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Morphogenèse de l'endostructure osseuse de l'ilion humain

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Résumé

L'acquisition progressive pendant le stade infantile humain de la posture orthograde et de la locomotion bipède est responsable d'importants changements morphostructuraux de l'os au niveau du bassin et de l'articulation coxofémorale. Cette étude utilise des techniques d'analyse numérique d'images radiographiques et de relevés microtomographiques à haute résolution pour caractériser les propriétés texturales du réseau trabéculaire et les variations topographiques de l'enveloppe corticale dans une série ontogénétique de 15 ilions d'individus âgés entre 0 et 40 ans. Les résultats suggèrent que les principales structures de l'architecture trabéculaire fonctionnelles à la distribution et dissipation des charges posturales et locomotrices sont déjà reconnaissables à partir de la tranche d'âge d'un à deux ans, en association avec l'initiation d'une marche bipède non assistée. ***Pour citer cet article : V. Volpato, C. R. Palevol 7 (2008).***

Abstract

Bone endostructure morphogenesis of the human ilium. Through the human infantile stage, the progressive acquisition of the orthograde posture and bipedal locomotion is responsible for important morphostructural bony changes at the pelvis and the coxofemoral joint. This study uses digital processing techniques applied to a set of radiographic and microtomographic images to characterise the textural properties of the trabecular network and the topographic variation of the cortical shell in an ontogenetic series of 15 ilia from individuals aged between 0 and 40 years. The results suggest that the main structures of the trabecular architecture which are functional to the distribution and dissipation of the postural- and locomotor-related loads, are already recognizable at the age of 1–2 years, in association with the adoption of bipedal walking. ***To cite this article: V. Volpato, C. R. Palevol 7 (2008).***

Mots clés : Endostructure osseuse ; Morphogenèse ; Ilion ; Biomécanique ; Bipédie

Keywords: Bone endostructure; Morphogenesis; Ilium; Biomechanics; Bipedalism

Abridged English version

Introduction

Bone tissue responds and adapts to the external and internal biomechanical loads by alteration of its shape, mass and microstructure. Measurements of the topo-

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graphic variation of the cortical shell and trabecular thickness, of bone volume fraction and degree of textural anisotropy (struct orientation) provide accurate information about the nature, direction, and magnitude of the loads and the intimate relationships between individual and biomechanical environment [3,9,17,20,23,24].

In humans, the progressive acquisition throughout the infantile stage of a full orthograde posture and mature bipedalism is responsible for important morphostructural changes at the pelvis and the sacroiliac and coxofemoral joints [33,34]. During this period, the functional setting of a characteristic trabecular pattern at the proximal femur clearly reflects a shift in the loading regimes associated with the initiation of unassisted bipedal walking as obligatory locomotion mode [27].

While the modalities and age-related phases of functional structuration of the trabecular network of the human proximal femur have been detailed qualitatively and quantitatively [1,27,28], the setting dynamics of the so-called "anthropic" model [12,13,22] of the iliac cancellous architecture (Fig. 1) and its relationships with the cortical shell are still poorly known [2,3,8,15,29].

In order to assess at what stage of development the structural features functionally connected with the distribution and dissipation of the postural- and locomotor-related loads are recognizable in the human ilium, this study applies advanced digital images processing techniques to characterize the textural properties of the trabecular network and the topographic variation of the cortical shell in an ontogenetic series.

Material and methods

The sample consists of 15 ilia from normal individuals representing the neoperinatal (P, 0–3 months; $n = 2$), the infantile (I, 1–2 years; $n = 5$), the juvenile (J, 5–10 years; $n = 5$), and the adult (A, 20–40 years; $n = 3$) age stages. The specimens, all from modern osteoanthropological collections, have been detailed by radiography (RX) and high-resolution (45.5 μm) microtomography (SR-μCT). The record has been digitally processed according to the protocols developed by Macchiarelli et al. [13], Mazurier et al. [14], and Volpato et al. [37].

On each ilium, the following three textural parameters of the cancellous network [16,19] have been measured on seven regions of interest (ROI) sampling the iliac body and the blade (Fig. 2): trabecular thickness (tb.th.), given as the mean value of a minimum of five randomly selected rod-like struts measured according to the half maximum height method [31]; trabecular bone volume (BV/TV), given as the ratio of trabecular bone area to the total investigated area; degree of anisotropy (DA), an indicator of preferential orientation of the trabeculae, measured according to the line fraction deviation method (LFD; [6]) using the maxLFD value and its coefficient of variation [37].

On the 3D microtomographic-based reconstructions (software AMIRA v4.0, Mercury Computer Systems, Inc.), the thickness variation of the cortical shell has been measured according to four transversal parallel sections (s1–s4; Fig. 2).

Quantitative analyses have been performed by means of ImageJ v1.33 (National Institutes of Health) and MPSAK v2.9 (National Prehistoric Museum of Rome, in [4]) software packages. Estimated intra- and interobserver error of the measurements does not exceed 4 and 8%, respectively [37].

Results and discussion

In the investigated series of human ilia, the 2–3D characterization of the structural properties and comparative analysis of the age-related endostructural changes show that, since the age of 1–2 years (stage I), the trabecular architecture displays, at least qualitatively, the main topographic features typical of the adult condition (A) (Fig. 3).

Starting from a rather homogeneous neoperinatal (P) morphology of radial type (a common immature structural condition in mammals), the early setting of a functionally-related trabecular pattern is achieved through:

- an increase in structural heterogeneity of the network as a whole;
- a development of a distinct sacropubic (*spb*) and ilioischiatic (*iib*) bundles, which run through the blade towards the iliac body and cross at supra-acetabular level forming a "chiasma" of greater density (tc);
- a progressive destructuration of the iliac fossa;
- the generalized increase in trabecular thickness ($\bar{x}\mathrm{P} = 137$ μm versus $\bar{x}\mathrm{I} = 169$ μm);
- site-related differential densification of the network;
- a local decrease in textural anisotropy (Fig. 4).

An age-related significant proportional decrease of the surrounding cortical shell thickness is also recorded along both the body and the blade (Fig. 5). This trend results in a "sandwich-like" construction, which assures a quite effective morphostructural compromise between load resistance capacity and the constraints imposed by the rheologic properties of the bone [3].