Aus dem International Neuroscience Institute Hannover

STUDY OF PINEAL REGION VENOUS SYSTEM WITH THREE-DIMENSIONAL POST-PROCESSING OF MAGNETIC RESONANCE AND COMPUTED TOMOGRAPHY IMAGES: ANATOMICAL AND SURGICAL ASPECTS

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Das venöse System im Bereich der Glandula pinealis (Zirbeldrüse) ist komplex. Unsere bildgebenden Untersuchungen, mit Klassifikationen der unterschiedlichen Drainagemuster der Vena basalis Rosenthal durch 3D Rekonstruktionscomputerprogramme, bilden die Basis für ein besseres Verständnis dieses wichtigen venösen Architektur. Wir zeigen, daß computer -und magnetresonanztomographische Bildbearbeitungsprogramme zusammen mit Navigations -und Rekonstruktionsprogrammen in der Lage sind, in allen Fällen, das venöse Drainagemuster der kleinen und großen Venen um die Glandula pinealis darzustellen und dies ohne zusätzliche Untersuchungen. Außerdem zeigt die genaue Untersuchung der Patienten mit Läsionen im Bereich der Glandula pinealis, daß auch hier die Anatomie mit Neuronavigationscomputerprogrammen dargestellt werden kann, sogar wenn sie durch Tumoren verlagert ist und dies mit der gleichen Genauigkeit wie bei Patienten ohne Läsionen in diesem Bereich. Daher erlaubt diese Technik eine optimale präoperative Planung mit exakter Darstellung der verlagerten Anatomie und zusätzlich intraoperative Navigation. All dies trägt zur Erhaltung dieser Gefäße bei neurochirurgischen infra –oder supratratentoriellen Zugängen bei.

Schlüsselworter

Pinealisregion, Neuronavigation, Vena basalis Rosenthal, Anatomie, Neurochirurgie

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Abkürzungsverzeichnis

Basal vein (BV)

Computed tomography (CT)

Digital subtraction angiography (DSA)

Internal cerebral vein (ICV)

Internal occipital vein (IOV)

Magnetic resonance (MR)

Precentral cerebellar vein (PCV)

Superior cerebellar vein (SCV)

Superior vermian vein (SVV)

Supraculminate vein (SV)

Three-dimensional (3D)

Object

The purpose of this study was to determine the ability of software-assisted Three-dimensional (3D) reconstruction of magnetic resonance (MR) and computed tomography (CT) images performed using a neuronavigation system to delineate the anatomy and variation patterns of the pineal region venous complex. Additionally we examined the usefulness of this tool on the choice of the surgical strategy for the treatment of the tumor of this area.

In the first part of the research (1, 2) we demonstrated that reconstruction of MR and CT images with navigation software provides precise information about the anatomy of both major and minor veins of the pineal region in patients without tumors of this area.

In the second part (3), we studied with the same technique a group of patients affected by lesions of the pineal region itself demonstrating the utility of neuronavigation tool in the surgical planning.

Introduction

The intracranial veins have historically received little attention in the neurosurgical and anatomical literature. The main reason for this is the difficulty in defining a normal pattern, because cerebral veins show a broader range of anatomical variations than do cerebral arteries. The veins coursing in the pineal region delineate a complex and extremely variable network known to be difficult to outline. The internal cerebral vein (ICV) and the basal vein of Rosenthal (BV) are the main vessels draining into the vein of Galen: their intricate structure is still a challenge in anatomy and neurosurgical education. This main system is joined by smaller veins draining this region such as the precentral cerebellar vein (PCV), superior vermian vein (SVV), superior cerebellar vein (SCV), and internal occipital vein (IOV). These vessels are not only difficult to identify for their limited diameter, but are challenging to preserve during the approach to deep-seated lesions because of their position, which usually obstructs the surgical field.

Since the beginning of the twentieth century pineal region tumors have been a great issue for neurosurgeons because of their difficult accessibility and close relationship to important anatomical structures, resulting in significant morbidity and mortality rates. Nowadays the surgical treatment of lesions involving this region remains complex despite the progress of last decades: difficulties are caused primarily by the necessity to respect neural and vascular structures present in this deep-seated area.

During surgery, the sacrifice of these veins may lead to serious postoperative complications; therefore, care should be taken during preoperative planning to evaluate the course of these veins.

Material and Methods

First part: identification of venous variants in the pineal region in living subjects using navigation system

We retrospectively reviewed 100 patients, 70 of them male and 30 of them female, whose ages ranged from 14 to 80 years (mean age 47.3 years), and who were examined at our institute. Patients with posterior fossa lesions were preferred (53%) because of the likelihood of undistorted anatomy in the pineal region. Exclusion criteria consisted of a history of cranial surgery and signs of hydrocephalus on neuroimaging.

Of these 100 patients, a group of 50 composed of 34 men and 16 women between the ages of 18 and 69 years (mean age 46.7 years) had been studied using CT scans obtained on a Volume Zoom scanner (Siemens Medical) with contrast agents (axial slices, 1-mm slice thickness, 512 x 512 matrix, 140 kV, 120 mA, 200 mAs, no gantry tilt). A second group of 50 composed of 36 male and 14 female patients between the ages of 14 and 80 years (mean age 47.9 years) had been studied using MR images obtained on a Magnetom Sonata imager (Siemens Medical) with gadolinium (axial slices, 1-mm slice thickness, 384 x 384 matrix). After the imaging data had been stored in a Digital Imaging and Communication in Medicine (DICOM) file, they were transferred via a computer network to a neuronavigation workstation (CBYON suite, version 2.7) for 3D reconstruction and review.

In our first publication (1) we focused on identification of the ICV, BV, and the vein of Galen in the pineal region. Particular attention was given to the various connection patterns between these vessels. We developed a classification of the venous anatomy in the pineal region based on previous anatomical studies.

In the second published paper (2) We identified the superior vermian complex (SVV, SCV, and supraculminate vein [SV]), PCV, and IOV. Particular attention was paid to the drainage pathways of these vessels into the deep veins because they may frequently block the access to the quadrigeminal cistern in infratentorial supracerebellar and occipital transtentorial approaches.

Second part: depiction of vein of the pineal region with preoperative 3D magnetic resonance imaging navigation in patients harbouring tumors in this area.

In our third publication (3) we studied on the possibility to identify the anatomy of pineal region venous complex using neuronavigation software even if distorted by the presence of a space-occupying lesion and on the influence of pre- and intraoperative depiction of these anatomical relationships on the surgical strategy and results.

We used the neuronavigation software to depict the venous system of the pineal region in 14 patients affected by tumors of the pineal region: 12 male and 2 female, whose ages ranged from 2 to 75 years (mean age 37 years). These lesions included 5 glial tumors, 5 meningiomas, 1 germinoma, 1 teratoma, 1 pineal cyst and 1 metastasis.

The preoperative clinical manifestations included: cerebellar syndrome in 4 cases, signs of increased intracranial pressure in 3 cases, diplopia in 4 cases, hemiparesis in 1 case, trigeminal hypesthesia in 1 case. The imaging study included MR scans with gadolinium (axial slices, 1-mm slice thickness, 1-mm resolution, 384 x 384 matrix, 250-mm field of view, magnet size of 160 cm in length, 60-cm inner bore diameter) on a MRI scanner (Siemens Magnetom Sonata; Siemens Medical). The images were transferred via network to a neuronavigation workstation for 3D reconstruction. The images were enhanced to obtain an optimal visualization of both neurovascular structures and lesion for surgical planning. The tumor volume was then segmented and its spatial relationships with the venous complex and other anatomical structures were carefully investigated by rotation of the image in all the planes.

We focused on depiction of the ICV, BV and vein of Galen: considering our previous classification we categorized the connection pattern between BV and the other draining vessels (from distal to proximal) into five variants: Type 0, BV not present; Type 1, BV draining into the ICV; Type 2, BV draining at the union of the ICVs; Type 3, BV draining into the vein of Galen; Type 4, draining in the straight sinus. Moreover the type of anatomical distortion of the veins caused by the lesion was investigated and a simplified classification developed.

Results

Identification of the internal cerebral vein and basal vein

Three-dimensional reconstruction performed using both CT and MR imaging studies clearly identified ICVs in all patients along the vessel's entire course from the origin, through the union of anterior septal and thalamostriate veins, to their end, at which they drained into the vein of Galen. The identification was unequivocal in all patients examined.

We considered the BV to be divided in three segments: the first part passes from the union of the inferior striate vein, anterior cerebral vein, and deep middle cerebral vein to the anterior end of the cerebral peduncle; the second segment runs to the union of the BV and the lateral mesencephalic vein; and the last portion courses from this point to end in the quadrigeminal cistern. This last segment was depicted in 82 sides (82%) in the group of patients studied using CT scans and in 88 sides (88%) in the MR imaging group. The third segment of the BV was not present in 18 sides (18%) on CT scans and in 12 (12%) on the MR images. It was replaced by PMV in 14 sides (14%) in patients studied using CT scans and in six sides (6%) in the MR imaging group.

We classified the drainage of the last segment of the BV into the following five variants: Type 0, not present; Type 1, draining into the ICV; Type 2, draining at the union of the ICVs; Type 3, draining into the vein of Galen; and Type 4, draining into the straight sinus (**Figure 1**).

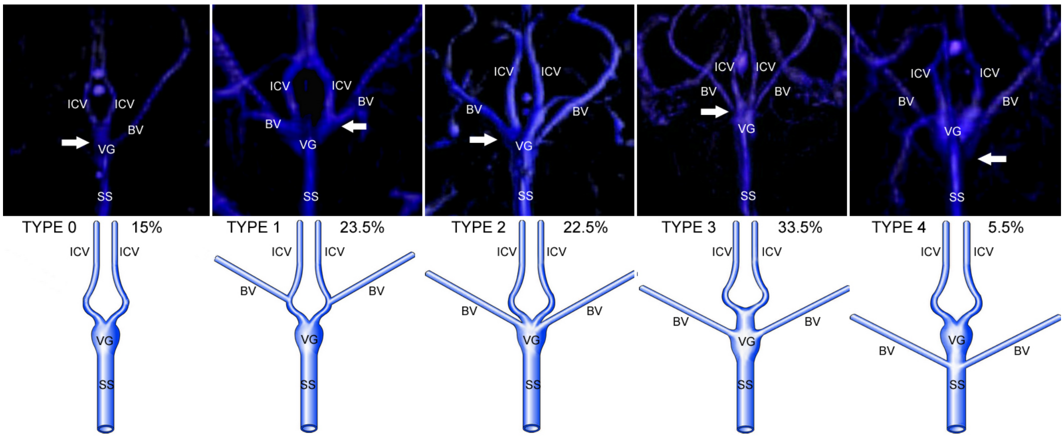

Figure 1: *Three-dimensional reconstructions based on CT and MR images post-processed with navigation software (upper) and schematic drawings (lower) representing the various patterns of drainage of the BV. Type 0, not present (15% of hemispheres); Type 1, draining into the ICVs (23.5% of hemi- spheres); Type 2, draining at the union of the ICVs (22.5% of hemispheres); Type 3, draining into the vein of Galen (VG; 33.5% of hemispheres); and Type 4, draining into the straight sinus (SS; 5.5% of hemispheres). Arrows designate the entry point of the BV.*

The prevalence of Types 0, 1, 2, 3, and 4 was 18, 19, 20, 36, and 7%, respectively, in patients studied using CT scans and 12, 28, 25, 31, and 4%, respectively, in the MR imaging group. The total frequency of Types 0, 1, 2, 3, and 4 was 30 (15%), 47 (23.5%), 45 (22.5%), 67 (33.5%), and 11 (5.5%), respectively. The frequencies of the variants showed no significant difference between the left and the right sides as well as between CT and MR imaging reconstruction. As shown in **Figure 2**, the distribution for venous drain- age patterns showed a significant difference between male and female patients in Types 0 and 3 (p = 0.025).

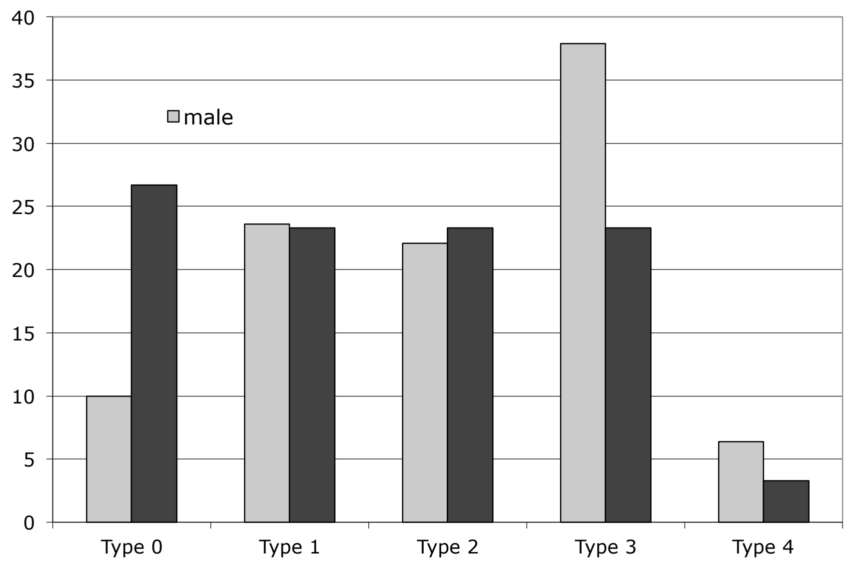

Figure 2: *The prevalence of different drainage types in male and female patients shows a statistically significant difference (p = 0.025) between groups. The third segment of the BV is absent in 26.7% of female patients and in only 10% of males. Numbers on the Y-axis represent percentage.*

In one patient with Type 1 draining pattern, we found an anatomical variation in which the BV drained into the ICV on the opposite side (**Figure 3**).

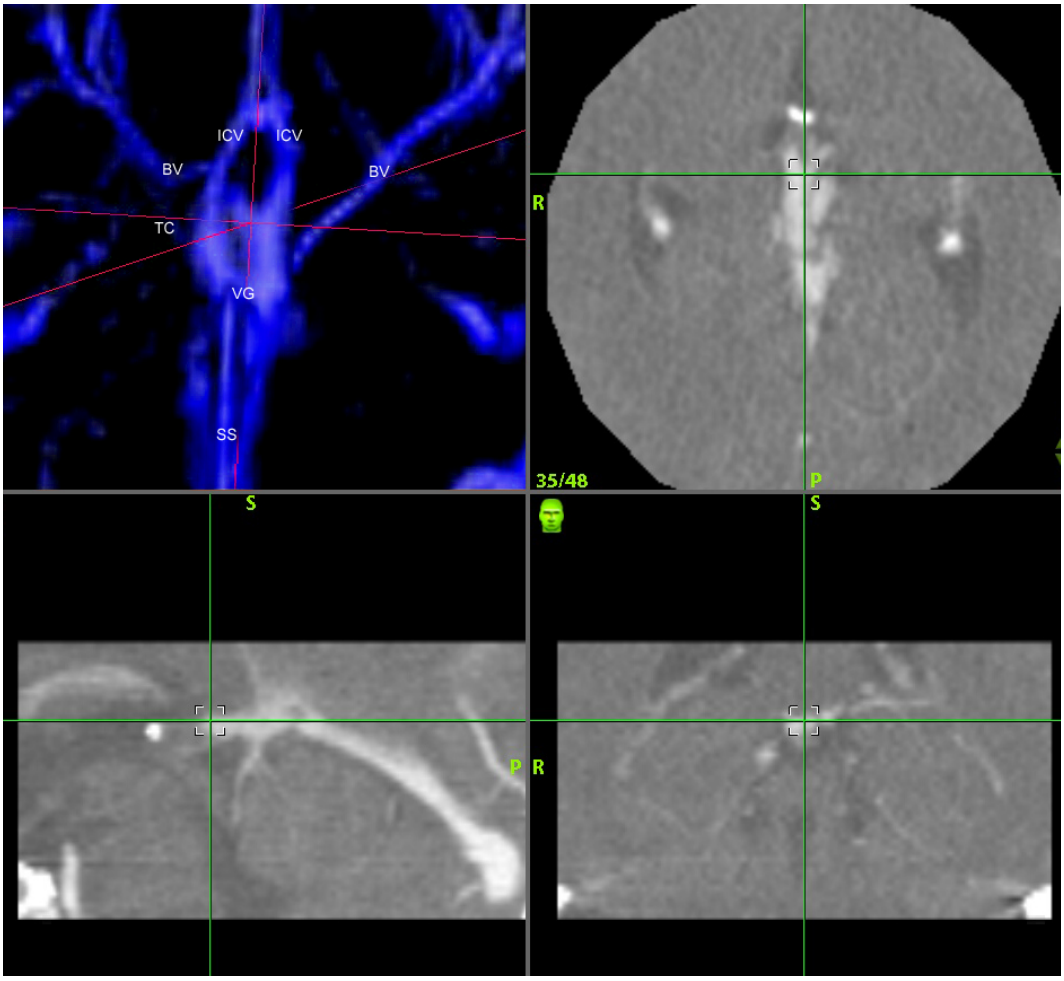

Figure 3: *Three-dimensional reconstruction based on neuronavigation using CT images revealing a rare variant of BV drainage. The left BV on the, after its course in the ambient cistern, passes under the ICV of the same side, joining the right ICV (target point). Note that the right-upper image is a mirror of the left one. TC = thalamocaudate vein.*

According to our objectives we can summarize our results regarding these main vessels as follows: we visualized the ICV in 100% of the cases. The last portion of the BV was depicted in 170 sides (85%); in the remaining 30 sides (15%), the BV was not found to be present.

Identification of the small veins in the pineal region

The veins draining the vermian part of tentorial surface of cerebellum can be divided into an anterior group and a posterior group; the anterior group joins the culmen and between the postcentral fissure to form the SVV. This vessel courses upward into the quadrigeminal cistern, reaching the veins of the pineal region.

The SV is a tributary of the SVV and originates at the level of the tentorial fissure and courses on the midline of the tentorial surface of the cerebellum parallel to the straight sinus draining the culmen.

Moreover, the galenic complex also receives the PCV (also referred as the vein of the cerebellomesencephalic fissure), an unpaired vessel that arises deep in the cerebellomesencephalic fissure at the inferior margin of the lingula. It ascends into the fissure to drain into the vein of Galen either directly or through the SVV forming the SC (**Figure 4, 5**).

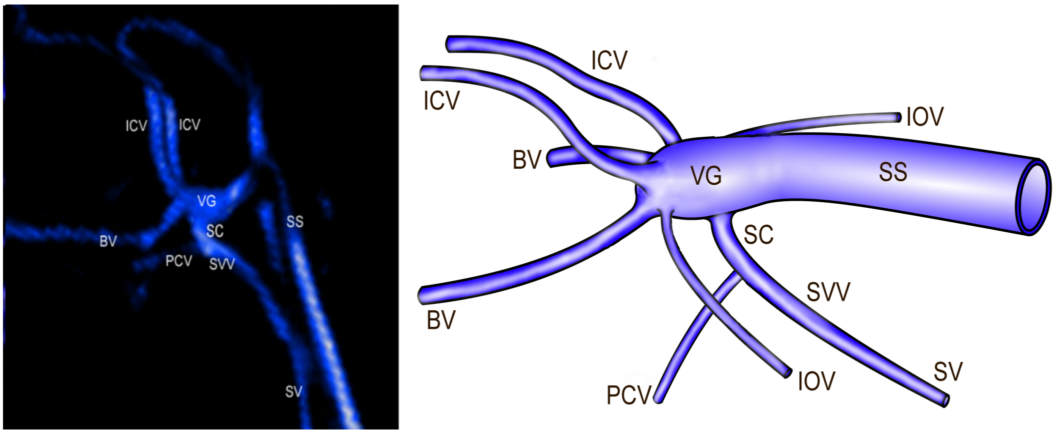

Figure 4: *Three-dimensional (3D) reconstruction based on neuronavigation using magnetic resonance imaging (MRI) and a schematic drawing showing the superior vermian vein (SVV) complex in the lateral view: the precentral cerebellar vein (PCV) joins the SVV, forming the superior cerebellar (SC) vein that drains into the vein of Galen (VG). BV, basal vein; ICV, internal cerebral vein; SS, straight sinus; IOV: internal occipital vein.*

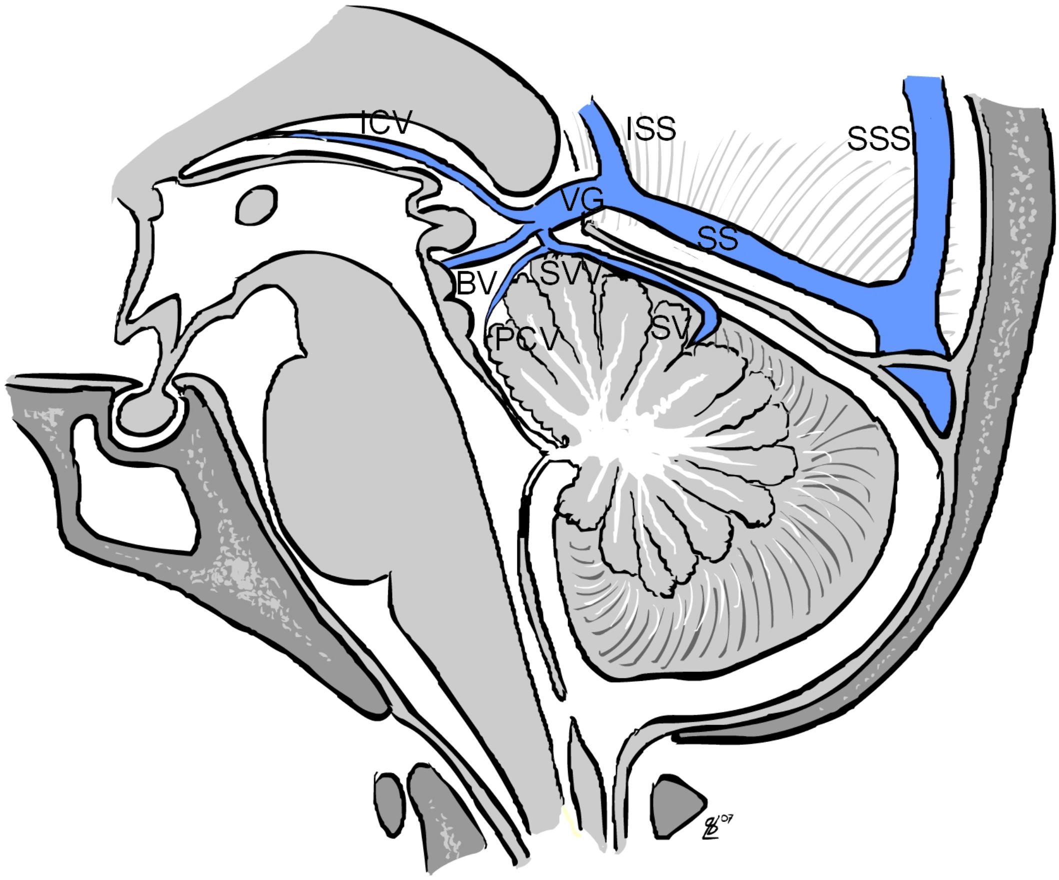

Figure 5: *Schematic drawing in the sagittal view showing the course of the SV and SVV on the cerebellar surface to drain into the VG. The PCV arises deep in the cerebellomesencephalic fissure and ascends to drain into the pineal region venous complex. BV, basal vein; ICV, internal cerebral vein; ISS, inferior sagittal sinus; SS, straight sinus; SSS, superior sagittal sinus.*

The IOV, also referred as the anterior calcarine vein because it drains the primary visual cortex, originates on the medial surface of the occipital lobe at the anterior portion of cuneus and lingual and then courses anteromedially in the quadrigeminal cistern to enter the pineal region venous complex.

We depicted the PCV, SVV, and its tributary SV in a total of 52 (52%) patients: 28 (56%) in the CT 3D group and 24 (48%) in the MRI 3D group. The IOV was followed during its entire course from the medial surface of the occipital lobe to the quadrigeminal cistern on a total of 99 (49.5%) sides: 66 (66.7%) sides in patients studied with CT 3D reconstruction and in 33 (33.3%) sides in patients studied using MRI 3D reconstruction. The IOV joined the basal vein and the vein of Galen in 39 (39.4%) and 60 (60.6%) hemispheres, respectively (**Figure 6 A, B**).

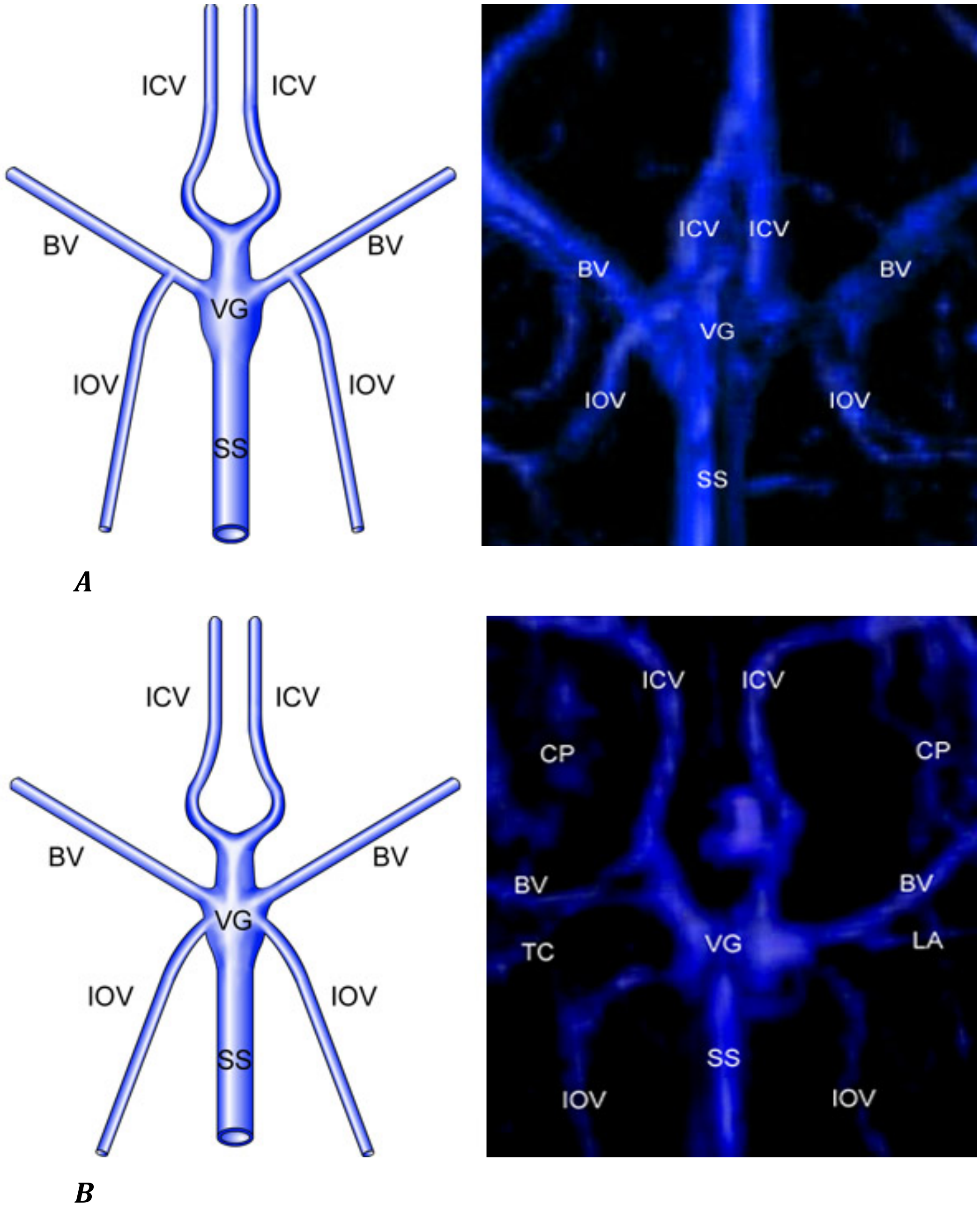

Figure 6 A, B: *Schematic drawing and 3D reconstruction of the pineal region venous complex in the superior view. A, the internal occipital vein (IOV) joins the basal vein in 39 (39.4%) hemispheres. B, the IOV joins vein of Galen in 60 (60.6%) hemispheres. BV, basal vein; ICV, internal cerebral vein; SS, straight sinus; VG, vein of Galen.*

Identification of the pineal veins in patients harboring tumor of this area

All patients underwent surgery with gross total removal of the lesion in 13 patients and endoscopic biopsy in 1 patient. The following surgical routes were used: infratentorial supracerebellar approach in 8 cases, interhemispheric parieto-occipital approach in 4 cases, lateral parieto-occipital craniotomy in 1 case, endoscopic third-ventriculostomy and biopsy in 1 case. No surgical mortalities occurred. Regarding morbidity, two patients (one operated via interhemispheric and one via supracerebellar route) underwent successful revision for subcutaneous accumulation of CSF. Postoperative neurological evaluation showed no new neurological deficits in 12 patients (86%). Out of these an improvement of the preoperative neurological deficits occurred in 3 patients (21%). In 2 patients (14%) a transient Parinaud syndrome disappeared within two weeks following surgery.
Using the neuronavigation software for 3D reconstruction of MRI images the ICV was clearly depicted along its complete course in all the subjects on both sides (100%). The last segment of the BV coursing from its union with the lateral mesencephalic vein to its end into the quadrigeminal cistern was identified in 25 sides on a total of 28 (89.3%) and absent in 3 of the 28 sides (10.7%). Categorizing the drainage patterns of the BV we obtained the following frequency: Type 0 (BV not present) in 3 sides (10.7%); Type 1 (BV draining into the ICV) in 7 sides (25%); Type 2 (BV draining at the union of the ICVs) in 5 sides (17.9%); Type 3 (BV draining into the vein of Galen) in 11 sides (39.3%); Type 4 (draining in the straight sinus) in 2 sides (7.1%). These data show no statistical significant difference ($p > 0.05$) with the values (respectively 12%, 28%, 25%, 31%, 4%) reported in healthy patients. In 7 of the 14 patients (50%) the drainage type of the BV was the same on both sides (mirror configuration).
Studying the distortion effect of the tumor on the galenic venous system, 3 directions of displacement were considered: craniocaudal, anteroposterior and lateral (**Figure 7**).

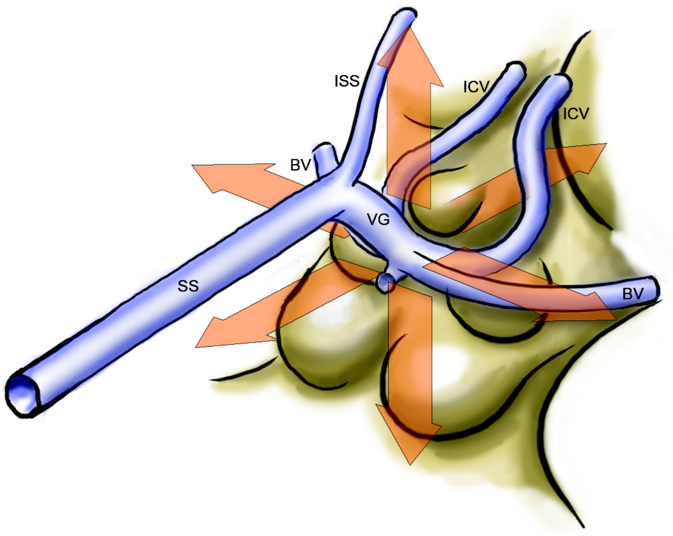

Figure 7: *Three-dimensional schematic drawing showing the various directions of displacement of the pineal region veins complex if distorted by a space occupying lesion. BV, basal vein; ICV, internal cerebral vein; ISS, inferior sagittal sinus; SS, straight sinus; VG, vein of Galen.*

The craniocaudal displacement was the most frequent: 7 patients (50%) presented a cranial dislocation, 5 patients (35.7%) caudal dislocation and there was no shift of the veins on this axis in 2 patients (14.3%). Considering the anteroposterior displacement: 3 subjects (21.4%) showed an anterior shift of the veins, 5 subjects (35.7%) posterior shift and there was no shift of the venous complex on this axis in 6 patients (42.9%). In the lateral direction the displacement was observed in 2 of the 14 patients (14.3%). When the three direction of distortion were evaluated together in the same subject, we observed a clear correlation between the displacement in the anteroposterior and craniocaudal direction: in all the 3 patients with an anterior shift of the venous complex a caudal displacement was associated (**Figure 8**);

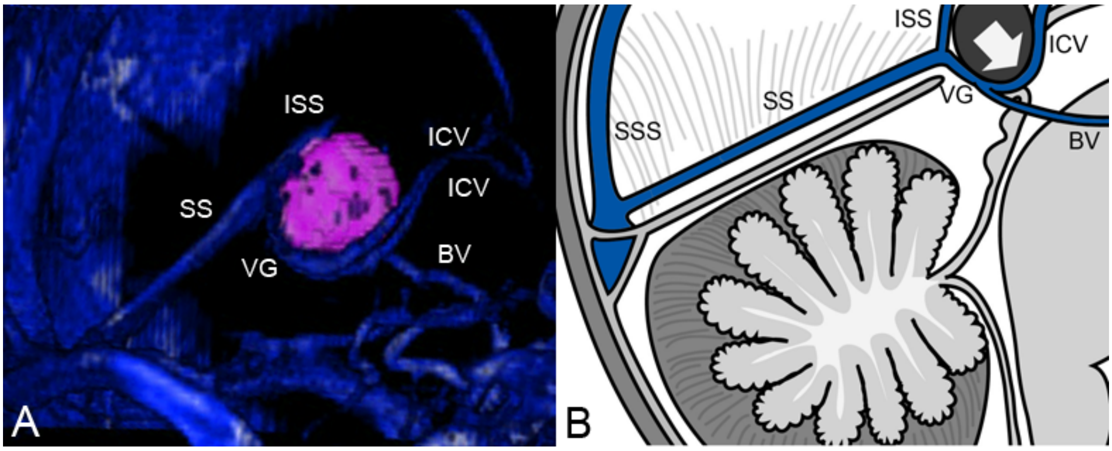

Figure 8: *Three-dimensional reconstruction based on neuronavigation using magnetic resonance images (A) and schematic drawing (B) showing the association of anterior and caudal displacement of the pineal region veins caused by a space occupying lesion (colored in violet in figure A). In this case the tumor was removed using an interhemispheric parieto-occipital approach. BV, basal vein; ICV, internal cerebral vein; ISS, inferior sagittal sinus; SS, straight sinus; SSS, superior sagittal sinus; VG, vein of Galen.*

in all the 5 patients with a posterior shift a cranial displacement was associated (**Figure 9**).

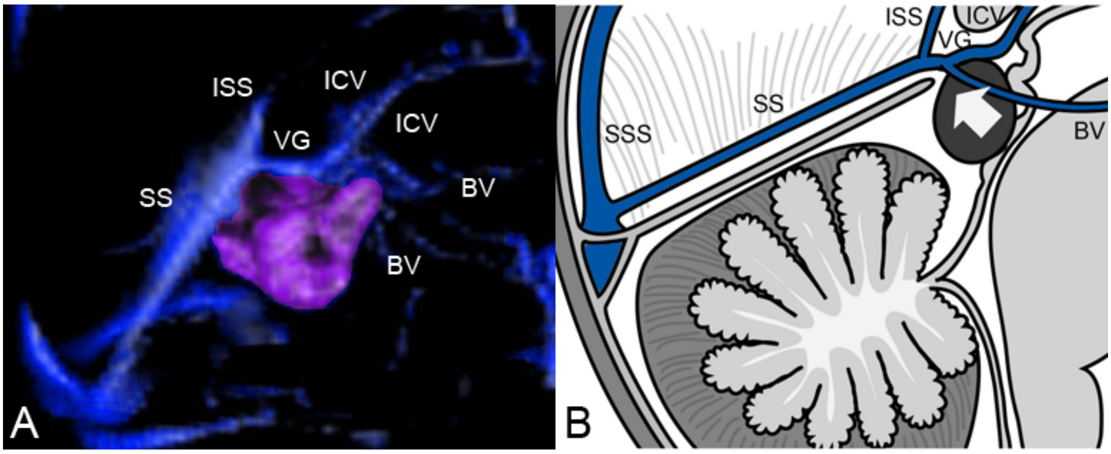

Figure 9: *Three- dimensional reconstruction based on neuronavigation using magnetic resonance images (A) and schematic drawing (B) showing the association of posterior and cranial displacement of the pineal region veins caused by a space occupying lesion (colored in violet in figure A). In this case a supracerebellar infratentorial approach was performed. BV, basal vein; ICV, internal cerebral vein; ISS, inferior sagittal sinus; SSS, superior sagittal sinus; SS, straight sinus; VG, vein of Galen.*

No patient had an anteroposterior shift of the veins without a craniocaudal displacement. On the other hand the craniocaudal displacement was observed without association with anteroposterior dislocation in 4 cases (2 cranial and 2 caudal). In one patient there was no distortion of the galenic venous system. In three cases there was an encasement of the galenic venous system. All these were associated with antero-caudal displacement of the veins.

The principal approaches used in this series were: supracerebellar infratentorial and interhemispheric parieto-occipital. The supracerebellar infratentorial approach was performed in 8 cases: 7 showing a cranial displacement of the deep veins (in 5 cases associated with a posterior displacement) and 1 showing only caudal displacement. The interhemispheric parieto-occipital approach was performed in 4 cases: all these patients presenting a caudal shift of the pineal veins (in 3 cases associated with anterior shift).

Discussion

The anatomy of pineal region veins is a complex issue that has usually been described with the aid of cadaveric dissection. For in vivo depiction of this region, however, digital subtraction angiography (DSA), CT scanning and MR angiography have been performed and the results detailed in previous publications. The study of anatomical structures by using neuronavigation systems has become routinely practiced in recent years for preoperative planning and intraoperative orientation. The CT and MR imaging–based neuronavigation system allows targeted approaches and exact intraoperative guidance to the intracranial lesions, shortening the time of surgery as well as reducing mortality and morbidity rates. Moreover, it may also be important in the planning of surgical procedures: reconstructed images of the vessels can be rotated 360 ° in any plane, not only providing a better representation of the spatial relationship between cerebral veins and the surrounding structures, but also predicting the patterns and the variants that will be encountered on the trajectory to reach the lesion.

Identification of major veins

In our study, we found the third segment of the BV draining in four different configurations, if it was present. These patterns have been classified from the proximal to the distal draining point of the BV, as follows: ICV, union of the ICVs, vein of Galen, and straight sinus.

The BV flows into the vein of Galen (Type 3) in the majority of cases (39.4% of depicted BVs), whereas the path- way that showed less prevalence (6.5% of depicted BVs) was the union with the straight sinus (Type 4). The anatomical study of Chaynes also revealed the union of the BV with the vein of Galen (Type 3) as the most common variant (35.1%), whereas the drainage into the straight sinus (Type 4) was the least common (8.1% of the existing BVs). The comparison of these data with our findings showed no significant difference.

Suzuki and colleagues identified the drainage points of the BV in the posterior or anterior portion of the vein of Galen, the ICV, the tentorial sinus, and the superior petrosal sinus by using 3D CT angiography. The flow in the tentorial or superior petrosal sinus is a pathway of the second segment of the BV (from the anterior end of the cerebral peduncle to the union of the BV and the lateral mesencephalic vein), as the same author and colleagues explained in a previous publication: thus, the drainage of the third segment is confined to the ICV and the entire course of the vein of Galen. The variants described in the aforementioned radiology publication can be included in Types 1, 2, and 3 of our classification; however, direct union of the BV with the straight sinus (Type 4) is missing. Even if there are no data in the cited article about the frequency of the various drain- age patterns of the last segment of the BV, the lack of union between the BV and straight sinus supports our finding that this variant is rare. The agreement with previous anatomical and radiological studies regarding the different types of drainage of the third segment of the BV and their prevalence confirms the reliability of CT and MR imaging neuronavigation in the identification of the veins we have studied, and their variants.

Absence of the basal vein

The data in our study confirm the great complexity of the venous system localized in the pineal region. We were able to identify the ICV in all cases, and we found the last segment of the BV in 170 sides (85%); it was replaced by the PMV in 20 sides (10%)

and was not present in 10 (5%). This is in accordance with previous anatomical and radiological studies on the subject: the anatomical study published by Chaynes demonstrated that the posterior portion of the BV was present in 74% of the hemispheres. It was replaced by the PMV in 14%, whereas in the remaining 12% it did not exist because the second segment of the vein drained into the lateral mesencephalic vein. Suzuki and associates studied the BV over its entire course by using 3D CT angiography, and they found that the last segment of the BV flowed into the vein of Galen in 87.8% of patients, even if anastomoses between the first and second segments were not confirmed in 36.9% of these. Thus, in agreement with our study, in the remaining 12.2% the BV was not present. Moreover, these authors observed that the great variation in the drainage pathway of the complete BV is due to different longitudinal anastomosis patterns between primary embryological veins. These findings support the hypothesis that in 30 sides (15% of the hemispheres in our cases) the last portion of the BV was not depicted because it was not present at all. Another possibility for the missing BVs is, of course, a technical problem with the resolution of veins on neuroimaging studies, but due to the fact that in previous anatomical studies the BV was not always present, we can suppose a real absence of this vein in 30 (15%) of 200 of our hemispheres.

Sex-Related Differences

Statistical analysis of our results demonstrates that the anatomy of deep veins in the pineal region varies significantly according to gender. In our group, the absence of the BV (Type 0) in female patients has a significantly higher prevalence (26.7%) compared with findings in males (10%). This finding may have pathological correlations. Benign intracranial hypertension, also known as pseudotumor cerebri, is a syndrome characterized by increased intra- cranial pressure in patients with normal cerebral anatomy on neuroimaging studies and no alteration in cerebrospinal fluid composition. Various mechanisms have been indicated as responsible for this condition, and these factors have been hypothesized to result in an increase of intracranial venous pressure. Pseudotumor cerebri is more common in the female population, with prevalence between 89 and 92%. The significant absence (Type 0) of the last segment of the BV in female patients may play a role in the alteration of venous flow. Venous drainage problems were thought to be the underlying cause in 25% of cases of pseudotumor cerebri. The observed gender-related variation in venous outflow may create a basis for the female predisposition to benign intracranial hypertension.

Depiction of minor veins

Our results were compared with those of previous studies. Suzuki et al. observed the SVV using 3D CT-angiography in only 5% of the patients and the IOV in almost all patients, but the study did not provide exact numbers. Using DSA, Kiliç et al. depicted the SVV and IOV in 50% and 55% of the specimens, respectively. In comparison, the same authors were able to show the SVV and IOV in only 20% and 35% of specimens, respectively, with magnetic resonance venography using a 2-dimensional time-of-flight technique. In contrast with the cited radiological literature, the anatomic study of Chaynes using cadavers demonstrated the IOV and SVV as present in all of them.

Comparison of these results of anatomic and imaging studies shows large differences in the identification of smaller vessels; this may be owing to the size of the veins that renders their depiction still difficult using current imaging techniques, as demonstrated by other studies using DSA and magnetic resonance venography.

Drainage of internal occipital vein

The IOV drains the anterior part of the medial and inferior surface of the occipital lobe, representing the main draining vessel of the visual cortex. The width of this vein before drainage shows great variability, ranging from 0.8 to 2.8 mm: the size of the vein is related to the extent of its drainage area. Furthermore, the union of the posterior pericallosal vein that drains the posterior part of corpus callosum, cingulate gyrus, and precuneus may also influence the diameter of this vein. We were able to delineate the IOV in 49.5% of cases. Even if in accordance with DSA data (55%, see previously), the comparison with anatomic studies shows that the IOV was missed in half of our specimens. This finding is probably attributable to the difficulty in the depiction of this vessel when its size is small. Furthermore, because of the limited resolution (1 mm) of MRI and CT, the vessels might be missed, especially if these are smaller than 1 mm. Because of the above-mentioned relationship between vessel size and drainage territory, the cases in which the IOV can be clearly demonstrated can be considered at higher risk of the development of postoperative venous infarction in cases of injury. The IOV ends in the pineal region venous complex. Anatomic and radiological studies show that this vessel drains mainly into the vein of Galen and the basal vein. In our study, we demonstrated that the IOV joined the vein of Galen in 60 (60.6%) and the basal vein in 39 (39.4%) hemispheres; the cases in which the IOV drained at the level of the junction between the basal vein and the vein of Galen were included in the first group. This leads to a distinction between medial and lateral drainage of the IOV and may be important in surgical planning. When approaching the pineal region, an IOV draining into the vein of Galen may hamper the surgical field because of its medial course to reach this vessel. Conversely, drainage into the basal vein results in a more lateral course with less probability of obstructing the view and being stretched by occipital lobe retraction.

Dislocation of pineal veins in patients affected by tumors of this area

Physiological anatomy of the pineal region veins is a complex topic, becoming much more difficult to understand in pathological condition. The dislocation of these structures caused by a space-occupying mass is the most important aspect and depends on many factors. The first variable that should be considered is the tumor type: more than 17 distinct lesions with different sites of origin can involve the quadrigeminal cistern. Principally the tumor origin and its direction of growth influence the type and grade of dislocation of the galenic venous complex. Another important factor influencing the dislocation of pineal veins is their normal anatomy itself.

In our study we focused on a 3D concept of pineal venous complex dislocation in which 3 directions of displacement were considered: craniocaudal, anteroposterior and lateral. We observed a clear correlation between the displacement on the anteroposterior and craniocaudal direction: in 3 patients there was an antero-caudal and in 5 a postero-cranial displacement. No patient had an anteroposterior shift of the veins without a craniocaudal displacement. Only in 4 cases there was a displacement on the sagittal plane without shift on the axial plane. Moreover the displacement of the venous complex involved the final portion of ICVs, last segment of BV and the vein of Galen.

These findings may be explained if the above-mentioned anatomy of these vessels is considered. The observed oblique displacement, association of anteroposterior and craniocaudal shift, is due to the oblique position of the ICVs and vein of Galen in the quadrigeminal cistern. This oblique configuration causes this type of dislocation to be more frequent in the presence of a growing mass. For exemple if the veins would have a perpendicular course to the axial plane, an isolated anteroposterior shift would be most frequent. The observed shift of particular segments (final portion of ICVs, last segment of BV and the vein of Galen) of the venous complex has also an anatomical basis. Considering the veins from origin of the ICVs to the straight sinus we found two "fixed" parts represented by the course of the ICVs into the tela choroidea and of the straight sinus into the junction between falx and tentorium. In between there is a cisternal "not-fixed" segment corresponding to the final ICVs and vein of Galen situated in the quadrigeminal cistern. This central part, as well as last segment of BV, is more influenced by the tumor growth for the near absence of fixing structures. These observations show that even if the venous displacement follows anatomical criteria, its individual variability on the three planes is very difficult to predict without the use of a 3D imaging technique.

Surgical considerations

Pineal veins closure can led to a broad spectrum of consequences. In some cases it may be well tolerated as shown in previous studies, however the damage of these vessels usually has severe consequences such as: diencephalic edema, hyperpyrexia, tachycardia, tachypnea, miosis, rigidity of the limbs, mental changes and coma. These observations show why the pineal veins can be a limiting factor for total removal of tumors in this area. Therefore these vessels play a central role in the preoperative planning of the surgical approach. The first consideration regards the venous displacement: as shown in the present study, these structures can be dislocated by tumors in all three spatial planes. Even if the craniocaudal shift remains the most frequent and the most relevant for the preoperative planning, also the anteroposterior and lateral displacement should be depicted and considered preoperatively. However the major advantage of neuronavigation for approaching this region remains the intraoperative use. The approach is usually selected to avoid venous obstruction of the surgical field; consequently these vessels are usually behind the tumor when seen from surgeon's perspective. In these situations a tool that can in real time show the position of venous complex and its 3D relationship with the lesion is of great importance in order to avoid the damage of these deep venous structures. With the exception of an endoscopic biopsy and a lateral parieto-occipital craniotomy for a hemispheric glioma extending to the pineal region, we used two types of approach: infratentorial supracerebellar in 8 and interhemispheric parieto-occipital in 4 patients. The key points for the selection of the approach as shown in this study are tumor extension and venous displacement. The main supra or infratentorial extension of the lesion gives the best indication for the surgical trajectory and is the first parameter for its selection. However also the venous displacement and dislocation plays an important role: of the 8 cases operated via supracerebellar approach, 5 presented a postero-cranial, 2 cranial and only 1 an inferior displacement. Furthermore of the 4 cases operated via interhemispheric parieto-occipital route, 3 presented an antero-caudal and 1 an anterior displacement. This underlines the importance of avoiding the presence of the veins between the surgeon and the lesion. Exceptional in a single case we used a supracerebellar route even if a caudal displacement of the venous complex was present because of the large subtentorial extension of the lesion (tentorial meningioma). Another important point of discussion is the drainage type of BV. The BV, when present, can drain distally (Type 1: drainage into ICV), centrally (Type 2 and 3: drainage in ICVs junction and Galen) and proximally (Type 4: drainage into straight sinus): these different drainage patterns have surgical relevance. The central variants (Type 2 and 3) can be more problematic for the approach because the ICVs junction and the vein of Galen are the segments usually situated in the center of surgical field of view: thus the presence of the BV ending in these area complicates the anatomy of the region. Moreover, as stated above this part is more prone to dislocation due to the fact that has not dural or ependymal adhesions ("not-fixed" segment). These factors can increase the risk of BV damage during surgery.

Conclusions

The venous system of the pineal region is complex and shows a great number of anatomical variations. Thus surgery of the pineal region is a great challenge even for expert neurosurgeons. Our imaging study, which includes classification of different drainage patterns of the BV by using 3D reconstruction software, provides the basis for a better understanding of this venous complex. We show that CT and MR imaging with navigation software reconstruction can in all instances delineate the venous drainage pattern of major and minor veins around the pineal gland without additional examination. Moreover, the analysis of patients affected by pineal region lesions demonstrates that this anatomy an be depicted using a neuronavigation software even if distorted by tumors with the same accuracy as in subjects not harbouring lesions of this area. We observed that the dislocation of the veins is possible in all the spatial planes with an association of the posterior and cranial displacement so as of the anterior and caudal displacement. Thus this technique provides an optimal preoperative planning with precise depiction of the distorted anatomy and subsequent intraoperative navigation for the preservation of these vessels either in the supratentorial or infratentorial approaches.

Zusammenfassung

Das venöse System im Bereich der Glandula pinealis (Zirbeldrüse) ist komplex und zeichnet sich durch eine große Anzahl anatomischer Varianten aus. Dadurch ist die chirurgische Behandlung der Pinealisregion auch für sehr erfahrene Neurochirurgen eine große Herausforderung. Unsere bildgebenden Untersuchungen, mit Klassifikationen der unterschiedlichen Drainagemuster der Vena basalis (Rosenthal; BV) durch 3D Rekonstruktionscomputerprogramme, bilden die Basis für ein besseres Verständnis dieses wichtigen venösen Architektur. Wir zeigen, daß computer -und magnetresonanztomographische Bildbearbeitungsprogramme zusammen mit Navigations -und Rekonstruktionsprogrammen in der Lage sind, in allen Fällen, das venöse Drainagemuster der kleinen und großen Venen um die Glandula pinealis darzustellen und dies ohne zusätzliche Untersuchungen. Außerdem zeigt die genaue Untersuchung der Patienten mit Läsionen im Bereich der Glandula pinealis, daß auch hier die Anatomie mit Neuronavigationscomputerprogrammen dargestellt werden kann, sogar wenn sie durch Tumoren verlagert ist und dies mit der gleichen Genauigkeit wie bei Patienten ohne Läsionen in diesem Bereich. Wir fanden, daß die Verlagerung der Venen in allen Raumrichtungen möglich ist, wobei eine Verbindung zwischen posteriorer und kranialer Verlagerung und anteriorer und kaudaler Verlagerung zu beobachten ist. Daher erlaubt diese Technik eine optimale präoperative Planung mit exakter Darstellung der verlagerten Anatomie und zusätzlich intraoperative Navigation. All dies trägt zur Erhaltung dieser Gefäße bei neurochirurgischen infra –oder supratratentoriellen Zugängen bei.

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