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Growth of the human brain and skull slows down at about 2.5 years old

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Abstract

Brain and skull changes in postnatal growth were studied on a sample of 199 children and teenagers from 2 months to 21 years (42% under 3). Four measurements were taken on the para-median sagittal section of MRI brain scans: the glabella–opisthocranion and basion–vertex distances, and the 'cerebral hemisphere' and 'infratentorial' surfaces. Data were fitted by the cubic-spline method. Results have shown a slowing down for both brain and skull measurements between 2 and 3 years, earlier in boys. The tight relationship in growth timing between brain and skull is of great interest in palaeoanthropology, allowing inferences on brain changes from hominid skulls. ***To cite this article: A.-M. Guihard-Costa, F. Ramirez-Rozzi, C. R. Palevol 3 (2004).***

Résumé

Infléchissement de la croissance crânio-encéphalique chez l'homme actuel vers deux ans et demi. La croissance postnatale du cerveau et du crâne a été étudiée chez 199 enfants et adolescents, âgés de deux mois à 21 ans (42% < 3 ans). Sur les coupes sagittales médianes des scans IRM de cerveaux ont été mesurées les distances glabelle–opisthocrânion et basion-vertex, les surfaces des hémisphères cérébraux et de la région sous-tentorielle. Les données ont été modélisées par la méthode des *splines* cubiques. On observe un net ralentissement de la croissance du crâne et du cerveau entre deux et trois ans, un peu plus tôt chez les garçons. La concordance des rythmes de croissance du crâne et du cerveau rend possible des inférences concernant l'encéphale à partir de mesures effectuées sur les crânes fossiles. ***Pour citer cet article : A.-M. Guihard-Costa, F. Ramirez-Rozzi, C. R. Palevol 3 (2004).***

Keywords: Brain; Skull; Postnatal growth; Evolution; Palaeoanthropology

Mots clés : Cerveau ; Crâne ; Croissance postnatale ; Évolution ; Paléoanthropologie

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1. Introduction

Cette étude avait deux objectifs : d'une part, de mettre en évidence d'éventuels changements de rythmes de croissance du cerveau au cours de la période post-natale, particulièrement au cours de la petite enfance, période peu documentée dans la littérature ; d'autre part, de mettre en relation ces changements de croissance encéphaliques avec les modifications du rythme de croissance des dimensions crâniennes au cours de la même période.

2. Patients et méthodes

Cent dix-neuf enfants et adolescents (72 filles et 127 garçons), âgés de deux mois à 21 ans, ont été sélectionnés parmi plusieurs milliers de sujets examinés entre 2000 et 2002 dans l'unité de neuroradiologie du Centre hospitalier national d'ophtalmologie des Quinze-Vingts (Paris). Seuls les enfants présentant un cerveau anatomiquement normal à l'IRM furent inclus dans l'étude. Les enfants âgés de moins de 3 ans représentaient 42% de l'échantillon.

Quatre variables ont été choisies pour le présent travail. Elles ont été relevées sur les coupes parasagittales médianes d'IRM cérébrale de chaque enfant :

- deux dimensions crâniennes d'utilisation courante en anthropologie (les distances glabelle–opisthocrânion (Gl–Op) et basion–vertex (Ba–Ve) ;
- deux variables cérébrales représentatives de deux régions distinctes de l'encéphale (la « surface de l'hémisphère cérébral » (HemS) et la « surface infratentorielle » (InfS).

Ces mesures sont représentées sur la Fig. 1.

Pour chacune des quatre variables, les données transversales recueillies ont été reportées en fonction de l'âge et modélisées par la méthode non paramétrique des *splines* cubiques, méthode qui permet un lissage flexible et modulable des données. Le facteur de lissage a été choisi de façon à minimiser les points d'inflexion mineurs et à ne conserver que les points d'inflexion majeure des courbes. Les courbes de *splines* cubiques ont été calculées séparément chez les filles et chez les garçons.

3. Résultats

Les courbes de *splines* cubiques correspondant aux quatre variables sont représentées sur les Figs. 2–5. Un évident ralentissement de la croissance des dimensions cérébrales et des dimensions crâniennes est visible entre deux et trois ans. Ce ralentissement a lieu un peu plus tôt chez les garçons que chez les filles.

4. Discussion

Plusieurs études antérieures avaient déjà montré que la croissance cérébrale ne s'accroît plus significativement après neuf ou dix ans, voire dès cinq ans. Cependant, aucune étude n'avait jusqu'à présent montré l'existence d'un point d'inflexion de la croissance cérébrale vers deux ans et demi.

Il est d'autre part remarquable que les changements de vitesse de croissance du crâne soient simultanés aux changements de vitesse de croissance des grandes régions encéphaliques. Cette observation présente un grand intérêt pratique pour les anthropologues et paléoanthropologues, puisque, si elle se trouvait confirmée par d'autres études, elle permettrait de tirer des inférences concernant les rythmes de croissance de différentes régions internes du cerveau à partir de mensurations du crâne sec.

1. Introduction

Few studies have been orientated to establish morphological age-related changes in brain during childhood [3] and no study aimed to observe the relationship between these changes and age-related modifications in skull measurements largely used in human palaeontology. The aim of this study is (1) to tackle brain changes in post-natal ontogeny, especially in early childhood, (2) to determine modifications in some skull measurements, and (3) to observe whether brain and skull modify closely.

2. Patients and methods

2.1. Patients

This retrospective study included a sample of 199 children selected among several thousands patients examined during the period 2000–2002 in the Neuroradiology Unit of the 'Centre hospitalier national d'ophtalmologie des Quinze-Vingts', Paris. All selected children had undergone a brain MRI examination for neurological or ophthalmologic reasons, but their brain scans were diagnosed as anatomically normal.

The sample included 72 girls and 127 boys. Children age ranged from 2 postnatal months to 21 years (Table 1). We deliberately biased the sample in favour of young subjects, since they are rare in the literature: 84 (42%) of the patients were under three years old.

The age of each patient was calculated by difference between the date of examination and the date of birth, and reported in completed months. These age values were then transformed in decimal fractions of years, in order to clarify the figures.

2.2. Methods

MRI scans covering the whole brain were performed by one operator on a 1.5-Tesla whole body imager, using a standard quadrature head coil. Images used in this study were acquired in T2-weighed sequences. More details on the technique are available elsewhere [9].

Four measurements, taken on the para-median sagittal section (Fig. 1) were considered for the present study:

- the glabella–opisthocranion distance (Gl–Op);
- the basion–vertex distance (Ba–Ve);
- the 'cerebral hemisphere' surface (hems), as plotted in Fig. 1;
- the 'infratentorial surface' (infs), delimited by the basioccipital bone, the foramen magnum, the occipital bone up to the endinion, the *cerebellum tentorium* up to the *corpus callosum*, and a line from this point to the posterior edge of the *sella turcica*.

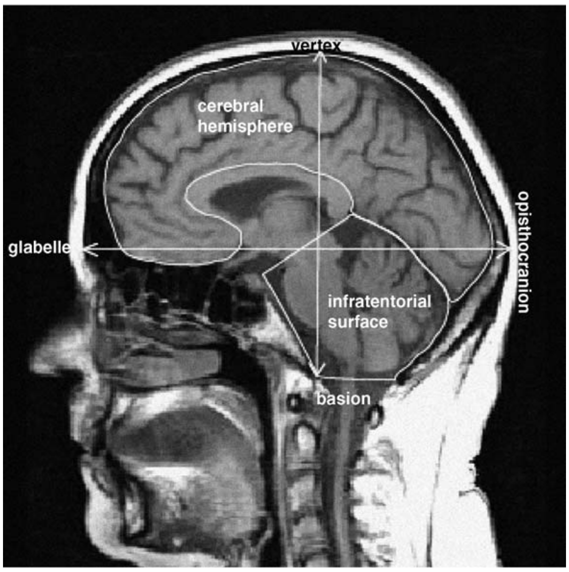

Fig. 1. Illustration of the four variables studied on a parasagittal section of a brain. **1** = Glabella–opisthocranion distance; **2** = basion–vertex distance; **3** = cerebral hemisphere surface; **4** = infratentorial surface.

Fig. 1. Représentation des quatre variables étudiées sur une coupe parasagittale d'encéphale. **1** = Distance glabelle–opisthocrânion ; **2** = distance basion–vertex ; **3** = surface de l'hémisphère cérébral ; **4** = surface infratentorielle.

The two first variables are well-known reliable measurements, usually utilized by anthropologists in studies on hominid evolution and human variability. The two surfaces were also carefully delineated, with clearly identified anatomical landmarks, in order to give accurate evaluation of the growth of the cerebral hemisphere, and of the infratentorial part of the brain.

To fit the data, we chose a non-parametric flexible model: the cubic spline method. In this method, successive third-degree polynomials are sliced together such that the resulting curve is continuous and smooth at the splices. The estimation is done by minimizing an objective function that is a combination of the sum of the squares error and a penalty for curvature integrated over the curve extent [7]. A smoothing parameter λ allows us to choice the degree of flexibility of the resulting curve. In this study, we tested several values of λ, to get an idea of the general pattern of the ex-

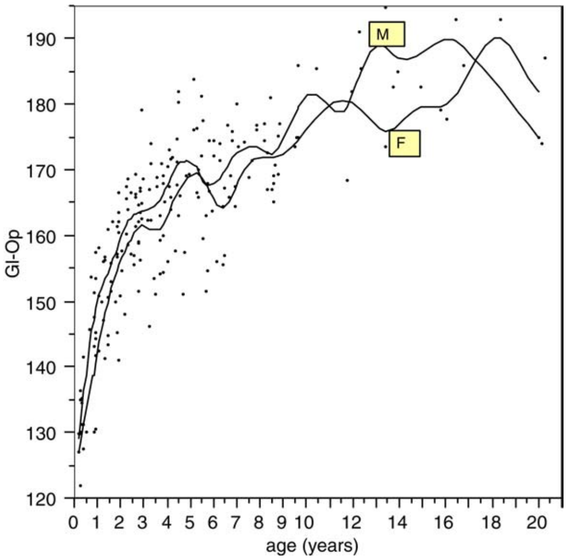

Fig. 2. Glabella–opisthocranion distance (Gl–Op) in relation to age. Spline fits ($\lambda = 0.25$) for females (F) and males (M).

Fig. 2. Distance glabelle–opisthocrânion (Gl–Op) en fonction de l'âge. Lissage par splines cubiques (λ = 0,25) chez les filles (F) et chez les garçons (M).

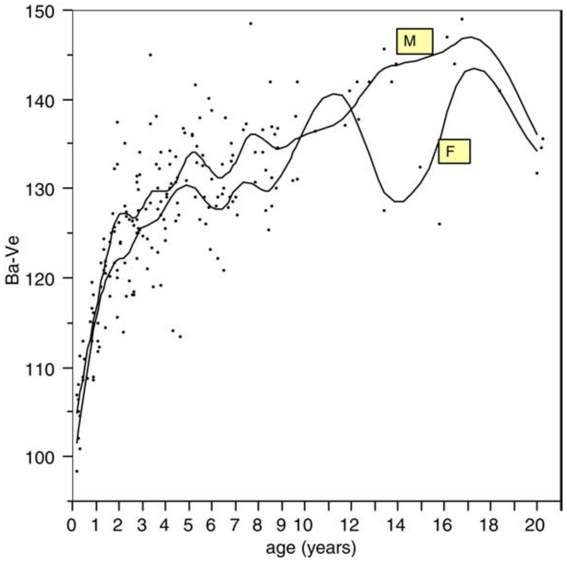

Fig. 3. Basion–vertex distance (Ba–Ve) in relation to age. Spline fits ($\lambda = 0.25$) for females (F) and males (M).

Fig. 3. Distance basion–vertex (Ba–Ve) en fonction de l'âge. Lissage par splines cubiques (λ = 0,25) chez les filles (F) et chez les garçons (M).

pected value of the distribution of y across x, and determine which splices were of interest, i.e. which splices were observable whatever the degree of flexibility of the curve. We found the best readable curves for $\lambda = 0.25$. Spline fits were computed separately for boys and girls.

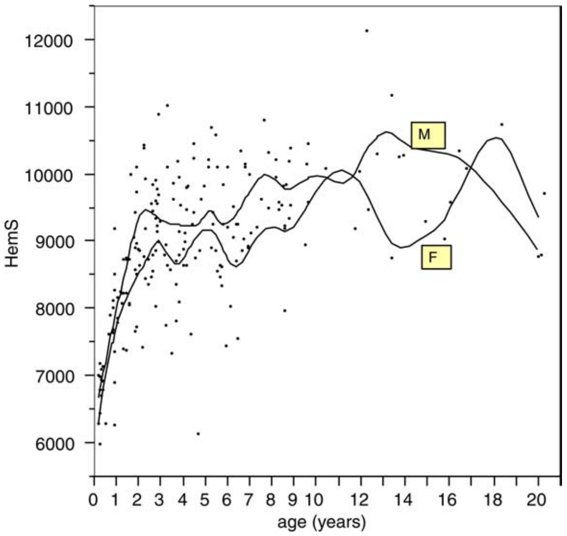

Fig. 4. Cerebral hemisphere surface (HemS) in relation to age. Spline fits ($\lambda = 0.25$) for females (F) and males (M).

Fig. 4. Surface de l'hémisphère cérébral (HemS) en fonction de l'âge. Lissage par splines cubiques (λ = 0,25) chez les filles (F) et chez les garçons (M).

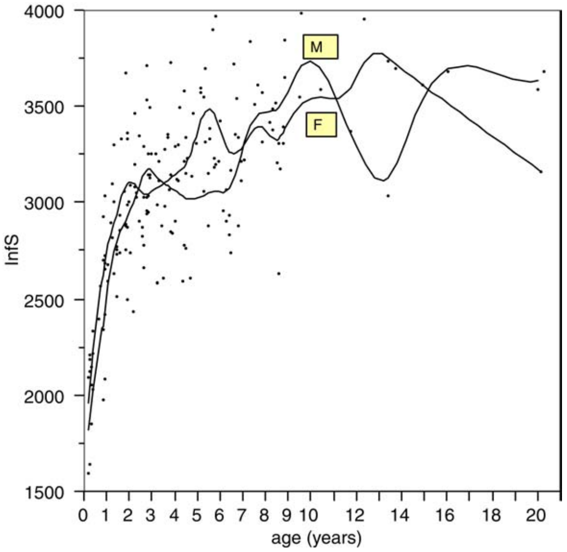

Fig. 5. Infratentorial surface (InfS) in relation to age. Spline fits ($\lambda = 0.25$) for females (F) and males (M).

Fig. 5. Surface infratentorielle (InfS) en fonction de l'âge. Lissage par splines cubiques (λ = 0,25) chez les filles (F) et chez les garçons (M).

3. Results

The smoothing spline fits corresponding to the four variables are presented in Figs. 2–5. Evident slowing down of the growth rates occurs between two and three years, with slight differences of timing between the four variables:

- inflexion point for Gl–Op: 2.5 (boys); 2.8 (girls)
- inflexion point for Ba–Ve: 2.1 (boys); ±1.9 (girls, difficult estimation)
- inflexion point for HemS: 2.3 (boys); 2.8 (girls)
- inflexion point for InfS: 1.9 (boys); 2.8 (girls).

Taking into account the great flexibility of the spline fitting, these values slightly vary with different values of λ. Nevertheless, the point of inflexion between 2 and 3 years is the ultimate to disappear with increasing smoothing (increasing λ), so it may be considered as an important phenomenon from a biological point of view.

A slight time lag is observed between boys and girls, boys having their peak of growth earlier than girls. This gender difference in postnatal brain growth will be studied for more variables in a further study.

A great dispersion of values, mainly in later ages, is noticeable on the figures: this illustrates the very important variability in the growth of brain and skull structures.

4. Discussion

Our results for later growth stages in brain are in agreement with previous studies, the brain structures show a minimum change in volume from 9–10 year to adulthood [1,8]. The high variability found has been already observed previously [4].

Differences in brain growth rate have been reported between prenatal and post-natal periods, prenatal period characterising by a high rate of brain growth. However, several studies mention that this high rate in brain growth would remain until 9–10 years of age, at which volumetric increase achieved 95% of the volume of adult brain [1]. Schaefer et al. [8] failed to observe age-related changes in brain from 0 to age 20, but individuals were grouped in five years classes that probably have masked differences at early age. Head size would increase steady from three months to age 10 [5], but this suggestion would be due to the use of simple regression analysis. It is largely accepted that brain size does not increase significantly after age 5 [3,4]. Increase in brain size and in some brain structures is only reported in those studies that included individuals with age under 5 [2,6], but they suppose a steady growth from 0 to 5.

Our results suggest that growth is not steady during the first 5 years, but there is a high rate of growth until age 2–3 and from there, it becomes low and steady to adolescence. Figures in Courchesne et al. [2] are coherent with those presented in this study. However, they use a binomial regression that unables to identify the inflection point of growth rate.

Brain growth drives the growth of the skull and the volume of the skull reflects the size of the brain [5]. An important point in our study is to show that changes in skull occur simultaneously with modifications in brain. The rate of change in skull distances is high to age 2–3 and becomes low latter. It means that distances between largely used landmarks in skull behave in a similar manner as surface changes in brain. It would suggest that age-related changes in skull could be used to estimate modifications in the brain. If this relationship is confirmed by further studies, since bones are the only element to tackle the evolution of hominid brain, morphological changes in brain evolution could be inferred from the study of the skull in different hominid species.

Our study confirms a change in the growth rate of brain in early childhood and brings evidence that changes in the skull follow in a similar way. The use of a non-parametric flexible model allows us to precise that changes in growth rate in brain and skull occur at age 2–3.

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