Technical Note

Midline as a landmark for the position of the superior sagittal sinus on the cranial vault: An anatomical and imaging study

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Abstract

Background: Craniotomies involving the midline are regular practice in neurosurgery, during which injury to the superior sagittal sinus (SSS), an uncommon yet devastating event, may occur. The midline tends to be the most common landmark used to identify the position of the SSS. In this study we examined the reliability of the midline as a landmark for the SSS.

Methods: We performed bilateral craniectomies on eight cadaveric heads, preserving the coronal, sagittal, and lambdoid sutures. The width of the SSS and its displacement from midline were measured on the cadaveric specimens and on 105 normal magnetic resonance images (MRIs) of the head at the following locations: halfway between nasion and bregma (NB), bregma (B), halfway between bregma and lambda (BL), lambda (L), and inion (I).

Results: In all cadaveric specimens, the SSS was partially or totally displaced toward one side of midline, usually to the right. It tended to be closer to midline in the frontal region and more displaced posteriorly. The SSS usually drained into the right-side transverse sinus. The mean width of the SSS was 4.3, 5.9, 6.9, 7.9, and 7.8 mm, and the average displacement from midline was 4.3, 6.3, 5.5, 6.9, and 6.0 mm for NB, B, BL, L, and I, respectively. These measurements were then compared with those obtained from the MRIs.

Conclusion: The SSS was consistently displaced on either side of midline. Thus, the midline is not reliable for identifying the SSS, and caution should be used within 6–10 mm on either side of midline.

Key Words: Confluence of sinuses, superior sagittal sinus, sagittal suture, torcular Herophili

INTRODUCTION

Understanding the anatomy of the superior sagittal sinus (SSS) and its position in relation to the midline has been problematic and is poorly understood in the literature.[5] In fact, most of our knowledge on the position of the SSS has been derived from radiological studies.[8] Interestingly, the SSS was one of the earliest

anatomical structures to be described. During the ancient period of anatomical investigation in Alexandria, Herophilus studied the cerebral sinuses and named the confluence of sinuses the "torcular Herophili."[7,9] Several other anatomists, such as Vesalius, redescribed the anatomy of the SSS.[9] Neurosurgically relevant anatomical description can be attributed to Cushing, who attempted to divide the SSS into segments for the purpose of understanding meningioma origin and creating classifications based on location.[6]

Damage to the SSS is a potential complication of any paramedian midline cranial vault approach. Inadvertent injury of the sinus, usually during craniotomy, can lead to severe bleeding. Such injuries are difficult to repair and can result in devastating consequences. To avoid such complications, neurosurgeons typically use the midline, which is the line on the surface of the skull connecting the nasion and the inion, as a reference to estimate the position of the SSS. Correlation between the SSS and the sagittal suture was previously described in the literature;[16] however, there has not been a correlation between the SSS and the sagittal midline, which is more relevant for neurosurgical case planning (especially when image-guided surgical navigation is unavailable or inadequate).

In this study, we used anatomical specimens and magnetic resonance images (MRIs) of the head to evaluate the reliability of using the midline as an anatomical reference for the position of the SSS. The results can be used to avoid injuring the SSS during paramedian and midline cranial approaches, especially when intraoperative image guidance is unavailable.

METHODS

Eight silicone-injected/formalin-fixed Caucasian cadaveric heads were used. All heads were normal in structure, that is, without disease processes of the face, scalp, cranium, or cranial contents. None of the specimens had signs of craniosynostosis or hyperostosis. Major vessels of these specimens were identified and injected with colored silicone to trace the intracranial and extracranial vessels and dural venous sinuses. After reflection of all soft tissue of the scalp, the midline was identified and marked on the skull from the nasion to the inion. A bilateral craniectomy was performed that preserved the coronal, sagittal, and lambdoid sutures. Through a small gap in the sagittal suture, the SSS was exposed completely at five points: (i) Halfway between the nasion and bregma (NB), (ii) bregma (B), (iii) halfway between bregma and lambda (BL), (iv) lambda (L), and (v) inion (I). The roof of the sagittal sinus was opened, and the width of the sinus and any displacement from midline [Figure 1] were measured with calipers at all five points.
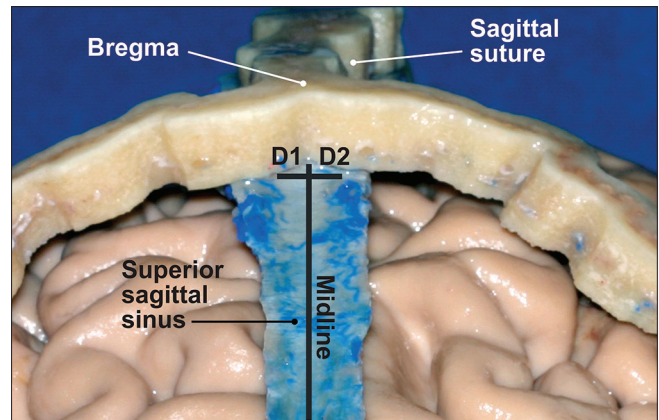

Figure 1: Anatomical measurements at bregma. D1 and D2 represent displacements of the superior sagittal sinus from midline. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.

We randomly chose 105 normal MRIs of the head from the archives of the Department of Radiology at the Madre Teresa Hospital in Belo Horizonte, Brazil. The sample consisted of 63 women and 42 males, with a mean age of 42.4 years (range, 7–87 years; all patients Caucasian). Studies with intra- and extracranial pathology were excluded. MRIs (postcontrast T1-weighted sequence) were ordered by physicians for other medical reasons and were performed with a Siemens Magnetom Vision 1.5 T scanner (Siemens Corporation, Washington, DC). No special sequences were performed for the purpose of this study that would interfere with the T1-weighted sequence image results.

The landmark used to identify the midline on the images was the longitudinal fissure of the brain. The width of the SSS and its displacement from midline were measured using Voxar 3D (Toshiba Medical Visualization Systems Europe, Ltd., Edinburgh, United Kingdom) software at NB, B, BL, and L. This software enables advanced analysis of the uploaded image sequences in any plane and in large volumetric datasets. This means that image quality and technical tilt of the scan can be eliminated as variables affecting measurement and interpretation.

We also observed which transverse sinus drained the SSS (dominant transverse sinus). The four points of interest were first identified on sagittal MRIs. The measurements were then taken from coronal and/or axial MRIs of the head.

RESULTS

[Table 1] shows the mean width of the SSS as measured on the cadaveric specimens and the MRIs. [Table 2] shows the mean lateral displacement of the SSS in the cadaveric specimens and on the MRIs.

In all specimens, the SSS was a single structure. In one specimen the sagittal suture was deviated to the left of midline. Despite the ectopic sagittal suture, the SSS was related to midline. The lateral displacement of the SSS from midline followed a similar pattern. The lateral displacement of the torcular Herophili to the inion was a mean of 6.0 ± 2.1 mm [Figure 2]. The positions of the SSS were classified as exactly underneath midline, displaced to the left of midline, or displaced to the right of midline. [Figure 3] summarizes the positions of the SSS in relation to the midline for the anatomical specimens at the five measurement points.

Table 1: Width of the SSS on anatomical specimens and MRIs

Point	Width of SSS (mean±SD (mm))	
	Anatomical specimens	MRIs
NB	4.3±0.9	7±2.6
Bregma	5.9±1.1	9.3±2.5
BL	6.9±1	12.4±2.6
Lambda	7.9±2.4	12±3
Inion	7.8±1.6	NA

BL: Halfway between the bregma and lambda, MRIs: Magnetic resonance images, NA: Not applicable, NB: Halfway between the nasion and bregma, SD: Standard deviation, SSS: Superior sagittal sinus

Table 2: Mean lateral displacement of the SSS from midline on anatomical specimens and MRIs

Point	Displacement of SSS (mean±SD (mm))	
	Anatomical specimens	MRIs
NB	4.3±1.6	2.4±3.5
Bregma	6.3±5.8	4.5±3.5
BL	5.5±3.5	5.9±3.5
Lambda	6.9±2.4	6±3.6
Inion	6±2.1	NA

BL: Halfway between the bregma and lambda, MRIs: Magnetic resonance images, NA: Not applicable, NB: Halfway between the nasion and bregma, SD: Standard deviation, SSS: Superior sagittal sinus
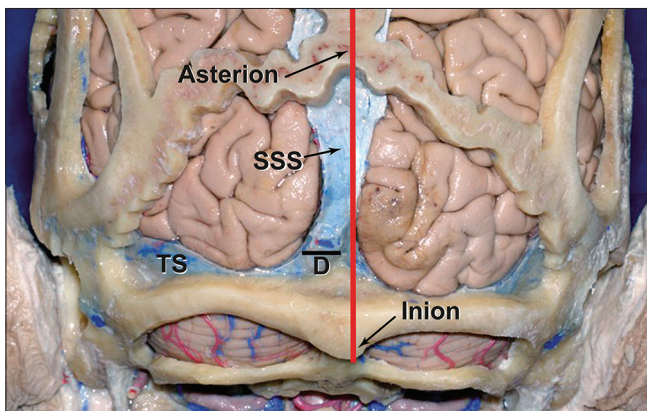

Figure 2: Anatomical measurements at lambda and inion. D is the displacement of the superior sagittal sinus (SSS) from midline (solid red line). TS, transverse sinus. *Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*

The positions of the SSS in relation to the midline in the MRIs are summarized in [Figure 4]. The SSS tended to be closer to midline in the frontal region and displaced as it coursed back toward the inion [Figure 5]. The SSS was usually completely outside the boundaries of the midline at the inion and drained into one of the transverse sinuses, usually the right side [Figure 6]. A dominant transverse sinus was present in 89.4% of the patients.

DISCUSSION

Historical considerations
The first modern neurosurgical attempt to systematically divide the SSS and illustrate its course was by Harvey Cushing and Louise Eisenhardt in 1938. Initially, Cushing sketched a two-dimensional rendering of the SSS with origin from the crista galli and termination from the torcular Herophili. When he superimposed the approximate location and size of 51 cases of parasagittal global tumors on the drawing, he astutely observed that the SSS could be divided into three regions based on the symptomatology and shared tumor characteristics. The 'central' third of the SSS housed 32 of the 51 tumors
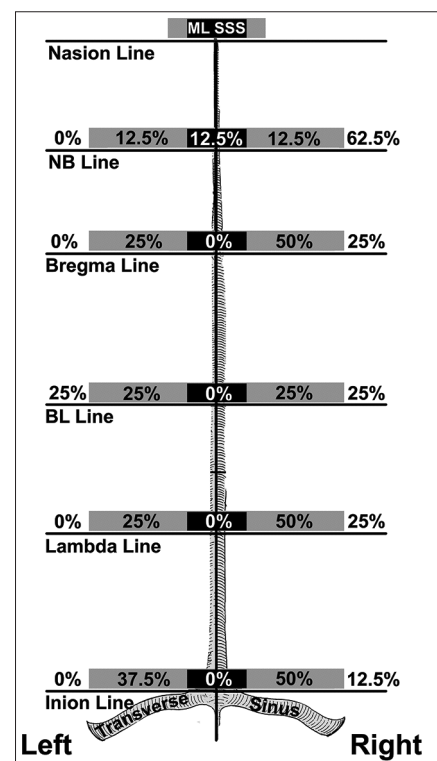

Figure 3: Schematic representation of the displacement of the superior sagittal sinus (SSS) from midline in the anatomical specimens. The frequencies of the SSS exactly at midline are represented in the black shaded areas. Sinuses partially displaced to the left or right are in the gray shaded areas. Sinuses completely displaced toward one side are outside the shaded areas. The midline is represented by the black longitudinal line. NB, halfway between the nasion and bregma; BL, halfway between bregma (B) and lambda (L); ML, midline. *Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*
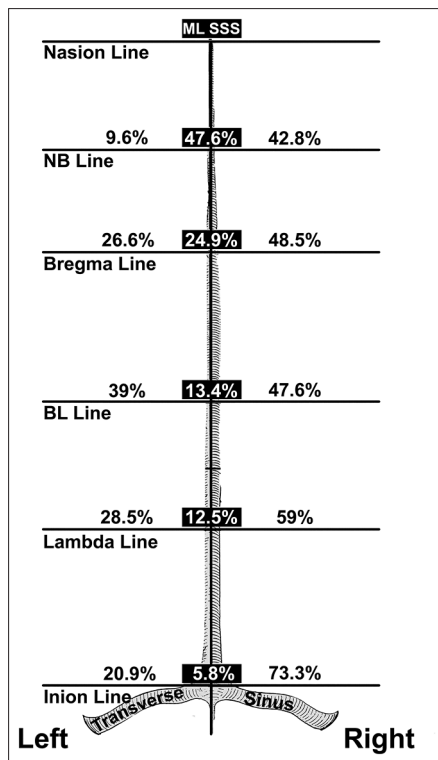
Figure 4: Schematic representation of the displacement of the superior sagittal sinus (SSS) from midline on magnetic resonance images. The frequencies of the SSS exactly at midline are represented in the black shaded areas. The sinuses displaced to the left or right are listed outside the black shaded areas. The midline is represented by the solid black longitudinal line. NB, halfway between the nasion and bregma; BL, halfway between bregma and lambda; ML, midline. *Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*
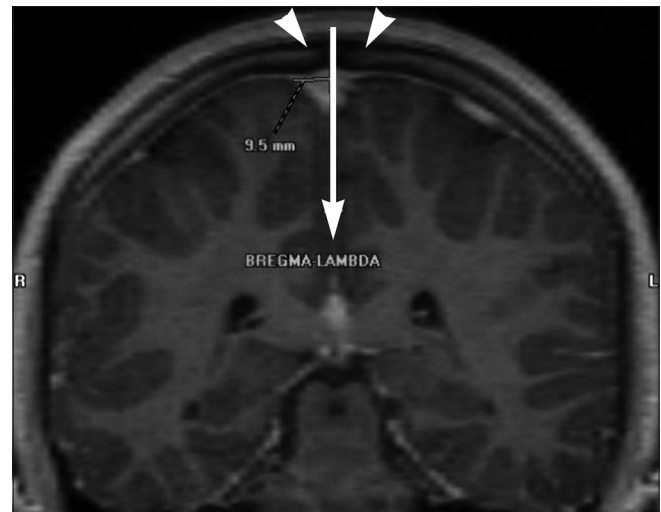

Figure 5: Coronal magnetic resonance image shows the displacement of the superior sagittal sinus toward the right at halfway between bregma and lambda. The sagittal suture is the hypointense gap at the top of the head (arrowheads). *Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*

and consistently had the smallest tumors of the series. In addition, 30 of the 32 cases were associated with convulsive seizures with Jacksonian progression. The 'frontal' third of the SSS included 13 of the 51 tumors, and the 'occipital' third of the SSS included 6 of the 51 tumors. Tumors in these regions were consistently larger than those found in the central region. According to Cushing, presenting symptoms of tumors in the frontal and occipital zones were identical, with headache and failing vision secondary to optic atrophy in all of the frontal tumor cases and in five of the six occipital cases.[6]

More recently, angiography of the SSS has led to describing the its sections according to relative quantity of bridging veins (BVs) and direction of drainage of the veins."[3,8,12] In 2007, Han *et al.* demonstrated, based on dural entrance of BVs, that a given SSS could have four segments, with segment 1 being the most anterior and segment 4 being the most posterior. In this model, segments 1 and 3 are those that contain clusters of BVs; segments 2 and 4 have a relative paucity of venous drainage. In the 30 cadaver heads studied by Han *et al.*, the average length of the two anterior segments (segments 1 and 2) was approximately 5 cm, and the average length of the posterior segments (segments 3 and 4) was approximately 7 cm.[8]

Anatomical considerations

The SSS is the longest cranial dural venous sinus and extends posteriorly from the crista galli to the sinus confluence at the internal cranial surface. Its mean length ranges from 23 to 30 cm, which makes the dural sinus the most vulnerable to injury.[4,6]

The embryology of the SSS is complex. Its position on the cranial vault seems to depend on embryological signals from the falx cerebri between the cerebral hemispheres rather than on signal from the bone at the midline.[10] This likelihood probably accounts for cases in which the SSS is unrelated to the sagittal suture and is displaced with the falx to one side.[10,15] Basically, the SSS begins as a plexiform structure that develops during embryonic and fetal life, transforming into the single venous channel of the adult.[10,14]

Tubbs *et al.*[16] studied 30 formalin-fixed adult cadavers to establish the relationship between the sagittal suture and SSS. All specimens had a midline sagittal suture. In most specimens, the SSS deviated to the right: 53.7% at B, 67% at BL, and 63% at L. The sinus was exactly beneath the midpoint of the sagittal suture in 37% of the specimens at B, in 33% at BL, and in 20% at L. Displacement of the sinus toward the left side was uncommon.

Unlike these previous studies, we used the midline, which extends backward from the nasion to the inion, as a reference for the position of the SSS. This landmark was chosen for several reasons. First, it is different from the sagittal suture, which can be used only between B and L. In contrast, the midline can be used to estimate
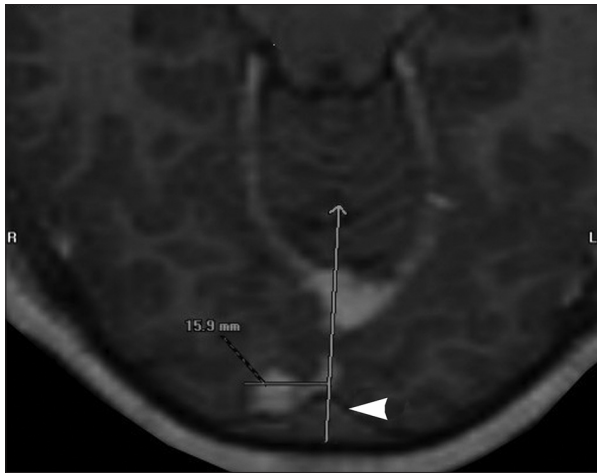
Figure 6: Axial magnetic resonance image shows the displacement of the superior sagittal sinus toward the right at the region of the torcular. The internal occipital protuberance is indicated by the arrowhead. *Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*

the position of the entire length of the SSS, including the segment covered by the suture. Second, the midline is visible on MRI and computed tomography images. Consequently, it is a relevant landmark for estimating the position of the SSS before surgery, especially when image guidance is unavailable. Finally, from an embryological perspective, the position of the SSS seems to be more closely related to the midline than to the sagittal suture.[10]

Our findings reinforce and expand upon the conclusions of Tubbs *et al*.[16] and Samadian *et al*.[11] The entire length of the SSS was usually displaced from midline, typically toward the right. We used the Voxar 3D software to estimate the displacement of the SSS on MRIs. Although this method may be less accurate than direct measurement, the differences between the position of the SSS and the midline on MRIs would likely be distorted only a short distance and hence would not influence our final results.

Traditionally, the inion has been used to estimate the position of the torcular Herophili on the cranial vault. The torcular Herophili is found at one side of the external occipital protuberance, typically on the right side, where the transverse sinus is more developed.[2,18] Tubbs *et al*. failed to confirm this finding,[17] and they did not consider the inion to be a reliable landmark for estimating the position of the torcular Herophili. In another study, the right transverse sinus was dominant in 75% of 30 cadaveric specimens.[16] Ziyal *et al*.[19] found the center of the torcular to be 1.7 cm below the inion in 30 cadaveric specimens. Bisaria *et al*.[2] studied 110 adult cadavers to evaluate the variations of the torcular. They concluded that in most cases the SSS was divided by a dural partition, which was rarely found at midline, and formed two unequal channels that drained into the transverse sinuses. In 20 hemispheres the SSS drained exclusively into the right transverse sinus. In our study, the SSS drained into the right transverse sinus on 62.8% of the MRIs and in 62.5% of the anatomical specimens.

Surgical considerations

Median and paramedian cranial vault approaches always risk injuring the SSS. Such injuries usually occur during the craniotomy, when the Gigli saw or the bit of the high-speed drill lacerates the walls of the sinus. Even before Cushing's advances, surgeons were fearful of causing such damage and therefore habitually cut bone flaps 2 cm lateral to midline.[6]

The medial margin of a unilateral frontal craniotomy tends to be in close proximity of the midline. Therefore, the segment of the SSS halfway between the nasion and B can be exposed, especially if the craniotomy is placed on the right side. When the SSS is severely injured during a craniotomy, the sinus can be treated by ligation if the involved segment is near the nasion. We strongly recommend repairing the sinus if it is injured beyond the NB point. Ligation distal to this point is likely to lead to venous infarction.[13]

The bone flap of the anterior transcallosal approach is usually planned so that two-thirds extend anterior and one-third extends posterior to the coronal suture. Therefore, the SSS is at risk of damage at two of the craniometric points used in this study: NB and B. Depending on the objective, the surgeon can plan the bone flap to expose the entire width of the SSS or only its border. In our study, the incidence of the SSS displaced to the right of midline at both of these points was high, but the exact location of the SSS is best identified on coronal MRIs before surgery. When MRI is unavailable, burr holes should be placed at least 1 cm lateral of midline on the left side and 2 cm lateral of midline on the right side to avoid injuring the SSS.

Parasagittal tumors of the rolandic region can be exposed through a median interhemispheric approach. Typically, the craniotomy reaches or crosses midline. The SSS is partially or completely exposed at the segment related to the midpoint between B and L.[1] The sinus is seldom beneath midline at this point; it will likely be displaced to the right of midline. This segment of the sinus cannot be interrupted, and damage to the sinus can be difficult to repair. Some surgeons therefore place burr holes a few millimeters away from midline to avoid placing a hole exactly above the SSS. Such burr holes are either placed toward the ipsilateral or contralateral side of the craniotomy, depending on the surgeon's objective. Because the SSS is usually displaced from midline, a paramedian burr hole could expose the SSS. At this segment of the sinus, we suggest identifying the position of the SSS on MRI when possible to avoid poor placement of the burr hole.

The posterior transcallosal approach exposes about half of the course of the SSS anterior to L. The borders of the craniotomy can expose the margin or the entire width of the SSS at BL and L. Because the SSS is usually displaced toward the right in this region, we recommend applying the same surgical principles described for reaching rolandic parasagittal lesions through a posterior transcallosal approach.

The torcular Herophili, transverse sinus, and segment of SSS between the inion and L can be exposed during an occipital craniotomy. The SSS is widest in this area, and damage to the sinus or torcular can lead to catastrophic bleeding. Therefore, the craniotomy must be planned and performed carefully to avoid injuring the SSS. Because of the trajectory of the SSS toward the dominant right transverse sinus, the sinus is usually displaced (often completely) toward the right side in this region.[2,16,18]

CONCLUSIONS

The midline is not an accurate landmark for determining the course of the entire SSS across the cranial vault. In most cases, the sinus is partially and sometimes completely displaced from midline, usually toward the right side. The position of the SSS is easily observed on MRIs. We therefore recommend obtaining this study, when possible, to avoid damaging the SSS when performing surgical approaches in the vicinity of midline.

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