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ORIGINAL ARTICLE - NEUROSURGICAL ANATOMY

Bridging vein and tentorial sinus in the subtemporal corridor during the anterior transpetrosal approach

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Abstract

Background The bridging vein (BV) and the tentorial sinus (TenS) are important venous structures in neurological surgery. These venous structures during the anterior transpetrosal approach (ATPA) have not been reported. The objective of this study is to examine the BV and the TenS in the subtemporal corridor during the ATPA and propose a technique to identify the BV preoperatively.

Methods This study included 126 patients treated via the ATPA. The BV and the TenS located in the operative fields were analyzed. Furthermore, in the preoperative evaluation, the cross-sectional shapes of the intradural vein and the interdural sinus were analyzed by curved planar reconstruction (CPR), and the flattening rate was calculated. Flattening rate = (a-b)/a = 1-b/a (a: long radius, b: short radius).

Results Seventeen BVs and 18 TenS were identified. The bridging site was divided into two groups: tentorial and middle fossa. The middle fossa group was divided into three subgroups: cavernous sinus, middle fossa dural sinus, and middle fossa dural adherence. Five isolated TenS were sacrificed and no venous complications were observed. The mean flattening rate was 0.13 in the intradural vein and 0.51 in the interdural sinus, respectively ($P = 0.0003$).

Conclusions We showed classification of the BV, and preservation of the BV and TenS during the ATPA. Furthermore, we found that the interdural sinus was significantly flatter than the intradural veins. Measuring the flattening rate by CPR may be useful to identify BVs preoperatively.

Keywords Anterior transpetrosal approach · Bridging vein · Curved planar reconstruction · Tentorial sinus · Venous preservation

Introduction

In neurological surgery, venous preservation is an important consideration to avoid postoperative complications [14]. Bridging veins (BVs), in which the intradural vein continues to the interdural sinus, can be injured when stretched. Stretching of BVs occurs when the brain is retracted without awareness of the veins' existence. Damage to BVs may result in severe disturbances of venous return and subsequent brain edema [18, 20, 21]. To avoid injury, the entrance site where the BV empties into the interdural sinus needs to be identified preoperatively.

The tentorial sinus (TenS) is also an important venous structure, particularly during surgeries around the tentorium [12] and may present an obstacle in procedures such as tentorial incision. Preservation and hemostasis of the TenS is needed to reduce venous congestion and massive bleeding.

The anterior transpetrosal approach (ATPA), which is suitable for petroclival lesions and prepontine vascular lesions, was established by Kawase et al. in 1985 [7, 8, 23]. Venous complications, such as those occurring in the superficial middle cerebral vein (SMCV) and the petrosal vein, have been overcome with the development of ATPA [4, 13, 19]. Since the ATPA is fundamentally an extra- and intradural subtemporal approach, with an anterior petrosectomy and a tentorial incision to reach the petroclival area, BVs and the TenS can be encountered in the subtemporal corridor. BVs and the TenS have only been reported in cadaveric studies [2, 3,

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15, 17], and have not been analyzed during the ATPA in a real practical series. Therefore, we examined the BV and the TenS in the subtemporal corridor during the ATPA and proposed a technique to identify the BV preoperatively.

Materials and methods

The review board of our institution approved this retrospective study and written informed consent was obtained from all patients for imaging examinations.

Venous analysis

BVs and the TenS in the subtemporal corridor, identified during operation, were examined from the operative videos and records of 126 patients (37 men and 89 women, aged 6 to 78 years) treated via the ATPA from December 2005 to August 2016. The frequency, component patterns, distribution, and preservation of BVs were analyzed. Postoperative venous complication was defined as postoperative temporal lobe swelling or bleeding. In addition, bleeding and hemostasis of the TenS were analyzed. The BV was defined as the vein that was confirmed to continue from the intradural vein to the interdural sinus intraoperatively. The intradural veins include the temporal basal veins (TBVs), which run on the base of the temporal lobe; the sphenopetrosal veins (SphPVs), which are variations of the SMCV; and the basal vein of Rosenthal (BVR). The petrosal vein in the posterior fossa was excluded in this study. The interdural sinus includes the TenS, which lies between two membranes consisting of the tentorium, and the middle fossa dural sinus (MFDS), which lies between two dural layers of the middle fossa. Venous preservation was confirmed as morphological preservation from the intraoperative findings because postoperative venous evaluation was not performed in all patients. Furthermore, for the preoperative discrimination between the intradural veins and the interdural sinus, cross-sectional shapes of both were analyzed with curved planar reconstruction (CPR) in patients whose preoperative computed tomography venography (CTV) was obtained.

CTV protocol

All examinations were performed with a 320-detector row CT scanner (Aquilion ONE; Toshiba Medical Systems, Otawara, Japan) equipped with 320 detector rows (each 0.5-mm wide) covering 16 cm of volume per rotation. Initially, a test bolus scan was performed at the level of the carotid bulb to determine the optimal timing of dynamic scans using an intravenous injection of nonionic contrast media (20 ml) at a rate of 5 mL/s, followed by saline (20 ml). Subsequently, CT digital subtraction angiography (CTDSA) scans were obtained after a 50-mL bolus injection of contrast media at the rate of 5 mL/s, followed by saline (20 ml). CTDSA scans consisted of a volume scan before the arrival of contrast media to provide an unenhanced mask volume data set for subsequent bone subtraction, and intermittent volume scans every 2 s over 10 s (rotation time 1 s) as venous phases. Other scan parameters were as follows: field of view, 25 cm; slice thickness, 0.5 mm; tube voltage, 80 kV; and current-time product, 350 mAs (first and last phases) and 200 mAs (other phases).

Cross-sectional analysis of veins

Cross-sectional analysis was performed by CPR using image processing software Synapse Vincent (Fujifilm, Tokyo, Japan) or AW server (GE Healthcare, Chicago, IL, USA). For each patient, the intradural vein or the interdural sinus was tracked as the region of interest. The vessels were manually selected by a single neurosurgeon, who identified the intradural vein or interdural sinus based on intraoperative videos and operative records on two separate occasions. Images of the planes orthogonal to the long axis of the veins were generated and the flattening rate was measured, which was calculated based on the following equation: flattening rate = (a-b)/a = 1-b/a (a: long radius, b: short radius). Zero represents the circle and closer to 1 represents the ellipse. A CPR analysis is illustrated in Fig. 1.

Statistics analysis

The normality of the data was evaluated using the Shapiro-Wilk test. Variables that were normally distributed were compared using the Student *t* test and variables which were not normally distributed were compared using the Mann-Whitney's *U* test. Differences were considered significant at $p < 0.05$.

Results

Seventeen BVs in the subtemporal corridor were identified in 17 (13.5%) of 126 patients. The distribution of BVs is shown in Fig. 2. The bridging site was divided into two groups: the tentorial group, which empties into the tentorial sinus, and the middle fossa group, which empties into the middle fossa dural structures (Table 1). The middle fossa group was divided into three subgroups: the cavernous sinus (CS), MFDS, and middle fossa dural adherence (MFDA). The CS subgroup empties into the CS, the MFDS subgroup empties into the middle fossa floor dural sinus, and the MFDA subgroup adheres to the middle fossa dura (Table 1). The bridging intradural veins in each group were as follows: TBV 29.4% (5/17) and BVR 5.9% (1/17) in the tentorial group; TBV 5.9% (1/17) in CS subgroup; TBV 23.5% (4/17) and SphPV 5.9% (1/17) in MFDS subgroup; and SphePV 29.4% (5/17) in MFDA subgroup (Fig. 3) (Table 1). There was no BV emptying into the superior petrosal sinus (SPS). Venous preservation was achieved in all BVs and there was no postoperative venous complication such as temporal lobe

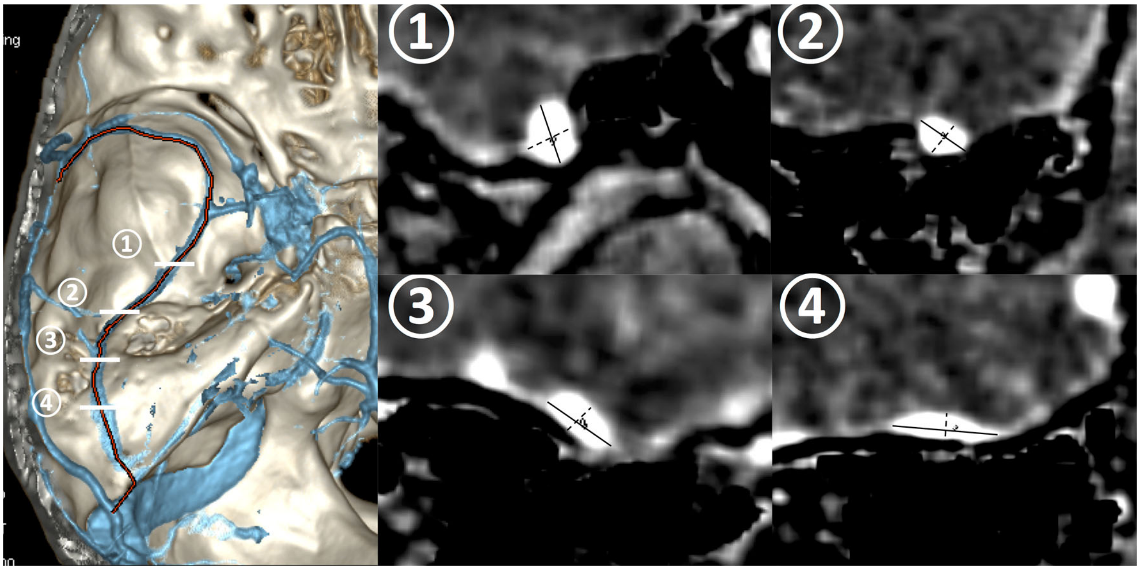

Fig. 1 Cross-sectional analysis of vessels by curved planar reconstruction. The intradural veins or interdural sinuses were tracked as the region of interest. The images of the planes orthogonal to the long axis of the veins were generated and flattening rate was calculated. Solid lines represent the long radius (a) and dotted lines the short radius (b). Flattening rate = (a-b)/a = 1-b/a. Zero represents the circle and closer to 1 represents the ellipse

swelling or bleeding (Table 2). In the tentorial group, tentorial incision was done anterior to the bridging site (Fig. 4a). In the MDFS subgroup, the temporal dural incision was performed anterior to the site where the veins (TBV or SphPV) empty into the MFDS (Fig. 4b). In the MDFA subgroup, venous adherence to the middle fossa dura was detached as much as possible and the temporal dural incision was performed anterior to the bridging site (Fig. 4c). Although minor bleeding was found in one entrance site of the BV, in which the TBV continued to the MFDS (MFDS subgroup) (Fig. 2), hemostasis was achieved by Surgicel® (Ethicon, Somerville, NJ, USA), an absorbable hemostat made of an oxidized cellulose polymer, and the vein was preserved (Table 2).

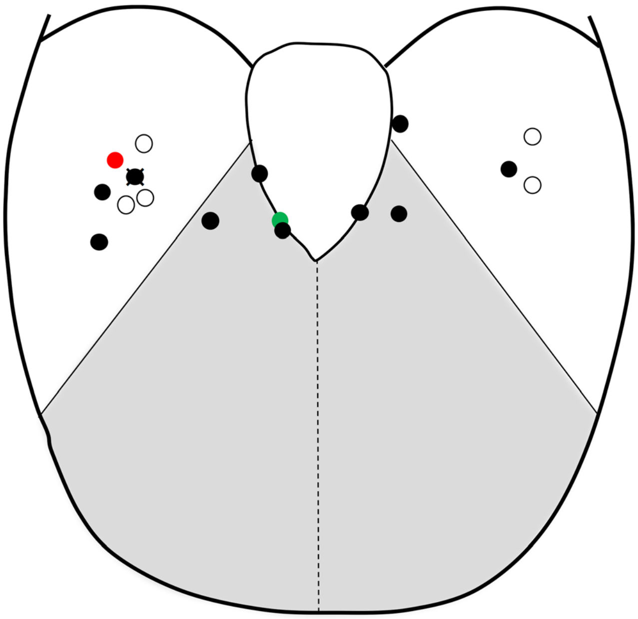

Fig. 2 The distribution of the dural entrance site of bridging veins encountered during the anterior transpetrosal approach. The bridging site was divided into two groups: tentorial (gray area) and middle fossa (white area). Black dots show entrance of the temporal basal vein into the dura, the red dot shows entrance of the sphenopetrosal vein into the dura, the green dot shows entrance of the basal vein of Rosenthal to the dura, and white dots show the bridging site of the sphenopetrosal vein adhering to the dura. The black dot with "X" shows the bleeding point of the bridging vein

The TenS in the subtemporal corridor were identified in 18 (14.3%) of 126 patients. Six TenS were components of BVs, which were included in the tentorial group of the BV, and 12 TenS were isolated. Preservation was achieved in seven isolated TenS (Table 2). In the isolated TenS, a tentorial incision was performed to avoid cutting part of the TenS (Fig. 5a), or a tentorial incision was performed at tumor attachment since TenS was occluded at this site (Fig. 5b). Bleeding was observed in five isolated TenS and was stopped by Ligaclip® (Ethicon, Somerville, NJ, USA) 3, Surgicel® 1, and both 1 (Table 2). There was no postoperative venous complication in the isolated TenS (Table 2).

Cross-sectional analysis

Preoperative CTV was performed in 19 patients; ten BVs and nine TenS were included. The total number of targeted venous structures was 25 (10 intradural veins and 15 interdural sinuses). The mean long and short radii of the vessels detected by CTV were 2.94 mm (1.4–5.2 mm) and 1.78 mm (0.7–4.1 mm), respectively. There was no significant difference in the mean long radius between the intradural vein and the

Table 1 Classification of bridging vein

Bridging point	No. of bridging point	Bridging veins, no.
Tentorial group	6	Temporal basal vein, 5; BVR 1
Middle fossa group	11	
-CS subgroup	1	Temporal basal vein, 1
-MFDS subgroup	5	Temporal basal vein, 4; Sphenopetrosal vein, 1
-MFDA subgroup	5	Sphenopetrosal vein, 5

BVR basal vein of Rosenthal, *CS* cavernous sinus, *MFDA* middle fossa dural adherence, *MFDS* middle fossa dural sinus

interdural sinus. The mean flattening rate was 0.13 in the intradural vein and 0.51 in the interdural vein, respectively (Fig. 6). The interdural vein was showed significantly flatter than the intradural vein ($p = 0.0003$).

Discussion

Bridging vein

BVs are important in neurological surgery since injury of these veins may result in severe brain damage [18, 20, 21]. There is some evidence of postoperative venous complications after lateral cranial base approaches [5, 10]. In this study, BVs were found during the ATPA in 17 (13.5%) of 126 patients. The bridging site was classified as described in the result section (Figs. 2 and 3) (Table 1). The current finding is the first report of the BV during the ATPA in a real clinical series.

Previous studies examining BVs are listed in Table 3. The classifications of the BV vary since the approach and observation area in each study are different. However, there is partial overlap between the studies. The observation area of each study is shown in Fig. 7. Oka et al. examined all superficial cerebral veins and classified BVs based on their termination

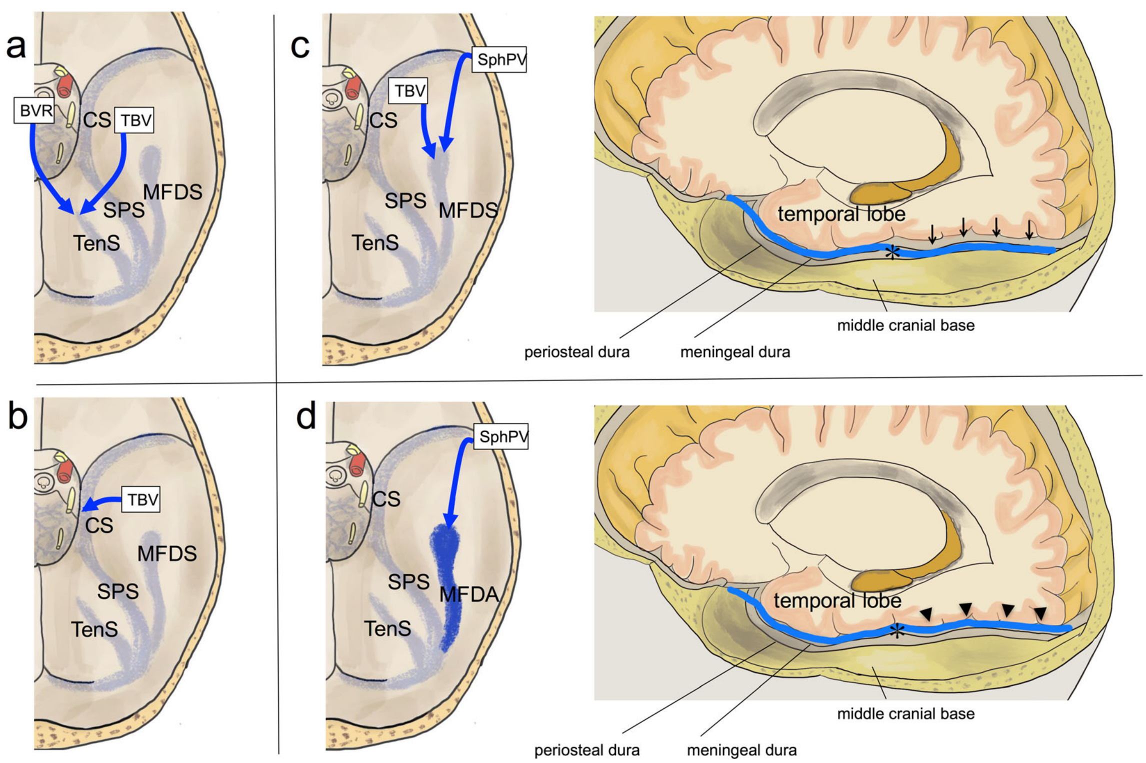

Fig. 3 Classification of the bridging sites encountered in the subtemporal corridor during the anterior transpetrosal approach. **a** Tentorial group. The temporal basal vein (TBV) and the basal vein of Rosenthal (BVR) empty into the tentorial sinus. **b** Cavernous sinus (CS) subgroup in the middle fossa group. The TBV empties into the CS. **c** Middle fossa dural sinus (MFDS) subgroup in the middle fossa group. The TBV and the sphenopetrosal vein (SphPV) empty into the MFDS. Asterisk depicts the bridging site. Black arrows show interdural sinus in between the meningeal dura and the periosteal dura. **d** Middle fossa dural adherence (MFDA) subgroup in the middle fossa group. The SphPV adheres to the middle fossa dura. Asterisk depicts bridging site. Black arrowheads show venous adhesion to the middle fossa dura. BVR basal vein of Rosenthal, CS cavernous sinus, MFDA middle fossa dural adherence, MFDS middle fossa dural sinus, SphPV sphenopetrosal vein, SPS superior petrosal sinus, TBV temporal basal vein, TenS tentorial sinus

Table 2 Preservation, bleeding, and hemostasis of bridging vein and tentorial sinus

Group	Preservation	Bleeding	Hemostasis, no.	Venous complication
Tentorial group	6/6	0/6	–	0/6
Middle fossa group	11/11	0/11	–	0/11
-CS subgroup	1/1	0/1	–	0/1
-MFDS subgroup	5/5	1/5	Surgicel®, 1	0/5
-MFDA subgroup	5/5	0/5	–	0/5
Isolated tentorial sinus	7/12	5/12	Ligaclip®,3; Surgicel®, 1; Ligaclip® with Surgicel®, 1	0/12

CS cavernous sinus, *MFDA* middle fossa dural adherence, *MFDS* middle fossa dural sinus

site (Fig. 7a) (Table 3) [15]. Their sphenoidal group overlaps with our middle fossa group. Their tentorial group in the previous study also included our tentorial group. Furthermore, they reported that the BVs from the basal surface frequently adhered to the dura mater covering the middle fossa. These veins correspond to our MFDA subgroup. Guppy et al. examined the venous drainage of the lateral and inferior surfaces of the temporal lobe (Fig. 7b) (Table 3) [2]. Although they did not classify the termination of the BV, they showed three basic venous configurations of the inferolateral temporal lobe. Their venous lake type includes our tentorial group. Sakata et al. examined the termination of the temporal BVs during the transpetrosal approach (Fig. 7c) (Table 3) [17]. Their tentorial group had drainage into the medial part of the tentorium and their petrosal group has entry around the SPS, including the tentorium. Considering these results, our tentorial group corresponds to their petrosal group rather than their tentorial group. They showed that the BV into the middle fossa floor dural sinus was identified in only one specimen. This vein corresponds to our MDFS subgroup. Han et al. examined the entry site of BVs in the middle fossa (Fig. 7d) (Table 3) [3]. Their cavernous sinus area corresponds to our CS subgroups and middle fossa floor area corresponds to our MFDS subgroup. They did not examine BVs emptying into the TenS.

In our study, the observation was performed within the operative field of the ATPA, and the area examined was limited to the middle area of the middle fossa and the anterior area of the tentorium (Fig. 7e) (Table 3).

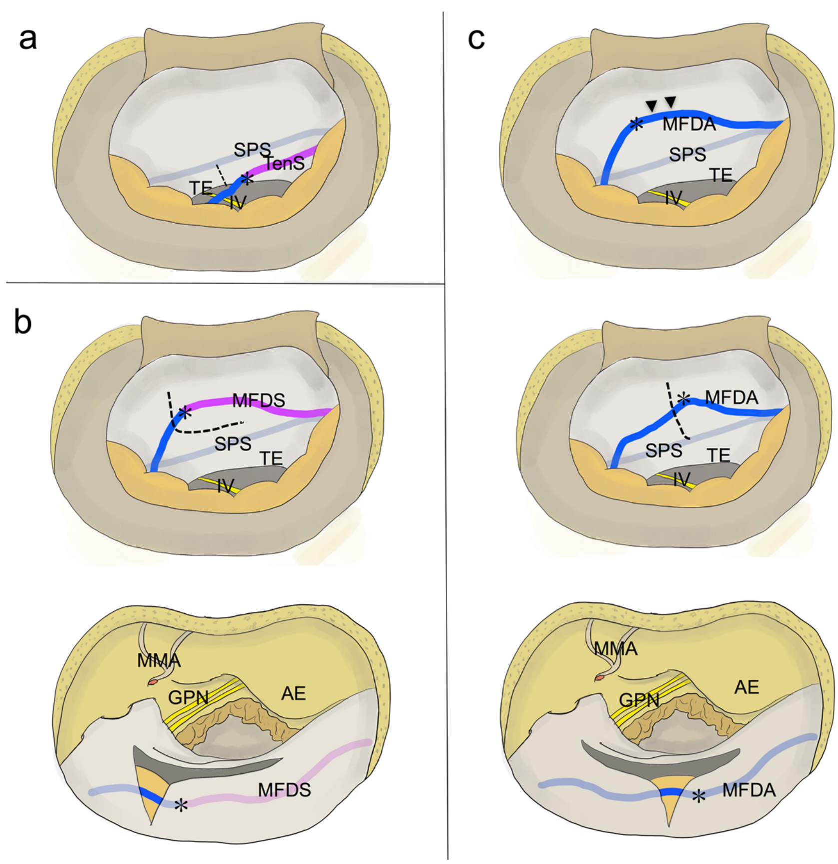

Fig. 4 Schema of preservation of the bridging vein to the middle fossa dura. **a** In the tentorial group, the tentorial incision was made anterior to avoid cutting the bridging site. **b** In the middle fossa dural sinus (MFDS) subgroup, the temporal dural incision was made anterior to the site where the vein empties into the middle fossa sinus. **c** In the middle fossa dural adherence (MFDA) subgroup, adherence to the dura was detached as much as possible and the temporal dural incision was made anterior to the bridging site. Blue line shows the intradural vein. Purple line shows the interdural sinus. Dotted line: dural incision, arrowheads: dural adhesion of the vein, asterisk: bridging site IV: trochlear nerve, AE arcuate eminence, GPN greater petrosal nerve, MFDA middle fossa dural adherence, MFDS middle fossa dural sinus, MMA middle meningeal artery, SPS superior petrosal sinus, TE tentorium, TenS tentorial sinus

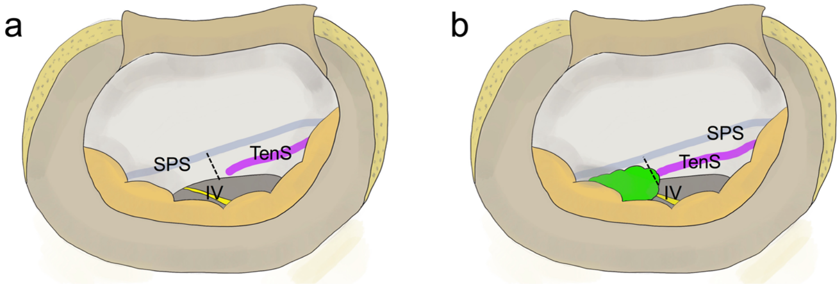

Fig. 5 Schema of preservation of the isolated tentorial sinus during the tentorial incision. The tentorial incision was performed to avoid cutting part of the tentorial sinus (**a**) or the tentorial incision was made at tumor attachment since the tentorial sinus was occluded at this site (**b**). Purple line shows the interdural sinus. Green mass shows tumor. Dotted line: dural incision, asterisk: bridging site IV: trochlear nerve, SPS superior petrosal sinus, TenS tentorial sinus

Tentorial sinus

The TenS encountered in the subtemporal corridor of the ATPA were analyzed. In 1989, Matsushima et al. classified TenS into four groups using cadaveric specimens: Group I, sinus draining from the cerebral hemisphere; group II, sinus draining from the cerebellum; group III, sinus originating from the tentorium itself; and group IV, sinus originating from a vein bridging to the tentorial free edge [12]. The TenS identified during the ATPA in the current study corresponded to groups III and IV. The TenS can be injured when ligating the tentorium. Thus, we first controlled the bleeding by Surgicel® with fibrin glue. If the TenS is largely open, hemostasis can be achieved with a Ligaclip®. Kasuya et al. reported hemostasis of the bleeding from the TenS in the microvascular decompression of trigeminal neuralgia [6]. They described that the bleeding point was suctioned and Surgicel® with fibrin glue was applied.

Preservation of the BVs and the TenS during the ATPA

Since postoperative venous complications can occur when the BV is injured [18, 20, 21] and the temporal lobe is tightly compressed without awareness of its existence, preservation of this vein is important. In this study, we showed preservation of the BVs and the isolated TenS (Figs. 4 and 5). Kyoshima et al. reported on the dura-reflecting technique in the subtemporal approach [9]. Our preservation for BV emptying into the MFDS corresponds to this technique.

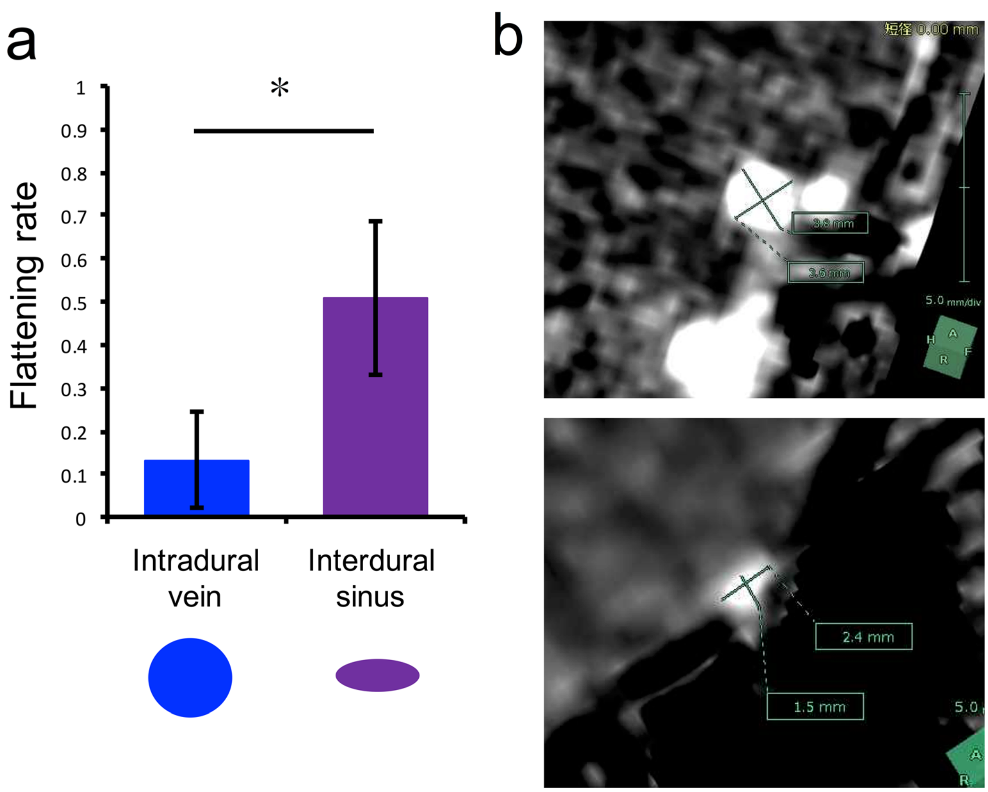

Fig. 6 Cross-sectional analysis of the intradural vein and the interdural sinus. **a** Mean flattening rate of the intradural vein and the interdural sinus. $*P < 0.05$. **b** Representative pictures of the long and short radii of the intradural vein (upper) and the interdural sinus (lower)

Table 3 Literature review on bridging vein

Authors and year	Objects	No. of objects	No. of side	No. of bridging point	Observation method	Classification of bridging vein
Oka et al. [15], 1985	Cadaver	10	20	NA	Removal of cranial cap and cerebral hemispheres	Superior sagittal, sphenoidal, tentorial, and falcine group
Guppy et al. [2], 1997	Cadaver	21	40	NA	Subtemporal-retrosigmoid -suboccipital craniotomy	Candelabra, multiple independent draining, and venous lake type
Sakata et al. [17], 2000	Cadaver	10	20	44	Transpetrosal approach	Transverse sinus, tentorial, and petrosal group
Han et al. [3], 2010	Cadaver	30	60	202	Brain and brainstem removal	Sphenoid wing, cavernous sinus, middle fossa floor, and petrosal area
Present study	Patients	126	126	17	Anterior transpetrosal approach	Tentorial and middle fossa group

Various veins encountered during the ATPA

The ATPA includes multiple procedures such as epidural detachment, anterior petrosectomy, temporal dural incision, SPS/tentorial ligation, and procedures in the posterior fossa [7, 8, 23]. In each step, we may encounter important veins such as the SMCV, temporal BV, TenS, and petrosal vein. In this study, we focused on the subtemporal corridor during the ATPA, and examined the BVs and the TenS.

We previously reported on the classification of the SMCV variation encountered in the steps of epidural detachment, anterior petrosectomy, and temporal dural incision during the ATPA and modification of the procedure to preserve the SMCV variations [19]. In our previous study, the SMCV was classified into six subtypes: Type 1, cavernous or absent; type 2a, medial sphenobasal; type 2b, lateral sphenobasal; type 3a, sphenopetrosal vein; type 3b, sphenopetrosal vein to sinus; and type 3c, sphenopetrosal sinus. Type 3b in this classification partially overlaps with the MFDS and MFDA subgroups.

The petrosal vein is also important during the ATPA. Watanabe et al. reported classification of the petrosal vein based on the normal drainage point into the SPS [22]. Mizutani et al. showed anastomosis from the petrosal vein to the basal vein in the petroclival meningioma treated by the ATPA [13]. Knowledge of these venous anatomies is necessary in the steps of SPS ligation and in the posterior fossa procedure of the ATPA.

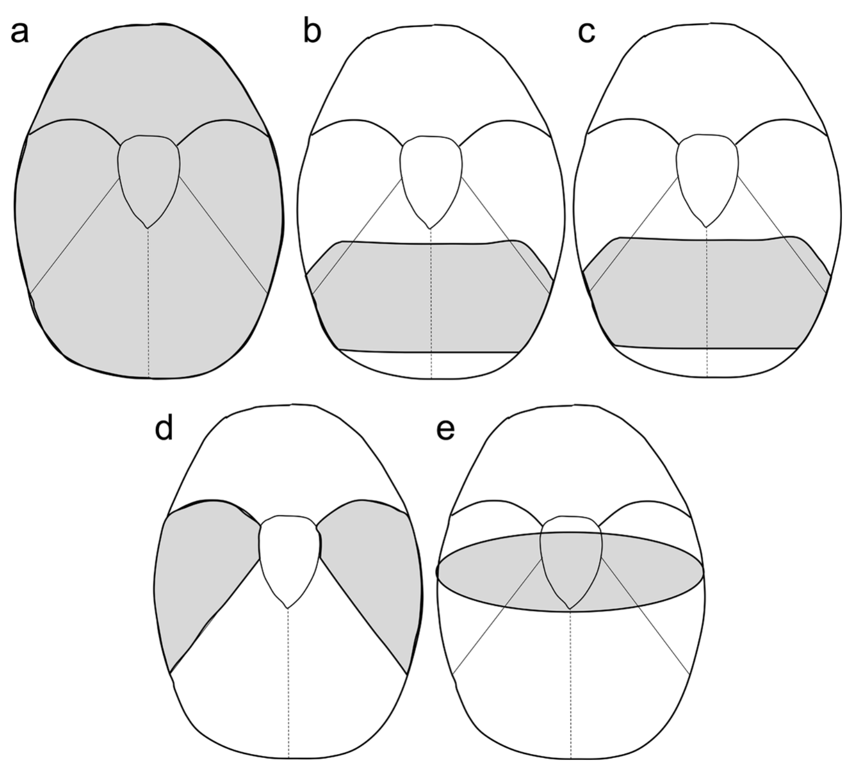

Fig. 7 The observation area of the previous studies on the bridging veins. Gray area shows each observation area. **a** The area observed by Oka et al. with removal of cranial cap and cerebral hemispheres. **b** The area observed by Guppy et al. with subtemporal-retrosigmoid-suboccipital craniotomy. **c** The area observed by Sakata et al. with transpetrosal approach. **d** The area observed by Han et al. with brain and brainstem removal. **e** The area observed in this study with the anterior transpetrosal approach

Preoperative evaluation of the BV

To preserve BVs, it is important to predict its existence preoperatively. In this study, we proposed the CPR technique to identify the BV preoperatively. By using CPR, we detected vessels with long and short radii of 2.94 mm (1.4–5.2 mm) and 1.78 mm (0.7–4.1 mm), respectively. Han et al. preoperatively evaluated the BVs by DSV, CTV, and MRV, and detected BVs with mean diameters of 2.9, 3.1, and 3.4 mm, respectively [3]. These results indicate that the CPR technique in CTV can detect vessels as small as those found in the DSV. CPR is a well-established processing technique for volumetric CT data sets that allows for visualization of vessel pathways and evaluation of a 3D tubular objection on a single 2-dimentional image [11]. Currently, the most common indication of CPR includes tubular analysis such as carotid stenosis, suspected atherosclerotic disease, and congenital/vascular malformations of the gastrointestinal tract [1, 16, 24]. Histological analysis of BVs also showed that the shape of the lumen changes from a round lumen in the intradural vein to a flat lumen in the interdural sinus [3]. Considering this result, it is necessary to distinguish the shape of the intradural veins from that of the interdural sinus to estimate the entrance site of BVs. In this study, we showed that the interdural sinus was significantly flatter than the intradural veins using CPR. The difference in flattening rate between the intradural veins and the interdural sinus may be useful in evaluating BVs preoperatively.

Limitations

The limitation of this study is that the lack of postoperative confirmation of venous preservation. In this study, we confirmed venous preservation as morphological preservation in intraoperative findings since postoperative venous evaluation was not performed in all patients.

Conclusions

We have described the BV and the TenS during the ATPA. We proposed classification of the BV, and preservation of the BV and the TenS. Furthermore, we have shown that the interdural sinus was significantly flatter than the intradural veins by CPR. Measurement of the flattening rate by CPR could be useful in identifying BVs preoperatively.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (the Keio University Center for Clinical Research) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

Informed consent Informed consent was obtained from all individual participants included in the study.

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