fossil dated to 17.1-19.0 kya. Dental calculus (commonly observed in foragers) is present on the teeth of LB1, but there are no observable caries. The pattern of dental attrition in the mandibles of both LB1/2 and LB6/1 (moderate to extensive flat wear across the entire arch) is consistent with that seen in Plio-Pleistocene *Homo* fossils and in modern hunter-gatherers, and is not typical of most agriculturalists. We conclude that the dental-work and farming hypotheses are falsified and therefore irrelevant to the debate over the taxonomy and phylogeny of *H. floresiensis*. Am J Phys Anthropol 145:282–289, 2011. ©2011 Wiley-Liss, Inc.

The diagnosis of *Homo floresiensis* (Brown et al., 2004; Morwood et al., 2005) as a new hominin species that persisted in isolation until the end of the Pleistocene in insular Indonesia has generated intense interest and more than a little controversy in paleoanthropology. Details of its discovery, geological context, geochronology, associated fauna, archeology and anatomy are summarized elsewhere (Morwood and van Oosterzee, 2007; Morwood and Jungers, 2009). The validity of the new species designation has been challenged by several hypotheses of systemic (and mutually exclusive) pathologies [see Aiello (2010) for a recent review]. Our goal here is not to revisit this part of the debate. We focus our attention instead on specific dental challenges to the status of *H. floresiensis* as a valid new species.

Based primarily on photographs, Henneberg and Schofield (2008) concluded that the first left mandibular molar ($LM_1$) of the type specimen (LB1) exhibits "unnatural anomalies", including a dental filling and associated "endodontic work" (and the latter necessarily implies treatment of the pulp chamber and/or roots). Henneberg and Schofield (2008, p.82) assert, without providing analytical details, that "the skeleton could not be more than 3,000 or 4,000 years old, and probably much younger"; the hypothetical dental work suggested to them that LB1 "is a very recent modern human," perhaps "as young as 40 years." These recent dates would necessarily call into question the published radiometric dates of 17.1–19.0 kya for LB1 (Roberts et al., 2009).

Henneberg's "previous experience as a dental assistant had led him to interpret unusual characteristics spotted on the tooth's crown as indicating endodontic work had been carried out by a modern dentist using a drill and cement filling" while LB1 was still alive (Henneberg and Schofield, 2008: 76). Remnants of the enamel were said to "bear signs of dental drilling in a manner prescribed for dentists working on a caries cavity and, secondly, the surface of the filling material has been abraded and pitted by considerable chewing" (Henneberg and Schofield, 2008, p. 83). This inference was touted as consistent with the type and degree of tooth wear seen on the left side of the jaw and a "matt-white" (sic) substance covering the entire central area of the $LM_1$ crown. Henneberg is also on record as claiming that dentists began working in the Liang Bua region of Flores in the 1930s, and "they might have used a temporary filling of a white cement rather than the permanent metal amalgams used in Western countries today" (Culotta, 2008). Obviously, if LB1 had been treated by a dentist on Flores in the 1930s, then the diagnosis of *H. floresiensis* as a separate, extinct species of our genus would be effectively refuted. Henneberg and Schofield also contend that the missing upper right third molar of LB1 had "rotted away," and this somehow "conceals a possibility that LB1's dentition might show dental caries, a very rare condition among hunter-gatherers, but fairly common among agricultural peoples" (*op. cit.*, p.85).

Henneberg's claims have not gone unchallenged. Brown (2008) posted a vigorous rebuttal on his website that was based in part on medical CT scans of the skull. Although the resolution of his reconstructed images was less than optimal, it allowed him to look inside the $LM_1$ of LB1 via digital dissection. He observed what appeared to be a normal pulp cavity, and he could discern no evidence of a dental filling. He argued further that the white tint of the exposed dentine was an expected effect

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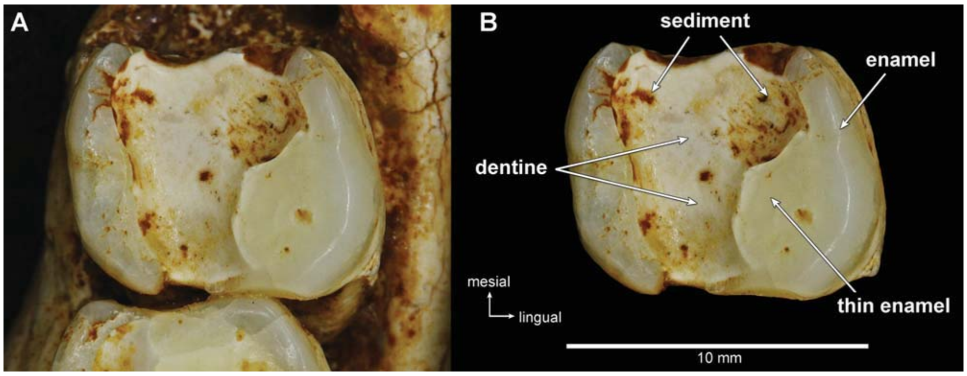


**Fig. 1.** The $LM_1$ of LB1, exhibiting wear-related loss and thinning of occlusal enamel. The exposed dentine is stained white.

of burial in a karst cave. Others have expressed doubts about the likelihood of Henneberg's scenario [see Culotta (2008) and Wong (2008)]. However, Henneberg is said to remain "undeterred" and has called for others to take a fresh look at the tooth in question (Culotta, 2008). Other than in the book by Henneberg and Schofield, this part of the debate has taken place only in online scientific news commentaries, internet blogs (e.g., Hawks, 2008), and personal web pages (e.g., Brown, 2008).

Henneberg and Schofield (2008: 81) also posit that the "teeth recovered from Liang Bua displayed a type and severity of dental wear common in people of agricultural communities." Brown (2008), in turn, argued that "the tooth wear and oral health of LB1 are in all respects typical of older Paleolithic and hunter/gatherer humans, and living apes, and distinct from the Mesolithic and more recent human burials in the Holocene layers at Liang Bua." We independently re-examine these competing observations and inferences via direct observations on the original fossils and by application of digital radiography, micro-CT scanning, and image analysis. We also compare the severity of dental attrition and quantify the pattern of tooth wear in *H. floresiensis* and various groups of fossil *Homo*. Other aspects of oral health are also considered, including the presence and significance of dental calculus deposits on the teeth of LB1.

## MATERIALS AND METHODS

The mandible and dentition of LB1 were X-rayed in the Instalasi Dental Radiologi, RSUP Fatmawati in Jakarta in January 2009. High-resolution CT images of the mandible and teeth were also obtained by using the microfocal X-ray CT system TX225-ACTIS (Tesco Co.) at the University Museum, The University of Tokyo, in April 2009. Original scans were taken at 130 kV and 0.17 mA with a 1-mm-thick copper plate prefilter to lessen beam-hardening effects. Other scanning parameters included a 512 × 512 matrix, 80-$\mu$m pixel size, and 80-$\mu$m slice thickness and interval. Images were reconstructed using the software package ANALYZE 9.0. Micro-CT has been shown elsewhere to be a valuable tool in detection and characterization of caries in fossils and archeological specimens (Rossi et al., 2004).

To quantify potential differences in radiodensity of the dentine and seek objective evidence of a bona fide dental filling in the $LM_1$, gray levels were recorded across mesiodistal scans of *in silico* longitudinal sections taken through $LM_1$, $LM_2$, and $LM_3$ of LB1's mandible using ImageJ freeware (Ferreira and Rasband, 2010). These intensity values are plotted for comparison, and average gray values for each tooth are compared using a robust analysis-of-variance (Welch's $F$-statistic) and nonparametric statistics (Kruskal–Wallis test).

To compare the pattern and rate of dental attrition, the wear severities are recorded for I1, C, M1, and M2 using Smith's eight-grade scoring method of occlusal

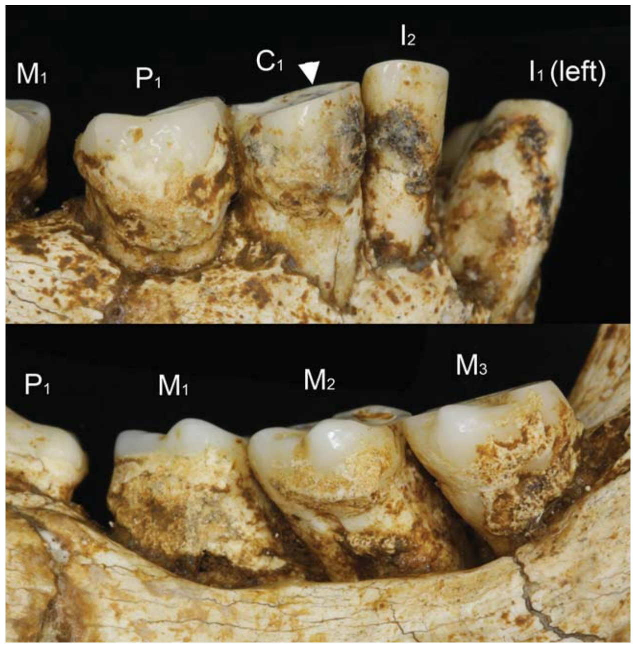


**Fig. 5.** Buccal (labial) aspect of the right anterior teeth (top) and lingual aspect of the right molars (bottom) of the LB1 mandibular teeth. Note the moderate to heavy calculus deposition and alveolar resorption in the molar region. Some parts of the calculus and worn dentinal surfaces (indicated by an arrow head) are stained dark, but these should not be confused with caries. The right $P_2$ (or $P_4$) is lacking. At this position, the alveolar bone is smooth with no signs for its alveolus either externally and internally (our macroscopic and micro-CT-based examinations, respectively). Brown and Maeda (2009) inferred that this tooth was lost during life. However, an alternative interpretation of congenital absence of the $P_2$ is more likely, because there is no interproximal wear facet on the distal surface of the $P_1$ (or $P_3$), and a large, single facet on the mesial $M_1$ may be that for the lost $dm_2$.


**Fig. 2.** **A:** An occlusal view of the mandible of LB1. Note that exposed dentine is stained white in teeth other than the $LM_1$. **B:** A digital radiograph of the LB1 mandible; there is no radiopacity in the $LM_1$ that would signal a non-cosmetic dental filling of any kind.

tooth wear (Smith, 1984), allowing interpolation of intermediates between stages. Data comprising the comparative *Homo* sample (*H. habilis*, *H. erectus sensu lato*, Neanderthals and other middle Pleistocene *Homo*, and Late Pleistocene *H. sapiens*) are extracted from Kaifu (2000). The averaged scores from the right and left sides are used for each comparative specimen, but the data from both sides are presented separately for *H. floresiensis* (LB1 and LB6), so that possible side differences may be taken into account.

## RESULTS AND DISCUSSION

### Dental wear

Figure 1 provides a close-up view of the $LM_1$ of LB1/2. It is indeed heavily worn (Brown, 2008; Brown and Maeda, 2009) but not unusually so for teeth of human hunters and foragers (Campbell, 1939; Murphy, 1959; Molnar, 1971; Smith, 1984; Richards and Miller, 1991; Deter, 2009; personal observations). Most of the enamel has been removed by attrition from the occlusal surface of the $LM_1$. The remaining enamel forms a ridge on the buccal and lingual margins, and there is a thin layer of persisting enamel on the lingual side. The softer dentine has been scooped out and now has a flat white appearance (Brown, 2008). There is some sediment adhering on the occlusal surface, and there appears to be some chipping and/or interproximal wear on the mesial margin. There is no evidence of either caries or drilling on the remaining enamel surfaces of this tooth. The relationship between advanced dental wear and caries is complex, and generalizations are not immediately obvious (Maat and Van der Velde, 1987; Meikeljohn et al., 1992). As Hillson (2001: 271) notes in reference to human archeological remains, "occlusal and approximal attrition may remove large amounts of the tooth, and it is not possible to make any assumptions about this history in relation to caries."

Figure 2 illustrates an occlusal view of the entire mandible of LB1/2 next to a digital radiograph of the same. Asymmetry in L-R tooth wear is evident. This is not necessarily indicative of unbalanced mastication (Henneberg and Schofield, 2008; Brown and Maeda, 2009), but is related to twisted (horizontally rotated) occlusion between the maxillary and mandibular dentitions, probably associated with posterior positional plagiocephaly (Kaifu et al., 2009). The radiograph reveals no evidence of dental fillings in the $LM_1$ or any other teeth of the mandible.

Both the anterior and posterior teeth of the mandible are worn flat, a characteristic also shared with another mandible from the Pleistocene levels of the cave, LB6/1 (Brown and Maeda, 2009). Contrary to the aforementioned opinion that the teeth recovered from Liang Bua exhibit a severe degree of dental attrition typical of people from farming communities (Henneberg and Schofield, 2008), such heavily worn anterior teeth (i.e., moderate to heavy wear across the entire arch) are ubiquitous trends not only in early Holocene hunter–gatherers but also in various fossil groups of *Homo* throughout the Pleistocene (Hinton, 1981; Smith, 1983; Kaifu, 1999, 2000). The severity of tooth wear in human communities has actually reduced since the development of agriculture and, most dramatically, since the industrial revolution. Skeletal evidence from various regions of the world suggests that the first indication of this decrease was a drop in anterior tooth wear of early agriculturists (Kaifu et al., 2003). The relatively heavy anterior tooth wear in *H. floresiensis* is clearly indicated in Figure 3, which compares anterior (I1, C) and posterior (M1 and M2) tooth wear to various Pleistocene *Homo* groups. The wear scores for *H. floresiensis* are available from both LB1 (maxilla and mandible) and LB6 (mandible); the raw scores for I1, C, M1, and M2 are given as follows:

LB1-right maxilla (−, 5, 5, 4)
LB1-left maxilla (−, 5, 5, 4)
LB1-right mandible (−, 4.5, 3.5, 3.5)
LB1-left mandible (6, 5, 6, 4)
LB6-right mandible (−, 4, 6, 4)
LB6-left mandible (−, 4, 4, 3)

In every comparison, the positions of LB1 and LB6 are within the range of variation exhibited by Pleistocene *Homo*, or more narrowly, premodern *Homo*. Figure 4 compares the scores for M1 and M2. In many individuals plotted here, the wear score on M1 is slightly greater than that on M2 due to earlier eruptional age for the former, although this is not always the case. The positions

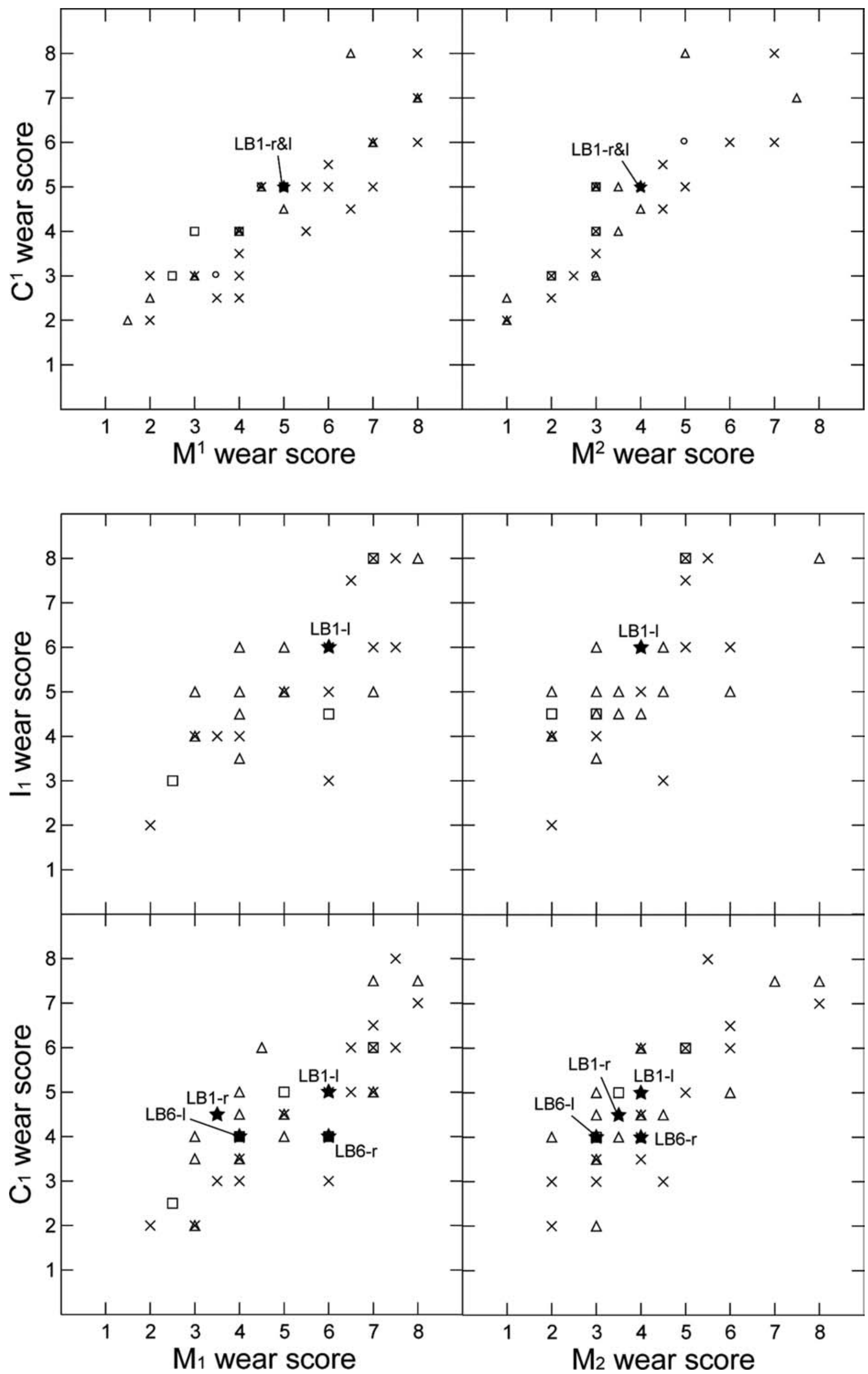


**Fig. 3.** Bivariate plots of Smith's wear scores (Smith, 1984) between the anterior (I1, C) and molar (M1, M2) teeth. A larger score implies heavier tooth wear. Symbols: circles, *H. habilis* (Africa); square, *H. erectus sensu lato* (Africa, Asia); triangles, Neanderthals and other middle Pleistocene premodern *Homo* (Africa, Europe); crosses, Late Pleistocene *H. sapiens* from the Paleolithic contexts (Africa, Europe, Asia); filled stars, *H. floresiensis*.

of the two *H. floresiensis* specimens are again encompassed by the variation seen in the pre-*Homo sapiens* sample.

As Brown and Maeda (2009) mentioned, the flat occlusal wear plane seen in LB1 and LB6 is similar to those in hunter–gatherers, including Pleistocene hominins, and is distinguished from the highly angled wear seen in agriculturalists (Smith, 1984). Although the lingual cusps of the right molars of LB1 are much less worn (the wear restricted to the enamel with no dentine exposure) compared to their buccal cusps (a large dentine patch exposed on each cusp), this is best ascribed to the above-mentioned twisted occlusion [see Fig. 2 in Kaifu et al. (2009)]. The exposed dentine on the occlusal surfaces of

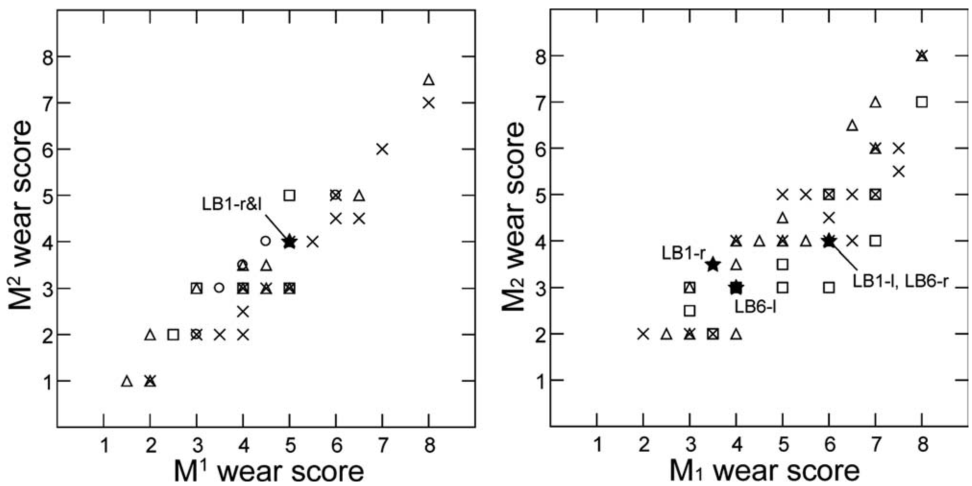


**Fig. 4.** Bivariate plots of Smith's wear scores (Smith, 1984) between the M1 and M2. Symbols as in Figure 3.

the LB1/2 and LB6/1 teeth tend to be concave or "cupped," and this is markedly so on the left M1 of LB1 where a substantial portion of the occlusal enamel has been lost. This is not unusual for a tooth of premodern *Homo*, as is evinced by similarly cupped dentinal wear on the premolars and molars of a *H. erectus* mandible, Sangiran 22 from the early Pleistocene of Java [Fig. 3 in Kaifu et al. (2005)]. Thus, the pattern and rate of occlusal wear in *H. floresiensis* are consistent not only with modern hunter–gatherers but also with fossil species of *Homo*.

## Dental calculus and caries

As Brown and Maeda (2009) described, LB1 is free of dental caries, but there is moderate to heavy dental calculus with associated periodontal disease and alveolar recession in the molar regions. Some parts of the exposed dentinal surfaces and calculus are stained dark, but these should not be confused with caries (see Fig. 5). Calculus without caries is not unusual; in fact, Hillson (2001) has noted a weak negative relationship between dental caries and frequency of calculus deposits. The presence of calculus and/or periodontal disease itself is not unique to people in agricultural societies, but is known in various pre-Neolithic people and some species of wild primates (Arensberg, 1996; Brown and Maeda, 2009). It is well documented in modern human foragers too (e.g., Walker and Hewlett, 1990; Lieverse, 1999). A case with calculus deposition (an isolated $M^3$ labeled as Njg 2005.05) and a possible case for periodontal disease (loss of $M_1$ and associated alveolar bone absorption in Sangiran 9) are also reported in *H. erectus* from Sangiran, Central Java (Kaifu et al., 2005, 2007). Cases with heavy calculus deposition are often reported from historic times, but it can also develop in hunter–gatherer societies when an individual has problems in occlusion, such as loss of opposing teeth (Hanihara et al., 2004). We suspect that the moderate to heavy degree of calculus deposition in LB1 may have been a by-product of her distorted occlusion, with a resultant decrease in any "cleansing effect." There are no grounds, therefore, to assert that the condition of LB1's oral health is the result of an agricultural diet. The suggestion that the upper right wisdom tooth of LB1/1 had "rotted away" is unwarranted speculation.

## Dental work?

In LB1, the dentine is stained white in *all* teeth that expose it, including incisors and canines [also see Fig. 4 in Brown and Maeda (2009)]. Diagenesis (transformations occurring after final deposition) in dental tissues is a well-known phenomenon (Wilson and Pollard, 2002; Dauphin and Williams, 2004), and dentine tends to be impacted more than enamel because it is much more porous and permeable (Hinz and Kohn, 2010). Dentine can be discolored via differential uptake of soluble minerals and organic material from the surrounding sediments, and a white "chalkiness" in the exposed dentine like that seen in LB1 is not exceptional (e.g., Sengupta et al., 1999). LB1 was recovered from a wet limestone cave (Westaway et al., 2009) at a depth of almost 6 m, and diagenesis with staining should be expected. Henneberg and Schofield (2008) have confused diagenesis for dental work.

Figure 6A is a detailed reconstruction of the $LM_1$ from the micro-CT scans, and the vertical line through the dentine indicates the position of the longitudinal (mesiodistal) section through the tooth seen below in Figure 6B. The pulp cavity (p) and parts of the root canals are visible (black); the mesial root is fractured, presumably postmortem. No enamel is preserved in this section. The remaining dentine is mottled in appearance, and variation in gray levels is also seen below the pulp cavity and into the distal root. There is no evidence of either a high-contrast or a low-contrast dental filling above the pulp cavity nor is there any apparent modification of the pulp cavity or roots related to putative endodontic treatment. There is also no indication of any preparation of the tooth crown to improve retention of a very large filling. Figure 7 offers three more sections through the $LM_1$, a coronal one (Co) seen in panel B and two horizontal ones (H1 and H2, seen in panels C and D, respectively) through the dentine above the pulp cavity. The enamel margins are visible in these sections, and the dentine appears irregularly and diffusely mottled regardless of section direction or level; there is no well-defined border that might signal a dentine-filling interface. There is also no evidence that the pulp cavity or root canals were ever breached and treated by a dental instrument.

Figure 8 reveals important similarities between the other two molars on the left side and the $LM_1$. This is a

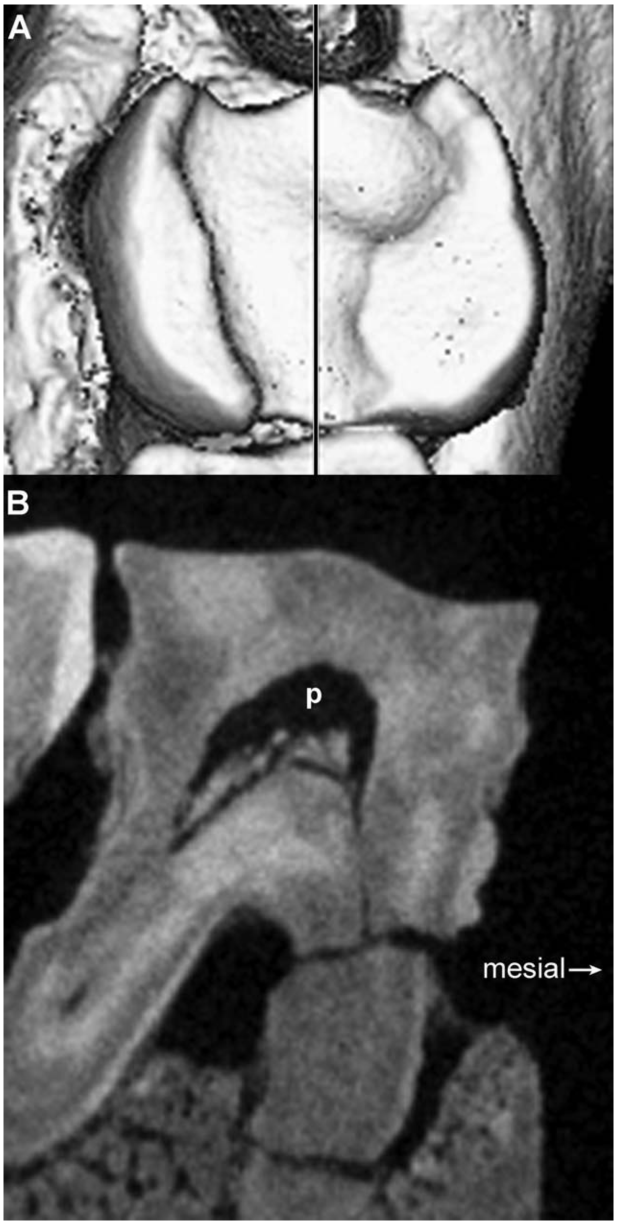


**Fig. 6.** **A:** A digital reconstruction of the micro-CT scans of the $LM_1$; the vertical line indicates the section seen below in panel **B**. A longitudinal (mesiodistal) section through the LM1; "p" indicates the pulp cavity. There is no evidence of a dental filling or endodontic work on the pulp cavity or root canal.

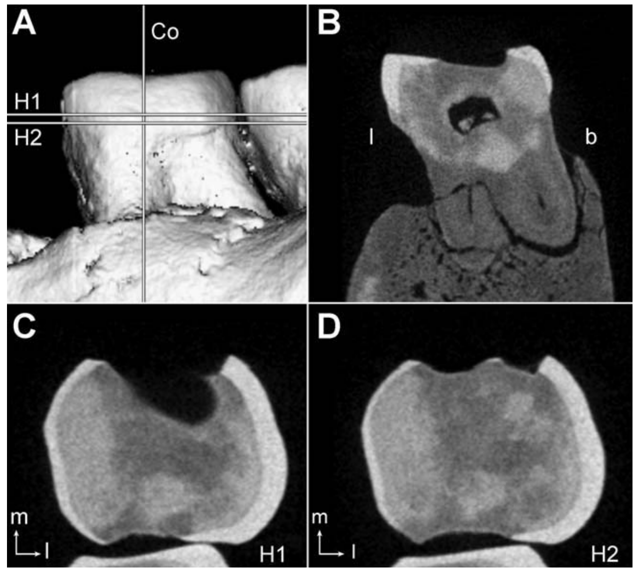


**Fig. 7.** **A:** Section planes of the micro-CT reconstruction of $LM_1$ are indicated. **B:** A coronal (Co) section. **C:** A horizontal section (H1) through the dentine. **D:** A slightly deeper section (H2) through the dentine. l, lingual; m, mesial, b, buccal. There is no evidence of a dental filling or endodontic treatment in any section.

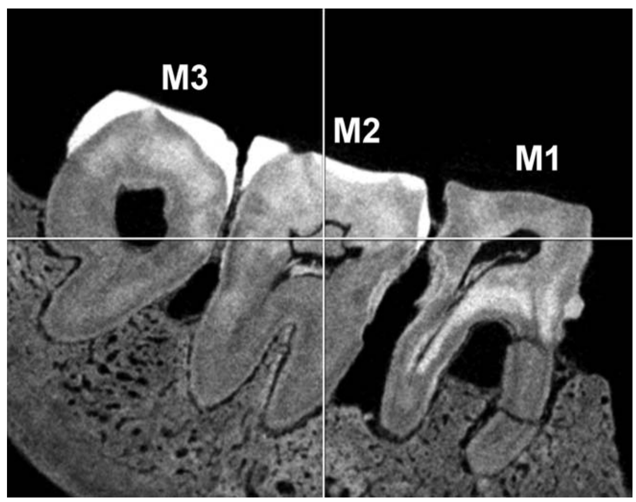


**Fig. 8.** A micro-CT scan through the three left mandibular molars. The dentine of all three teeth is similarly mottled due to irregular absorption of sediment solutions from the limestone cave. Organic debris is evident in the pulp cavities of $M_1$ and $M_2$, but there is no evidence that the pulp cavities or root canals were ever breached and modified by a dental instrument.

longitudinal (mesiodistal) section through left $M_1$–$M_3$, with the cross-hairs centered on the pulp cavity of the $LM_2$. Radiopaque (bright white) occlusal enamel is evident on the less worn $LM_2$ and $LM_3$, but the dentine of these teeth exhibits variation in intensity comparable to that seen in the $LM_1$. Debris of presumably organic origin can be seen in the pulp cavities of both the $M_1$ and $M_2$. The radiolucent pulp cavities appear black and exhibit obvious boundaries with the more radiopaque dentine. The variation in gray levels across dentine transects above the respective pulp cavities is plotted in Figure 9. All three transects exhibit random but limited variation in intensity that is related to the mottled and diffuse visual appearance of the various sections through the teeth. The peak gray level in the $LM_1$ and $LM_3$ is similar and less than that seen in the $LM_2$. There are significant differences in average gray levels among the three molars (Welch's $F$, $P < 0.001$); the $LM_2$ has the highest average value, and the $LM_1$ has the lowest (Table 1). However, there is no discrete area of either markedly increased or markedly decreased radiopacity that might signal a filling. One would expect high to very high contrast for typical, noncosmetic dental fillings (e.g., amalgam alloy, gutta-percha, or white zinc oxide eugenol), and a correspondingly elevated plateau in gray

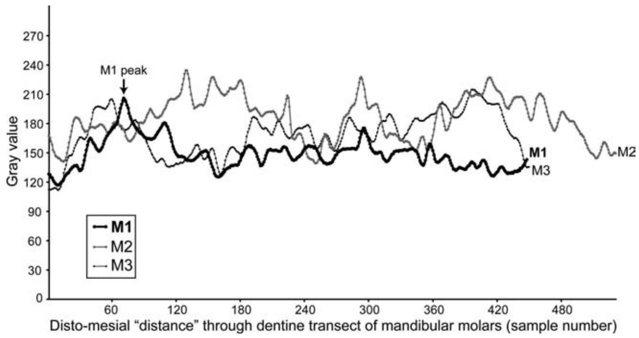


**Fig. 9.** A plot of gray values along subocclusal transects through the dentine of the three molars. $LM_1$ has the lowest average intensities; $LM_2$ has the highest average and peak values. There are no abrupt plateaus or focal regions of high or low intensity that can be interpreted as dental fillings in any of the molars.

*TABLE 1. Gray values for distomesial transects through the subocclusal dentine of LB1's left mandibular molars*

| | M1 | M2 | M3 |
|---|---|---|---|
| ***N*** (sampling points) | 448 | 531 | 450 |
| Mean value | 148 | 185 | 169 |
| Standard deviation | 16 | 23 | 22 |
| Coefficient of variation | 10.8 | 12.4 | 13.0 |
| Range | 116–206 | 139–234 | 111–214 |

Note: maximum gray value (e.g., for enamel) is 250.
Robust ANOVA (Welch's $F$) reveals significant differences among the three molars in average gray value ($P < 0.001$), and this result was confirmed by a nonparametric Kruskal–Wallis test.

values somewhere along the transect of $LM_1$ should reflect this—if it existed. Conversely, in the unlikely event that a radiolucent, temporary white cement filling (e.g., acrylic) was used on LB1 in the remote highlands of Flores Island, one would still expect to see discrete borders in the micro-CT scans and a trough in gray levels between dentine and the hypothetical filling in the $LM_1$; and there are none. In sum, there is no visual or quantitative evidence for endodontic work or a dental filling of any kind.

### Context

Contextual information is also relevant to this debate. The skeleton of LB1 was buried almost 6-m deep in a remote limestone cave (Liang Bua) near what is now the rural village of Ruteng in the highlands of Flores. It has been dated to 17.1–19.0 kya, and there are white tuffaceous silts derived from volcanic eruptions above LB1 dated to 13.4–10.2 kya, thereby providing a *terminus ante quem* for the type specimen (Roberts et al., 2009). The depth and antiquity of the deposit militate strongly against the recent historical date implied by Henneberg and Schofield's combined dental work/farming hypothesis.

## CONCLUSIONS

Our findings corroborate and extend the primary conclusions reached earlier by Brown (2008) and Brown and Maeda (2009). Photographs, a digital radiograph, and micro-CTs scans of the left molars of LB1 all reveal no evidence of a dental filling in the left $M_1$. Occlusal wear and white mineral staining of the exposed dentine were confused by Henneberg and Schofield (2008) for a dental filling, but all teeth of LB1 with exposed dentine exhibit comparable degrees of chalkiness. The pulp cavity and the root canals of the tooth were never breached in life and exhibit no evidence of endodontic treatment. Challenges to the geochronology and validity of the extinct species *Homo floresiensis* based on this serious misconception can be firmly rejected and added to the growing list of pathological misdiagnoses (Aiello, 2010). Tooth attrition in LB1/2 and LB6/1 is consistent with the degree and pattern seen in Plio-Pleistocene *Homo* and modern human hunter–gatherers (extensive flat wear across the arch), and there is no scientific basis for concluding that the oral health of *H. floresiensis* was either related to or compromised by an agricultural diet.

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