Brief Communication: The Size of the Human Frontal Sinuses in Adults Presenting Complete Persistence of the Metopic Suture

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KEY WORDS skull; frontal bone; osteology; variants; development

ABSTRACT The notion of absence of the frontal sinuses in human individuals presenting a persistence of the metopic suture is considered as classical in many treatises of reference; however, precise studies are very rare and even controversial. The purpose of this study was thus to provide original data to confirm or refute this classical affirmation with the perspective of some original insights into biological significance of the frontal sinuses and the factors influencing their exceptional polymorphism. The material consisted of 143 dry skulls of adult individuals (European *Homo sapiens*), distributed in two groups: 80 skulls presenting a complete frontal closure with total disappearance of the metopic suture, and 63 skulls presenting a complete persistence of the metopic suture. Each skull was radiographed in oblique projection using the occipitomental view. A simple morphological quantification of the sinus size was defined with four categories: (1) aplasia, (2) hypoplasia, (3) medium size, (4) hyperplasia. Statistically significant difference in frontal sinusal size was found between both groups of skulls. Absent and small sinuses were considerably more frequent in skulls with persistence of the metopic suture (57.9 vs. 11.9%): small frontal sinuses (hypoplasia) were much more frequent (50.8 vs. 9.4%), although the frequency of absence of frontal sinuses (aplasia) was only slightly higher (7.1 vs. 2.5%). Am J Phys Anthropol 154:621–627, 2014.

The frontal sinus (*sinus frontalis*), one of the paranasal sinuses, is a paired (left and right) pneumatic cavity principally located in the squamous part of the frontal bone between the outer and inner tables; it opens into the lateral wall of the corresponding nasal cavity by the ethmoidal infundibulum, a small aperture situated at the anterior part of the middle meatus, i.e., between the middle and inferior conchae. The biological and functional significance of the frontal sinuses as well as factors influencing their presence, development and morphology remain speculative and many factors affect their size and shape (Hauser and De Stefano, 1989; Blaney, 1990; Quatrehomme et al., 1996; Nambiar et al., 1999; Christensen, 2005; Ponde et al., 2008; Tatlisumak et al., 2008; Tang et al., 2009; David and Saxena, 2010; Cakur et al., 2011; Patil et al., 2012; Goyal et al., 2013; Jain, 2013). Among the explanations given in literature, the frontal sinuses may lighten the skull, occupy spaces not otherwise functionally utilized, add resonance to the voice, maintain and regularize the temperature of the orbital structures or even of the brain. The human frontal sinuses are absent or rudimentary at birth; growth begins around the end of the first year and the sinuses reach full size after puberty, and sometimes continues to the age of 24 years (Augier, 1931; Libersa and Faber, 1958; Porbonikova, 1974; Szilvassy, 1981, 1982; Brown et al., 1984; Scheuer and Black, 2000). The absence and smallness of the frontal sinuses in adults could thus be interpreted as a juvenile pattern, as already noted by Augier (1931), who qualified the absence of frontal sinuses as "sinusal infantilism". As they are deep structures, the anatomical study of the frontal sinuses was difficult for a long time: the frontal bone needed to be sawn or drilled until X-rays were discovered by Wilhelm Röntgen in 1895. Radiological approaches have demonstrated that size and shape of the frontal sinuses are highly variable; moreover, the left and right sinuses are rarely symmetrical. The existence of a sexual dimorphism mentioned by some authors, in particular larger frontal sinuses in males than females, remains controversial (Szilvassy, 1981, 1982; Yoshino et al., 1987; Harris et al., 1987a, b; Ponde et al., 2008; Goyal et al., 2013). The geographical origin of the individuals also influences the morphology of the frontal sinuses according to studies conducted on identified and precise populations (Kim, 1962; Hanson and Owsley, 1980; Ikeda, 1982; Harris et al., 1987b; Aydinlioglu et al., 2003; Cakur et al., 2011). These variations and the almost unique morphology of the frontal sinuses for each individual are useful for personal identification in forensic medicine (Schuller, 1921; Yoshino et al., 1987; Harris et al., 1987a, b; Kullman et al., 1990; Quatrehomme et al., 1996; Nambiar et al., 1999; Cameriere et al., 2008; David and Saxena, 2010; Patil et al., 2012). A strong genetic determination has been observed in some family samples, particularly in cases of absence (Blandino and Longo, 1956; Caggioli, 1961; Holmes and Walton, 1969), even if differences have been reported in the frontal sinuses of monozygotic twins (Asherson, 1963); several

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congenital syndromes have been identified involving the morphology of the frontal sinuses and their absence (Mocellin, 1968; Holmes and Walton, 1969; Reyes de la Rocha et al., 1987). Various intracranial constraints seem also to modify the sinusal morphology (Auque et al., 1987). The influence of climatic conditions and adaptation to a cold environment have been suggested from the high frequency of absence of the frontal sinuses observed in Eskimos (30.0–40.7%); however, this could not be clearly established, due to the multifactorial control of the sinusal development (Koertvelyessy, 1972; Hanson and Owsley, 1980).

The metopic suture (*sutura metopica*; from the Greek *meta*: in the middle, between, and *opa*: face, eyes, literally "in the middle of the face" or "between the eyes", and then *metopon*: forehead) is a normal and constant feature in fetuses and newborns. It separates the left and right centers of ossification of the frontal bone (hence the ancient synonyms of "midfrontal suture" or "*sutura mediofrontalis*"). This suture is situated almost exactly on the median line; it extends from the nasion, anteriorly and inferiorly, to the anterior angle of the bregma (intersection of the sagittal and coronal sutures, corresponding to the anterior fontanelle in newborns), posteriorly and superiorly. The metopic suture is in continuity posteriorly with the sagittal suture, separating the left and right parietal bones, and anteriorly with the nasal suture, separating the left and right nasal bones. This suture usually disappears at the end of the first year or in the beginning of the second year of life, and in almost all cases before the fourth year (Augier, 1931; Torgersen, 1950, 1951; Manzanares et al., 1988; Scheuer and Black, 2000; Vu et al., 2001; Bajwa et al., 2013).

The complete persistence of the metopic suture in adult individuals (*sutura metopica persistens*; Terminologia anatomica, 1998), often called "metopism", is one of the most spectacular nonmetrical variants of the human skull. As it is spontaneously evident in dried skulls, it has been identified and described since ancient times (Vesalius, 1543; Colombo, 1559). It separates the frontal bone into two almost symmetrical halves and the sagittal and metopic sutures form with the coronal suture a characteristic cross (ancient notions of "crosshead" or "*caput cruciatum*"; Welcker, 1862). The frequency of persistence of the metopic suture in adult individuals varies between 0.0 and 13.0% and is influenced by geographical origin according to many studies conducted on precise and identified populations (Anoutchine, 1880; Topinard, 1885; Le Double, 1903; Limson, 1924; Berry and Berry, 1967; Agarwal et al., 1979; Ajmani et al., 1983; Hauser and De Stefano, 1989; Hanihara and Ishida, 2001; Baaten et al., 2003). This persistence corresponds to a hypostotic variant and can be interpreted as the retention by adults of a fetal and juvenile trait (Le Double, 1903; Augier, 1931; Hauser and De Stefano, 1989; Scheuer and Black, 2000; Hanihara and Ishida, 2001).

The notion of absence of the frontal sinuses in individuals presenting a persistence of the metopic suture is considered as classical in many treatises of reference (Schmidt and Freyschmidt, 1989). The precise origin of this affirmation remains unknown but is particularly ancient. Bauhin (1605) already noted: "This sinus is not observed in children until one year, in those whose face is low and pug-nosed, and in those in whom the forehead is divided" (Book III chapter VI, p. 526; translated from Latin). Bartholin (1651) similarly wrote: "At the top of the nose above the eyebrows are situated cavities or sinuses of large expanse (however nonexistent 1. in little girls until one year; 2. in those whose face is low and pug-nosed; 3. in those for who the forehead is divided)" (Opuscule IV chapter VI, p. 485; translated from Latin). This affirmation remains quite unchanged through the centuries, for example Le Double (1903), in his treatise of reference on the variants of the cranial bones, noted the following concerning the absence of the frontal sinus: "This default of conformation seems to be more common in metopic individuals" (translated from French). However, detailed and precise studies concerning this notion are scarce and this classical affirmation remains to be demonstrated. One of the most ancient statistical series published in the literature is that of Welcker (1862), who studied the frontal sinuses by sawing the bone in 20 dried skulls and found four cases of bilateral and five cases of unilateral absence of the frontal sinus (i.e. in total 13/40 cases of absence or 32.5%). Further studies are very rare and even controversial, most authors concluding that contrarily to the classical affirmation in the literature no relationship exists between the absence of the frontal sinuses and the metopic suture (Rochlin and Rubaschewa, 1934; Monteiro and Ramos, 1953; Hiltemann, 1954; Monteiro et al., 1957; Marciniak and Nizankowski, 1959; Baaten et al., 2003). The purpose of this study was thus to provide new and detailed data in order to confirm or refute this classical affirmation on the possible links between these two cranial nonmetrical traits.

MATERIALS AND METHODS

Osteological material

The material used in this study consisted of 143 dry skulls of adult individuals (European *Homo sapiens*), distributed in two groups.

Skulls of reference with frontal closure. In total, 80 dried skulls presenting a complete frontal closure with total disappearance of the metopic suture, and exempt from pathological changes, were studied. They came from adult individuals whose sex, age, and origin were precisely known: 40 males and 40 females, aged from 25 to 69 years, and from the Upper Rhine region (Alsace and Baden-Wurtemberg, Western Europe). These skulls belong to the anthropological collections of the Institute of Normal Anatomy, Faculty of Medicine, Strasbourg, France (Le Minor et al., 2009).

Skulls presenting a metopic suture. In total, 63 dried skulls presenting a complete persistence of the metopic suture (i.e. from nasion to bregma), and exempt from pathological changes, were studied. No individual biographical data were available for these skulls. All of them showed complete eruption of the permanent dentition and could therefore be considered as coming from adult individuals. These skulls belong to the osteological collections of the previously mentioned Institute of Normal Anatomy (Strasbourg) and to the Anatomical Museum Delmas-Orfila-Rouvière, Department of Anatomy, Saints-Pères University Center, Paris, France (Delmas et al., 1995).

Radiographical method

Each of the 143 skulls studied was placed in the same reference position using the classical orbitomeatal plane

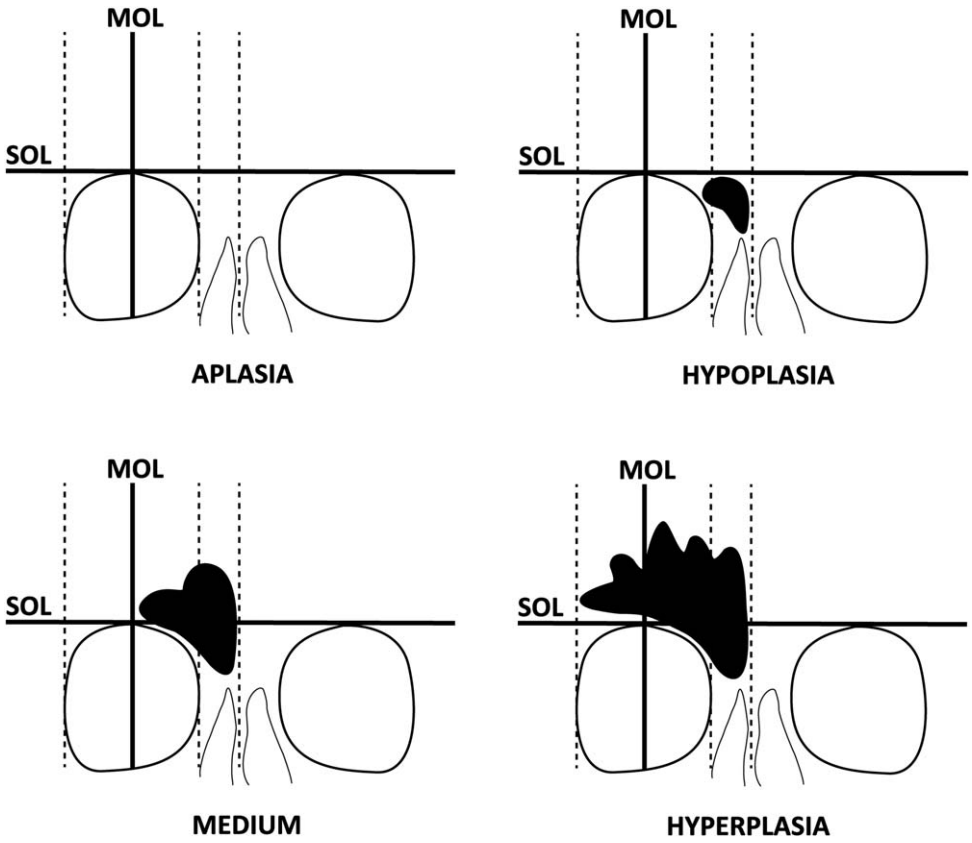

Fig. 1. Morphological quantification of the size of the right frontal sinus used in the present study (identical symmetrical approach for the left frontal sinus). SOL: supraorbital line. MOL: midorbital line. Dotlines: midsagittal line; medial orbital line (vertical line passing through the most medial orbital point); and lateral orbital line (vertical line passing through the most lateral orbital point).

(OM). The skull was maintained with a cephalostat and radiographed in oblique projection using the occipitomental view (Blondeau's or Waters' view: OM-50°) which is classically used for the clinical study of the frontal sinuses. The radiographs were acquired in the Department of Radiology of the Strasbourg University Hospital.

Morphological quantification of the frontal sinus size

The left and right frontal sinuses were analysed for each of the 143 skulls (i.e. 286 sinuses in total). A simple morphological quantification of the sinus size (left or right) was defined using two facial reference lines (Schmittbuhl and Le Minor, 1998; Schmittbuhl et al., 1999):

1. Supraorbital line (SOL): horizontal line tangent to the superior margin of both orbits and passing through the upper point of the left orbital opening and the upper point of the right orbital opening.
2. Midorbital line (MOL): vertical line, drawn for each orbit (left or right), parallel to the midsagittal line, and passing through the middle of the orbital breadth defined between the lateral orbital line (vertical line passing through the most lateral orbital point) and the medial orbital line (vertical line passing through the most medial orbital point).

The sinusal size was classified into four categories: (1) aplasia: absence of frontal pneumatization, (2) hypoplasia: frontal sinus limited to the area under the supraorbital line, (3) medium size: frontal sinus limited to the area medial to the midorbital line, and (4) hyperplasia: frontal sinus extending in the area lateral to the midorbital line (Fig. 1).

Statistical analysis

The occurrences observed for the four size categories in the two groups of skulls were compared using χ^2 test (value of $P < 0.05$ retained as indicating statistically significant difference) in Microsoft Excel (2010).

RESULTS

Detailed results regarding the size categories of the frontal sinuses observed in the 80 skulls of reference presenting frontal closure (i.e., 160 sinuses) and in the 63 skulls with persistence of the metopic suture (i.e., 126 sinuses) are presented in Table 1. No significant sexual dimorphism was observed in the skulls presenting frontal closure, and thus males and females were grouped allowing clearer comparison with the skulls with metopic suture (Fig. 2A).

Statistically significant difference in frontal sinusal size was found between both groups of skulls (χ^2 test: $P < 0.0001$). Small frontal sinuses (hypoplasia) were much more frequent in skulls with persistence of the metopic suture (50.8 vs. 9.4%), though the frequency of

TABLE 1. Size categories of the frontal sinuses (left + right) in skulls presenting frontal closure and in skulls with persistence of the metopic suture observed in the present series

Frontal sinus size	Frontal closure			Metopic suture
	Males	Females	Total	
Aplasia	1.2% (1)	3.8% (3)	2.5% (4)	7.1% (9)
Hypoplasia	5.0% (4)	13.7% (11)	9.4% (15)	50.8% (64)
Medium	77.5% (62)	75.0% (60)	76.2% (122)	40.5% (51)
Hyperplasia	16.3% (13)	7.5% (6)	11.9% (19)	1.6% (2)
Total	100.0% (80)	100.0% (80)	100.0% (160)	100.0% (126)

Within brackets: number of cases for each category.

absence of frontal sinuses (aplasia) was only slightly higher in skulls with metopic suture (7.1 vs. 2.5%). The medium size was the predominant category for skulls presenting frontal closure (76.2%), and hypoplasia for skulls with metopic suture (50.8%). Great frontal sinuses (hyperplasia) were rare in skulls with metopic suture (1.6 vs. 11.9%). On the whole, absent and small sinuses were considerably more frequent in skulls with metopic suture (57.9 vs. 11.9%; Fig. 2B).

Left and right occurrences in size categories of the frontal sinuses are given in Tables 2 and 3. Symmetrical size dispositions were largely predominant with similar frequencies in skulls presenting frontal closure and in skulls with metopic suture (68/80 i.e., 85.0%, and 55/63 i.e., 87.3%, respectively). In asymmetrical size dispositions, the greatest sinus was observed with similar frequencies for both the left and right sides (6/6 in skulls presenting frontal closure, and 3/5 in skulls with metopic suture). The absence of the frontal sinus in the 80 skulls presenting frontal closure was bilateral in one case (1.3%) and unilateral in two cases (2.5%); in the 63 skulls with metopic suture it was bilateral in three cases (4.8%) and unilateral in three cases (4.8%).

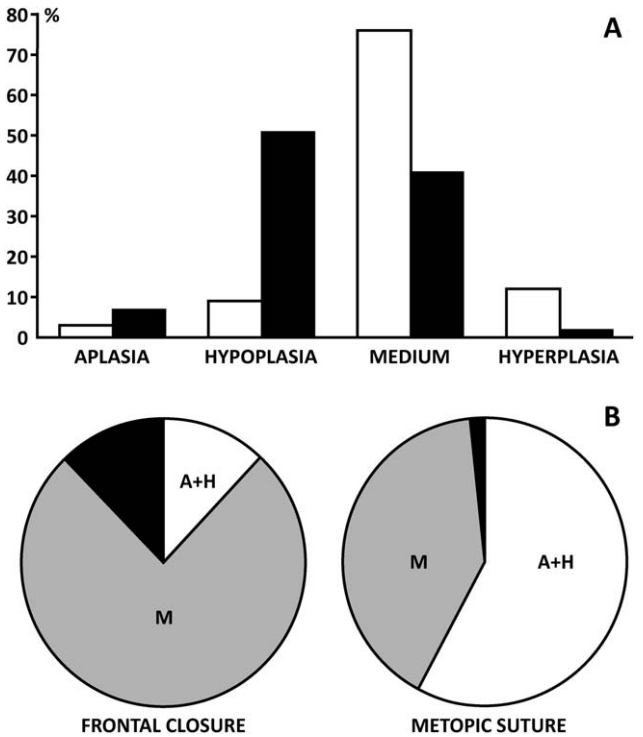

Fig. 2. Size categories of the frontal sinuses (left and right) in the skulls presenting frontal closure (total 80, i.e. 160 sinuses) and in the skulls with persistence of the metopic suture (total 63, i.e. 126 sinuses) observed in the present series. **A:** Bar chart of the four size categories. White bars: frontal closure. Black bars: persistence of the metopic suture. **B:** Pie charts grouping absent and small sinuses (i.e., three size categories). White area: aplasia and hypoplasia (A + H). Grey area: medium size (M). Black area: hyperplasia.

DISCUSSION

Methodological aspects

The frontal sinuses in individuals presenting a persistence of the metopic suture has only been studied in the case of their absence (aplasia or agenesis) (Welcker, 1862; Rochlin and Rubaschewa, 1934; Monteiro and Ramos, 1953; Hiltemann, 1954; Monteiro et al., 1957; Marciniak and Nizankowski, 1959; Baaten et al., 2003). The complete absence of the frontal sinuses is indeed an astonishing disposition since no physiological or clinical consequence is observed; the question of the functional interest and significance of the sinusal presence remains unsolved (Blandino and Longo, 1956; Caggioli, 1961; Nowak and Mehls, 1977; Shapiro and Schorr, 1980; Schmidt and Freyschmidt, 1989; Blaney, 1990; Aydinlioglu et al., 2003; Cakur et al., 2011; Jain, 2013). It is a nonnegligible methodological advantage to focus the study on two binary nonmetrical variants: frontal sinuses (present/absent) and metopic suture (present/absent).

Taking into account more information than the simple binary presence/absence of the frontal sinuses is interesting, as demonstrated by the significant results of the present study. The morphological quantification of the sinus size into four simple, quick, and reproducible categories (aplasia, hypoplasia, medium size, and hyperplasia; Fig. 1) presents the advantage of being easily applied by both visual examination and computer-assisted image analysis. The two facial reference lines are classical and had been used in previous studies (Schmittbuhl and Le Minor, 1998; Schmittbuhl et al., 1999); the supraorbital line (SOL) has also already been used for the morphological quantification of the sinusal size (Libersa and Faber, 1958).

The criteria used for the definition of the size categories are of course determining. Libersa and Faber (1958) considered, as in the present study, that small sinuses (hypoplasia) were situated under the supraorbital line; similarly, Rouvière and Delmas (1978) defined "small sinuses" as "those whose cavity has no extension in the vertical part of the frontal bone and are only limited to the superomedial angle of the orbital cavity" (translated from French). Szilvassy (1981, 1982) considered that a sinusal area of less than 0.8 cm^2 was equivalent to frontal sinus absence which resulted in an increase in the frequency of occurrence of absence. For this reason, it is instructive and possibly more reproducible to define and analyse a size category grouping absent and small sinuses (Fig. 2B). At the other extreme of the range of variation, great frontal sinuses have rarely been studied specifically (Brown et al., 1984; Urken et al., 1987a, b; Schmidt and Freyschmidt, 1989).

The study of the size of the frontal sinuses could also be performed using precise quantification of their area

TABLE 2. Skulls presenting frontal closure

Frontal sinus size (frontal closure)	Aplasia L	Hypoplasia L	Medium L	Hyperplasia L	Total
Aplasia R	1	1	0	0	2
Hypoplasia R	1	5	2	0	8
Medium size R	0	1	56[a]	3	60
Hyperplasia R	0	0	4	6	10
Total	2	7	62	9	80

Left and right occurrences of size categories of the frontal sinuses observed in the present series.
L: Left; R: Right.
[a] Predominant category.

TABLE 3. Skulls with persistence of the metopic suture

Frontal sinus size (metopic suture)	Aplasia L	Hypoplasia L	Medium L	Hyperplasia L	Total
Aplasia R	3	2	0	0	5
Hypoplasia R	1	29[a]	2	0	32
Medium R	0	1	23	1	25
Hyperplasia R	0	0	1	0	1
Total	4	32	26	1	63

Left and right occurrences of size categories of the frontal sinuses observed in the present series.
L: Left. R: Right.
[a] Predominant category.

TABLE 4. Aplasia (or absence) of the frontal sinuses in adult individuals

Study	*n*	Geographical origin of individuals	Aplasia	
			Unilateral	Bilateral
Çakur et al. (2011)	410	Turkish	1.2%	0.7%
Present study	80	Upper Rhine	2.5%	1.3%
Kim (1962)	500	Korean	4.6%	1.6%
Goyal et al. (2013)	100	Indian	10.0%	2.0%
Jain (2013)	238	Indian	0.8%	2.5%
Nowak and Mehls (1977)	2,820	German	7.4%	3.6%
Aydinlioglu et al. (2003)	1,200	Turkish	4.8%	3.8%
Boege (1902)	203	German	6.9%	4.9%
Caggioli (1961)	100	Italian	–	5.0%
Rochlin and Rubaschewa (1934)	100	Russian	4.0%	7.0%
Monteiro et al. (1957)	245	Portuguese	4.8%	8.3%
Cameriere et al. (2008)	99	Northern Irish	2.0%	10.0%
Ikeda (1980)	722	Japanese	–	16.6%
Tang et al. (2009)	198	Chinese (Han)	12.7%	16.6%
Koertvelyessy (1972)	153	Alaskan Eskimos	–	30.0%
Hanson and Owsley (1980)	145	Canadian Eskimos	–	40.7%

Frequency according to the main series in the literature (by increasing frequency of bilateral aplasia).

TABLE 5. Aplasia (or absence) of the frontal sinuses in skulls with persistence of the metopic suture in adults

Study (metopic suture)	*n*	Geographical origin of individuals	Aplasia	
			Unilateral	Bilateral
Welcker (1862)	20	German	25.0% (5)	20.0% (4)
Rochlin and Rubaschewa (1934)	110	Russian	16.4% (18)	28.2% (31)
Monteiro et al. (1957)	80	Portuguese	2.5% (2)	7.5% (6)
Marciniak and Nizankowski (1959)	252	Polish	7.1% (18)	7.9% (20)
Baaten et al. (2003)	8	Lebanese	– –	87.5% (7)
Present study	63	Upper Rhine	4.8% (3)	4.8% (3)

Frequency in the literature.

on radiographs by computer-assisted image analysis or of their volume using CT scan (Tatlisumak et al., 2008); however, simple, quick, and costless radiological method that generates an ordinate variable allowing classification of the size of the frontal sinuses seems of particular practical interest. Complementary to the size, the shape of the sinuses in case of persistence of the metopic suture could be evaluated in further studies. Detailed classifications of the sinusal morphology have been described (Kim, 1962; Walander, 1965; Szilvassy, 1981, 1982; Yoshino et al., 1987; Hauser and De Stefano, 1989; Quatrehomme et al., 1996; Christensen, 2005; Cameriere et al., 2008; Ponde et al., 2008; Prossinger, 2008; David and Saxena, 2010); however, it is not so evident that these more complex approaches would provide pertinent information in the case of the present problematics.

Size of the frontal sinuses and persistence of the metopic suture

The classical affirmation of absence (aplasia) of the frontal sinuses in individuals presenting a persistence of the metopic suture is not confirmed by the results of the present study. The frequency of absence of the frontal sinus observed in skulls with persistence of the metopic suture of 7.1% in the present series and of 2.5% in skulls of reference presenting frontal closure (Table 1; Figure 2) stay within the range observed in general populations (0.7–10.0%; Table 4), with exceptions of higher frequencies in Japanese and Chinese populations (16.6%), and of the highest frequencies in Alaskan and Canadian Eskimos (30.0–40.7%), interpreted as reflecting the influence of climatic conditions and the adaptation to cold environment (Koertvelyessy, 1972; Hanson and Owsley, 1980).

The results of the rare studies in the literature concerning the absence of the frontal sinuses in skulls with persistence of the metopic suture are given in Table 5. The frequency of bilateral absence varies between 7.5 and 28.2% according to the series, and most authors conclude that no relationship exists between the absence of the frontal sinuses and the metopic suture, contrarily to the conventional wisdom (Rochlin and Rubaschewa, 1934; Monteiro and Ramos, 1953; Hiltemann, 1954; Monteiro et al., 1957; Marciniak and Nizankowski, 1959). The frequency of bilateral absence observed in the present series is the lowest in the literature (4.8%). The highest frequency of absence (87.5%) observed by Baaten et al. (2003) is of reduced significance since the series consists of only eight individuals.

The observation of a significantly higher frequency of small frontal sinuses (hypoplasia) in skulls with persistence of the metopic suture (50.8 vs. 9.4%; see Table 1) is the most original result of this study since no similar data exist in the literature. On the whole, absent and small sinuses are considerably more frequent in skulls with metopic suture (57.9 vs. 11.9%; Fig. 2B). As geographical origin influences the morphology of the frontal sinuses (Kim, 1962; Hanson and Owsley, 1980; Ikeda, 1982; Harris et al. 1987b; Aydinlioglu et al., 2003; Cakur et al., 2011), it would be of interest to study the frequency of hypoplasia in other populations.

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