

Biological Rhythms in Teeth Reveal Developmental Differences Between Modern Humans and Neanderthals

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While it is commonly understood that tree trunks contain rings representing years of growth, few people know that teeth also permanently mark the passing of time. Over the past few decades, scientists have been examining microscopic clues locked inside teeth to reconstruct the evolution of human growth and development. Primates, including humans and great apes, begin growing their teeth prior to birth and continue this process throughout adolescence. Importantly, the pace of tooth growth tracks the timing of overall development, including brain growth, weaning, and the timing of reproduction. This essay highlights the intimate developmental records we each carry inside our own mouths, and reviews evidence from tooth growth suggesting that a long childhood may be unique to our own species.

Reading the Map of Time Inside Teeth

Figure 1. Neanderthal canine tooth crown replica (left) showing microscopic horizontal growth lines contrasted for scale with the ridges on a human thumb (right). Photo by Tanya Smith.

Like many natural systems, dental formation is characterized by biological rhythms or intrinsic clocks that function independently of light or sleep cycles. Tiny regular lines are laid down during enamel and dentine secretion, which record the passing of days and the speed of growth as tooth crowns and roots take shape (Figure 1). These growth records begin in utero and continue until the last tooth is formed (typically the third molar or “wisdom tooth”), which is completed by the beginning of adulthood. Faithful records of rhythmic secretion and developmental stress, including a line formed during birth, remain unchanged for millions of years.¹

To read the mineralized map inside teeth, it is important to understand that enamel and dentine are secreted by special cells that move in opposite directions from one another, leaving behind long, thin growth tracks known as enamel prisms or dentine tubules. Experimental studies have proven that the fine light and dark bands that make up prisms and tubules are circadian (daily)

features (Figure 2).² As the linked sheets of cells move outward while rhythmically secreting, a longer-period rhythm is also produced every 6–12 days in humans and great apes. These lines conform to the shape of the developing tooth and also appear on the outer surfaces of crowns and roots (see sidebar). Counts and measurements of these features have been used to determine the timing of tooth formation, stress experienced during development, and the age at death in juvenile fossils.³ Importantly, this method provides an accurate approach for assigning age, does not require reference populations, and may also provide insight into neurological or skeletal development.

Until recently, this mineralized map was best read from the inside of a sectioned tooth,



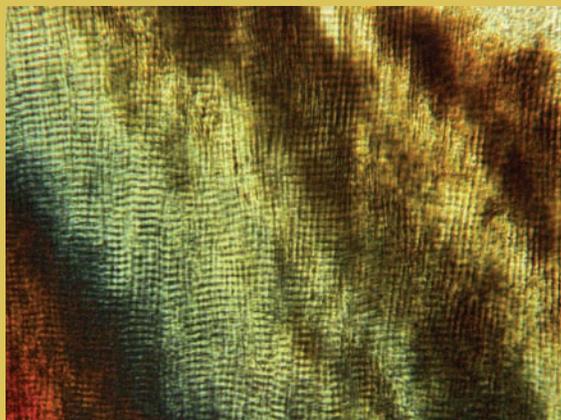


Figure 2. High magnification polarized light image of a two-million-year-old fossil hominin molar showing daily lines in enamel. These light and dark bands run horizontally across the vertical enamel prisms, and are spaced approximately 5.5 microns apart. Fifty to 55 lines can be counted from the bottom to the top of the image, representing 50–55 days of tooth growth.

necessitating sawing teeth to make thin slices. Recent developments in synchrotron X-ray imaging have allowed scientists to unlock the microscopic structure of teeth non-destructively.⁴ By harnessing the power of the European Synchrotron Radiation Facility in Grenoble, France, scientists have been able to see inside hundreds of invaluable fossil human teeth virtually in three-dimensions. Previously inaccessible specimens can now be imaged in remarkable detail. This new approach has shed some important light on hotly debated issues,

including when and in which species the modern condition of a prolonged childhood may have arisen.

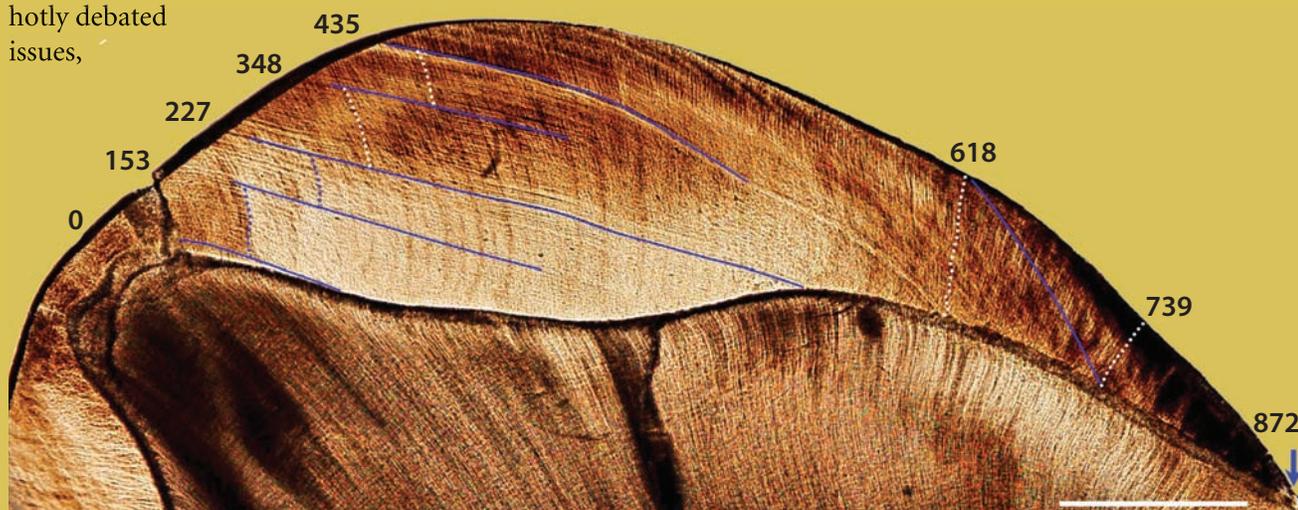
Live Fast and Die Young, or Grow Slow and Die Old?

Reconstructing the evolution of human development from a severely limited fossil record is a fundamental challenge. While it is well established that humans are developmentally unique among living primates, weaning earlier and reproducing later than expected, the adaptive significance and evolutionary origins of our prolonged childhood are unresolved.⁵ Tooth histology, involving quantification of microscopic growth, is the most effective means of determining developmental rates, eruption ages, and age at death in juvenile hominins. Studies of biological rhythms in teeth have revealed that Pliocene to Early Pleistocene hominin dental development was more rapid

NEANDERTHAL MOLAR DEVELOPMENTAL MAP

This thin slice of a Belgian Neanderthal molar was prepared by carefully cutting a tooth (which was later reconstructed with dental restorative materials). The birth (neonatal) line is indicated by the first blue line on the lower left (0), with subsequent time indicated for a series of stress events as 153 days, 227 days, 348 days, 435,

and 618 days post-natal age. This part of crown (made up of enamel) finished forming at 872 days of age, and by cross-matching this first molar to other later-forming teeth, it was possible to estimate that this juvenile died at 8.0 years of age. The scale bar is equal to 1 mm. See Smith et al. (endnote 7) for further details.



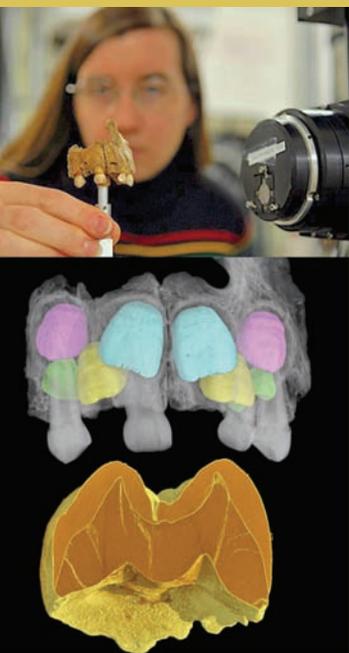


Figure 4 (above). State-of-the-art synchrotron imaging of the tiny upper jaw (maxilla) of the Engis 2 Neanderthal. Synchrotron X-rays allowed scientists to virtually isolate the permanent teeth inside the bone (center image), count tiny growth lines inside the first molar teeth (lower image), and establish that this individual died at age 3. See Smith et al. (endnote 8) for further details. To watch a 3-D animation of how the individual's age was determined, visit: www.heb.fas.harvard.edu/Press. Fossil courtesy of the Université de Liège and Michel Toussaint. Photo by Larry Engel (PBS), J.P. Zermeno (Harvard University), and Paul Tafforeau (ESRF).

than that of recent humans.⁶ Scientists, however, have been debating for more than 80 years whether Neanderthals, our evolutionary cousins, grew differently than modern humans.⁷ Recent studies have reached contradictory conclusions as methodological limitations have led to incomplete data, and population-level variation has been poorly understood in living and fossil hominins. We have recently overcome these limitations, however, by characterizing dental development and age at death in several fossil juveniles via non-destructive synchrotron imaging.⁸

Over the course of this five-year study, we assessed tooth formation and calculated age at death in a diverse sample of fossil hominins from the past 160,000 years. Our sample includes several invaluable European Neanderthal juveniles, such as the first hominin fossil to be discovered (Figure 4), as well as some of the earliest fossil *Homo sapiens* populations to have left Africa 90,000–100,000 years ago. We found that most Neanderthal tooth crowns grew more rapidly than modern human teeth, resulting in significantly faster dental maturation. In contrast, fossil *H. sapiens* juveniles show greater similarity to recent humans. These findings are adding to the growing body of evidence that subtle developmental differences exist between us and our Neanderthal cousins, including cranial and post-cranial growth. Furthermore, the recent sequencing of the Neanderthals genome has provided tantalizing genetic clues that point to differences in cranial and skeletal development between Neanderthals and modern humans.

Neanderthal dental development appears to be intermediate between early members of our genus (e.g., *Homo erectus*) and living people, suggesting that the characteristically slow development and long childhood is a recent condition unique to our own species. This extended period of maturation may facilitate additional learning and complex cognition, possibly giving early *Homo sapiens* a competitive advantage over their contemporaneous Neanderthal cousins.

Acknowledgements

Special thanks to the coauthors, collaborators, and curators who have made this work possible, as well as to Bill Fash for the invitation to contribute to this issue. This research is supported by Harvard University, the Max Planck Society, and the European Synchrotron Radiation Facility.

Notes

1. Reviewed and further illustrated in Smith, T.M., "Incremental Dental Development: Methods and Applications in Hominoid Evolutionary Studies." *Journal of Human Evolution* 54 (2008) 205–224. Smith, T.M. and P. Tafforeau, "New Visions of Dental Tissue Research: Tooth Development, Chemistry, and Structure." *Evolutionary Anthropology* 17 (2008) 213–226.
2. Bromage, T.G., "Enamel Incremental Periodicity in the Pig-tailed Macaque: A Polychrome Fluorescent Labeling Study of Dental Hard Tissues." *American Journal of Physical Anthropology* 86 (1991) 205–214. Smith, T.M., "Experimental Determination of the Periodicity of Incremental Features in Enamel." *Journal of Anatomy* 208 (2006) 99–114.
3. Reviewed in Dean, M. C., "Tooth Microstructure Tracks the Pace of Human Life-History Evolution." *Proceedings of the Royal Society*. B. 273, (2006) 2799–2808. Smith, "Incremental Dental Development."
4. Tafforeau, P., R. Boistel, E. Boller, A. Bravin, M. Brunet, Y. Chaimanee, P. Cloetens, M. Feist, J. Hosszowska, J.-J. Jaeger, R.F. Kay, V. Lazzari, L. Marivaux, A. Nel, C. Nemoz, X. Thibault, P. Vignaud, and S. Zabler, "Applications of X-Ray Synchrotron Microtomography for Non-Destructive 3D Studies of Paleontological Specimens." *Applied Physical Anthropology* 83 (2006) 195–202. Smith, T.M., Tafforeau, P.T., Reid, D.J., Grün, R., Eggins, S., Boutakiout, M., Hublin, J.-J., "Earliest Evidence of Modern Human Life History in North African Early *Homo Sapiens*." *Proceedings of the National Academy of Sciences* 104 (2007) 6128–6133. Tafforeau, P.T. and T.M. Smith, "Non-Destructive Imaging of Hominoid Dental Microstructure Using Phase Contrast X-Ray Synchrotron Microtomography." *Journal of Human Evolution* 54 (2008) 272–278.
5. Smith, B.H., and R.L. Tompkins. "Toward a Life History of the Hominidae." *Annual Review of Anthropology* 24 (1995) 257–279.
6. Dean, C., M.G. Leakey, D. Reid, F. Schrenk, G.T. Schwartz, C. Stringer, and A. Walker. "Growth Processes in Teeth Distinguish Modern Humans from *Homo Erectus* and Earlier Hominins." *Nature* 414 (2001) 628–631.

News & Notes

Theodore C. Bestor, professor and chair of the Department of Anthropology, has been elected vice president of the Association for Asian Studies; his term begins 2012–13. The Association for Asian Studies (AAS)—the largest society of its kind, with approximately 7,000 members worldwide—is an interdisciplinary scholarly association. Previous AAS presidents from Harvard’s Department of Anthropology include James Watson and Stanley Tambiah.

Ilisa Barbash, associate curator of visual anthropology, and **Lucien Castaing-Taylor**, associate professor of anthropology, premiered their film “Sweetgrass,” at the Berlin International Film Festival in February 2009 and had its U.S. premiere at the New York Film Festival in September 2009. It was also shown at the Flaherty International Film Seminars, the Era New Horizons Film Festival (Poland), The Vancouver International Film Festival, Pesaro Film Festival (Italy), CPHX Dox (Denmark), International Documentary Film Association Festival (Netherlands), Festival International du Film d’environnement, (France) and won Best Film in the international competition at the Astra Film Festival in Romania. The film is distributed by Cinema Guild.

Nicholas Harkness will join the Department of Anthropology as assistant professor in Fall 2011. **Harkness** holds a Ph.D. from the University of Chicago, and holds a B.A. in German Studies from Columbia University. Harkness’s dissertation, titled “The Voices of Seoul: A Study of Chronotopic Shift at the Phonosonic Nexus,” draws on multimodal semiotic analysis to explore how differing models of time, space, and person become linked to perceptions,

practices, and conceptualizations of voice in Seoul, South Korea. While completing Ph.D. coursework, Harkness carried out a research and curriculum-design project for the Chicago Opera Theater, supported by the University of Chicago Center for East Asian Studies, to prepare Chicago Public Schools students for a performance of John Adams’s “Nixon in China.”

Michael Herzfeld will receive an Honorary Doctorate from the University of Macedonia, Thessaloniki, Greece. Herzfeld will give his acceptance address in the form of a conference keynote speech, in Greek, on “*The Social Production of Difference in the Global Hierarchy of Value: Stereotypes and Transnational Experience in Greece and the Balkans.*” The conference is titled “*Myths of the Other in Balkans: Representations, Social Practices and Performances.*” Professor Herzfeld, who is the author of several books about Greek society and culture and has conducted research there for many years, has also conducted fieldwork in Italy and Thailand.

Professor Herzfeld’s recent documentary, “*Roman Restaurant Rhythms,*” has been accepted for distribution by Berkeley Media LLC.

Arthur Kleinman is now the Victor and William Fung Director of Harvard’s Asia Center, where he has begun new programs on Islam in Asia; Rice; Responses to Natural Disasters; and Health and Biotechnology.

Matthew Liebmann, assistant professor of archaeology is a Clements Center Fellow for the Study of Southwestern America at Southern Methodist University this fall where he is

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7 Smith, T.M., M. Toussaint, D.J. Reid, A.J. Olejniczak, and J.-J. Hublin, “Rapid Dental Development in a Middle Paleolithic Belgian Neanderthal.” *Proceedings of the National Academy of Sciences, USA* 104 (2007) 20220–20225.

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