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Is our brain changing?

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Abstract

Cerebral and neurocranial asymmetries have been interpreted as a functional character of hominids, linked to the lateralization of brain functions. In this framework we introduce a computer assisted quantitative method to analyse the distribution of fronto-occipital petalial and the jugular foramen asymmetries, using it to study an ancient Italian population. The results are compared with data from modern populations, suggesting that changes in the distribution of occipital petalia and jugular foramen asymmetries may have occurred over about 2000 years.

Keywords: Cranial asymmetries, petalial asymmetries, human evolution, jugular foramen.

Résumé

Les asymétries cérébrales et neurocrâniennes ont été interprétées comme un caractère fonctionnel des hominidés, en liaison avec la latéralisation des fonctions cérébrales. Dans le cadre de ce travail, nous avons introduit une méthode quantitative assistée par ordinateur, afin d'analyser la distribution des asymétries des petalia *fronto-occipitaux et celles des fosses jugulaires. Ce type d'analyse a été appliqué à une population ancienne d'Italie. Les résultats ont été comparés avec les données de populations modernes. Ils suggèrent que des changements dans la distribution des asymétries des* petalia *occipitaux et des fosses jugulaires ont eu lieu il y a quelque 2000 ans.*

Mots-clés : asymétries crâniennes, asymétrie des petalia, évolution humaine, fosse jugulaire.

1. INTRODUCTION

All vertebrates show constant asymmetries in the vascular tree, in the disposition of internal organs and in the length of upper and lower limbs (Robertson, 1997; Dogra & Singh, 1970; Singh, 1970; Pande, 1973; Latimer & Lowrance, 1965; Gannon, 1998; Galaburda, 1978; Braitemberg, 1970; Magara, 1998).

In human beings is well described the lateralization in the use of the hand (handedness), associated with the asymmetry of the dimension of limbs, in favour of the more used one (Dogra & Singh, 1970, Singh, 1970; Latimer & Lowrance, 1965). This last asymmetry is present already in the foetus, when functional lateralization of the hand is not yet developed (Pande & Singh, 1971), in agreement with the hypothesis that asymmetries are genetically established. For this reason, a lot of attention is devoted to the genes responsible for left-right asymmetries, such as Shh, Nodal, Pitx 2, Dynein, activin B, cAct RII, cSnR (Robertson, 1997; Kaletta *et al.*, 1997; Supp *et al.*, 1997; Isaac *et al.*, 1997; Ryan *et al.*, 1998).

At the level of the nervous system, functional and morphological asymmetries of the hemispheres are known, such as the *planum temporale* asymmetry, correlated with the lateralization of language areas (Kandel & Schwartz, 1985). Similarly, the asymmetry of the surface of the central sulcus, correlated to the prevailing use of one side of the body (White *et al.*, 1994), and the asymmetries of auditory areas (Galaburda *et al.*, 1978; Magara *et al.*, 1998) have been depicted. These asymmetries are expressed in several mammals (Gannon *et al.*, 1998; Galaburda *et al.*, 1978; Holloway, 1982), although some are typical of only certain species (Braitenberg & Kemali, 1970; Magara *et al.*, 1998). It is likely that cerebral asymmetries appear early in life, being present in the foetus (Galaburda *et al.*, 1978).

Le May (1976), using CT scans, described a morphological asymmetry of the brain consisting in left occipital and right frontal lobes being wider than the contralateral ones. Since cerebral lobes produce an indentation of the inner and outer aspects of the neurocranium (petalia), a similar neurocranial asymmetry is produced (Galaburda *et al.*, 1978). These are present also in hominids. For instance, Le May and Culebras (1972) found that the impressions of the Sylvian Sulcus in the La Chapelle-aux-Saints skull appear to show a long horizontal placed left sulcus, and a shorter, upwardly curved right sulcus, as in the brain of most modern right-handed human. A similar pattern is suggested by the endocast of Peking man (Le May & Culebras, 1972). Moreover, the cast of Pithecanthropus I shows right occipital petalia, whereas that of Pithecanthropus II shows the more common pattern of left occipital petalia found in modern man (McGregor, 1925).

In this study we present results of the analysis of skull asymmetries in an ancient

Italian population. To this aim, we applied a new quantitative technique to analyse cranial asymmetries and studied the correlation of petalial asymmetries with asymmetries of the jugular foramen. Since the asymmetry of the two jugular foramen in this sample differ from that reported in modern men, these data suggest that the distribution of cerebral vessels asymmetry changed in a relatively short period of time, associated with a change in the distribution of petalial asymmetries in the population. Similar changes in the blood vessel tree have been described in other body regions and in very short range of time (Henneberg & George, 1995).

2. MATERIAL AND METHODS

2.1. Skulls

The observations have been carried out on 40 skulls of adult subjects preserved in the Museum of Anatomy of the Second University of Naples. These derive from two sources: 1) necropolis of Pontecagnano (Naples); 2) necropolis of Cuma and Pompei (Naples), and date around the I century AC. One skull has been excluded from the study because it presented a large lesion at the occipital bone, possibly due to surgical intervention. Moreover, skulls damaged at the external auditory meatus have been excluded because they could not be properly fixed in the stereological apparatus.

2.2. Photographic method

The measurement of the asymmetry of an object needs the definition of a reference plane, that we indicate as symmetry plane. Many studies, in fact, face the problem of facial asymmetries (a minor number focus on neurocranial asymmetries: Kadanoff, 1978; Marmary, 1979; Lang, 1981; Grayson, 1985; Gozil, 1996). In particular, a median line can be used to study asymmetries (Berger, 1964; Marmary, 1979; Gozil, 1996).

The definition of a median line is relatively easy in the skull, since reference points are available for its localization. Therefore, we defined the symmetry plane as that passing through inion, lambda, bregma and metopic suture.

These reference points represent well defined and functionally significant regions (see Richtsmeier, 1995). It has to be noted that this plane is perpendicular with good approximation to the axis assing through the external auditory meatus (horizontal axis), which has been therefore chosen as the fixed axis of rotation of the skull (fig. 1).

It is therefore possible to compare the two halves of the frontal and occipital bones, divided by the symmetry plane, and thus establish the presence of a petalial asymmetry. In fact, if two surfaces X and Y, symmetrical in respect to a reference (symmetry) plane, are projected on a plane perpendicular to the symmetry plane, then the projected surfaces X′ and Y′ will also be symmetrical in respect to the reference plane. Similarly, projecting skull surfaces on a plane (where a flat photosensible device represents in fact a projecting plane) perpendicular to the symmetry plane (each plane parallel to the horizontal axis AB is perpendicular to the

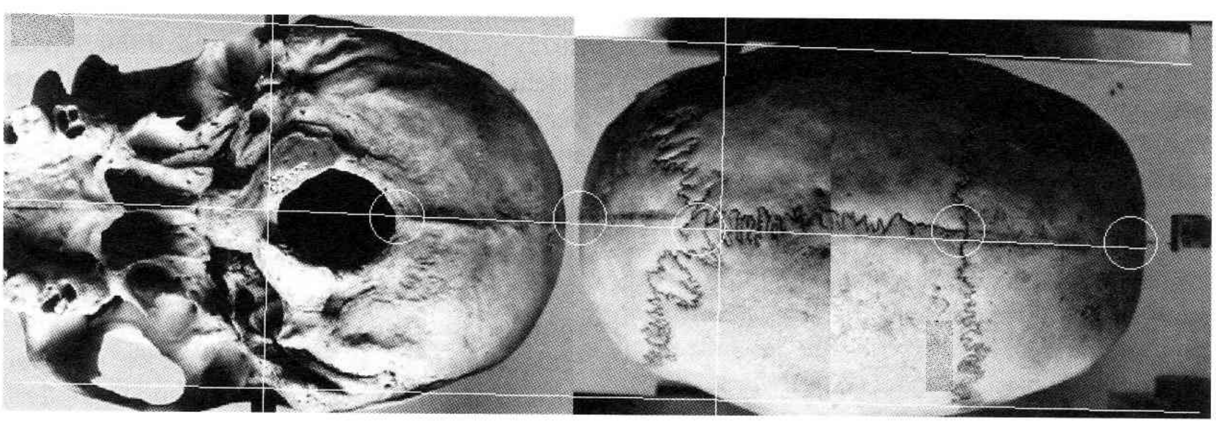

Fig. 1 — The horizontal axis is perpendicular to the symmetry plane. A skull has been fixed in a stereotaxic apparatus and rotated in three positions as described in the text. A line passing through the symmetry points (basion, inion, lambda, bregma, metopic suture) is drawn together with the horizontal axis passing through the auditory meatus.

symmetry plane PS), the projected surfaces will be symmetrical if the skull areas were symmetrical. It is therefore sufficient to have a camera parallel to AB and rotate the skull around AB in order to have the skull projected on a plane perpendicular to the symmetry plane.

This has been obtained with a stereotaxic apparatus, maintaining the skull by tapered bars inserted into each external auditory meatus (fig. 1), and mounting the photocamera parallel to the horizontal axis. Then the skull was rotated in order to take a picture of the frontal and occipital bones and the jugular foramen. The reference points of the skull then allow drawing the position of the symmetry plane and divided the frontal and occipital bones in two halves.

To this aim we used an *Olympus Electronic Cl110* digital camera (box size 512 × 512). Images were captured from a fixed distance, maintaining the camera parallel to the horizontal plane as above described, and the skull in the stereotaxic apparatus imaged in three positions: **P1)** the skull was rotated in order to show the esocranial aspect of the base of the skull; **P2)** the skull was horizontally placed and inclined in order to have the inion (symmetry point) on the posterior edge of the cranial profile; **P3)** the skull was horizontally placed and inclined in order to have the supraorbital ridges not visible on the anterior cranial profile (thus avoiding the interference of frontal sinuses). In this last position a needle pointed to the metopic suture (symmetry point), which was below the supraorbital ridges and otherwise not visible in the picture (fig. 2). The symmetry points were: inion, lambda, bregma, metopic suture. The horizontal axis passed through the two external auditory meatus.

Digital images have been analysed with an image analysis software *ImageJ*[1]. Three different observers have measured the following regions: in P1 the area of each jugular foramen, in P2 the area of each half of the frontal bone, in P3 the area of each half of the occipital bone (fig. 2). The frontal bone has been divided in two halves by a line from the bregma to the metopic suture, the occipital bone by a line from lambda to inion (fig. 2).

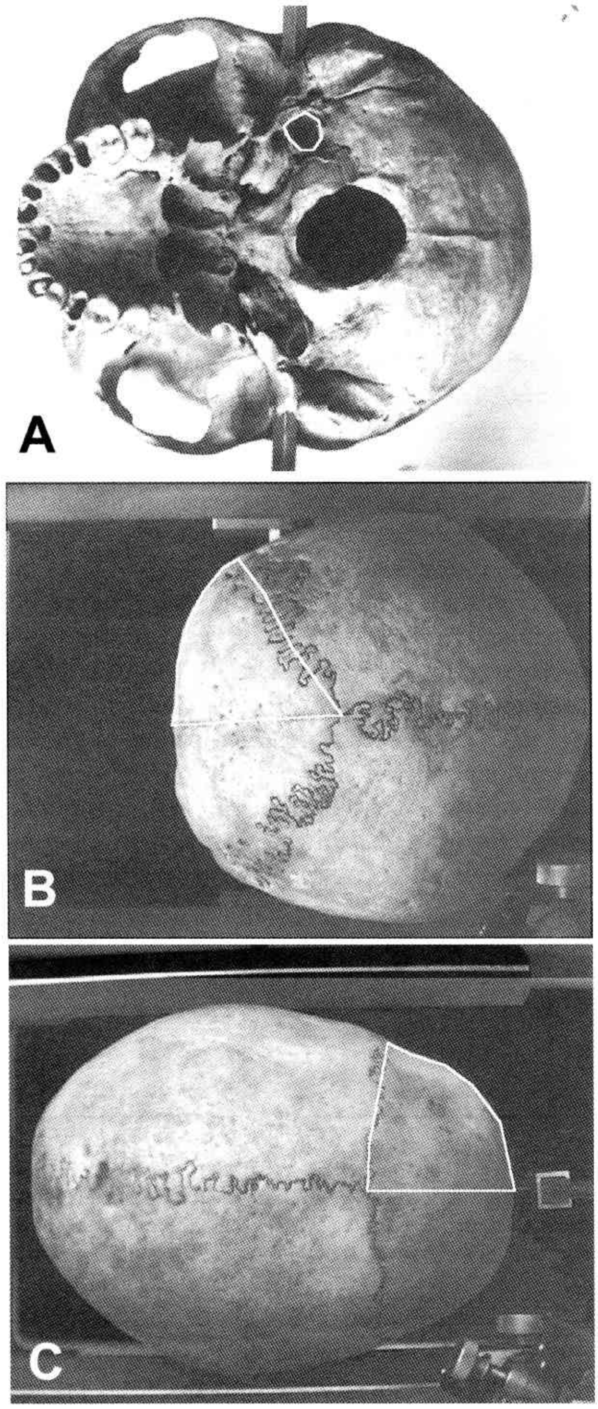

Fig. 2 — Delimitation of the areas for analysis of skull asymmetries. A. basal aspect of the skull in position P1 (see text), with one of the jugular foramen delimited; B. posterior aspect of the neurocranium in position P2. One half of the occipital bone has been delimited; C. upper aspect of the skull in position P3, with half frontal bone delimited; note the needle indicating the position of the metopic suture.

2.3. Statistical analysis

The contingency tables have been realised by considering as asymmetrical the specular surfaces that differed by 4% over the total area.

[1] http://rsb.info.nih.gov/ij/

The incidence of asymmetries in the sample of ancient skulls was compared to that in modern skulls using data from Rüdinger, Meckel, Sperino (1884), Pitzorno (1892, 1894), Henneberg (1992), Galaburda (1978).

3. Results

Our approach to the study of neurocranial asymmetry is based on the surface measurements. To this aim we defined the symmetry plane passing through inion, lambda, bregma and metopic suture. This plane divides the skull in two halves and is perpendicular to an axis passing through the two external auditory meatus (horizontal axis, fig. 1).

The photographic method is highly reproducible. The correlation coefficient of the asymmetry index (as described in Magara, 1998) between observers was, in fact, high ($r = 0.80$, $p < 0.05$). The frequency distribution of cranial asymmetries in 40 ancient skulls is reported in table 1. The asymmetry of the jugular foramen was present in 95% of the skulls, with a higher number of subjects, with wider right jugular foramen.

	L > R	R > L	L = R
Jugular foramen	32%	63%	5%
Frontal petalia	14%	51%	35%
Occipital petalia	31%	38%	31%

Table 1 — Distribution of asymmetries in one ancient Italian population (n = 40). One side was considered greater than the other when the difference between the two was greater than 4% over the entire surface.

A great number of the skulls did not show any neurocranial (frontal, occipital) asymmetry (35% and 31% for frontal and occipital petalia respectively). The remaining skulls showed a greater incidence of left frontal petalial asymmetry (51%). There was no side preference for the occipital petalial asymmetry (31% with larger left occipital petalia, 38% with larger right occipital petalia).

4. Discussion

Morphometric data can be collected by simple inspection-judgment (so-called semi-quantitative methods) or measuring angles or lengths between anatomical landmarks. Whenever possible, angular measurements provide better information than length measurements, since this allow one to focus on the relationship between components (Gözil, 1996). Surface measurements are less sensible to displacements of single anatomical landmarks, since they are based on the definition of a contour. The computer assisted analysis, joined to classical anthropometrics measurements can give quantitative, highly reproducible results, without expensive instrumentations. The use of multiple anatomical landmarks and 3D reconstruction appears to be the natural evolution of this technique, although it requires more expensive tools (see Aldreidge, 2002; Richtsmeier, 1995).

Our data are in agreement with previous observations that when the terminal part of the superior sagittal sinus (SSS) deviates on the right, draining into the right transverse sinus, the right sigmoidal sinus is larger, and the opposite happens when the SSS deviates on the left (Sperino, 1884; Henneberg & Symons, 1992).

The direction of drainage of the SSS in the right or left transverse sinus (TS) has been previously correlated to the larger dimension of the contralateral occipital lobe (Henneberg & Symons, 1992). Moreover, a second observation correlates the cerebral asymmetries to a "developmental torque": the orbital rim and zygomatic arch are more developed on the right side, in contrast to the expansion of the cranial size, thus giving the appearance of a counter clock twist of the neurocranium (Le May, 1976; Lang, 1981; Hauser, 1989). This suggests that cerebral asymmetries result from a secondary effect of the asymmetrical neurocranial development.

Moreover, the influences of other factors such as hormonal changes during puberty should be taken into account when considering neurocranial asymmetries. For example, the asymmetry of the frontal sinus is very frequent and might interfere with the evaluation of the frontal part of the neurocranium. In our study this variable was controlled by inclining the skull in order to have the supraorbital ridges not visible on the anterior cranial profile.

It is interesting to compare the distribution of cranial asymmetries in a population who lived in Campania 2000 years ago with measurements taken on modern skulls (Table 2). From the qualitative point of view, the distributions in the ancient population (this study) and in modern

	Jugular foramen (%)			Frontal petalia (%)			Occipital petalia (%)		
	L > R	R > L	L = R	L > R	R > L	L = R	L > R	R > L	L = R
Sperino (1884)	15	53	32						
Meckel	19	63	18						
Rüdinger	25	67	8						
Pitzorno (1892)	32	63	5	22	31	47	30	38	32
Galaburda *et al.* (1978)				11	64	25	51	27	22
Henneberg *et al.* (1992)	10	76	14				66	31	3
Viggiano *et al.*	32	63	5	14	51	35	31	38	31

Table 2 — Distribution of asymmetries in modern and ancient populations. Data are expressed as percentage of cases from the total number of cases in the study.

populations are similar: larger right jugular foramen and frontal petalia compared to the controlateral side. In particular, the distribution of frontal petalia asymmetries matched that observed in modern populations (Table 2), and the distribution of occipital petalia was very close to the results of Sperino (1884), Meckel, Rüdinger, Pitzorno (1892). This distribution was comparable with that reported by Galaburda in 1978, but quantitatively different from Henneberg (1992). This must be ascribed to the low number of cases without asymmetric petalia reported by Henneberg (1992).

These differences could be due to the different methodology used in the studies, in particular regarding to the frontal and occipital petalial asymmetries. However, preliminary data suggest that the method here proposed gives results comparable when using other methods, although this one is more precise and reproducible. If this is confirmed, the differences found should rather reflect racial characters or a secular trend in the occurrence of jugular foramen asymmetries. Similar occurrences of changes in anatomical properties (such as height or anatomical variation in blood vessels) have been previously reported for other populations (Henneberg & George, 1995). It is therefore possible that in a period of time as long as two thousand years a change in the distribution of cerebral and vascular asymmetries is present.

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