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Frontal Sinus Morphometry in Relation to Surgically Relevant Landmarks in the Middle East Population: Can We Globalize?

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■ BACKGROUND: **The frontal bone is frequently approached during neurosurgical procedures. Feared complications of such surgeries include cerebrospinal fluid leak, among others, and frequently result from a breach of the frontal sinus. For this reason, the sinus should be avoided when possible. The supraorbital notch (SON) is a reliable and easily identifiable surgical landmark and its relation to the frontal sinus has been previously studied. However, the frontal sinus shows significant variability in size and shape between populations.**

■ METHODS: **In the present study, we investigate the frontal sinus dimension and its relation to the SON in the Middle Eastern population.**

■ RESULTS: **The analysis of a set of computed tomography scans reveals a significant variation in size between genders, and we subsequently provide neurosurgeons in the region with population-targeted, gender-specific risk maps.**

■ CONCLUSIONS: **We finally conclude that a 2-cm margin rostral and lateral to the SON is safest.**

INTRODUCTION

The frontal sinuses are a pair of air-filled cavities located in the frontal bone, posterior to the superciliary arches.[1] Usually unidentifiable radiographically at birth, these structures begin to develop early in life until they reach their definitive morphology at approximately 20 years.[2] Studies documenting the development of frontal sinuses are still controversial, and there are significant variations between and within populations.[3] Women tend to have smaller sinuses than men,[4] although some studies deny gender differences.[5] Gender-specific variations in frontal sinus dimensions have even been suggested as a sex determination tool.[4,6] Most frequently, sinuses are reported to be asymmetrical,[7] and an occasional absence of one or both sinuses has been reported.[5,7,8] It is also believed that the morphometry is influenced by climate, with populations of cold regions having smaller frontal sinuses.[9] Possible later alterations further complicate this in advanced age and are believed to be caused by bone resorption, postmenopausal hyperostosis, chronic inflammation, and trauma.[9] Yet, the frontal sinus morphometry remains so unique that it has been successfully used for identification in forensic cases.[2,3,10]

The frontal sinus is frequently approached during neurosurgical procedures involving the frontal bone, including but not limited to frontal, supraorbital, orbitozygomatic, and pterional craniotomies, as well as during emergency supraorbital ventricular puncture and supraorbital minicraniotomy.[5,7,11] Ideally, the frontal sinus should be avoided to decrease the risks of postoperative complications. In fact, violation of the frontal sinus has been associated with cerebrospinal fluid leak, frontal sinusitis, and mucocele formation.[12] Mucocele formation could occur from 3 months to 36 years postsurgery, with no universally accepted management approach to date.[13] For this reason, it is essential to study the frontal sinus in relation to surgical landmarks. This can be especially helpful for preoperative preparations and in deciding the appropriate neurosurgical approach. Besides, this is also crucial in circumstances in which intraoperative neuronavigation is inaccurate or unavailable.

It has been established that the supraorbital notch (SON) is a relatively stable, reliable, and easily identifiable surgical landmark.[14] Its relation to the frontal sinus has been studied in

Key words
- Frontal sinus
- Supraorbital fossa
- Supraorbital notch
- Surgical landmark

Abbreviations and Acronyms
CT: Computed tomography
HRL: Horizontal reference line
SON: Supraorbital notch

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western populations,[5] in which the risk of frontal sinus injury at several positions relative to the SON has been described. For example, during decompressive hemicraniectomies, where the surgical incision can reach down to 2 cm above the SON, the frontal sinus is breached in 11% of patients. The risk decreases to reach as low as 1% at 2 cm lateral to the SON at the same horizontal plane.[5] In this context, having a risk map enables the neurosurgeon to weigh the risks of a specific surgical approach preoperatively, and therefore to prepare for the surgery accordingly. Most importantly, the risk map can be used to decrease the risk of breaching the frontal sinus, thereby reducing postoperative complication risk. It is therefore evident that the use of the SON as a surgical landmark constitutes a cheaper and more accessible alternative to neuronavigation and helps in planning for the surgery and in reducing complication risk. However, as mentioned previously, the frontal sinus dimension varies greatly between populations, and the recommendations that apply to one population might not apply to others. It is hence essential to study these relations in a population-specific manner, providing neurosurgeons in the region with more accurate and targeted statistics.

In the present article, we describe the frontal sinus morphometry in relation to the SON in the Middle Eastern population and provide a population-targeted risk map of the skull. We therefore provide neurosurgeons in the region with safe and reliable guidelines. This is especially important in our region, where neuronavigation is not always readily available and where physicians frequently rely on more easily accessible and affordable tools. In addition, to our knowledge, the present study is the first to replicate the study in the Middle Eastern population and will therefore testify about the generalizability of the previous findings to different ethnicities.

METHODS

This study was approved by the institutional review board at the American University of Beirut. We conducted a retrospective review of 214 noncontrast cranial computed tomography (CT) scans done between 2015 and 2018. Patients' demographics were retrieved from an institutional database including patients' age and gender. All patients <18 years of age were excluded as their frontal sinus might not have reached its definitive dimension. Neuroradiology reports were reviewed to identify any abnormalities, and when present, the corresponding scans were excluded. A total of 17 patients were excluded because of either unilateral or bilateral absence of frontal sinuses, or an underlying pathology. The analysis of the frontal sinus dimensions (height and lateral extent) and its relation to the SON was initially completed without stratification and then with stratification by gender.

We purposely selected cranial CT scans over sinus CT scans, as the latter were more likely to have been ordered in cases of suspected sinus pathologies. Cranial CT scans were obtained using the Siemens Somatom sensation 64 (Siemens, Erlangen, Germany) and the Philips ICT 256 (Philips, Amsterdam, the Netherlands). In both cases, the collected images had a 0.6-mm thickness and were obtained in the axial plane with coronal and sagittal reconstructions.

Sinus measurements were done on the Philips Intellispace Portal 7.0 (Philips) software for 3-dimensional reconstruction. The measurements were completed by 2 radiology and neurosurgery residents and further verified by a neuroradiologist to ensure the accuracy and precision of the results.

Three reference lines were virtually drawn: a horizontal reference line (HRL) passing through both SONs, a vertical midline passing through the crista galli, and another vertical reference line passing through each SON (**Figure 1**).

The measurements included the following: maximal height from HRL (whether midline or off midline); right and left maximal lateral extent from the vertical midline; right and left lateral extent from the vertical midline at 0, +1 cm, and +2 cm; and right and left lateral extent from the SON at 0, +1 cm, and +2 cm. The risks of frontal sinus injury illustrated in the risk maps represent the percent of frontal sinuses reaching the positions specified.

As an approximation of the overall size of the facial skeleton, the distance between the 2 frontozygomatic sutures and the distance between the HRL and the anterior nasal spine were taken for normalization.

Datasets were compared using the Student *t*-test and 1-way analysis of variance. All *P* values <0.05 were considered statistically significant. The strength of correlation was evaluated using regression analysis. A coefficient of determination R^2 below 0.3 was considered to represent only a weak correlation between the variables.

RESULTS

Demographics

A total of 214 CT scans were evaluated. Bilateral absence of the frontal sinus was present in 5 cases (2.35%). Left frontal sinus absence was noted in 4 cases (1.88%), whereas unilateral right frontal sinus absence was not encountered. Bilateral and unilateral absence of the frontal sinus, CT scans with identified abnormalities, and pediatric cases were excluded from subsequent analysis. Out of the remaining 197 cases, 114 (57.9%) corresponded to women and 83 (42.1%) corresponded to men (**Table 1**). The mean age was 43.9 ± 17.3 and ranged from 18–90 years.

Frontal Sinus Dimensions

The average vertical extent of the frontal sinus from the HRL was 2.0 ± 0.8 cm. Women had significantly shorter sinuses than men ($P < 0.001$), with a mean extent of 1.7 ± 0.7 cm and 2.3 ± 0.9 cm, respectively. The sinus extended >2 cm above the HRL in 85 (43.1%) cases and extended >4 cm above the HRL in 4 (2.0%) cases (**Table 2**). On average, the maximal lateral extent of the sinus from midline was 2.7 ± 0.8 cm on the right and 2.8 ± 0.8 cm on the left. The sinus width on the right and left did not differ significantly. On the right side, the mean lateral extent of the sinus from midline was 2.2 ± 0.7 cm at the HRL, 2.5 ± 0.9 cm at 1 cm above the HRL, and 1.3 ± 1.2 cm at 2 cm above the HRL. The right frontal sinus was significantly wider at 1 cm ($P < 0.001$). Similarly, the mean maximal lateral extent of the left frontal sinus was highest at 1 cm above the HRL, with a mean distance of 2.6 ± 0.9 cm, compared with 2.2 ± 0.7 cm at the HRL, and 1.6 ± 1.1 cm at 2 cm above the HRL ($P < 0.001$). Men had significantly wider sinuses ($P < 0.001$). The gender-

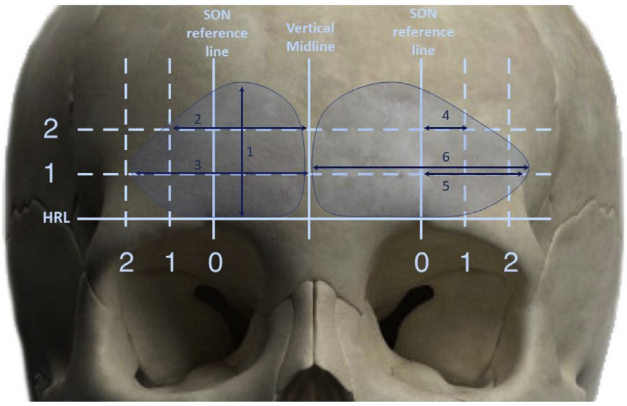

Figure 1. Schematic representation of the frontal sinus dimensions measured.

specific averages of the frontal sinus width are presented in Table 3.

The mean distance between the frontozygomatic sutures was 10.3 ± 0.5 cm, and the mean distance between the HRL and the anterior nasal spine was 6.0 ± 0.6 cm. There were no correlations between the frontal sinus dimensions and age (Supplementary Figures 1 and 2), the distance between the frontozygomatic sutures (Supplementary Figures 3 and 4), and the distance from the HRL to the anterior nasal spine (Supplementary Figures 5 and 6) ($R^2 < 0.3$).

Frontal Sinus Dimensions Relative to the SON in Women

At the HRL, the frontal sinus reached the SON in 49% of cases on both sides (Figure 2). At the same level, 5% of frontal sinuses extended ≥1 cm laterally to the SON on the right, whereas 3% reached the same extent on the left. At 1 cm above the HRL, an extension of the frontal sinus laterally to the SON was present in 39% of cases on the right, and 45% of cases on the left. At the same level, 9% and 10% of the sinuses extended ≥1 cm laterally to the SON on the right and left, respectively. The frequency dropped to 1% on both sides at ≥2 cm lateral to the SON at the same horizontal plane. At 2 cm above the HRL, the frontal sinus extended laterally to the SON in 4% of cases on the right, and 5% of cases on the left. An extent of ≥1 cm lateral to the SON at the same horizontal line was noted in 4% and 3% of cases on the right and left, respectively. The frequency of frontal sinuses reaching ≥2 cm laterally to the SON at the same horizontal line was 1% on the right, whereas it never reached the same position on the left (Figure 2).

Frontal Sinus Dimensions Relative to the SON in Men

At the HRL, the frontal sinus reached the SON in 60% of cases on the right, and 67% of cases on the left (Figure 3). At the same horizontal plane, 14% of frontal sinuses extended ≥1 cm

Table 1. Demographics of the Patients by Gender, Age, and Absence of Frontal Sinus

Characteristics	N (%)
Gender (n = 197)	
Female	114 (57.9)
Male	83 (42.1)
Age, years (n = 197)	
18–30	47 (23.9%)
30–60	111 (56.3%)
60–90	39 (19.8%)
Absence of frontal sinus (n = 214)	
Right	0 (0%)
Left	4 (1.88%)
Bilateral	5 (2.35%)

Table 2. Table Illustrating the Percent of Patients With Frontal Sinus Extension Above a Given Level in Relation to the Horizontal Reference Line

	Percent of Patients with Frontal Sinus Extension Vertically Above the HRL		
Distance Above HRL (cm)	Female (n = 114)	Male (n = 83)	Total (n = 197)
0	99%	100%	100%
1	80%	98%	87.3%
2	31%	60%	43.1%
3	5%	22%	12.1%
4	1%	4%	2.0%

HRL, horizontal reference line.

Table 3. Table Illustrating the Average Right Frontal Sinus Width at Several Positions Relative to the Horizontal Reference Line

	The Average Width of the Frontal Sinus on the Right		The Average Width of the Frontal Sinus on the Left	
Distance Above HRL	Female	Male	Female	Male
0	2.1 ± 0.6	2.4 ± 0.7	2.0 ± 0.6	2.4 ± 0.7
1	2.2 ± 0.9	2.7 ± 0.9	2.2 ± 0.9	2.9 ± 0.9
2	0.7 ± 0.8	1.9 ± 1.2	1.0 ± 1.0	2.1 ± 1.0

HRL, horizontal reference line.

laterally to the SON on the right, and 10% of sinuses reached the same position on the left. On both sides, 1% of sinuses reached 2 cm lateral to the SON at the HRL. At 1 cm above the HRL, 65% of frontal sinuses reached the right SON and 75% reached the left SON. At the same level, 17% and 22% of the sinuses extended ≥1 cm laterally to the SON on the right and left, respectively. The frequency dropped to 1% on the right, and 2% on the left at ≥2 cm lateral to the SON at the same horizontal plane. At 2 cm above the HRL, the frontal sinus extended laterally to the SON in 20% of cases on the right, and 29% of cases on the left. At the same horizontal line, the sinus extended ≥1 cm laterally to the SON in 6% of cases on both sides. Although the frequency of frontal sinuses reaching ≥2 cm laterally to the SON at the same horizontal line was 1% on the left, it was almost null on the right (Figures 1 and 3).

DISCUSSION

Frontal sinus violation is a common cause of complication after neurosurgical procedures involving access to the frontal bone.[5,15] Violation of the frontal sinus is associated with cerebrospinal fluid leak, frontal sinusitis, and mucocele formation.[12,15,16] The latter usually results from entrapment of sinus mucosa or obstruction of outflow and can present anytime from weeks to years postsurgery with varying severity.[13] Therefore accurate prediction of the anatomic position of the sinus and knowledge of the possible variations is essential in planning for successful surgeries with reduced postoperative complications.

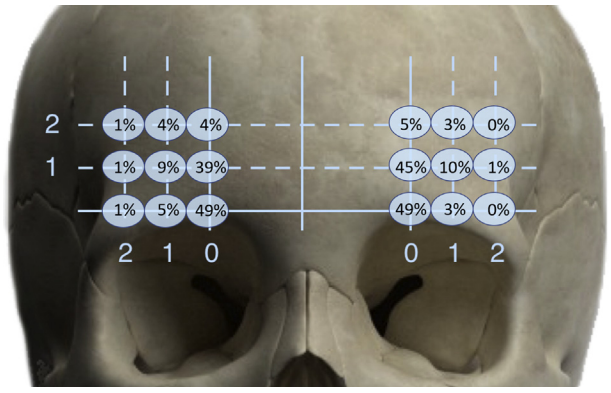

Figure 2. Figure representing the risk of frontal sinus injury at different positions relative to the supraorbital notch in Middle Eastern women.

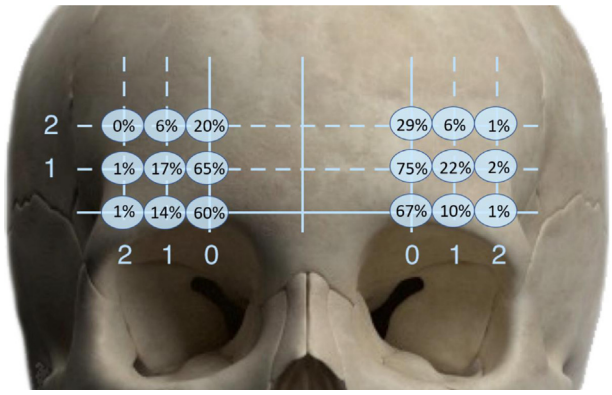

Figure 3. Figure representing the risk of frontal sinus injury at different positions relative to the supraorbital notch in Middle Eastern men.

The SON is an established stable morphometric parameter of the anterior cranial fossa and can be reliably used as a key surgical landmark for the frontal sinus.[14] Consistent with previous findings,[5] our results show that the lateral extent of the sinus was significantly higher at 1 cm above the HRL, and the risk of frontal sinus injury tends to be higher at this position, at any vertical plane. However, although no gender-specific risks have been observed in the Western population,[5] our study demonstrates significant differences between genders in the Middle Eastern population. In general, women tend to have smaller sinuses than men. Sexual dimorphism is to be considered if an incision falls within 1 cm laterally to the SON, at any vertical position. Within those dimensions, men have a higher risk of frontal sinus injury (Figures 1 and 2). However, when the incision extends to 2 cm laterally to the SON, at any vertical position, the risks of frontal sinus injury are similar across genders. In this context, we encourage that incisions to the frontal bone be completed at 2 cm laterally to the SON when possible. Otherwise, a gender-specific risk map could be used to estimate the risk of injury.

In surgical procedures involving access to the frontal bone, extending the incision to 2 cm above the SON decreases the risk of breaching the frontal sinus by approximately 77% (relative risk reduction). At 1 cm above the HRL, extending the incision 1 cm lateral to the SON reduces the risk by approximately 75%. The lowest risk of injury can be secured by extending the incision to 2 cm lateral to the SON at any horizontal line. Similar to previous reports,[5] our results show that incisions 2 cm lateral to the SON present a 1% risk of frontal sinus injury at most horizontal planes. Hence our results further support previous evidence

applicable to Western populations and attest to the generalizability of the findings.

Other recommendations to be considered include drilling at an angle of 50°, which has been reported to further decrease the risk of frontal sinus injury in cadaveric studies.[17] Interestingly, with advancements made in the field of augmented reality, a successful trephination of the sinus was completed in cadaveric specimens using reconstructed 3-dimensional holograms. This technology could soon represent an alternative to, or even outdo, neuronavigation.[18]

The limitations of the present study include sample size, specifically after stratification, and we recommend that further studies evaluate the gender-specific risks observed. In addition, it is essential to remind the readers that the risks reported do not apply to the pediatric population or patients with documented frontal sinus pathologies.

CONCLUSIONS

Frontal sinus violation is a common source of complication following procedures involving access to the frontal bone. Neuronavigation is often used to plan for such procedures and avoid a breach of the sinus. However, when neuronavigation is not accurate or available, the SON can be used as a reliable landmark to predict and minimize the risk of frontal sinus injury. In this study, we provide evidence of sexual dimorphism and illustrate gender-specific risk maps. Women tend to have smaller sinuses than men and lower risks of frontal sinus injury within 1 cm lateral to the SON. Consistent with previous findings, we encourage the use of a 2-cm safety margin when possible in both genders.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Ali Amine: Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Karl John Habashy:** Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Elie Najem:** Investigation, Writing - original draft, Writing - review & editing. **Rawad Abbas:** Investigation, Writing - original draft, Writing - review & editing. **Charbel Moussalem:** Writing - original draft, Writing - review & editing. **Shadi Bsat:** Writing - original draft, Writing - review & editing. **Roula Hourany:** Methodology, Writing - original draft, Writing - review & editing. **Houssein Darwish:** Conceptualization, Writing - original draft, Writing - review & editing.

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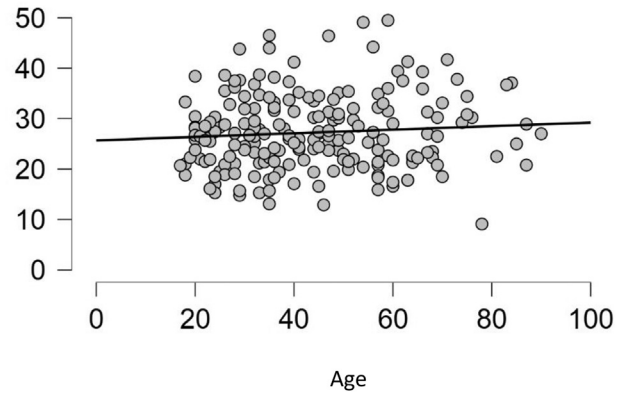
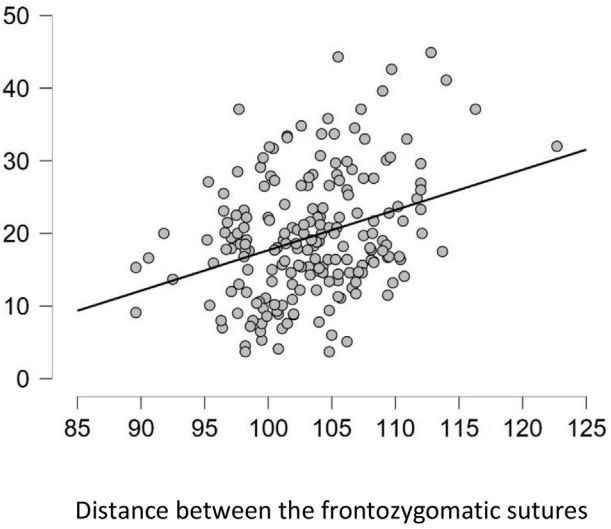
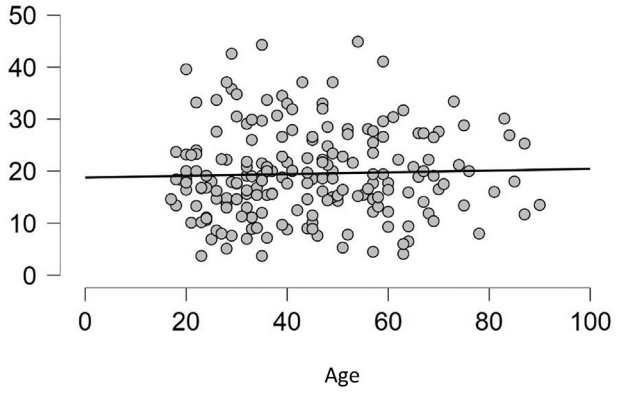
SUPPLEMENTARY DATA



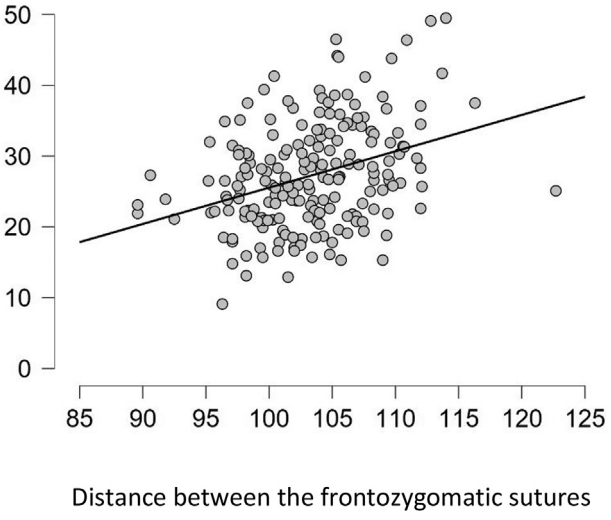
Supplementary Figure 1. Scatterplot representing the relationship between the maximal height of the frontal sinus and age ($R^2 = 0$).



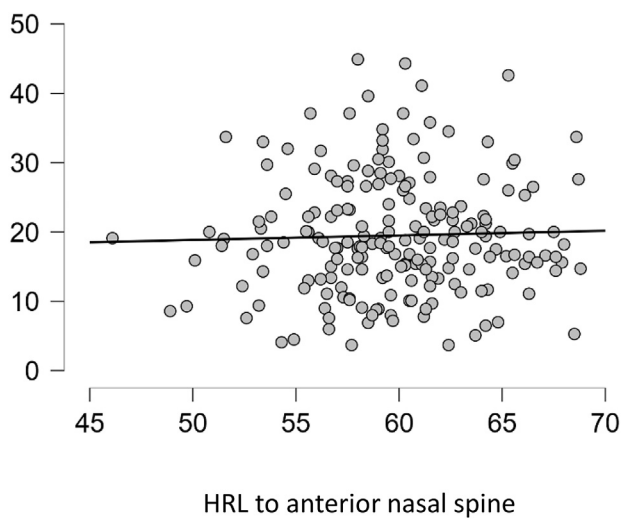
Supplementary Figure 3. Scattered plot representing the relationship between the maximum height of the frontal sinus and the distance between the frontozygomatic sutures ($R^2 = 0.11$).



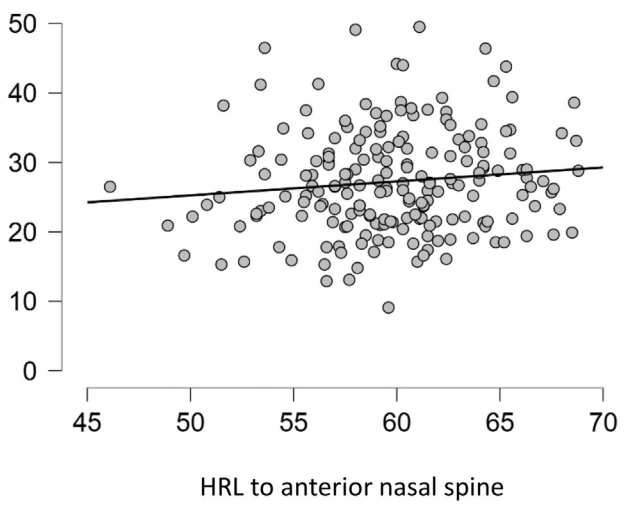
Supplementary Figure 2. Scatterplot representing the relationship between the maximal right lateral extent from midline and age ($R^2 = 0$).



Supplementary Figure 4. Scattered plot representing the relationship between the maximal right lateral extent of the frontal sinus and the distance between the frontozygomatic sutures ($R^2 = 0.12$).



Supplementary Figure 5. Scattered plot representing the relationship between the height of the frontal sinus and the distance between the horizontal reference line and the anterior nasal spine ($R^2 = 0$).



Supplementary Figure 6. Scattered plot representing the relationship between the maximal right lateral extent of the frontal sinus and the distance between the horizontal reference line and the anterior nasal spine ($R^2 = 0$).