

Bounding uncertainty: computational mechanics used to analyze the structural correlates of early hominid locomotion

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Abstract

Late Miocene fossils from the Lukeino Formation of Kenya's Tugen Hills have provided the earliest direct evidence for bipedal locomotion in a human ancestor. Here we explore the application of computational mechanics to understanding more fully the attributes of these fossil remains as well as their implications for potentially modifying probabilities of some chaotic state changes in femur structure of extant humans.

Keywords: Computerized tomography; Cortical bone; Trabecular bone; Femur neck fracture; Fossils

1. Introduction

In the title of this paper the key phrase 'bounding uncertainty' embodies the same sort of scope for purposeful ambiguity inherent in the English language as the much-quoted lines by Groucho Marx 'Time flies like an arrow. Fruit flies like a banana.' That is, the two words 'flies like' assume entirely different meanings according to context. Here, 'bounding uncertainty' could be taken on the one hand as the investigators' lack of conviction concerning the form or forms of activity suggested by the verb itself. What was the locomotion of the hominoid primate known as *Orrorin tugenensis* – bounding? running? striding? walking? something else? After all, we are dealing with highly fragmentary fossil remains of an individual member of a species never seen in life, nor even yet to any meaningful degree of completeness in its skeletal remains. That is, quite simply, we are uncertain whether *Orrorin* ever bounded. On the other hand, we might be using the operative term bounding in the sense of determining the limits or bounds to which we can computationally estimate any values that would give us some confidence in our knowledge. Before moving on to resolve this purposeful paradox, we will endeavor to place this paper in the context of this special session.

It is clear that uncertainties of various sorts increasingly are being recognized as having central positions in building models of the natural world. The domains of computational mechanics and computational dynamics appear to have come into existence to extend the approaches that typically are found in statistical mechanics, in order to comprehend more detailed structural aspects of systemic behavior than those that are reflected chiefly or entirely in terms of probability and degrees of randomness [1,2,3]. Attention is given to measures of disorder (temperature, thermodynamic entropy, etc.) in the pursuit of the order that is embodied in the structure of natural processes. This is a point to which we will return later, as we continue to extend our attempts to integrate the sciences of genetics and physics (or at least mechanics), both of which deal with vast arrays of information, though at different hierarchical levels of the natural world [4].

2. Main body of paper

The work in which we currently are engaged follows from a recent publication [5]. There we presented evidence, primarily from computerized tomography (CT), about internal bone structure of the femur neck in BAR 1002'00, which was recovered late in 2000 from the Lukeino Formation in Kenya's Tugen Hills. These deposits have been dated biostratigraphically,

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geologically, radiometrically, and by paleomagnetism to approximately six million years ago. The total sample of remains now comprises 20 fossils, including portions of two additional femurs (BAR 1003'00 and BAR 1215'00) plus other postcranial remains, as well as jaw fragments and teeth.

The specimen BAR 1002'00 is characterized by cortical bone that is markedly thinner superiorly than inferiorly at the junction of femur neck and shaft, exhibiting a superior:inferior ratio approximating 1:3. This pattern of bone deposition differs markedly from the approximately equal cortical thicknesses observed in extant African apes (chimpanzees and gorillas), which exhibit a $\leq 1:1$ ratio at the femoral neck – shaft junction, and approaches the condition seen in later hominids, including extant human, who show cortical bone proportions of $1:\geq 4$.

Our results supported previous inferences based chiefly on external morphology, indicating that the individual from which the femur BAR 1002'00 was sampled exhibited bipedal locomotion during its life. Controversy has been generated about these findings [6], as indeed about virtually all inferences that have been published by our international research group for the last several years.

There are, of course, multiple reasons for the uncertainties that remain: (1) BAR 1002'00, however informative in its proximal anatomical portion, nonetheless is incomplete, lacking the distal diaphysis and distal epiphyseal region of the bone that would include the knee joint, certain anatomical attributes of which can be important indicators of bipedal locomotion. (2) Even given its incompleteness, BAR 1002'00 is a unique specimen, in the sense that no other femur preserving the same intact portions of head, neck, and proximal shaft is known until more than two million years later. (3) Because BAR 1002'00 comprises a sample of one individual, at this point it remains impossible to know whether it is representative of the central tendency of the population from which it was sampled, or instead constitutes an outlier of some sort, with the possibilities that its known external features (such as an elongated neck) and estimated internal features (cortical bone superior:inferior ratio of about 1:3) might be either more or less like later humans than its congeners. (4) The preservation of BAR 1002'00 can be characterized, according to one's preferences, either as remarkably good (in that its internal anatomy can be discerned in some detail) or frustratingly poor (since some mineralization exists, which complicates the precision with which cortical bone can be distinguished from trabecular bone). (5) The original CT scans of BAR 1002'00 have been criticized by some [6] as exhibiting some deficiencies in resolution and having been '... taken at the wrong angle'.

We are in a position to respond to these perceived limitations. To begin with, other members of our research team, French and Kenyan, are now in the field, actively seeking to increase the size of the study sample. In addition, when funds are made available for this purpose, we are committed to having the BAR 1002'00 specimen rescanned, which we feel might well be productive, given the technical advances in computerized tomography that have accrued over the four years that have intervened since the original scans were made. New scans can be taken at any particular angle that might be seen as desirable; however, given the capabilities inherent in the software that we have used (AMIRA), even now it is possible to slice digitally in virtually any conceivable plane (as we already have done in our recent paper). Other avenues of research include possibility of digital enhancement of the existing scans, and mathematical modeling of various structural attributes (via finite element modeling, etc.).

Our belief in the basic science interest of this project was reinforced to a gratifying – indeed, even to us quite unexpected – degree by the widespread interest that followed our publication [5]. But then, these findings do comprise the earliest direct evidence (again, by approximately two million years) for bipedal locomotion, the signature adaptation of the human lineage that leads to all of us.

3. Conclusions

At this point we feel that it is important to emphasize the potential value of further, and perhaps more practical and valuable, extensions of our research on the *Orrorin tugenensis* fossil material. These hominids from the still obscure dawn of our ancestry represent not only a population with members who once lived, but also a functional morphological pattern that no longer exists, anywhere. Among living hominoid primate species, chimpanzees and humans share a hip joint that is homologous in its placement and elements, but structurally as well as functionally different. Patterns of cortical bone structure in the femoral necks of these species differ in good part because over the course of ≥ 6 million years, hip joint muscles have changed in their masses and attachments. As just one example, the muscle that for the obvious reason of its prominence is termed the *gluteus maximus* in humans, is a muscle of relatively minor extent in chimpanzees. What of the population from which the BAR 1002'00 femur fragment is sampled? While its neck approaches later humans in the proportions of superior to inferior cortical bone, this bone is absolutely thicker all around. To return to the central theme of our earlier (2003) paper [4], knowing whether the observed cortical thicknesses

represent artifacts of preservation and/or observation, as opposed to some blend of (phylo)genetic programming and bone modeling in response to developmental stress during life, holds the potential for understanding what now, unfortunately, is one of most frequently observed chaos-like state changes: spontaneous fracture of the femur neck in growing numbers of an increasingly aged present human population. Just as present states of hominoid primate adaptation hold the key to reconstructing past patterns of hominid locomotion, what may have been a novel metastable state in hip joint structure of our earliest known ancestors could now provide a basis for future therapeutic advances.

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