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The scaling of human osteocyte lacuna density with body size and metabolism

Gamme de densité de lacunes d'ostéocyte chez l'homme en fonction de la taille corporelle et du métabolisme

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ABSTRACT

The aim of our research is to document osteocyte lacuna density (OCD) and its biological significance among humans of known life history. Twelve human midshaft femurs obtained from sub-Saharan Africans (Malawi) of Bantu origin and known life history were prepared for backscattered electron microscopy in the scanning electron microscope (BSE-SEM). Lacunae have a characteristic size and aspect ratio in BSE-SEM images that allowed them to be identified and automatically enumerated relative to the detected bone area in all of the images processed; values for adult whole femoral midshaft cross sections averaged about 100,000 osteocyte lacunae. Statistical tests reveal significant relationships between both OCD and osteocyte lacuna area with body height. It appears that the same increase in energetic efficiency observed in interspecific comparisons of the mass specific metabolic rate of bone at larger body sizes also characterizes body size categories among humans. Long period biological rhythms that regulate rates of cell proliferation explain some aspects of human body size variability.

Mots clés :
Densité de lacunes d'ostéocyte
Prolifération cellulaire

RÉSUMÉ

Le but de notre recherche est de documenter la densité de lacunes d'ostéocyte (OCD) et sa signification chez des Hommes à histoire de vie connue. Douze diaphyses de fémurs humains provenant d'Africains sub-sahariens (Malawi) d'origine bantoue et d'histoire de

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Taille corporelle
Métabolisme
Oscillation Havers-Halberg
Rythme « multidien » (multijournalier)

vie connue ont été préparées pour examen au microscope à électrons rétrodiffusés en microscopie électronique à balayage (BSE-SEM). Les lacunes ont un rapport taille-aspect caractéristique sur les images BSE-SEM, ce qui permet de les identifier et de les dénombrer automatiquement en fonction de la zone osseuse détectée sur toutes les images analysées ; les valeurs, dans les sections de diaphyse fémorale complète d'adulte, sont en moyenne de 100 000 lacunes d'ostéocyte. Des tests statistiques révèlent des relations significatives entre l'OCD et la surface des lacunes d'ostéocyte, d'une part, et la taille corporelle, d'autre part. Il apparaît que la même augmentation de puissance énergétique, observée dans les comparaisons inter-spécifiques du taux de masse métabolique de l'os, pour des tailles corporelles plus grandes, caractérise aussi des catégories de taille corporelle chez l'Homme. Les rythmes biologiques à période longue qui régulent les taux de prolifération expliquent certains aspects de la variabilité de taille du corps humain.

1. Introduction

Research on the chronobiology of mammalian mineralized tissues has provided evidence for a many-days "multidien"[1] metabolic rhythm that regulates body mass, which in turn manifests the life history continuum (Bromage et al., 2009, 2012). In enamel, the length of this rhythm is equal to the duration of time between one stria of Retzius to the next, the repeat period, and in bone it is the duration of time to form one lamella. This rhythm, called the Havers-Halberg Oscillation (HHO), is argued to regulate body mass by means of varying rates of cell proliferation and thus the cumulative growth of all major tissue and organ masses (Bromage and Janal, 2014). However, to date, this research has not included the growth of bone mass, nor has it extended to comparisons within a species to discover whether interspecific principles apply.

Here we examine intraspecific human osteocyte lacuna density (OCD). The speed at which bone is formed has much to do with the number of bone forming cells, the osteoblasts, that are available to lay down a mineralizable matrix. The rate of osteoblast proliferation establishes the rate at which these cells may become incorporated into lacunae within the bone matrix as osteocytes. Variability in the rate of incorporation among humans may provide metabolic information and help us to address intraspecific concomitants of the HHO within the species.

Evidence suggests OCD is negatively related to body mass in mammalian interspecific comparisons (Bromage et al., 2009; Mullender et al., 1996a). This is consistent with differences in life history strategy taken by mammals of varying body size and life history; small mammals having "fast" life histories manufacture their bone quickly for a relatively short period of time in deference to larger mammals that live "slow" life histories and produce their bone more slowly.

We thus have some understanding of the relationship between OCD and body mass among mammals of varying body size. But what of modern humans that have more body mass variability than most other mammals (Mutch et al., 2009)? This remarkable fact begs for an inquiry into the intraspecific relationship among humans and the mechanisms by which bone and body size are achieved. Given our understanding of why mammals reveal a negative relationship with body mass given their diverse life histories, we would expect that OCD among humans would be positive. We reason that if life history is held reasonably constant, then differences in body size among humans must reflect varying rates of osteoblast proliferation and osteocyte incorporation consistent with expectations of their HHOs, which vary from 6 to 12 days (Smith et al., 2007), with arithmetic means of 9 days in females and 8 days in males (Bromage et al., 2011a)

For instance, people with longer HHOs will be smaller, growing more slowly due to slower rates of bone cell proliferation than larger people that have shorter HHOs (the average size difference between males and females in all regional human populations agrees with the HHO sex difference).

2. Materials and methods

Twelve cadavers derived from sub-Saharan Africans (Malawi) of Bantu origin and known life history were selected from the gross anatomy program of the University of Malawi College of Medicine (UMCOM) (Table 1). UMCOM staff administered a questionnaire to the next of kin in which medical, social, economic, and life history information was sought. The medical history is particularly relevant to disease risk in Malawi. Social and economic history information relates to living conditions and employment. We also acquired common life history variables, such as age, height, and weight (mass). In addition, questions were developed to solicit information relating to autonomic function.

Midshaft femurs were obtained from each individual and processed for backscattered electron microscopy in the scanning electron microscope (BSE-SEM). Briefly, specimens, were subject to polymethylmethacrylate substitution and embedding. Each cured block was sawn through midshaft with a Buehler (Lake Bluff, IL) Isomet low-speed saw, hand ground through graded carbide papers to 1200 grit on a Buehler Handimet II and polished on a

[1] Biological periods longer than one day do not have an idiom associated with this phenomenon. We use the term "multidien", formed irregularly from the Latin *multis* 'many' + *dies* 'days'.

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