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Morphometric CT angiographic study of the SSS and its adjacent structures: A comparative analysis between elderly and nonelderly individuals of a Han Chinese population

Fasheng Zhao, Kan Xu, Zibo Zhou, Jinlu Yu *

Department of Neurosurgery, First Hospital of Jilin University, Changchun, 130021, China

A R T I C L E I N F O

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A B S T R A C T

Objective: The superior sagittal sinus (SSS) is an important structure, but few studies have analyzed it using computed tomography angiography (CTA).
Methods: This study was performed to examine the angiographic anatomy of the SSS and its adjacent structures using CTA in Han Chinese participants. According to age, participants were divided into elderly and nonelderly groups. The parameters of the SSS and adjacent structures were measured, recorded and analyzed statistically.
Results: A total of 500 Han Chinese participants were enrolled in this study, including 346 in the elderly group and 154 in the nonelderly group. In the elderly group, regarding inferior sagittal sinus (ISS) development, 187 ISSs were absent, 85 were visible, and 74 were clear. In the nonelderly group, 62 ISSs were absent, 54 were visible, and 38 were clear. In the elderly group, the Rolandic bridging vein diameter was 3.6 ± 0.8 mm; in the nonelderly group, the diameter was 3.9 ± 1.1 mm. The statistical results showed a difference in ISS development between the elderly and nonelderly groups ($P < 0.05$). The relationship of age with ISS development was assessed using linear regression analysis, and the results indicated that ISS became gradually occluded with age ($P < 0.05$). The statistical results also showed a difference in the Rolandic bridging vein diameter between the elderly and nonelderly groups ($P < 0.05$). The relationship of age with the Rolandic bridging vein diameter was assessed using linear regression analysis, and the results indicated that the Rolandic bridging vein tended to become thinner with age ($P < 0.05$).
Conclusion: This study found that more ISSs may become occluded and that the Rolandic bridging vein may become thinner with age. Other parameters of the SSS and its adjacent structures may not be affected by aging. In addition, our study also provided normal CTA parameters of the SSS and its adjacent structures in Han Chinese people.

1. Introduction

The superior sagittal sinus (SSS) courses in the midline of the brain, beginning behind the frontal sinuses, and grows larger as it continues posteriorly in the SSS groove and drains into the torcular herophili [1]. The SSS is an important structure that provides drainage for the cerebral hemisphere veins [2]. A strong understanding of the SSS is of clinical importance; in addition to acting as the draining passage, the SSS plays an important role in meningeal lymphatic network circulation and clearance of cerebrospinal fluid

* Corresponding author. Department of Neurosurgery, First Hospital of Jilin University, 1 Xinmin Avenue, Changchun, 130021, China.
E-mail addresses: jlyu@jlu.edu.cn, jinluyu@hotmail.com (J. Yu).

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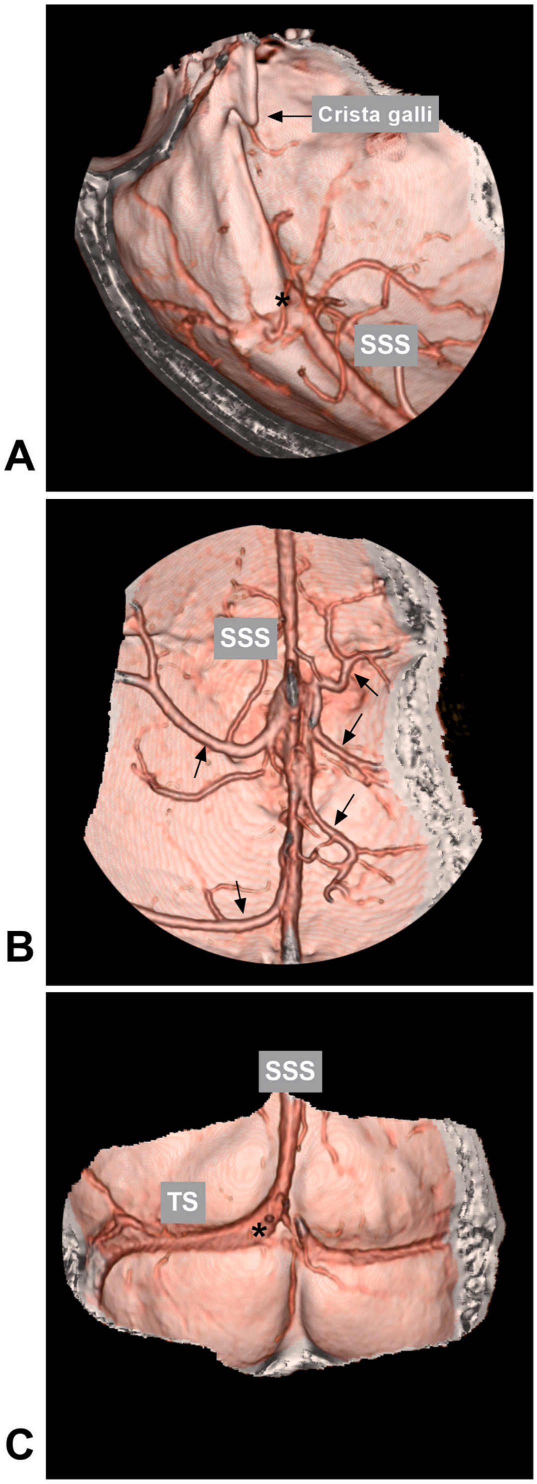

Fig. 1. Normal SSS presentation on CTA.
A: CTA showing the anterior part of the SSS; the SSS is absent from the crista galli (arrow). The asterisk indicates the beginning of the SSS. B: CTA showing the middle part of the SSS, with several bridging veins draining into it (arrows). C: CTA showing the posterior part of the SSS. The asterisk indicates the termination of the SSS.
Abbreviations: CTA: computed tomography angiography, SSS: superior sagittal sinus, TS: transverse sinus.

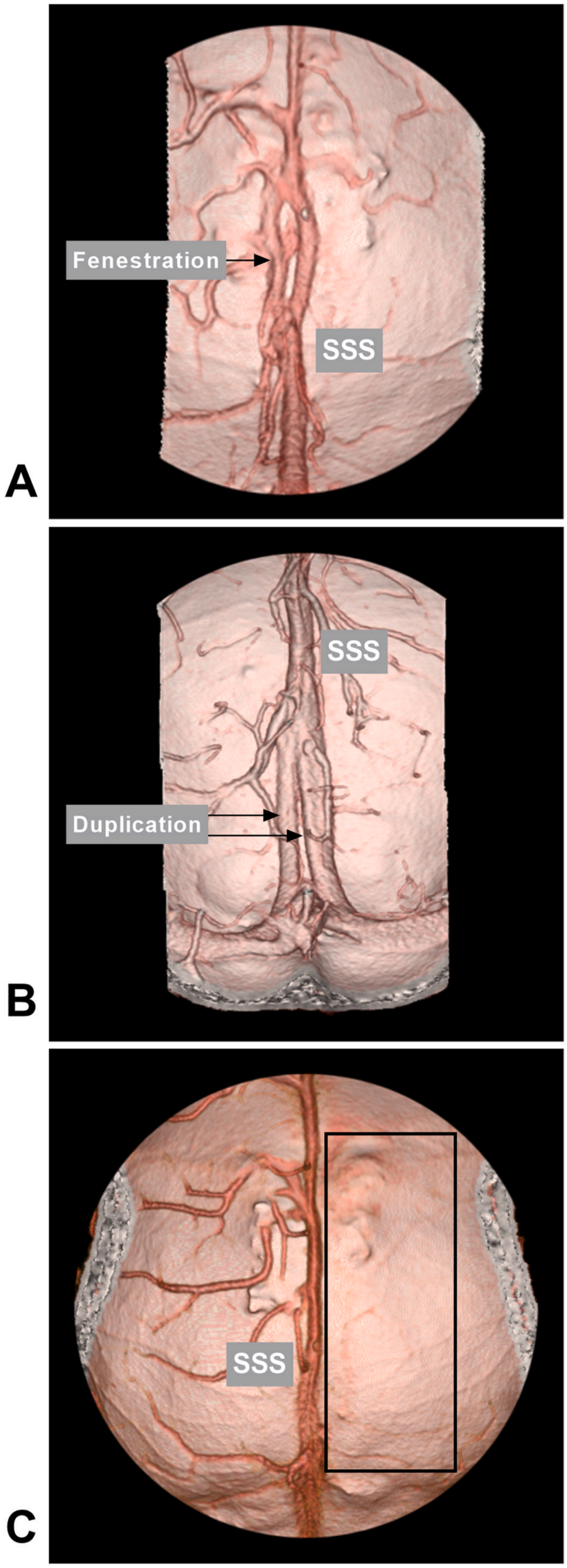

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Fig. 2. Abnormal SSS development on CTA.
A: CTA showing a fenestration (arrow) in the middle of the SSS. B: CTA showing a duplication in the posterior SSS. C: CTA showing agenesis in one hemisphere (frame).
Abbreviations: CTA: computed tomography angiography, SSS: superior sagittal sinus.

[3–5]. The SSS is involved in many diseases, such as thrombosis, injury, dural arteriovenous fistula, and meningioma [6–9]. Therefore, it is worth studying the SSS and its adjacent structures.

Previous studies on the anatomy of the SSS were mostly based on cadavers, magnetic resonance imaging or catheter angiography [2,10,11]. Few studies have used computed tomography angiography (CTA) to examine the anatomy of the SSS and its adjacent structures [12]. CTA is a minimally invasive and rapid examination tool that can provide information on veins and bone using late arterial and venous phase data. Therefore, CTA can be used to study the anatomy of the SSS and its adjacent veins. In this study, data were obtained from Han Chinese subjects, a population cohort that has rarely been reported. Similar to other intracranial vessels, morphological changes can occur in the SSS with aging. Therefore, in the present study, the subjects were divided into elderly and nonelderly groups to identify angiographic anatomical differences. To date, no similar study has explored this issue.

2. Materials and methods

A CTA study of the SSS and its adjacent structures was performed on healthy Han Chinese participants at our institution between January 2019 and January 2023. The ethics committee of our institute approved this study (No. 2022-KS-084). All methods were performed in accordance with the relevant guidelines and regulations.

2.1. Inclusion and exclusion criteria

The participants had no intracranial tumors or vascular diseases that could affect the measurement or description of the SSS and its adjacent structures. Contrast-enhanced imaging with CTA in the late arterial phase or venous phase (also called CTV) was clear, and the SSS and its adjacent structures could be clearly seen and measured (Fig. 1A–C). Participants with congenital abnormalities in the SSS, such as fenestrations, duplications and agenesis, were excluded (Fig. 2A–C). Participants younger than 18 years of age were excluded.

2.2. Software and tools used for postprocessing

The raw CTA data were processed on a GE Workstation (version 4.7) (GE Healthcare; Cytiva). The volume rendering tool was primarily used for three-dimensional reconstruction; then, structures that affected the measurement and recording were removed using the cropping tool. The width and height of the SSS were obtained using the measure distance tool, and the curved length of the SSS was measured using the two-click AVA tool. All parameters were measured 3 times by Fasheng Zhao and Zibo Zhou, and the average value was used for analysis.

2.3. Grouping

According to age, the participants were divided into the elderly (≥60 years) group, control nonelderly (<60 years) group and combined group [13].

2.4. Measured and recorded parameters

The curve lengths were measured, including the SSS, the absent anterior SSS, and the SSS groove from the crista galli to the internal occipital protuberance, from nasion to bregma, and from lambda to inion. The width and height of the SSS were also measured at bregma, lambda, and inion (Fig. 3A–B). The sides (left, middle or right) of any SSS deviations into the torcular herophili and the distance of the deviations were recorded (Fig. 4A). The number of bridging vein trunks into the SSS in the lateral hemisphere was recorded (Fig. 1B). The diameter of the Rolandic bridging vein was recorded (Fig. 4B). The presence of the SSS (integral/absent) and the ISS (absent (grade 0)/visible (grade 1)/clear (grade 2)) (Fig. 5A–C) were recorded.

2.5. Statistical analysis

Statistical assessments were performed using GraphPad Prism (version 8.02) software (GraphPad Software, Inc.) to find differences between groups. The unpaired *t*-test was used for comparing two continuous variables. Fisher's exact test or the chi-squared test was used to compare count data between two groups or among multiple groups. The relationship between independent and dependent variables was analyzed using linear regression. $P < 0.05$ indicates statistical significance.

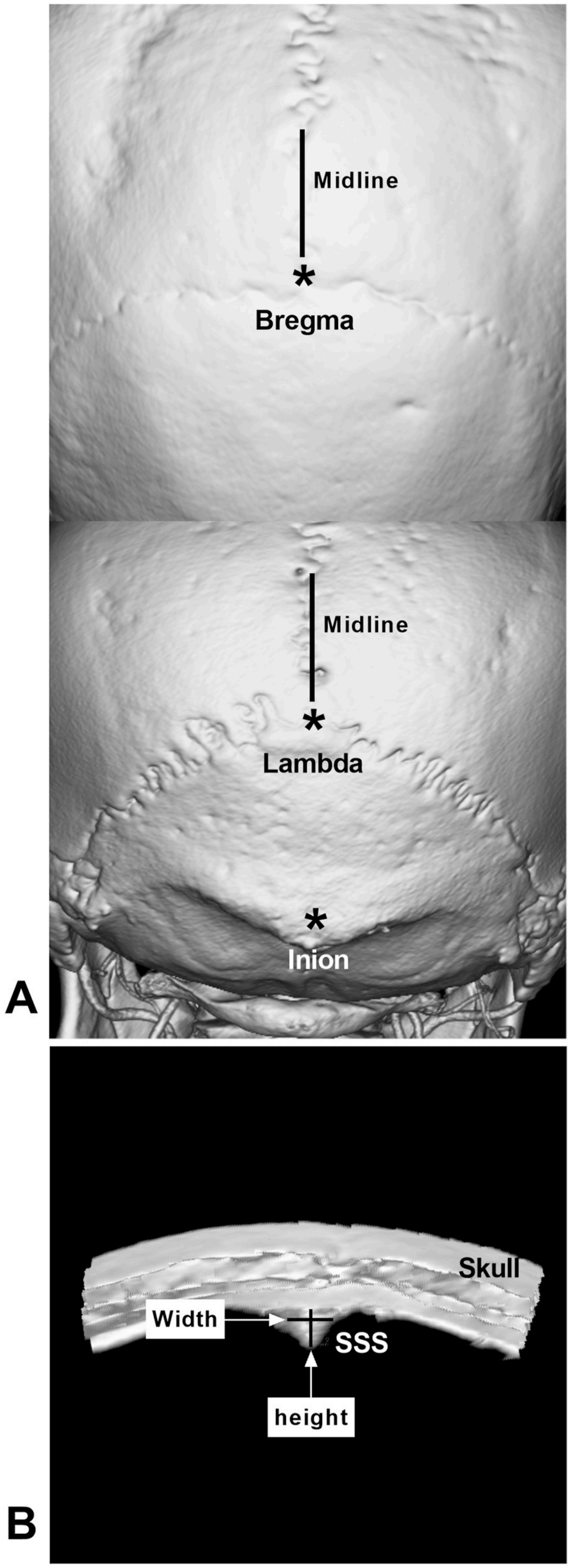

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Fig. 3. Measurement of SSS width and height on CTA.
A: Upper panel: CT showing the bregma (asterisk); Lower panel: CT showing the lambda (upper asterisk) and inion (lower asterisk). B: In the CT image, the "width" arrow indicates the SSS width, and the "height" arrow indicates the SSS height.
Abbreviations: CT: computed tomography, SSS: superior sagittal sinus.

3. Results

3.1. General information

A total of 558 CTAs among the Han Chinese participants were screened; 34 CTAs were excluded due to an unclear SSS and adjacent structures, and 16 CTAs were excluded due to the presence of fenestrations, duplications and agenesis.

The remaining 500 Han Chinese participants met the inclusion criteria for further investigation. There were 382 normal CTAs among the healthy participants who underwent routine physical examinations and 118 normal CTAs among participants who experienced headache without intracranial diseases. A total of 346 participants were placed in the elderly group, and the remaining 154 participants were placed in the nonelderly (control) group. Details on the general information is shown in Table 1.

3.2. Measured and described parameters

In the elderly group, regarding ISS development, 187 ISSs were absent, 85 were visible, and 74 were clear. In the nonelderly group, 62 ISSs were absent, 54 were visible, and 38 were clear. The detailed data are shown in Tables 2 and 3. In the elderly group, the Rolandic bridging vein diameter was 3.6 ± 0.8 mm; in the nonelderly group, the diameter was 3.9 ± 1.1 mm. The detailed data are shown in Tables 2–4 and Fig. 6A–C.

3.3. Statistical results

Data on continuous variables were analyzed, including SSS length, absent SSS length, SSS groove length, length from nasion to bregma, length from lambda to inion, and SSS width and SSS height at different points. No differences were found between the elderly and nonelderly groups (Table 2). Data on counting variables were analyzed, including SSS development, SSS deviation and ISS development. The statistical results showed a difference in ISS development between the elderly and nonelderly groups ($P < 0.05$), indicating that an increasing number of ISSs will become occluded in individuals as they age (Table 3). The relationship of age with ISS grading was assessed using linear regression analysis, which yielded the following relationship: $Y = -0.009379*X+1.315$, $P = 0.0072 < 0.01$. This result indicates that the ISS becomes gradually occluded with age (Fig. 7A).

Other continuous variable data were also analyzed, including the distance of the SSS deviation from the midline, number of ipsilateral bridging vein trunks, and Rolandic bridging vein diameter. The statistical results showed a difference in the Rolandic bridging vein diameter between the elderly and nonelderly groups ($P < 0.05$), which indicated that the Rolandic vein diameter may become smaller in individuals as they age (Table 3). The relationship of age with the Rolandic bridging vein diameter was assessed using linear regression analysis, which yielded the following relationship: $Y = -0.02423*X+5.148$ (left hemisphere), $P < 0.0001$; $Y = -0.02410*X\ 5.167$ (right hemisphere), $P < 0.0001$. This result indicates that the Rolandic bridging vein tends to become thinner with increasing age (Fig. 7B–C).

4. Discussion

Understanding the SSS anatomy is crucial for successful open surgery and endovascular treatment [9]. The SSS is a relatively independent system; it can also include the ISS and the bridging veins into the SSS. The SSS and its adjacent structures are worthy of study, but to date, there have been no large-sample angiographic studies about the SSS and its adjacent structures in Han Chinese people. The current study was therefore conducted to assess this unmet need. When studying the anatomy of the SSS and its adjacent structures, the data are often obtained from cadavers or angiography, including CTA, CTV, magnetic resonance venography (MRV) and digital subtraction angiography (DSA) [2,10,11,14]. In Table 5, we summarize the SSS anatomy data provided in previous reports. Due to differences in the measurement method and vessel status, the data from cadavers and angiography may be different. In addition, racial differences can also be responsible for the large variability between parameters.

Han et al.'s Chinese study about the SSS and its bridging veins showed no differences between cadavers and DSA [15]. However, some studies have demonstrated differences between these two groups of techniques [12,16]. In general, the parameters of the SSS and its adjacent structures in cadaveric specimens are systematically shorter or lower than those obtained on angiography due to technical reasons and the vessel filling state [12]. For instance, in Brockmann et al.'s study, the values from CTV were larger than those from cadavers, with SSS lengths of 25.6 ± 1.6 cm and 19.2 ± 1.4 cm, respectively [12].

In our study, the SSS length for the Han Chinese subjects was 26.4 ± 2.6 cm on CTA, similar to that reported by Han et al. and Brockmann et al. However, among the reports in Table 5, a large variability can be observed. Therefore, our study can only provide CTA data of the SSS and its adjacent structures in certain Han Chinese people. The difference in SSS length in previous reports may be due to a hypoplastic anterior SSS [2,16]. In our study, only 31 % of SSSs were integral. In these cases, compensatory drainage occurs through a large superior frontal vein that joins the SSS in the frontal region [17].

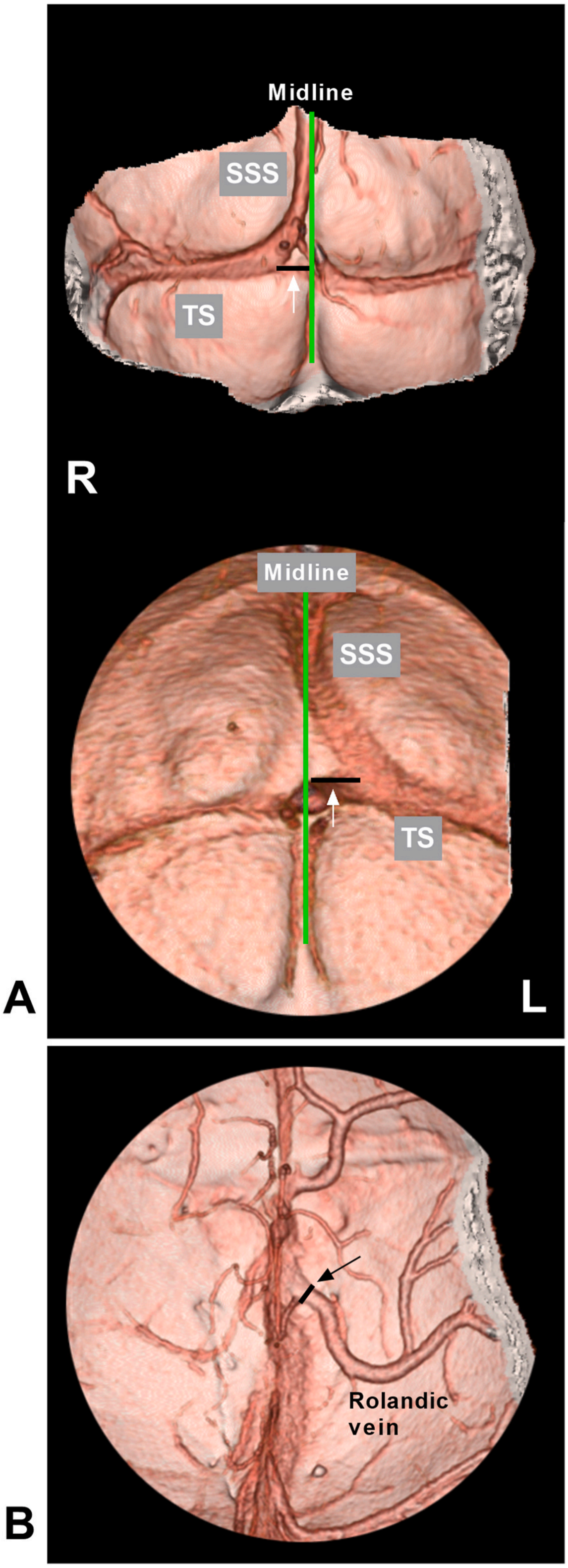

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Fig. 4. SSS deviation and Rolandic vein diameter measurement.
A: CTA showing right (upper panel) and left (lower panel) deviations of the SSS at inion; the arrows indicate the distance of the SSS **deviation** from the midline. B: CTA showing the diameter of the Rolandic bridging vein (arrow).
Abbreviations: CTA: computed tomography angiography, SSS: superior sagittal sinus.

With increasing age, the SSS may change in length or width and height at different locations. However, this study did not show a difference with aging, which indicates that the SSS, as a large sinus, can resist degeneration with aging. However, the ISS is a slender sinus, and we did find a difference in its development with age. The ISS is a venous channel in the inferior margin of the falx cerebri that drains into the straight sinus; it may communicate with the SSS, and the connection can be substantial [18]. We found that with aging, more ISSs were invisible, perhaps due to occlusion or regression with aging.

The typical shape of the SSS in cross-section appears triangular. The SSS has two lateral angles at its junction with the dura mater covering the convexities and an inferior angle at its junction with the falx [10]. The base and height of the triangle are variable; in our study, the base of the SSS in cross-section at lambda was largest. However, the height of the SSS grew from the CS to its termination. The findings are similar to those of the previous reports in Table 5. Most importantly, this study provided data on the SSS width and height from bregma to lambda in the Han Chinese population (Fig. 6C).

Regarding the draining veins of the SSS, there are numerous normal variants, and the average number of draining veins ranges from 13 to 19 vessels for each hemisphere of the cortex [2,10]. This number is generally equal on each side for any given individual. These tributaries terminate as bridging veins emptying into the SSS [1,7,10]. There is usually a free segment of the bridging vein in the subdural space between the vein's exit from its bed in the pia-arachnoid and its entrance into the SSS. The number of bridging veins has rarely been reported. In the report by Han et al. on DSA, the number ranged from 4 to 13 in the unilateral hemispheres [15]; in this study, the number was 3–10 in the total population. Our data were from CTA, and due to resolution differences, our data were different from those in Han et al.'s report [15].

Of all the bridging veins, the largest is the Rolandic bridging vein, connecting with the Trolard vein (superior anastomotic vein), which may be in a precentral, central or postcentral location [19], and which can be identified with CTA. As a very important and relatively constant bridging vein, changes in the Rolandic vein can react to those in other brain bridging veins. With age, these bridging veins may experience degeneration, whose investigation was one of our study's purposes. In Han et al.'s report in Chinese people, the Rolandic vein diameter was 3.3 ± 0.8 mm in diameter [15]. In our study, the Rolandic bridging vein diameter was 3.7 ± 0.9 mm in the general population, similar to the above study. In addition, we also found that the Rolandic vein was thinner in elderly individuals than in nonelderly individuals, which was an important finding, indicating that brain bridging veins may become atrophic with aging.

Although the SSS may drain equally to the right and left transverse sinuses or predominantly or wholly to either side, the right transverse sinus receives the majority of its drainage (commonly three times as much as the left transverse sinus) [2,9,11,20]. In our study, the rate of right deviation of the SSS was 70.2 %, and the rate of left deviation was 15.8 %; the distances of the left and right deviations were 7.1 ± 4.1 mm and 7.9 ± 3.1 mm, respectively, but this difference was not significant, indicating that although left deviation is uncommon, the degree of deviation is similar to that on the right.

5. Conclusions

Our study provided normal CTA anatomy parameters of the SSS and its adjacent structures in Han Chinese participants. This study also found that more ISSs may become occluded and that the Rolandic vein may become increasingly thinner with age. Other parameters of the SSS and its adjacent structures may not change with age.

6. Limitations

The complexity of brain venous structures makes it difficult to describe the SSS, and thus our study may not exactly reflect the real-world data of the SSS and its adjacent structures. These limitations may also be enhanced by the lower resolution of CTA with respect to DSA. In addition, only 3.8 % of the participants in our study were considered very old (>80 years), which may have affected the accuracy of the data.

Ethics statement

This study was approved by the Ethics Committee of the First Hospital of Jilin University (No. 2022-KS-084). All methods were performed in accordance with the relevant guidelines and regulations. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

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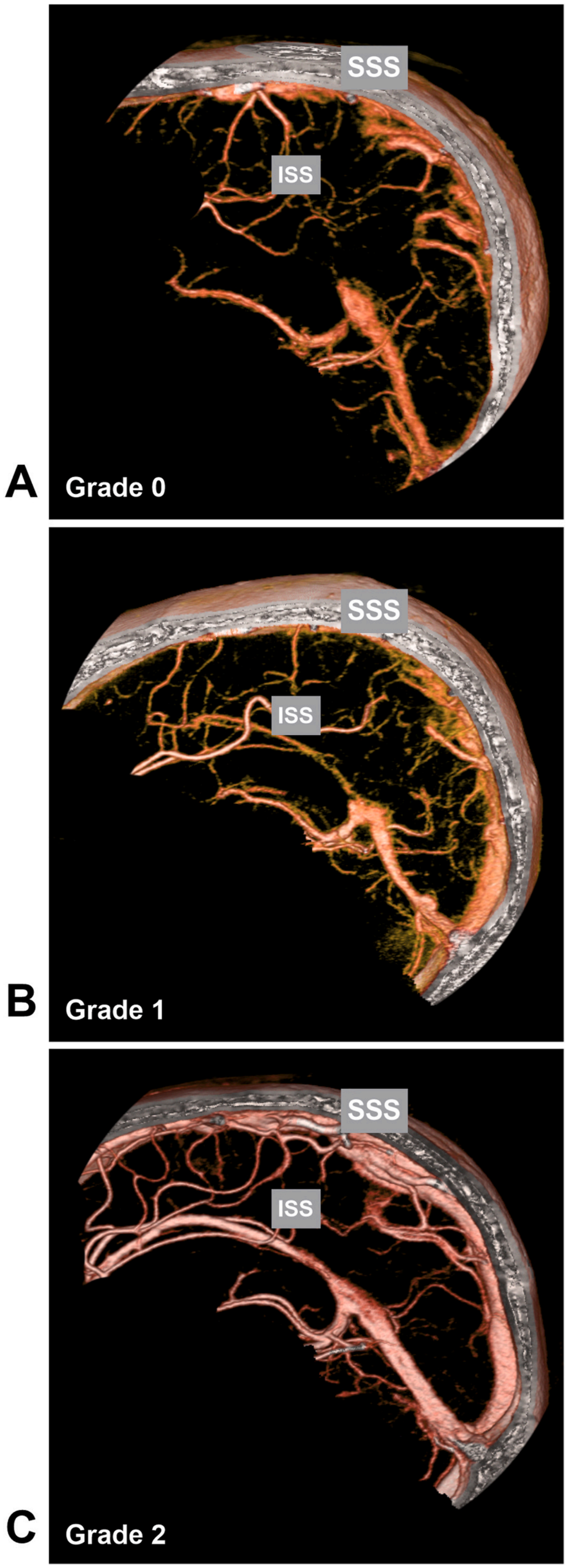

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Fig. 5. ISS development and grading.
A: CTA showing an absent ISS, belonging to grade 0. B: CTA showing a visible and thin ISS, belonging to grade 1. C: CTA showing a clear and well-developed ISS, belonging to grade 2.
Abbreviations: CTA: computed tomography angiography, ISS: inferior sagittal sinus, SSS: superior sagittal sinus.

Table 1
General information.

	Combined group	Elderly group	Nonelderly group	P value
Age (years)	60.7 ± 13.3 (22–90)	68.1 ± 6.3 (60–90)	44.1 ± 9.2 (22–59)	<0.0001
Male/female	374/126	253/93	121/33	0.2202
Headache (no/yes)	382/118	260/86	122/32	0.3621

Note: In this table, between elderly and nonelderly groups, the unpaired *t*-test was used for age, and Fisher's exact test was used for the other data.

Table 2
Continuous variable data.

		Combined group	Elderly group	Nonelderly group	P value
SSS length (cm)		26.4 ± 2.6 (14.3–33.4)	26.5 ± 2.5 (14.3–33.4)	26.1 ± 2.8 (15.6–31.8)	0.1708
Absent SSS length (cm)		2.2 ± 2.2 (0–17)	2.1 ± 2.1 (0–13.2)	2.3 ± 2.3 (0–17)	0.3235
SSS groove length (cm)		28.6 ± 1.9 (17.6–43.5)	28.6 ± 1.6 (23.8–34.5)	28.5 ± 2.3 (17.6–43.5)	0.4466
Length from nasion to bregma (cm)		14.0 ± 0.9 (11.7–16.3)	14.0 ± 0.9 (11.7–16.3)	14.1 ± 0.8 (11.6–16.4)	0.2468
Length from lambda to inion (cm)		7.0 ± 1.1 (4.5–10.9)	7.0 ± 1.1 (4.5–10.5)	6.8 ± 1.1 (4.6–10.9)	0.2060
SSS width (mm)	Bregma	5.2 ± 1.2 (1.9–10.7) ***	5.3 ± 1.2 (1.9–10.7) *	5.3 ± 1.1 (2.4–8.3) **	0.4199
	Lambda	8.6 ± 1.3 (4.4–13.2)	8.6 ± 1.4 (4.4–14.2)	8.6 ± 1.5 (4.8–14.2)	0.7495
	Inion	7.7 ± 1.5 (4.1–17.6)	7.8 ± 1.5 (4.1–17.6)	7.9 ± 1.7 (4.7–16.4)	0.1663
SSS height (mm)	Bregma	4.5 ± 1.3 (1.0–8.6)***	4.5 ± 1.3 (1.0–8.6)*	4.6 ± 1.2 (2.4–7.8)**	0.2764
	Lambda	5.6 ± 1.0 (2.6–9.2)	5.6 ± 1.0 (2.6–9.2)	5.6 ± 1.1 (3.1–8.4)	0.9618
	Inion	6.7 ± 1.3 (3.6–10.7)	6.7 ± 1.3 (3.5–10.7)	6.6 ± 1.3 (3.5–9.8)	0.7295

Note: In this table, the P value reflects the comparison between the elderly and nonelderly groups, and the unpaired *t*-test was used. One asterisk indicates 493 cases in the merged group, two asterisks indicate 152 cases in the nonelderly group, and three asterisks indicate 341 cases in the elderly group. In other data, there were 500 cases in the merged group, 154 cases in the nonelderly group, and 346 in the elderly group.
Abbreviations: SSS: superior sagittal sinus.

Table 3
Counting variable data.

	Combined group	Elderly group	Nonelderly group	P value
SSS development (Integral/absent)	155/345	114/232	41/113	0.1740
SSS deviation (Left/middle/right)	79/70/351	60/48/238	19/22/113	0.3640
ISS development (Absent/visible/clear)	249/139/112	187/85/74	62/54/38	0.0122

Note: In this table, the P value was from the comparison between the elderly and nonelderly groups, and the chi-square test or Fisher's exact test was used.
Abbreviations: ISS: inferior sagittal sinus, SSS: superior sagittal sinus.

Table 4
Other continuous variable data.

	Side or group	Value	P value
SSS deviation from midline (mm)	Left (79)	7.1 ± 4.1 (2.3–19.2)	0.3620
	Right (351)	7.9 ± 3.1 (2.1–16.9)	
Number of ipsilateral bridging vein trunks	Left (500)	5.6 ± 1.5 (3–10)	0.7753
	Right (500)	5.6 ± 1.5 (4–10)	
	Elderly group (692)	5.6 ± 1.5 (3–10)	0.3587
	Nonelderly group (308)	5.8 ± 1.3 (7–9)	
Rolandic vein diameter (mm)	Left (500)	3.7 ± 0.9 (2.0–6.5)	0.5824
	Right (500)	3.7 ± 0.9 (2.3–6.6)	
	Elderly group (692)	3.6 ± 0.8 (2.0–6.3)	0.0284
	Nonelderly group (308)	3.9 ± 1.1 (2.3–6.6)	

Note: In this table, the unpaired *t*-test was used between the left and right sides and between the elderly and nonelderly groups.
Abbreviations: SSS: superior sagittal sinus.

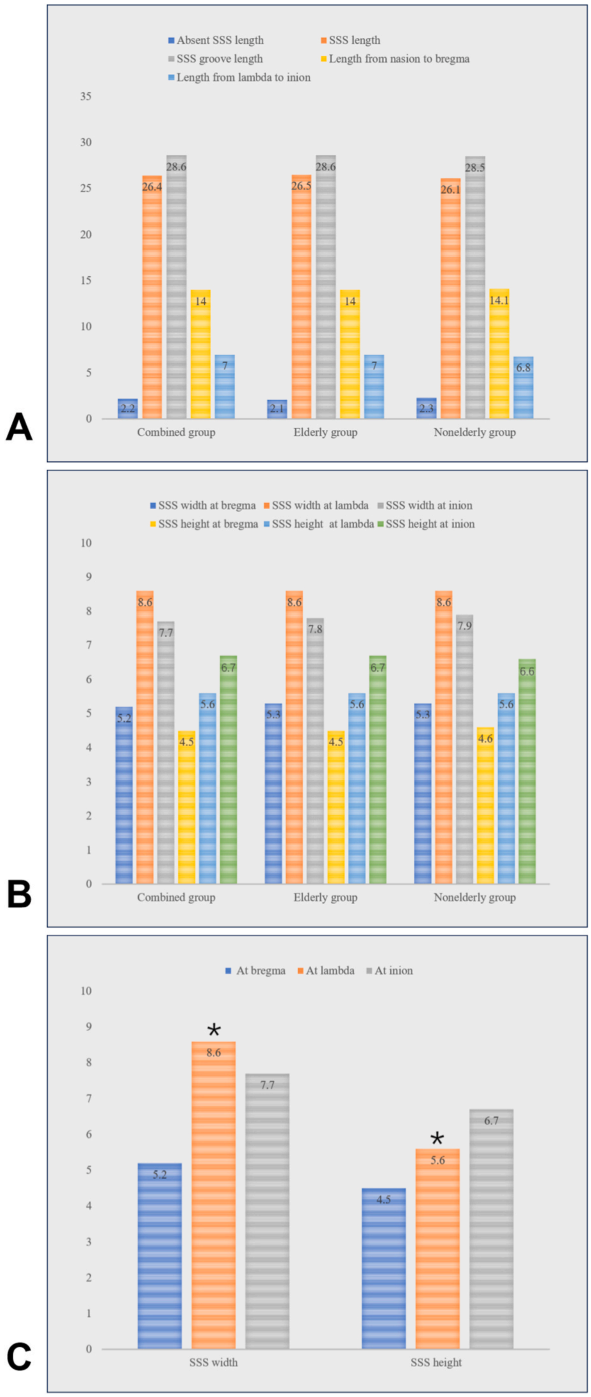

Fig. 6. Column diagram of the main parameters of the SSS.
A: Diagram showing various SSS lengths, including absent and present SSS lengths, in different groups; the unit of measure is cm. B: Diagram showing the width and height of the SSS at different locations in different groups; the unit of measure is mm. C: Diagram showing the width and height of the SSS at different locations in the combined group. The measuring unit was mm, and the asterisks indicate that the width was greater than the height at lambda.
Abbreviations: CTA: computed tomography angiography, SSS: superior sagittal sinus.

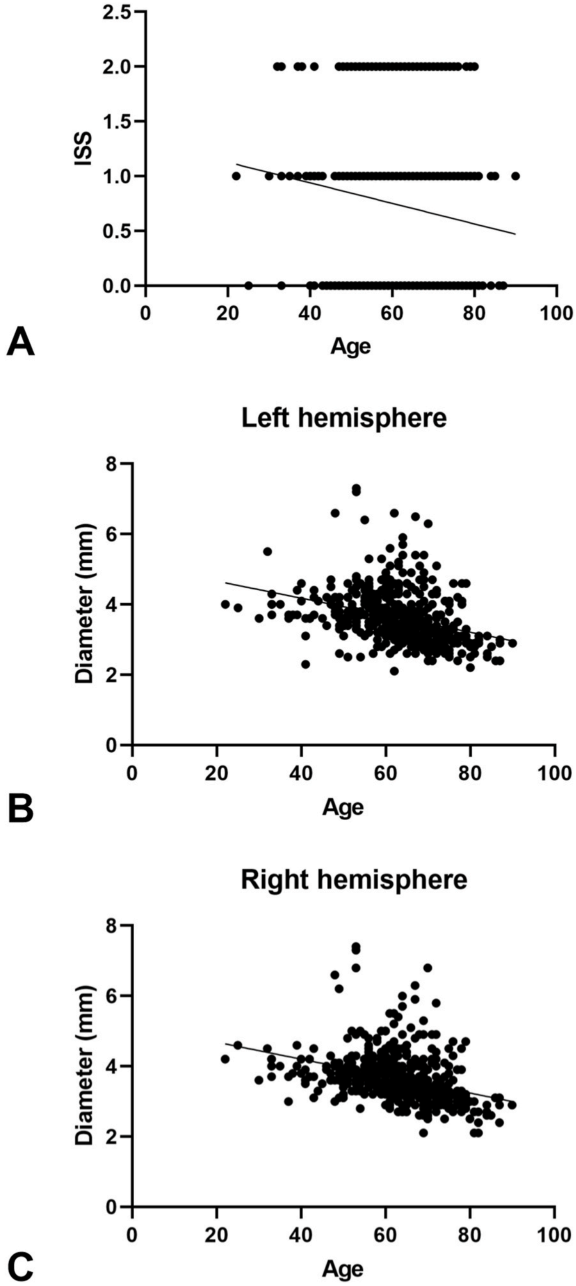

Fig. 7. Diagram of linear regression analysis.
A: Diagram showing a decrease in ISS grade with age. B–C: Diagram showing that the Rolandic bridging vein in the left hemisphere (B) and right hemisphere (C) tends to thin with age.
Abbreviations: CTA: computed tomography angiography, SSS: superior sagittal sinus.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Fasheng Zhao: Data curation, Writing – original draft. **Kan Xu:** Writing – review & editing. **Zibo Zhou:** Data curation, Formal analysis, Software, Writing – original draft. **Jinlu Yu:** Conceptualization, Writing – review & editing.

Table 5
Data on SSS anatomy in previous reports.

Author/Year	Country	Data source	Main finding
Andrews et al., /1989 [10]	USA	10 cadavers	SSS width at middle anterior frontal region: 4.3 ± 1.0 mm, height: 3.6 ± 1.3 mm; SSS width at anterior occipital region: 9.8 ± 2.1 mm, height: 6.9 ± 1.7 mm.
Han et al., /2007 [15]	China	37 cadavers	SSS length: 24.2 ± 2.0 cm; Rolandic vein diameter: 3.1 ± 1.1 mm.
		36 DSAs	SSS length: 23.4 ± 2.6 cm; Rolandic vein diameter: 3.3 ± 0.8 mm.
Samadian et al., /2011 [11]	Iran	50 cadavers	SSS width at bregma: 6.2 mm; SSS width at lambda: 9.4 mm; Right deviation: 64 % of cadavers.
Brockmann et al., /2011 and 2012 [12,21]	Germany	9 cadavers	SSS length: 19.2 ± 1.4 cm; SSS width at bregma: 5.2 ± 1.1 mm, height: 4.7 ± 1.0 mm.
		30 CT angiographies	SSS length: 25.6 ± 1.6 cm; SSS width at bregma: 6.7 ± 2.0 mm, height: 5.3 ± 1.8 mm.
Reis et al., /2015 [9]	Brazil and USA	8 cadavers	SSS width at bregma: 5.9 ± 1.1 mm; SSS width at lambda: 7.9 ± 2.4 mm. SSS right deviation at inion: 6.0 ± 2.1 mm.
		150 MR angiographies	SSS width at bregma: 9.3 ± 2.5 mm; SSS width at lambda: 12.0 ± 3.0 mm.
Bruno-Mascarenhas et al., /2017 [2]	India	12 cadavers	SSS length: 33.9 cm; SSS width at bregma: 4.3 mm, height: 3.6 mm; SSS width at lambda: 9.9 mm, height: 6.9 mm.
Juskys et al., /2022 [22]	Lithuania	Cadavers	SSS width at bregma: 10.2 mm, width at lambda: 13 mm.

Abbreviations: SSS: superior sagittal sinus, CT: computed tomography, MR: magnetic resonance, DSA digital subtraction angiography.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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