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SYSTEMES VEINEUX DE LA BASE DU CRÂNE ET DE LA JONCTION CRANIO-CERVICALE: ANATOMIE MACROSCOPIQUE ET RADIOLOGIQUE ET IMPLICATIONS CLINIQUES

Thèse

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par

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A mi abuela Maruja,

Con todo mi cariño

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Acknowledgements:

The work presented in this manuscript is obviously not only mine.

Dr Philippe Gailloud was the first one to observe a venous channel in the lateral wall of the cavernous sinus, and linked it to the drainage of the superficial middle cerebral vein. This observation opened the door to all the investigations of the cerebral venous system that appear in the present paper. He also performed the study on the angiographic anatomy of this venous channel, whose results are included here. I am indebted to him for awakening in me the interest for neurovascular anatomy and many other enlightening fields.

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List of abbreviations:

Abréviations françaises	
ADS	Angiographie digitalisée par soustraction
CCA	Confluent condylien antérieur
FAVD	Fistule artérioveineuse durale
FCA	Fosse crânienne antérieure
FCM	Fosse crânienne moyenne
FCP	Fosse crânienne postérieure
SC	Sinus caverneux
SLC	Sinus latérocaverneux
SPC	Sinus paracaverneux
SPAS	Sinus de la petite aile du sphénoïde
SphS	Sinus sphénopariétal de Breschet
SPSQ	Sinus pétrosquameux
VCMS	Veine cérébrale moyenne superficielle
VFC	Veine émissaire du foramen caecum
English abbreviations	
ACC	Anterior condylar confluent
ACF	Anterior cranial fossa
AMMV	Anterior branch of the middle meningeal veins
CS	Cavernous sinus
DAVF	Dural arteriovenous fistula
DMCV	Deep middle cerebral vein
DSA	Digital subtraction angiography
EJV	External jugular vein
EVVP	External vertebral venous plexus
ICA	Internal carotid artery
IJV	Internal jugular vein
IPS	Inferior petrosal sinus
IVVP	Internal vertebral venous plexus
LCS	Laterocavernous sinus
LSW	Lesser sphenoid wing
MCA	Middle cerebral artery
MCF	Middle cranial fossa
MMV	Middle menigeal veins
PCF	Posterior cranial fossa
PCS	Paracavernous sinus
PGF	Postglenoid foramen
PP	Pterygoid plexus
PSS	Petrosquamosal sinus
SLSW	Sinus of the lesser sphenoid wing
SMCV	Superficial middle cerebral vein
SOV	Superior ophthalmic vein
SphS	Sphenoparietal sinus of Breschet
SPS	Superior petrosal sinus
SS	Sigmoid sinus
SSS	Superior sagittal sinus
TS	Transverse sinus
VAVP	Vertebral artery venous plexus
VFC	Vein of the foramen caecum
VVS	Vertebral venous system

Résumé

Introduction

Le drainage veineux du crâne se fait par les veines cérébrales, les sinus veineux de la dure mère, et les veines du neurocrâne, qui comprennent les veines méningées, diploïques et émissaires. La complexité et la grande variabilité de ce système rend son étude difficile, au point que son anatomie reste, de nos jours, loin d'être complètement élucidée. Or, le système veineux est de plus en plus considéré, d'un point de vue physiologique, clinique, et pathophysiologique, comme jouant un rôle prépondérant dans l'homéostasie de la circulation cérébrale (Greitz D 2004), et le développement de nombreuses pathologies vasculaires cérébrales et spinales (Brunereau L et al 1998, Dillon WP 1997, Kiley MA 2002). Son importance est reconnue dans diverses affections vasculaires telles que les anomalies du développement veineux, les malformations et fistules artérioveineuses intracrâniennes, l'angiomatose leptoméningée (maladie de Sturge-Weber), et même, depuis peu, dans la genèse de l'hypertension intracrânienne idiopathique ou bénigne. L'hypertension veineuse, dénominateur commun de ces affections vasculaires, joue un rôle primordial dans l'apparition des manifestations neurologiques liées à ces maladies. Une compréhension détaillée de l'anatomie veineuse devient des lors indispensable dans la distinction entre la variante anatomique normale et l'anatomie pathologique, et intervient dans l'analyse morphologique et la classification des affections vasculaires encéphaliques (Brunereau L et al 1996, Cognard C et al 1998).

Notre intérêt s'est porté sur l'étude des systèmes veineux de la base du crâne et la jonction crânio-cervicale. La majorité du sang veineux encéphalique rejoint les sinus de la dure-mère de la fosse crânienne postérieure (FCP), en particulier les sinus transverses et sigmoïdes, pour ensuite être acheminée vers les veines jugulaires internes et les plexus veineux vertébraux internes et externes. Une petite partie du retour veineux encéphalique est acheminé vers les sinus veineux des fosses crâniennes moyennes (FCM) pour rejoindre le système jugulaire externe, qui lui est essentiellement impliqué dans le drainage veineux du viscéro-crâne. Le retour veineux encéphalique passant par les axes jugulaires internes et vertébraux est soumis à l'influence des variations posturales : en décubitus, les veines jugulaires internes représentent la voie principale du drainage veineux encéphalique, alors que le passage à la position debout privilégie un drainage veineux à travers des plexus veineux vertébraux internes et externes au détriment du système jugulaire interne. La complexité anatomique de ces systèmes veineux répond à la complexité d'ordre physiologique du retour veineux encéphalique.

L'observation sur cadavre d'un drainage de la veine cérébrale moyenne superficielle (VCMS) dans un sinus veineux contenu dans la paroi latérale du sinus caverneux est à l'origine de cette étude. En effet, une analyse systématique de la littérature anatomique, radiologique et chirurgicale, n'a révélé aucune référence de cette voie de drainage de la VCMS chez l'adulte, et nous avons donc entrepris une étude cadavérique de systématisation des voies de drainages de la VCMS dans la FCM. Une observation menant à une autre, il nous est vite apparu des imprécisions dans la description classique des veines et des sinus veineux de la base du crâne. A titre d'exemple, des corrosions du système veineux du crâne ont démontré deux vaisseaux parallèles longeant la petite aile du sphénoïde et destinés au sinus caverneux, l'un clairement méningé et l'autre cortical, qui répondent au sinus sphénopariétal de Breschet (SphS) et à la VCMS respectivement. Or cette observation est en contradiction avec les données de la littérature où la VCMS est assimilée au SphS sous la petite aile du sphénoïde, avant de rejoindre le sinus caverneux.

Les données présentées dans ce travail constituent le recueil de nos observations anatomiques sur les systèmes veineux de la base du crâne. La méthodologie comprend de nombreuses techniques passant par la dissection sur cadavre, les corrosions veineuses du système veineux du crâne, et finalement par les techniques d'imagerie que sont l'angiographie digitalisée de soustraction, et les études angiographiques par résonance magnétique et tomographie computarisée.

Matériels et Méthodes

L'anatomie veineuse de la base du crâne est complexe et doit être appréhendée par différentes techniques aux avantages et inconvénients spécifiques. Nous avons employé une combinaison de techniques anciennes et des plus récentes pour étudier les systèmes veineux en question.

La dissection après injection du système veineux apporte des éléments indispensables. Les produits d'injection utilisés ont été la gélatine teintée à l'encre de chine et le ciment acrylique rendu radio-opaque par l'adjonction de barrite. Trente-deux corps légués à l'anatomie ou autopsiés en pathologie ont ainsi été investigués (18 hommes et 14 femmes, ages de 23 à 95 ans, moyenne d'âge de 74 ans).

Une des limitations de l'approche anatomique consiste en la difficulté à obtenir une vue d'ensemble car de nombreuses structures doivent être réséquées au fur et à mesure de la dissection pour mettre à jour celles situées plus profondément. Par ailleurs, certaines régions anatomiques sont particulièrement difficiles d'accès, en particulier la base du crâne où les structures veineuses, fort délicates, sont logées dans du tissu osseux ou fibreux très dense.

Nos investigations ont pu bénéficier de méthodologies dont les anatomistes classiques ne disposaient évidemment pas. Ce n'est en effet qu'à partir des années cinquante du 20ème siècle, que l'angiographie cérébrale s'est établie en tant qu'instrument d'investigation en pratique radiologique (Johanson C 1954). L'étude anatomique par artériographie digitalisée par soustraction (ADS), permet une vue d'ensemble des systèmes veineux du crâne au temps veineux, et intègre des informations dynamiques avec une excellente résolution temporale et spatiale. Cette technique présente à son tour, le désavantage que la visualisation de certaines veines est difficile en raison de sur-projections de structures osseuses, suite à des phénomènes de lavage de produit de contraste, ou par des flux très lents. Un autre inconvénient réside dans la difficulté d'établir une relation topographique des veines car uniquement le cadre osseux peut être visualisé en ADS.

Dans l'étude de systématisation du drainage de la VCMS dans la FCM, nous avons analysé 100 temps veineux d'ADS de routine après injection sélective des artères carotides internes chez 65 patients consécutifs (13 à 86 ans, moyenne d'âge de 48.8). Nous avons aussi inclus, là où cela nous a paru pertinent, des cas d'ADS provenant de notre activité clinique de routine, qui illustrent à la fois l'anatomie veineuse de la base du crâne et l'implication clinique de nos trouvailles anatomiques.

L'étude angiographique par angio CT ou IRM nous a aussi permis d'illustrer certains points anatomiques pertinents. Plusieurs cas tirés de notre activité clinique de routine sont inclus dans ce travail. L'étude angiographique par angio CT, et à un moindre degré par IRM, permet d'apprécier la relation topographique entre les veines et les structures avoisinantes. Mais d'autres limitations apparaissent, telles qu'une moins bonne résolution spatiale et temporale, des artéfacts liés aux flux lents en IRM, et l'obscuration des petites structures veineuse situées en contact avec l'os au CT.

Finalement, l'étude par obtention de corrosions du système veineux après injection par un ciment acrylique sur cadavre frais, est un outil précieux qui permet, lorsque l'injection est de bonne qualité, une visualisation de tout le système veineux de la tête et du cou. L'inconvénient de cette technique est la perte de tous les tissus mous et durs lors de la corrosion, rendant impossible l'appréciation de la relation topographique entre les veines et les structures avoisinantes. Au total, 12 corrosions du système veineux du crâne ont été étudiés (8 hommes, 4 femmes, moyenne d'âge de 85 ans).

Résultats et Discussion

Les résultats sont présentés en trois parties correspondant aux trois fosses crâniennes. Cette division est non seulement anatomique, mais obéit aussi à des concepts d'ordre physiologique introduits plus haut.

Les veines de la fosse crânienne antérieure

La fosse crânienne antérieure (FCA), ne participe pas au drainage veineux encéphalique et ne contient pas de sinus veineux de la dure-mère. Les veines de la FCA sont d'ordre méningé et diploïque et ne drainent donc que le neurocrâne. On soulèvera en particulier une veine diploïque cheminant sur le toit de l'orbite qui à notre connaissance, n'a à ce jour pas été décrite dans la littérature. La littérature mentionne une veine émissaire passant par le foramen caecum (VFC), qui a été contestée par plusieurs auteurs, notamment chez l'adulte. Cette VFC est sensé relier les veines de la cavité nasale avec le sinus longitudinal supérieur. Nous n'avons jamais rencontré de VFC. En revanche, nous avons observé, lors d'angiographies cérébrales sur deux patients, une veine fonctionnellement analogue à la VFC, passant par un trou de la lame criblée, et qui véhiculait le retour veineux d'une partie de la cavité nasale vers le sinus longitudinal supérieur. Cette veine pourrait servir à transmettre des pathologies infectieuses et tumorales de la cavité nasale vers la FCA.

Le veines de la fosse crânienne moyenne

La fosse crânienne moyenne (FCM) participe au drainage de l'orbite, de l'encéphale et du neurocrâne. Les résultats de nos études plaident en faveur d'une révision des concepts anatomiques établis.

Les veines de la région latérosellaire

Nous proposons un concept du système veineux de la région latérosellaire, subdivisé en deux entités embryologiquement, morphologiquement et fonctionnellement indépendants. Elles peuvent entrer en connexion par des anastomoses secondaires, en l'occurrence :i) un système médial destiné au drainage de l'orbite, comprenant la veine ophtalmique supérieure, le sinus caverneux (SC) et le sinus pétreux inférieur ; ii) un système latéral destiné au drainage cortical de la convexité de l'hémisphère provenant essentiellement de la VCMS, mais participant parfois au drainage de la veine cérébrale moyenne profonde. Il existe trois voies de dérivation de la VCMS, qui sont par ordre de fréquence décroissant : i) le sinus paracaverneux (SPC) ; ii) un sinus veineux qui chemine d'avant en arrière entre les deux feuillets duremèriens formant la paroi latérale du SC, et que nous avons nommé sinus latérocaverneux (SLC) car nous n'avons pas trouvé de mention de ce sinus dans la littérature; et finalement iii) la terminaison classique dans le SC. Le SLC se draine soit vers les veines émissaires de la FCM, soit vers le sinus pétreux supérieur, soit vers la portion postérieure du SC. Lors de nos investigations, le SLC recevait de façon constante la VCMS, sauf pour un cas où il drainait exclusivement la veine cérébrale moyenne profonde en l'absence d'une VCMS. Nous avons pu observer des connections entre le SLC et le SC dans plusieurs cas. Le manuscrit décrit en détail la sémiologie anatomique et angiographique du SLC. Du point de vue clinique, il est important de reconnaître le SLC dans les pathologies vasculaires touchant la loge latérosellaire, telles que les fistules arterio-veineuses durales. En effet, la présence d'un SLC déterminera la stratégie thérapeutique de la fistule, à savoir, si l'approche sera endovasculaire ou neurochirurgicale.

Le sinus sphénopariétal de Breschet

En ce qui concerne le sinus sphénopariétal de Breschet (SphS) et la terminaison de la VCMS qui lui est souvent assimilée, nous avons trouvé d'importantes discordances avec la littérature. Nos observations sont les suivantes : le SphS correspond à l'assimilation artificielle de la portion pariétale de la branche antérieure des veines méningées moyennes et d'un sinus veineux de la dure-mère situé sous la petite aile de l'os sphénoïde, que nous appellerons, en accord avec d'autres auteurs, sinus de la petite aile du sphénoïde (SPAS). Ce sinus est en connexion avec le SC médialement, avec les veines méningées moyennes dans la région du ptérion, avec une veine diploïque de la grande aile du sphénoïde, et avec une veine diploïque du toit de l'orbite. Cette dernière se poursuit antérieurement jusqu'au trou supra-orbitaire où elle se projette dans une veine supra-orbitaire. En aucun cas avons-nous constaté de connexion entre le SPAS ou les veines méningées moyennes et la VCMS. Le concept d'un drainage de la VCMS vers le SphS répandu dans la littérature doit être abandonné. Le terme de SPAS doit aussi être préféré au terme de SphS pour les raisons précitées. Ces résultats anatomiques ont un intérêt clinique. Ainsi, le siège d'une fistule artérioveineuse durale (FAVD) sous la petite aile du sphénoïde, déterminera le grade de la fistule et guidera la décision thérapeutique. En effet, une FAVD sur le SPAS sera de grade I ou II, alors qu'une FAVD sur une SMCV longeant la petite aile du sphénoïde, sera obligatoirement de grade III ou IV (selon la classification de Cognard C et al 1998).

Le sinus pétrosquameux

Contrairement à la notion largement répandue de la rareté du sinus pétrosquameux (SPSQ), nous avons fréquemment observé un SPSQ chez l'adulte, bien qu'en général, sous une forme involuée. Dans un cas clinique chez une fillette de 7 ans, le SPSQ était excessivement élargis et offrait la seule voie de dérivation du sinus transverse, venant compenser ainsi l'absence de sinus sigmoïde et de veine jugulaire interne. Dans des cas similaires, le drainage encéphalique ipsilatéral à l'absence de sinus sigmoïde se fait vers le système jugulaire externe, et correspond alors au schéma veineux que l'on rencontre chez la plupart des mammifères excepté certains primates supérieurs et l'homme. Le SPSQ peut être démontré par diverses techniques radiologiques modernes et il doit être reconnu par le radiologue dans les bilans radiologiques préchirurgicaux de l'os temporal.

Les veines de la fosse crânienne postérieure et de la jonction crânio-cervicale

Le plus grand volume du drainage veineux encéphalique est véhiculé vers les sinus veineux de la fosse crânienne postérieure (FCP), et en particulier vers les sinus transverse et sigmoïde. Le système de la veine jugulaire interne prend ensuite en charge le drainage encéphalique vers le cœur.

Or, il a été démontré qu'il existe une variation posturale du drainage veineux encéphalique. En position couchée, le retour veineux s'effectue principalement par la veine jugulaire interne. Le passage à la position debout entraîne la bascule de ce retour veineux vers les systèmes veineux vertébraux.

Nous avons observé que ce drainage se fait par une série de veines émissaires dont le développement est variable et, pour certaines, lié à une relation de proportionnalité inverse. Les veines condyliennes latérale et postérieure et les veines émissaires occipitale et mastoïdienne permettent une communication avec le système veineux vertébral externe et en particulier avec le plexus veineux de l'artère vertébrale. En revanche, la veine condylienne antérieure offre une connexion entre le plexus veineux vertébral interne antérieur et un confluent veineux situé sur le versant extracrânien du trou hypoglosse. Ce confluent veineux que Trolard (1868) avait dénommé confluent condylien antérieur (CCA), est resté à ce jour inconnu dans la littérature, malgré son rôle important dans la circulation crânio-cervicale. En effet, le CCA offre de multiples connexions avec la veine jugulaire interne, le sinus pétreux inférieur, le plexus veineux des artères vertébrale et carotide interne, la veine condylienne latérale et les veines prévertébrales situées en avant de la membrane vertébro-basilaire. Il s'agit donc d'un point de confluence veineuse permettant la redistribution du sang lors des variations posturales. La connaissance de cette anatomie complexe est indispensable dans les traitements chirurgicaux ou endovasculaires des pathologies vasculaires ou tumorales loco-régionales, et pour l'accès endovasculaire veineux rétrograde à des régions situées à distance, telles que le sinus caverneux.

Conclusions

Ce travail a permis d'apporter des données anatomiques nouvelles et de clarifier certaines imprécisions touchant à la description du système veineux intracrânien, et en particulier de la base du crâne. L'impact clinique de ces observations est démontré par la présentation de patients dont le diagnostic et le traitement ont été modifiés en fonction de ces bases anatomiques. Nous nous permettons donc de penser que la présente thèse anatomique sera d'un intérêt concret, pratique, en particulier pour les neuroradiologues et les neurochirurgiens.

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General introduction

The object of the present manuscript is to provide a comprehensive study of the gross and radiological anatomy of the venous system of the base of the skull and the cranio-cervical junction in relation to encephalic drainage. Our philosophical approach is to provide useful anatomic information focused on clinical relevance, rather than producing a purely descriptive anatomy text of uncertain use for the clinician. Some of the anatomic observations here presented, such as the termination of the superficial middle cerebral vein (SMCV) into a venous channel within the lateral wall of the cavernous sinus (CS), have not been reported in the literature. On other occasions, we hope to clarify anatomic misconceptions, particularly concerning the sphenoparietal sinus of Breschet (SphS) and again, the termination of the superficial middle cerebral vein. Finally, though some of observations are not per say new in that we found rare, and at times somewhat obscure references dating to the 19Th Century, they fail to be mentioned in the modern anatomic, radiological, or surgical literature, and are hereby exposed as well. The merit of our anatomic forefathers from more than a century ago is immense, as they lay the basis of today's anatomical knowledge, despite limited investigational tools. It is to be expected that anatomical knowledge also evolves with the rest of the medical disciplines, and thus old concepts being reviewed and adapted to our current medical practice.

This work is based on anatomical observations obtained from standard brain dissections after injection of the venous system with couloured gelatins or acrylic cements, the study of venous corrosions casts, and also from "in vivo" imaging obtained with modern radiological tools used in the daily practice of neuroradiology, such as digital subtractions angiography (DSA), CT and MRI. For descriptive and functional purposes, the venous system of the base of the skull has been divided into three major sections: I. the venous system of the anterior cranial fossa; II. the venous system of the middle cranial fossa; and III. the venous system of the posterior cranial fossa and cranio-cervical junction. Each section is organized into an Introduction, Results, Discussion, and Conclusion including a review of the literature and the pertinent background.

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General material & methods

Introduction

Several investigation techniques were used to provide a better overall understanding of this complex venous anatomy, which would have been difficult to apprehend based on one technique alone. For instance, corrosion casts provide a detailed reproduction of the ensemble of the cranial venous system, but the soft and bony tissues having been dissolved after the injection of an acrylic cement, there is the inconvenience of not having clear anatomical landmarks other than those provided by familiar cerebral veins. Gross anatomic dissection following a venous gelatin or acrylic cement injection, does not present this disadvantage, but may be technically difficult and anatomical structures may be overlooked. This is especially true for the deep cervical regions, diploic vessels, and the outer surface of the base of the skull. Digital subtraction angiography (DSA) studies may provide similar information as corrosion casts with the added benefit of flow considerations, but countercurrent blood flow may obscure certain venous structures. Angio and phleblo-CT are a powerful tool, but discrimination between artery and vein may at times be difficult due to overlap of arteries and veins , and offer the limitation of not clearly delineating small vessels that are too close to the bone interface, as is the case with meningeal veins. Finally, MRI phlebography or injected 3D time of flight (TOF) angiography may be of limited value for disclosing small veins due to their lower spatial resolution. In addition, temporal resolution is low, and flow related techniques may fail to reveal slow-flowing venous structures.

Postmortem study

Classical anatomic dissections: after gelatine injection

Gelatin injections of the SMCV in 29 fresh human brains (17 males, 12 females; average age of 72.3 years at the time of death; ranging from 23 to 95 years old) were performed in the following manner to study the termination of the SMCV in the middle cranial fossa: the skull cap was opened with a circular incision and removed along with the dura mater. The SMCV, when present, or the largest SMCV when there was more than one, was punctured with a blue Venflon, and a mixture of coloured gelatine was injected (Merck, Germany). A different colour gelatine was injected in each side. The brain was then removed after cutting the venous bridges around the temporal pole, and the termination of the SMCV was noted in the middle cranial fossa (MCF). Whenever the SMCV drained into the laterosellar region, the lateral wall of the cavernous sinus CS was carefully dissected in search of any venous channel it might contain. This dissection consisted of separating the lateral and medial dural layers of the lateral wall of the CS, without opening the CS itself. The latter was performed in a second step giving special attention to possible venous connections through the dural medial layer, between an existing venous channel within the lateral wall of the CS and the CS.

The anatomic specimens were a courtesy of Dr JP Pizzolato, Department of Pathology, University of Geneva.

Classical anatomic dissections: after acrylic cement injection

Standard anatomic dissection was performed on 3 non-fixed specimens (2 females, 1 male, average age 82 years) after vascular injection as a complement to the corrosion cast studies. Blue methylmethacrylate was injected in the venous system as below (2.2 corrosion cast technique). Red methylmethacrylate was injected in the internal and external carotid territories via bilateral common carotid cannulations. The brain was removed before complete polymerization of the methylmethacrylate, care being taken to identify all the venous bridges attaching the brain to the base of the skull. The dura mater of the anterior and middle cranial fossa was dissected layer by layer in order to reveal any intradural vascular channel. The periosteal dural layer was then removed except for the dura surrounding the meningeal vessels coursing along the anterior and middle cranial fossae. The inner table of the sphenoid, frontal and parietal bones was progressively removed so as to expose diploic vessels. Finally, the floor of the MCF was resected in order to expose the pterygoid plexus. A similar procedure was performed in the PCF The outer surface of the base of he skull was also dissected in a stepwise fashion with the cervical spine in situ until the veins of the base of the skull and the cranio-cervical region where exposed. The three specimens (6 sides) used for standard anatomicdissections showed complete filling of the cranial and neurocranial venous systems.

Corrosion casts

Corrosion casts of the cranial and cerebral venous system were prepared from 12 non-fixed human specimens (8 females, 4 males, average age of 85 years). In each case, the internal jugular veins were carefully dissected in the neck and canulated with 6-mm metallic probes. The venous system was thoroughly rinsed with a saline solution. Leakage sites were identified and ligatured. A mixture of blue methylmethacrylate (Beracryl, Troller, Switzerland) and barium sulfate powder (HD 200 plus, Lafayette, Anaheim, CA, USA) was injected through both internal jugular veins until the angular veins became engorged. The specimens were then placed in a potassium hydroxide bath (40% solution, 40°C) until all surrounding soft and osseous tissues were dissolved.

In vivo study

Digital subtraction angiography studies

Wherever possible, pertinent DSA imaging is provided to illustrate the normal or pathological anatomy. The source of the angiographic data here reproduced originates from the diagnostic and interventional activity of our Neuroradiology Section at the Geneva Universtity Hospital and from the courtesy of Professors P Gailloud and K Murphy from the Division of Neuroradiology at Johns Hopkins Hospital in Baltimore. In particular, the DSA on which the drainage patterns of the SMCV were studied, were entirely provided and analyzed by Professors Gailloud and Murphy. This study included the prospective evaluation of 65 consecutive diagnostic cerebral angiograms performed between may and June 1999 (Division of Neuroradiology, The Johns Hopkins Hospital). Bilateral selective carotid studies were obtained in 55 patients and unilateral studies in 10 patients, allowing for 120 venous phases to be reviewed. From this point on, these 120 unilateral venous studies will be referred to as cases. Patient ages ranged from 13 to 86, with a mean value of 48.8. Imaging was obtained using biplane angiographic equipment (BN3000, Philips, The Netherlands) at a frame rate of 1 image per second. When a SMCV was present, its drainage pattern was evaluated in at least two different projections (generally AP and lateral views). In addition, the topographic relationship between the SMCV, the CS and the internal carotid artery (ICA) was systematically assessed with the sequential subtraction technique. By using venous images as masks for the subtraction process, this technique allowed simultaneous display and analysis of the arterial and venous phases of an angiographic study. The anatomy of the diploic venous channels was also studied.

MRI studies

MRI was perfomed on a Philips Intera 1.5T scanner (Philips Medical Systems, Best, The Netherlands). Different imaging protocols including angio and phlebo MRI were performed, and the data was drawn from routine activity in our Neuroragiology Section at Geneva University Hospital. Imaging protocols are explained in the legends of each figure.

CT studies

CT images were obtained on a Philips 16 channel multirow-detector, (MX 8000 IDT, Philips Medical Systems, Best, The Nederlands). The imaging protocol for the angio-CT was as follows: non-contrast images of 3 mm thickness were obtained from C1 to the vertex (index 0.7 mm, EB filter). Angio-CT was obtained after systemic bolus injection of 120 ml of contrast product. Slices were 1.5 mm thickness (index 0.7mm, pitch 0.663, UB filter) and started at the ascending aorta and ended at the vertex. Acquistion was initiated by bolus-tracking for arterial phase acquisitions. Phlebo-CT was performed without bolus tracking, acquisition starting 50 seconds after the bolus injection at the vertex and covering the head and cervical region up the level of C4. A late venous phase acquisition following the non-contrast acquisition protocol was obtained 2-3 minutes after bolus injection in both the arterial and phlebo-CT.

Clinical cases

Several clinical cases will be provided to illustrate the clinical implications of the anatomic findings. A detailed description of the cases will be provided in each appropriate section.

*   *   *

Part I: venous systems in the anterior cranial fossa

Introduction

The anterior cranial fossa (ACF) is not involved in the venous drainage of the brain, and contains no dural venous sinuses receiving encephalic blood. The veins encountered in the ACF, are usually not accessible to imaging techniques and involve diploic and meningeal vessels. As will be discussed later on in the following sections (Part II : Venous systems of the middle cranial fossa ; The sphenoparietal sinus of Breschet), a frontal diploic vein may be observed on DSA. The cortical veins of the inferior surface of the frontal lobes may drain into the anterior third of the superior sagittal sinus via anterior cortical veins, into the basal vein of Rosenthal by way of the anterior cerebral veins, into the superficial middle cerebral vein, and often by a combination of these possible drainage pathways in an inversely proportional fashion.

Contrary to the middle and posterior cranial fossas, there are no emissary veins in the ACF. A vein of the foramen caecum (VFC) is, however, frequently mentioned in the literature and often described as an emissary vein. The VFC connects the nasal and paranasal mucosa to the superior sagittal sinus, through the foramen caecum (Gray's Anatomy 1995). Though this vein may be found in lower mammals such as the mole (Thewissen JGM 1989), its existence in humans is questioned by various authors (Thewissen JGM 1989, Boyd GI 1930). We encountered two cases, here presented in the form of case descriptions, of intracranial drainage of the nasal mucosa by a frontal cortical vein into a superior sagittal sinus, demonstrated by digital subtraction angiography, which could be analogous to a VFC (San Millán Ruíz D et al 2006).

Case descriptions and results

Case 1

A 31-year-old woman with adult polycystic kidney disease underwent routine screening for intracranial aneurysm disease by MR imaging. The discovery of a small aneurysm at the right middle cerebral artery (MCA) bifurcation by MR angiography prompted further investigation by digital subtraction angiography (DSA). Four-vessel cerebral DSA confirmed the existence of a single 4-mm saccular aneurysm at the MCA bifurcation.

Incidentally, an unusual intracranial drainage pathway for the septal nasal mucosa was documented angiographicaly. The septal nasal mucosa was drained by a thin ascending nasal draining vein, which passed through the floor of the anterior cranial fossa and continued its course intracranially as a left frontal cortical vein. This left frontal vein received several pial tributaries from the superior frontal gyrus, before ending its course into the superior sagittal sinus (SSS) (Figures 1-3).

Figure 1 : DSA, left ICA injection, venous phase varying from early to late venous filling. Lateral vie The left septal nasal mucosa (white arrowhead) is drained by a thin ascending nasal vein (white arrow) the anterior-most aspect of the anterior cranial fossa. Intracranially, the thin vein continues its course as a frontal cortical vein (black arrowheads) and drains ultimately into the SSS. Note how the anterior third of the SSS is hypoplastic (double white arrow).

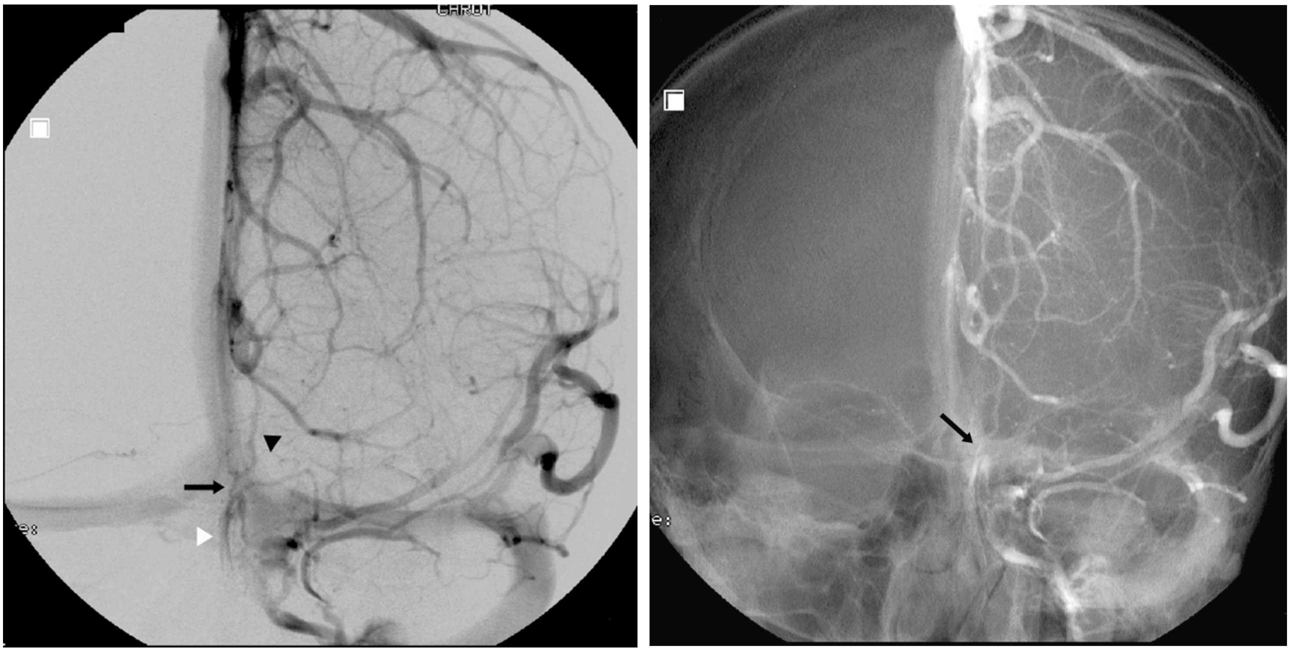

Figure 2: Case DSA antero-posterior projection, intermediate venous phase of left ICA injection, with (2a) and without subtraction (2b) (same legend as Figure 1). The medial left septal nasal mucosa appears as a slit like opacity. The thin ascending nasal vein occupies a slightly paramedian position, which is better appreciated relative to bony landmarks in the non-subtracted images (2b). In conjunction with the lateral views, the position of the ascending nasal vein is compatible with the position of a foramen of the cribriform plate. The frontal cortical vein ascends towards the SSS.

Figure 3: Case 1. DSA, left oblique projection, intermediate venous phase (same legend as Figures 1 a 2). The frontal cortical vein that drains the septal nasal mucosa receives several cortical pial veins (small blacl arrows) from the parenchyma of the superior frontal gyrus.

The ascending nasal vein was located in the anteriormost aspect of the floor of the anterior cranial fossa, and occupied a slightly paramedian position. This disposition was only found on the left side The anterior portion of the SSS was hypoplastic, being replaced by bilateral longitudinal frontal veins.

Case 2

A 39-year-old woman underwent follow-up cerebral DSA after surgical clipping of an anterior communicating artery aneurysm. DSA documented a small patch of nasal mucosa draining in the same fashion as in case 1. This drainage variant was not found in the right side. The anterior third of the SSS was also hypoplastic, being replaced by bilateral longitudinal frontal veins(Figure 4).

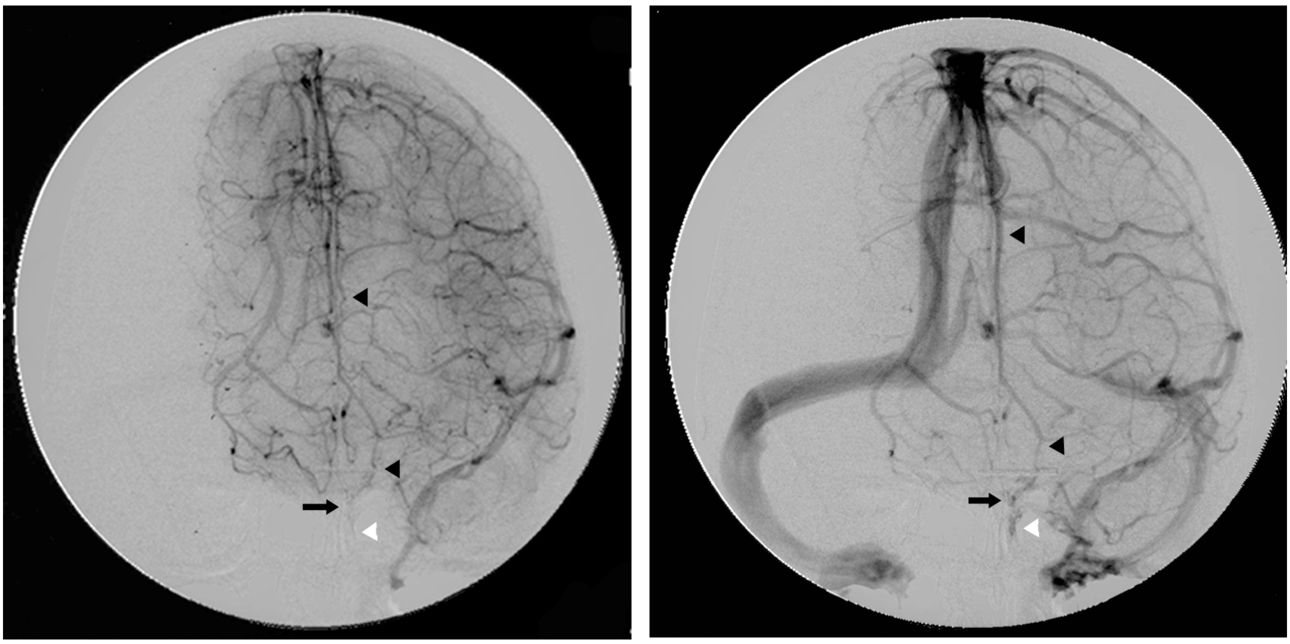

Figure 4 a-b: DSA, left ICA injection, early and intermediary venous phase. Anterior-posterior view (same legend as Figures 1-3). There is gradual filling of the left septal nasal mucosa (white arrowhead), which drains in the same fashion as case 1. Note the presence of a hypoplastic SSS, like in case 1.

Discussion

The existence in man of a VFC, that is, a vein connecting the nasal and paranasal mucosa to the SSS, has often been mentioned in classic anatomy texts (Grays's Anatomy 1995, Beaunis H and Bouchard A 1880 , Hédon CE 1888). However, Zuckerkandl (1885)could not demonstrate, using injection and corrosion techniques, any direct venous communication between the nasal mucosa and the SSS through the foramen caecum. He did, on the other hand, observe venous drainage pathways passing through the cribriform plate before entering the SSS, the venous plexus surrounding the olfactory tract, or the superficial cerebral veins of the frontal lobe.

The existence of the VFC has also been refuted by Kaplan et al (1973), who found no venous structure passing through the foramen caecum in a series of 201 autopsy cases that included subjects of all age categories. Although the foramen caecum was patent in all of the cases, it was filled with a fibrous material. Boyd (1930), studying the inside of 212 dry skulls, found only three cases in which the foramen caecum was permeable, and he described them as being so narrow that they could only give way to a fine hair. In twenty dissected specimens, Boyd found that the foramen caecum formed a pit filled with a root-like extension of dura mater, and was unable find a connection with the lumen of the SSS. The same was observed by Zuckerkandl (1885). Although these reports are contradictory regarding the patency of the foramen caecum, they are consistent with the concept that even when the foramen caecum is permeable, its small size or its fibrous content do not allow the passage of a macroscopically visible vein.

The situation may be different in newborns and during intrauterine life. Theile (1847) believed that the VFC was present in newborns. Zuckerkandl (1885) described a case in which blood vessels in the foramen caecum connected the superior sagittal sinus with veins of the soft tissues of the face including the nose. Luschka (1867) also reported the case of a newborn baby, in whom a large vein could be followed through the foramen caecum as far as to the veins of the face. Finally, Hedon (1888) reported, in his treatise on cerebral veins, the observation of VFC in infants, while admitting that it was rarely found in adult specimens.

In our two DSA cases, we encountered a portion of the nasal mucosa drained intracranially via a thin ascending nasal vein that crossed the floor of the ACF to continue as a left cortical frontal vein. In both cases, an hypoplastic anterior portion of the SSS was replaced by bilateral longitudinal frontal cortical veins, which on the left side, drained the nasal septal mucosa. Hypoplasia or absence of the anterior segment of the SSS and its replacement by longitudinal cortical veins is a relatively common anatomic variation. On the other hand, ascending intracranial drainage of the nasal mucosa is exceptional, and has, to our knowledge, not been previously reported from an angiographic standpoint. In both cases the ascending nasal vein was found to be in a slightly paramedian position on the antero-posterior views, and occupied the anteriormost aspect of the floor of the anterior cranial fossa on the lateral views. The exact site of passage of the ascending nasal vein through the ACF is difficult to ascertain based on the available angiographic data, but the paramedian location suggests passage through a foramen of the cribriform plate, rather than through a foramen caecum. Thus, the intracranial drainage of the nasal mucosa observed here differed from the classic description of a VFC in that it joined a frontal cortical vein before connecting to the SSS, and in that intracranial passage most likely occurred through a foramen of the cribriform plate. Functionally, however, it is analogous to a VFC.

As mentioned earlier, the available literature on the foramen caecum and VFC remains controversial but seems to offer at least one consistent line of thought, that is, that the VFC, if it exists, is more likely to be found in fetuses or newborn babies than later in life. This suggests a regressive process, not unlike the disappearance of other embryonic venous structures during the late fetal stages or early postnatal period. Again, such an hypothesis appears consistent with the paucity of reported observations of VFC in adults and, a fortiori, the absence of angiographic demonstration of the variant so far. In the case observed in our two patients, intracranial drainage of the nasal mucosa most likely occurred through a foramen of the cribriform plate. Foramina of the cribriform remain patent with age, thus, allowing for this connection to persist in adult life.

The anomalous venous drainage through the cribriform plate presented here, has both intra- and extracranial components, but should not be considered a cerebral emissary vein, as it does not offer an extracranial drainage route for encephalic blood, but rather an intracranial drainage route for the nasal mucosa. Finally, from a clinical perspective, the VFC and its cribriform plate equivalent represent a potential pathway for intracranial spread of infectious or tumoral processes originating from the nasal cavity. Furthermore, an anatomical disposition such as the one presented here, could also provide the anatomic substratum for the development of dural arteriovenous fistulae of the cribriform plate region with frontal cortical drainage (types 3 or 4).

Conclusion

The ACF is not involved in the venous drainage of the brain, as it contains no dural venous sinuses receiving encephalic blood. The veins encountered in the MCF are involved with meningeal and diploic venous drainage. Moreover, there are no emissary veins in the ACF. Though the existence of a VFC connecting the nasal mucosa to the superior sagittal sinus through the foramen caecum has been mentioned in classic anatomic descriptions, it has also been contested by several authors. We have found evidence of a functionally analogous vein to the VFC in two live patients during routine DSA workups. In rare cases, the nasal mucosa may drain intracranially through a vein traversing a foramen of the cribriform plate, which ultimately joins the superior sagittal sinus. This connection may provide a pathway for intracranial spread of sinu-nasal infectious or tumoral disease, and as well as providing an anatomic substratum for the genesis of dural arteriovenous fistulae of the ACF.

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Part II: venous systems in the middle cranial fossa

Background

In humans, the greatest portion of the encephalic drainage reaches the PCF, from which it will be directed primarily towards the internal jugular veins (IJV) or the vertebral venous system (VVS), depending on whether the body is lying supine or upright. The postural dependency of encephalic drainage has been described by several authors (Epstein HM et al 1970, Eckenhoff J 1970, Théron J and Moret J 1978, Valdueza J et al 2000), and relies on venous connections (Arnautovic KI et al 1997, San Millán Ruíz D et al 2002),which will be discussed in **Part III**.

In humans, the external jugular veins (EJV) are primarily involved in venous drainage of the viscero- and neurocranium, and offer only a small and variable participation in encephalic venous drainage. Two possible pathways connecting venous blood from the brain and the EJV system exist, and both involve the dural venous sinuses of the MCF. The first, more conspicuous, and most frequently occurring pathway involves the drainage of the superficial and deep middle cerebral veins (SMCV and DMCV) into the pterygoid plexus by way of the cavernous sinus and / or the emissary veins of the middle cranial fossa (MCF) (Hacker H 1974). This does not always occur as the SMCV and DMCV often alternatively drain towards the transverse sinus or basal vein of Rosenthal respectively (Wolf BS et al 1963, San Millán Ruíz D et al 1999, Gailloud P et al 2000). The second pathway is usually absent or inconspicuous in human adults, in keeping with its regression through foetal and early pre-natal life. It involves a connection between the anterior portion of the transverse sinus and the veins of the MCF, by way of a petrosquamosal sinus (PSS) (Cheatle AJ 1899, Padget DH 1957, Butler H 1957, 1967). The PSS courses along the petrosquamosal suture, either within a canal referred to as the temporal canal of Vergi (Wysocki J 2002) or within a groove, and exists the temporal squama through an emissary foramen situated in the temporal squama, often between the glenoid fossa and the root of the zygomatic process of the temporal bone, variably named the postglenoid foramen (PGF) or spurious jugular foramen (Cheatle AJ 1899, Boyd GI 1939, Padget DH 1957, Butler H 1957, 1967, Conroy G 1982, Wysocki J 2002). Although, this drainage pathway may be prominent in most mammals including “lesser” primates becoming a major route of encephalic venous drainage (Conroy G 1982, Wysocki J 2002), it is rarely of any real functional significance in humans as the IJV and VVS represent the major outflow pathways.

This section is divided into three parts. The first one covers the termination of the SMCV. The second will discuss anatomic findings concerning the SphS. Although not involved in the drainage of the encephalon, the SphS will also be discussed because it is often erroneously assimilated to the drainage of the SMCV. In fact, as we shall see in the second section of **Part II,** the entity of the

SphS is questionable. The last section covers the description of the petrosquamosal sinus and its clinical relevance when it becomes the major outflow pathway of the transverse sinus in association with extreme venous anomalies of the PCF.

The termination of the superficial middle cerebral vein

Introduction

The SMCV is found on the surface of the lateral fissure and drains the surrounding frontal, parietal and temporal cortical parenchyma. The extent of this drainage territory depends on the extension of the SMCV along the lateral fissure. Dorsally, the SMCV may connect to the superior and inferior anastomotic veins of Trolard and Labbé, that permit a derivation towards the superior sagittal (SSS) and transverse (TS) sinuses respectively. Ventrally, the SMCV crosses over the pole of the temporal lobe as a subarachnoid bridging vein, and drains into the MCF. This bridging veins of the pole of the temporal lobe are of clinical importance for neurosurgeons performing a pterional approach, as their sacrifice may lead venous infarction or hemorrhage. The SMCV may be absent, incomplete, that is the ventral or dorsal portion is missing, or multiple, up to 5 SMCVs may be present ipsilaterally.

Two drainage pathways of the SMCV in the middle cranial fossa (MCF) are described in the literature, into the CS and into a paracavernous sinus (PCS). When the SMCV joins the CS it pierces the dura of the anterior and superior aspect of the lateral wall of the CS. The PCS commences under the lesser sphenoid wing where it receives the connection to the SMCV, and then courses ventro-dorsally on the floor the MCF The PCS is classically said to terminate in the superior petrosal sinus (SPS) or at the junction of the SPS with the TS.

We describe a third drainage pattern of the SMCV in the MCF. In a large proportion of cases the SMCV joins a venous channel in the lateral wall of the CS.

The lateral wall of the CS is classically described as a double-layered structure enclosing the nerves III, IV, V_1 and V_2 (Gray's anatomy 1995). The presence of a venous structure in-between the two layers of the lateral wall of the CS has been mentioned occasionally, but remains controversial. Some authors consider the medial (inner) layer of the lateral wall of the CS as a septum containing nerves III, IV, $V_1$and V_2, which separates the CS cavity into a medial and lateral compartment, both filled with venous blood (Paturet G 1958). Umanski and Nathan (1982) studied the lateral wall of 70 cavernous sinuses and never found such a superficial compartment, though they did observe that the medial and lateral layers of the lateral wall of the CS were readily separable. Bonneville JF et al (1995) demonstrated the presence of veins in the lateral wall of the CS using dynamic CT. Occasional references to a venous structure enclosed in the lateral wall of the CS are found in the anatomic and surgical literature (Mercier R et al 1970, Dolenc V 1989). However, to our knowledge, there is no mention in the literature that the venous structures within the lateral wall of the CS linked to the termination of the SMCV.

The gross anatomy of this venous channel, that we have named the laterocavenous sinus (LCS), was studied by vascular injections of fresh human cadavers and the angiographic anatomy is also presented (cf Materials and Methods).

Results

Descriptions of the gross anatomy that follow are based on the observations harboured during the dissection of the specimens injected with coloured gelatin. In all, 29 brains were injected which represented 58 MCFs. We will refer to each MCF as a case for simplicity sake.

Gross anatomy of the superficial middle cerebral vein and its termination

The SMCV was absent in 29 % of the cases (absent in 17 out of 58; present in 41 cases). In 31% of the cases there was a unique SMCV, in 29% the SMCV was double, and in 11% it was triple. In one case, the ventral portion of the SMCV was absent, and therefore the SMCV did not drain into the MCF. Whenever the SMCV was multiple, these always drained into the same venous structure in the MCF, sometimes independently, at other times converging into a common venous trunk before joining their termination. The course of the SMCV, after it passed over the pole of the temporal lobe, was variable and depended on its termination. Whatever its termination, the classic description of the SMCV joining the lesser sphenoid wing in the region of the pterion, was never observed. Instead, the SMCV usually reached the junction of the middle and medial third of the lesser sphenoid wing. From here, it either coursed medially towards the laterosellar region, or inflexed dorsally along the floor of the MCF in the form of a PCS.

In 22 out of the 41 cases the SMCV drained towards to laterosellar region. In 10 of these cases, the SMCV joined the ridge of the lesser sphenoid wing and became attached to the overlying dura. It maintained, however, the characteristics of an arachnoid vein, that is , it did not become a dural venous sinus (Figure 5).

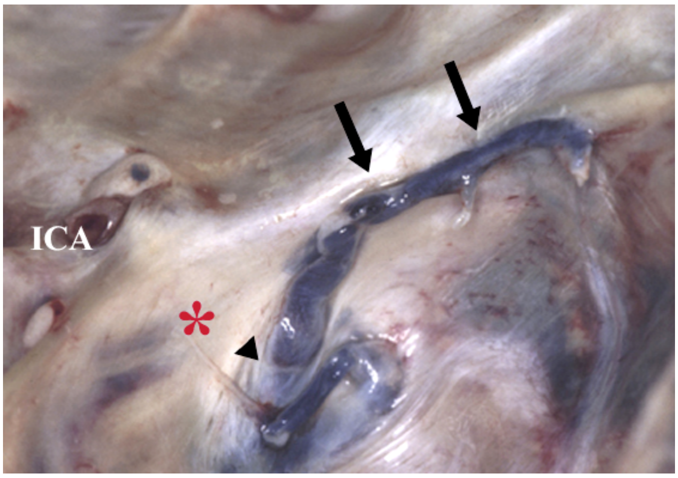


Figure 5: superior view of the right MCF. The SMCV l been injected with blue gelatin. It courses under the sphenoid wing (black arrows) towards the lateral wall of the CS (red asterisk). This is one of the occasions where the SMCV was adherent to the dura matter under the lesser sphenoid wing. Note that it maintains the characteristics of an arachnoid vein until it pierces the dura matter of the lateral wall of the CS (black arrow-head).

In the remaining cases, the SMCV remained subarachnoid in position until it reached the lateral wall of the CS (Figure 6).

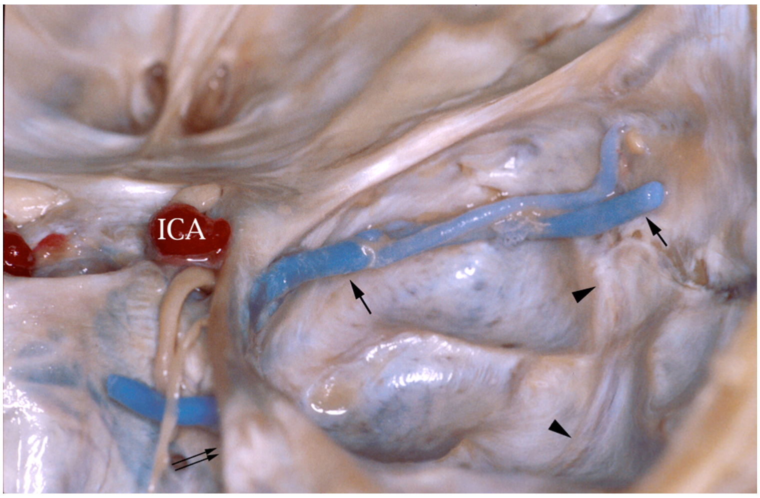


Figure 6 : Superior view of a right MCF. The SMCV (black arrow) drains into the laterosellar region into the CS. In this case, the SMCV is not adherent to the dura under the sphenoid lesser wing and courses freely in the subarachnoid space until it reaches the lateral wall of the CS. Again, transition from "arachnoid vein" to dural venous sinus is abrupt. Tentorial edge - double arrow; middle meningeal vessels – arrowheads.

Rarely, the wall of the terminal portion of the SMCV showed a gradual thickening before crossing the dura of the lateral wall of the CS.

Another observation, whose significance will be discussed further on in relation to the SphS, is that injection of gelatin into the SMCV never lead to the filling of the middle meningeal veins in the MCF.

The most frequent termination of the SMCV was found to be the PCS (19 out of 41 cases), followed by the LCS (14 out of 41 cases), and finally the CS (8 out of 41 cases). These terminations are all mutually exclusive and thus, were never found in combination of each other.

The PCS runs ventrodorsally in the floor of the MCF (Figures 7 and 8). It arises under the ridge of the lesser sphenoid wing, generally from the middle third, at the point where it receives the SMCV. The PCS is embedded in the superficial layer of the dura overlying the MCF, though in two occasions the SMCV did not adopt dural characteristics and maintained the appearance of an arachnoid vein that was adherent to the MCF dura mater.

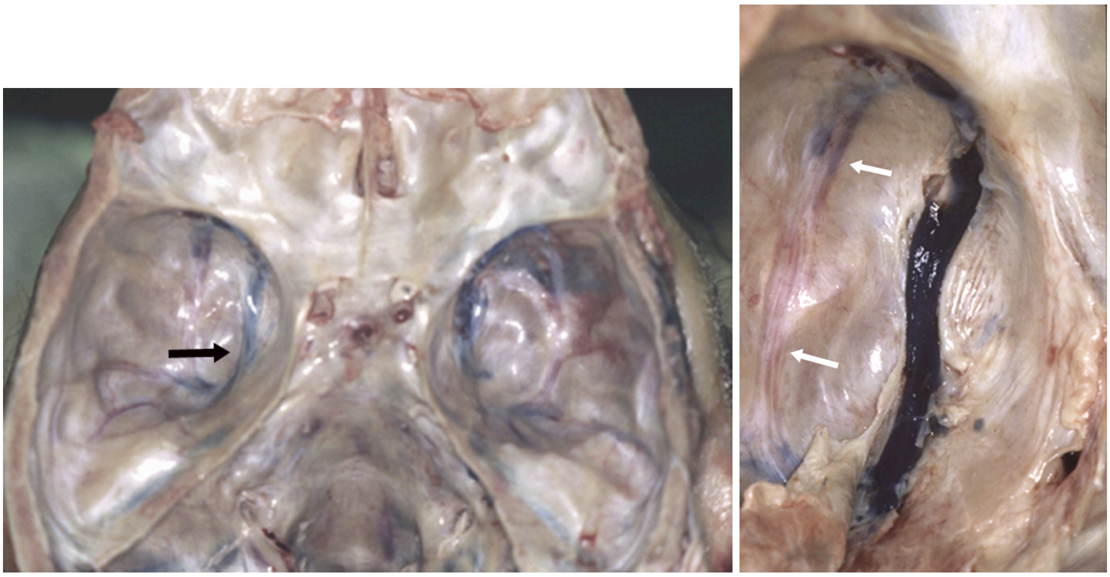


Figure 7 : Superior view of a left MCF showing the termination of the SMCV into a PCS. The PCS runs along the floor of the MCF and drains through the foramen ovale into the pterygoid plexus. 7a) left image. The dura of the MCF has not been removed. The PCS is injected with blue gelatin (black gelatin). 7) right image. Close up view. The superficial dura mater of the MCF has been removed to reveal the injected PCS. The PCS lies lateral to the gasserian ganglion (red asterisk). Note that there is no gelatin within the middle meningeal veins (arrows) demonstrating that there is no connection between the SMCV/PCS and the middle meningeal veins.

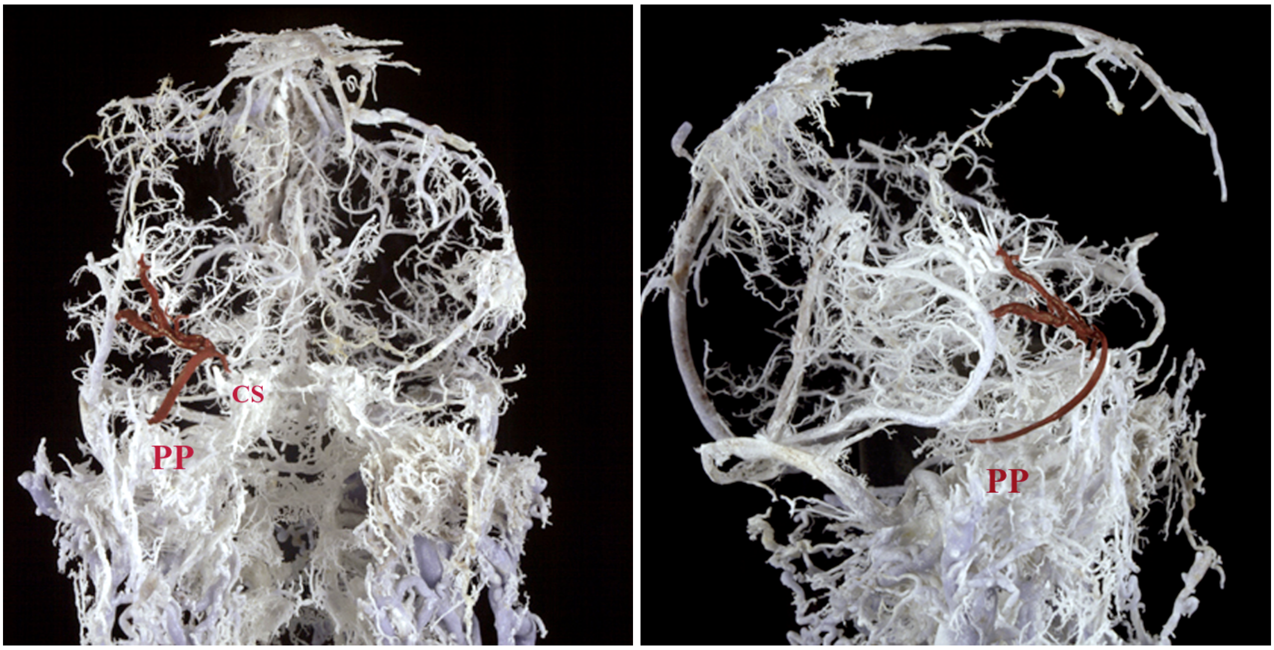


Figure 8 : Corrosion cast of the whole of the cranial venous system. The SMCV and a PCS have been coloured in red on the right side. 8a) left image. AP view showing the typical course of the PCS along the middle of the MCF. The CS and the pterygoid plexus (PP) are labeled. 8b) right image. Right lateral view of the corrosion cast showing the course of the PCS and its termination into emissary veins in the region of the foramen ovale with terminal drainage into the PP.

The termination of the PCS occurred, schematically, in two fashions: i) into the emissary veins of the foramen ovale and spinosum; ii) into the SPS or more rarely the TS. On several occasions, however, it drained both into the emissary veins of the MCF and into a SPS or TS. On one occasion, the PCS crossed the floor of the MCF and drained into a superior petrosal vein (of Dandy)

The LCS runs between the two dural layers of the lateral wall of the CS (Figure 9).

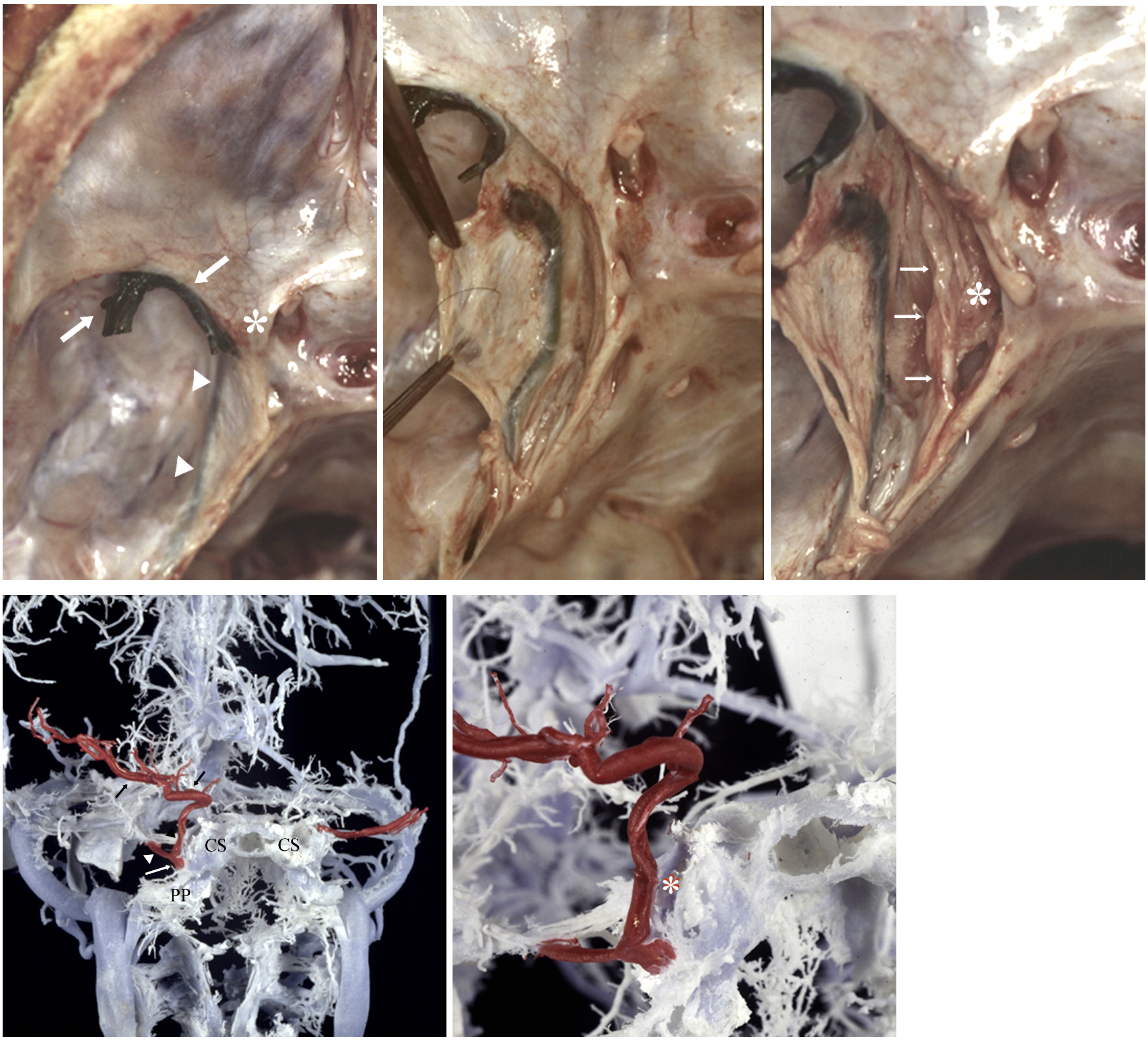


Figure 9 : 9a-c : superior view of a left MCF showing the termination of the SMCV into a LCS. 9a) top left image. The left SMCV (white arrows) has been injected with green gelatin. The SMCV runs under the sphenoid lesser wing and pierces the dura mater of the lateral wall of the CS at the level of the anterior clinoid process (white asterisk).The LCS (white arrowheads) is seen running posterioly towards the SPS. 9b) center top image. The two dural layers of the lateral wall of the CS have been separated, revealing the LCS that is adherent to the outer layer of the lateral wall. The CS has not yet been opened. 9c) right top image. The inner layer of the lateral wall has been detached (white arrows) revealing the insides of the CS (white asterisk). Note the absence of green gelatin within the CS demonstrating the absence of communication between the SMCV/LCS with the CS. 9d and e : right anterior oblique view of a corrosion cast. 9d) left bottom image. The SMCV (black arrows) drains into a LCS (black and white arrowheads). The LCS is not connected to the CS and it drains into the SPS posteriorly and into the pterygoid plexus (PP) through emissary veins in the floor of the MCF (thin white arrow). 9e) right bottom image. Close up view of 5d demonstrating a gap (asterisk) between the LCS and the CS which corresponds to the space occupied by the inner layer of the lateral wall of the CS (removed by the corrosion process).

It receives the SMCV in the anterior third of the lateral wall of the CS. The LCS drained into the SPS in 10 cases (71%) , into the emissary veins of the MCF in 3 cases (21%) , and into the posterior portion of the CS in one case (8%). On two occasions, en “passant connections” between the LCS and the CS were observed in the form of small foramina located in the inner layer of the lateral wall of the CS (Figure 10). Connection between the LCS and the CS in these two cases was confirmed by the presence of the same coloured gelatine in the CS as the one injected through the ipsilateral SMCV. Aside from these two cases and the one where the LCS drained into the posterior portion of the CS, gelatin of the same colour was found both in the LCS and the ipsilateral CS, though the communication between the two could not be established. This connection could have occurred through small anastomotic channels at the MCF, that escaped detection during the dissection, but which were demonstrated in the angiographic study. Excepting these cases, the CS ipsilateral to a LCS was either empty, or contained coloured gelatin coming from the controlateral SMCV. On one occasion, a LCS was observed in the absence of any identifiable SMCV. In this case, a small vein arising from the mesiotemporal region was found to be its tributary, and corresponded to the deep middle cerebral vein.

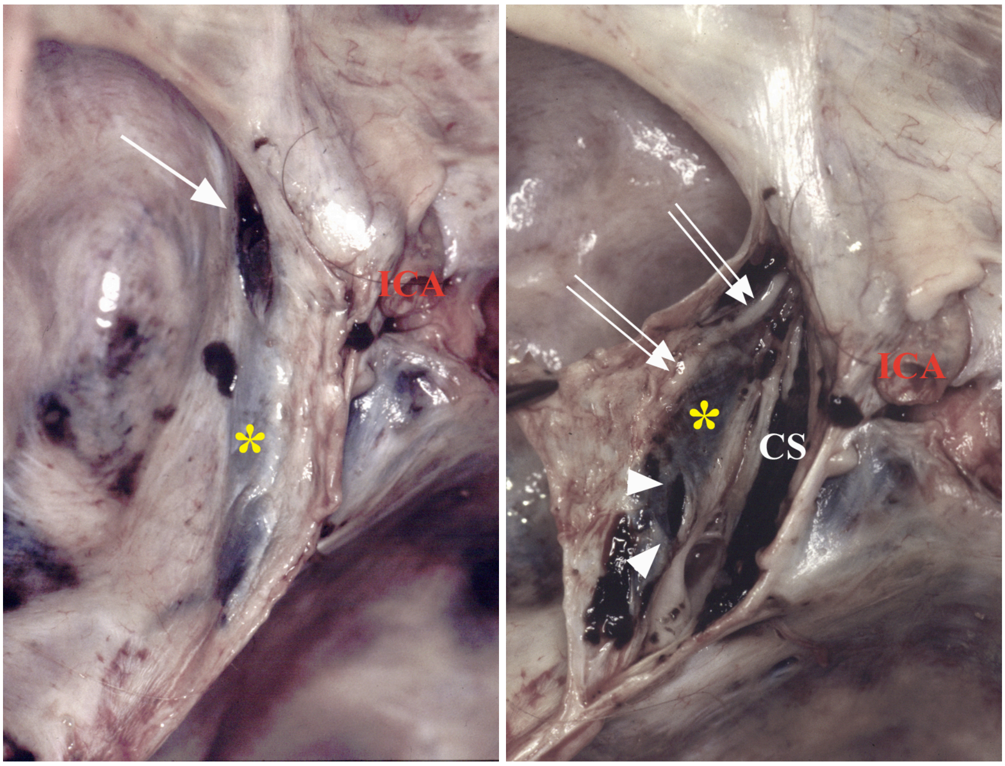


Figure 10 : 10a. superior view of a left MCF showing the termination of the SMCV (white arrow) into a LCS (yellow asterisk) which is visible within the lateral wall of the CS. 10b. the lateral wall of the CS has been dissected. Note how the inner and outer layers of the lateral wall are adherent in this case as opposed to the one showed in **Figure 9**. There is black gelatine inside the LCS and the CS. In this case, there were “en passant” connections (arrowheads) between the LCS (asterisk) and the CS. The double white arrows show the throchlear nerve which is firmly adherent to the lateral wall of the CS proximally.

The “classic textbook” termination of the SMCV into the CS was only observed on 8 occasions (Figure 6). In each case, the SMCV joined the anterior third of the lateral wall of the CS, except that instead of draining into a LCS, it crossed the full thickness of the lateral wall of the CS into the CS.

Connections between the CS and the SPS where found to be inconstant. Whenever present, the portion of the SPS that connected to the CS was found to be thinner than the portion closer to the junction with the TS. There was a clear increase in caliber of the SPS at the point where it connected to the superior petrosal vein (of Dandy). This connection was constant, and suggests that the SPS primarily represents a drainage pathway of the superior petrosal vein, rather than a derivation pathway to the CS. This observation is consistent with other reports in the literature (Théron J, 1972) and with Padget's (1956) observation that connections between the CS and the SPS are inconstant and secondary in nature, that is, they usually occur postnatally.

Angiographic anatomy of the termination of the superficial middle cerebral vein

The quality of venous imaging was found insufficient for precise anatomic analysis in 20 out of the 120 studied cases, either because of the presence of uncorrectable movement artifacts (18 cases) or large cavernous ICA aneurysms obliterating the laterosellar venous spaces (2 cases). The drainage pattern of the SMCV could thus be evaluated in the venous phases of 100 selective carotid studies. The SMCV was absent in 19 cases (19%). A classic termination of the SMCV into the antero-superior aspect of the CS was observed 20 times (20%). A PCS was found in 39 cases (39%), draining mainly into the pterygoïd plexus (PP) (44%) or the SPS (33%). A LCS was present in 22 cases (22%), draining mainly into the PP (27%) or the SPS (18%). A PCS draining into the CS after a short course in the middle temporal fossa was observed twice (5%), while termination of a LCS into the posterior aspect of the CS occurred in 7 cases (32%). A combination of two or three of these drainage routes was observed in 18% of PCS and in 23% of LCS. Anastomotic channels of small caliber linking the CS with either a LCS or a PCS were observed in 36% and 8% of cases, respectively. Slightly delayed filling of the CS with no evident connections was also observed. In such instances, the presence of small, angiographically undetectable anastomotic channels could not be excluded. A LCS was observed in the absence of the ipsilateral SMCV in 2 cases. In such instances, the LCS was the continuation of a vein draining the medial aspect of the temporal lobe, corresponding to a deep middle cerebral vein.

Discussion

Termination of the superficial middle cerebral vein in the middle cranial fossa

The termination of the SMCV in the MCF was found to occur in three fashions in the gross anatomy study: i) into a PCS (46% of the cases); ii) into a LCS (34%); iii) into a CS (20%), the classic textbook description. These terminations were never concomitant.

The LCS is found in-between the outer and inner layers of the lateral wall of the CS. It most frequently drains into the SPS (71% of the cases), but may also drain into the pterygoid plexus through the emissary veins of the MCF (21%) and into the posterior portion of the CS (8%). En passant connections between the LCS and the CS are rare but were observed in the form of small foramina on the medial layer of the lateral wall of the CS. The slit-like configuration of the LCS and its location between the dural layers of the lateral wall of the CS may explain why this channel may escape detection during anatomic dissection if no previous injection of the SMCV is performed, even in large series such as the one published by Umansky and Nathan (1982).

Drainage into a PCS is well documented in the literature, and aside from the fact that it appeared as the most frequent drainage pattern of the SMCV in our series, our findings are consistent with the descriptions reported in the literature (Figure 11).

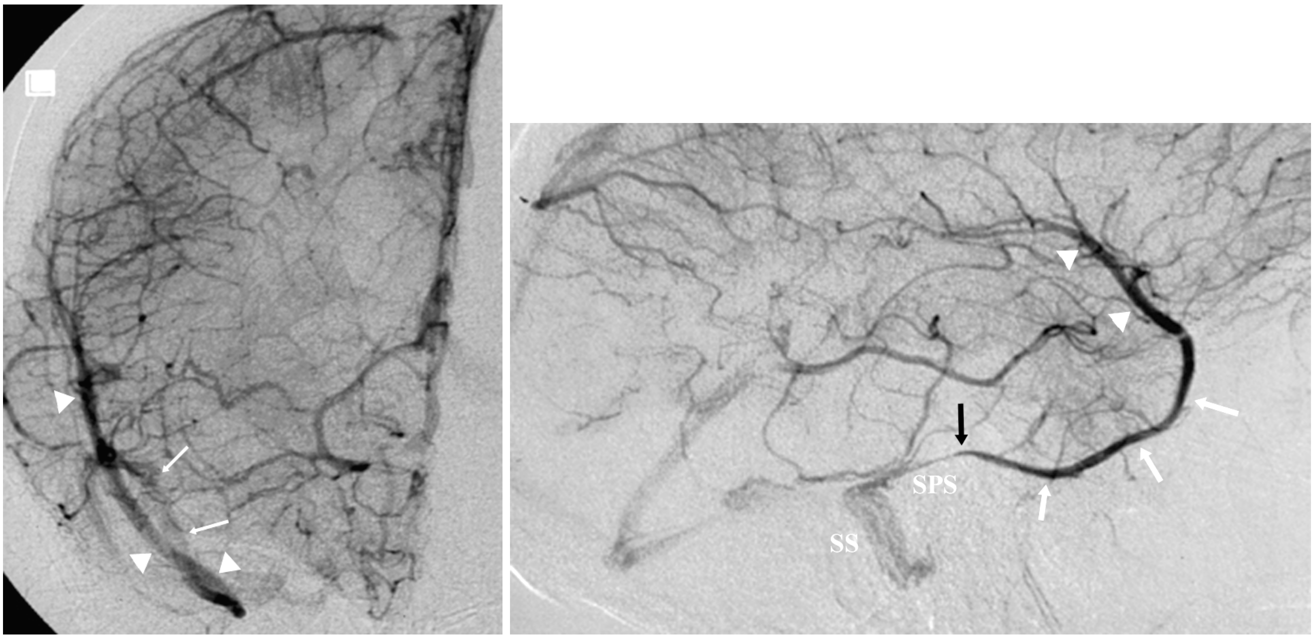
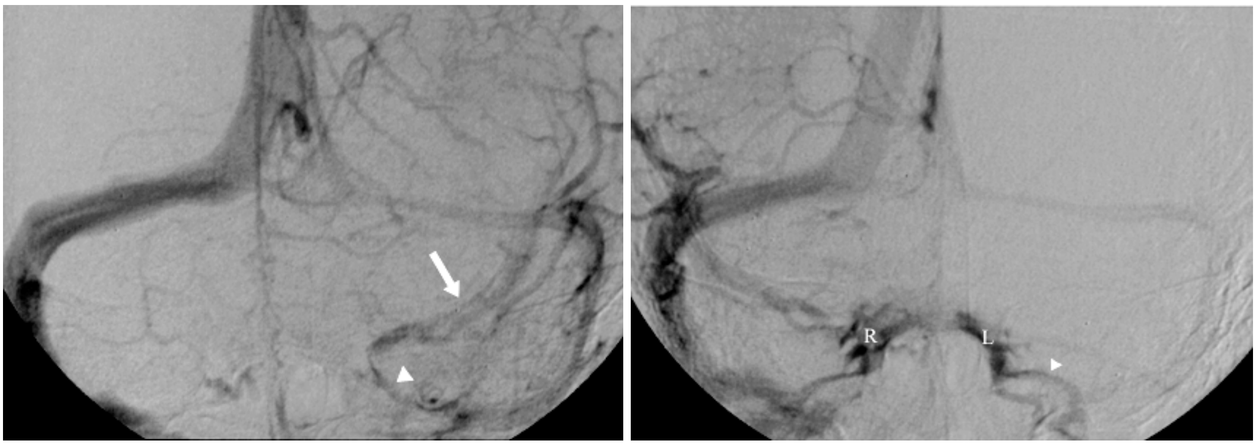


Figure 11: DSA, selective right ICA injection, venous phase demonstrating SMCV drainage into a PCS. 11a. left image. AP projection. The SMCV (white arrowheads) drains into a PCS (white arrows). The PCS is best appreciated on the lateral projection 11b. right image. In this case, the PCS drained into the superior petrosal sinus (SPS). The junction between the PCS and the SPS is marked by the narrowing of the posterior portion of the PCS (black arrow). The sigmoid sinus (SS) is opacified by the SPS.

This discrepancy may be explained by the fact that the termination of the SMCV into a LCS was overlooked in the literature, assimilating to the CS the cases in which the SMCV actually drained into a LCS. Combined, the drainage pathway of the SMCV through a CS or a LCS is more frequent than through a PCS. The termination of the PCS occurs variably into the emissary veins of the MCF, the SPS or the TS, a combination of these, or rarely, as seen on one occasion, into the superior petrosal vein.

Being in most cases the drainage route of a SMCV, the LCS usually carries venous blood coming from the ipsilateral cerebral convexity. If present, a LCS is thus best appreciated on the venous phase of anterior circulation DSA studies, i.e. selective injections of the common or internal carotid arteries. On lateral views, the LCS appears as a band-like opacity generally following an anterior-to-posterior and superior-to-inferior course projected over the sellar region and cavernous portion of the internal carotid artery (ICA) (Figure 12a).

Figure 12: DSA, venous phase, in a 59 year-old man investigated for carotid bifurcation atheromatous disease. Normal intracranial vasculature. 12a. top image. Left ICA injection, lateral view. The left SMCV (blacks arrow) continues as a LCS (arrowheads) coursing posteriorly and inferiorly, projecting over the sellar region. In this case, note that the LCS drains towards the pterygoid plexus (white arrow) through foramina in the middle cranial fossa floor. 12b. bottom left image. Left ICA injection, anteroposterior view. The left SMCV (arrow) is opacified as well as a left LCS (arrowhead). There is no opacification of the left CS.12c. bottom right image. Right ICA injection, anteroposterior view. Venous blood coming from the right cerebral hemisphere opacifies both the right CS (R) and left CS (L) through intercavernous connections. Note also opacification of the left inferior petrosal sinus (arrowheads), which was not visible on the left ICA injection.



However, since the LCS and CS lie in the same coronal plane, they are difficult to set apart on a lateral view alone. Analysis of the anteroposterior (AP) view is thus generally needed to distinguish a LCS from the medial and lateral compartments of the CS. When there is no connection between the LCS and the CS, the AP view will show a well-delineated LCS but no opacification of the ipsilateral CS (Figures 12b and c). On the other hand, when connections linking the LCS to the CS allow for their simultaneous opacification, their identification has to rely on their respective topographic relationship with the ICA, as it may be appreciated on an AP view. The medial and lateral compartments of the CS lie respectively medial and lateral to the cavernous segment of the ICA, abutting the ICA wall. The LCS is the outermost venous structure of the laterosellar region, separated from the lateral compartment of the CS by the inner dural layer of the lateral wall of the CS (Figure 13).

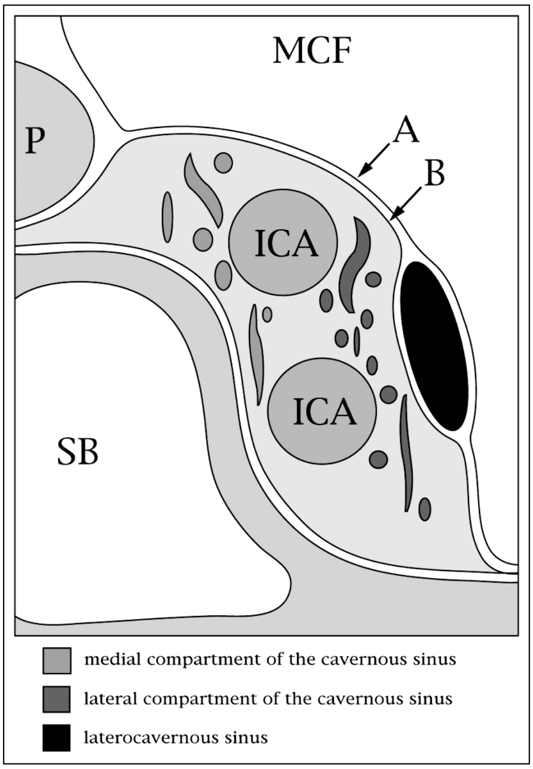


Figure 13 : Schematic representation of the laterosellar venous spaces, coronal view. The medial and lateral compartments of the CS and the LCS are shown in different shades of gray, as indicated at the bottom of the figure. The medial and lateral compartments of the CS are plexiform groups of veins lying on the medial and lateral aspect of the ICA, respectively. The LCS is venous structure showing the morphologic characteristics of a dural sinus, located in-between the outer (A) and inner (B) layers of the lateral wall of the CS. ICA indicates the cavenous segment of the ICA ; MCF, middle cranial fossa; P, pituitary gland; SB, sphenoid bone and sinus.

This inner layer may be seen as a thin vertical opacification defect between the LCS and the lateral compartment of the CS when these venous spaces are visible together (Figures 14a, 17a). The “slit-like” appearance sometimes adopted by the LCS may, however, render its detection uneasy if the CS is opacified simultaneously (Figure 15). By allowing the superimposition of arterial landmarks on venous structures, the sequential subtraction technique helps to accurately identify the laterosellar venous spaces (Figure 14). In particular, when only the LCS is opacified, the sequential subtraction technique will show that, unlike the lateral compartment of the CS, the LCS does not abut the wall of the cavernous ICA (Figure 14a).

Figure 14 : DSA, venous phase, in a 52 year-old woman investigated for subarachnoid hemorrhage. 14a. left image. Right ICA injection, anteroposterior view. A duplicated SMCV (black arrows) runs medially towards the CS region to continue its course as a LCS (black arrowhead), which terminates into the posterior aspect of the left CS via a small anastomotic channel (white arrowhead). The medial (M) and lateral (L) compartments of the CS and the left inferior petrosal sinus (white arrow) are well delineated. The right CS and inferior petrosal sinus are faintly opacified through intercavernous connections. The inner layer of the lateral wall of the CS is well appreciated as a curvilinear opacification defect located between the LS and the lateral compartment of the CS. 14b. right image. Right ICA injection, anteroposterior view, sequential subtraction technique. Simultaneous visualization of the arterial (white) and venous (black) phases confirms that the small anastomotic channel connects the LS to the lateral compartment of the CS, the latter abutting the lateral aspect of the cavernous segment of the left ICA.

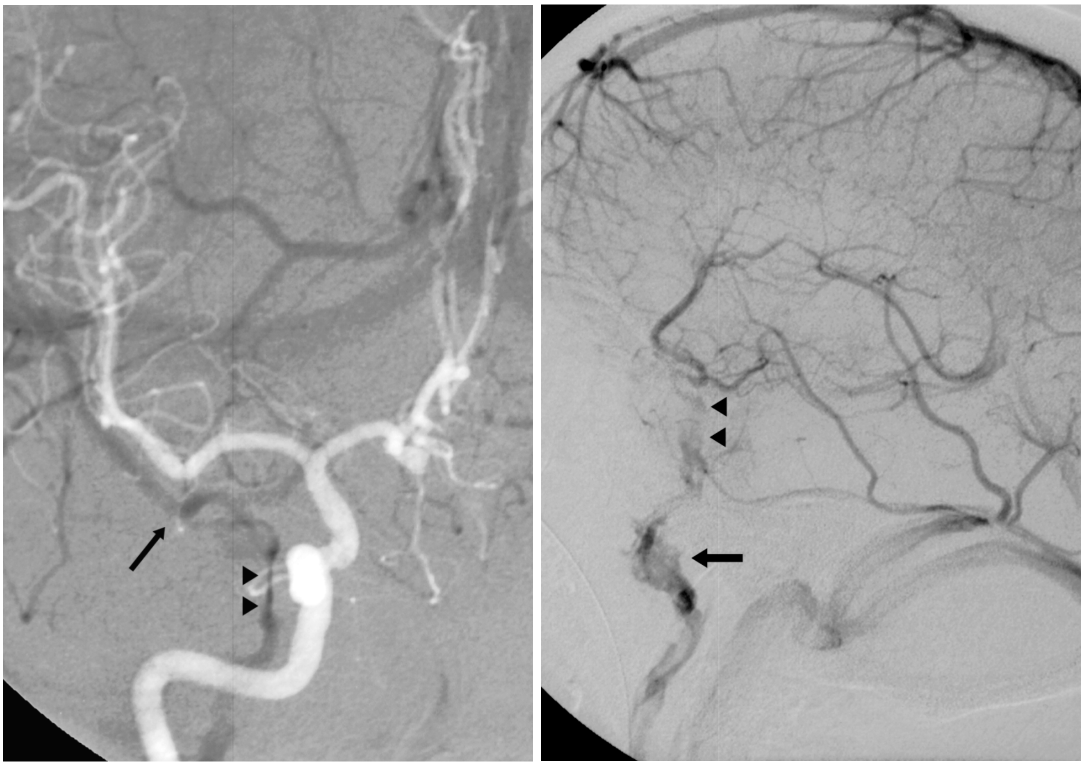


Figure 15. DSA, venous phase, in a 46 year-old man investigated for subarachnoid hemorrhage. Cerebral angiogram revealed an anterior communicating artery aneurysm. 15a. left image. Right internal carotid injection, anteroposterior view, sequential subtraction technique. The right SMCV (black arrows) courses medially towards the CS region. Just before draining into a LCS (black arrowhead), it receives a vein coming from the medial aspect of the temporal lobe, corresponding to a right uncal vein (white arrowhead). The LCS is lateral to the ICA, while not in its immediate proximity, and assumes a “slit-like” appearance. Since there is no connection between the LS and the CS, the latter do not opacify and the LCS is consequently well appreciated. When connections allow for opacification of both the LCS and the CS, a “slit-like” LCS may be difficult to observe angiographically. Note the saccular aneurysm located at the right A1-A2-anterior communicating artery junction. 15b. right image. Right internal carotid injection, lateral view. Owing to its thin configuration, a “slit-like” LCS (black arrowheads) faintly opacifies on a lateral view. Note the drainage pathway towards the pterygoid plexus (arrow).

Figure 16 : DSA, venous phase, in a 38 year-old man investigated for subarachnoid hemorrhage. 16a. left image. Left ICA injection, left anterior oblique view. A duplicated left SMCV (black arrows) courses medially towards the CS region but continues posteriorly as a LCS (arrowheads) and then a superior petrosal sinus (white arrows) ending in the left transverse sinus. There is no connection with the CS, which is not opacified. 16b. right image. Left ICA injection, lateral view, sequential subtraction technique. The arterial (white) and venous (black) phases are displayed simultaneously, allowing to appreciate their topographic relationship. The LCS (arrowheads) is seen overlying the cavernous segment of the left ICA. Posteriorly, it continues as the left SPS (white arrows) coursing over the petrous ridge before reaching the left transverse sinus (white arrowheads). Black arrow indicates left SMCV.

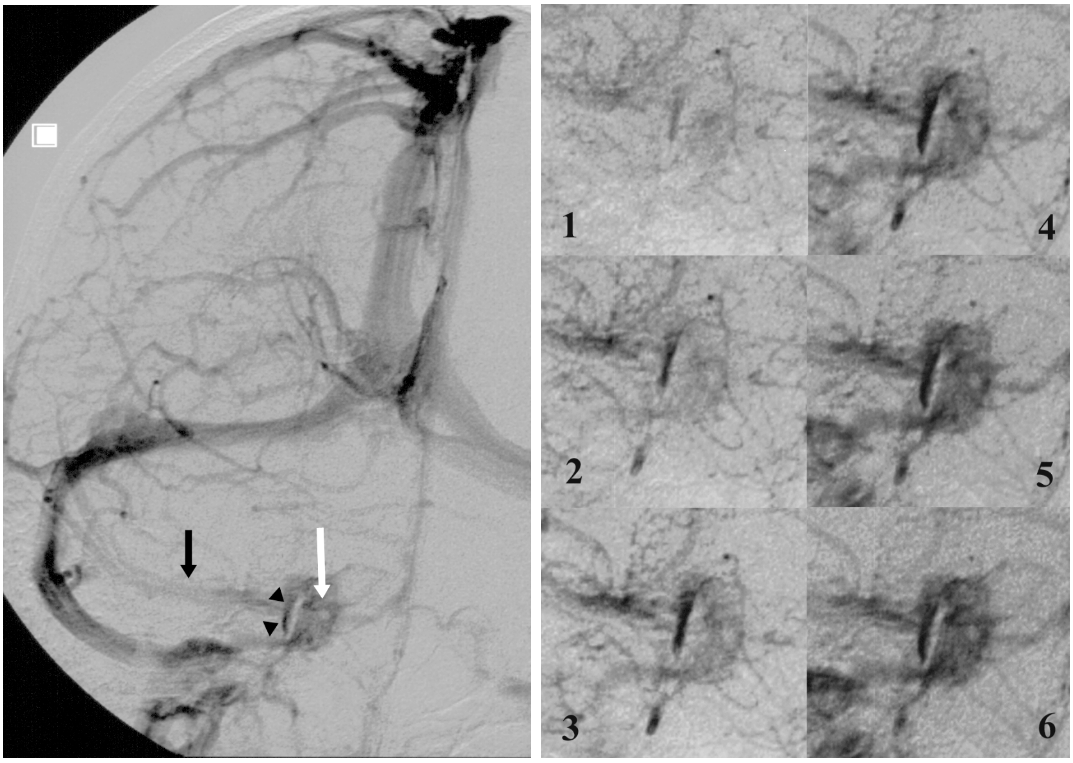


Figure 17 : DSA, venous phase, in a 68 year-old man investigated for carotid bifurcation atheromatous disease. 17a. left image. Right common carotid injection, anteroposterior view. A duplicated SMCV (black arrows) drains into a right LCS (black arrowhead). The right CS is opacified as well although no significant connections are observed. Note the linear opacification defect of the inner layer of the CS lateral wall, separating the LCS from the lateral compartment of the CS. A second, round opacification defect is visible within the CS itself, corresponding to the cavernous segment of the right ICA (white arrowhead). This anatomic landmark allows discerning the medial and lateral compartments of the CS. 17b. right image. Magnified view of the right laterosellar venous spaces. This dynamic sequence (1 to 6) was acquired at the rate of 1 image per sec. Note that the LCS appears early in the sequence while the medial and lateral compartments of the CS show homogeneous opacification after a delay of approximately 5 seconds. This is consistent with the findings of Bonneville et al (1991), who observed during dynamic CT of the laterosellar venous spaces a delay of 5 seconds between visualization of distinct laterosellar veins and homogeneous opacification of the CS. Note on the last image of the sequence the particularly well-delineated inner layer of the CS lateral wall.

The three drainage pathways of the LCS observed in the gross anatomy study were identified angiographically: i) towards the ipsilateral TS via the SPS (Figure 16), ii) towards the PP via the emissary veins in the floor of the MCF (Figure 12a and b), and iii) towards the posterior aspect of the CS (Figure 14). Combinations of these patterns may also be observed. The predominance of the superior petrosal pathway over the pterygoid pathway found in the gross anatomic study does not show through our angiographic observations, where the outflow towards the PP appears slightly dominant. This discrepancy may be related to the blood flow in the SPS, which seems to be directed anteromedially towards the CS, at least from the point of termination of the superior petrosal vein (Théron J 1975). Even if anatomically present, the SPS may thus fail to opacify on anterior circulation studies, and would be clearly delineated only when it represents the major or unique drainage pathway of the SMCV. This hypothesis is compatible with our angiographic findings (Figure 16).

Connections between a LCS and the CS were seen to take two different forms in the gross anatomy study: i) the LCS may terminate in the posterior aspect of the CS (Figure 14), or ii) the LCS may present along its course en passant anastomoses with the CS, established either via small apertures in the inner layer of its lateral wall. A third type of connections appeared in the angiographic study via small anastomotic channels in the MCF, which could explain the finding of gelatine of the same colour in the CS and the LCS in the two cases of the gross anatomic study where no connections could be demonstrated. All types of connections were observed more frequently angiographically than in the anatomic series. In particular, termination into the posterior aspect of the CS appears as a frequent outflow route for the LS, found in 32% of angiographic cases, compared to 8% reported in the gross anatomic study. This difference between the two studies is not clearly elucidated, but may at least be partially related to the difference in methods (anatomic dissection vs. DSA) and the relatively small number of anatomic specimens investigated.

Although simultaneous opacification of the LCS and CS may be observed, the LCS most often opacifies prior to the medial and lateral compartments of the ipsilateral CS (Figure 17). Three anatomic situations must be considered to understand these different patterns of opacification: i) simultaneous opacification occur when the LCS and the CS communicate via large anastomotic channels or when the LCS terminates into the posterior aspect of the CS; ii) when the LCS and CS are completely separated, the CS essentially drains blood from the high-resistance arterial beds of the ophthalmic and external carotid territories via the superior ophthalmic vein, while the LCS drains blood from the low-resistance cerebral arterial bed via the SMCV. The low resistance of the intracranial bed is coupled with a shorter circulation time, resulting in earlier opacification of the LCS; iii) delayed opacification of the CS may also be observed when small anastomoses connect the LCS to the CS and allow for slow filling of the later with blood of cortical origin. Delayed opacification of the CS thus occurs when the CS and the LCS are either totally separated (situation ii) or connected via small-size anastomoses (situation iii). In both cases, a transcavernous endovascular approach to the LCS would prove difficult or impossible for purely anatomic reasons. On the other hand, simultaneous opacification of the CS and LCS indicating the presence of large connections (situation i) would favour a transcavernous route to the LS. A CS opacifying before a LCS was observed in one instance only, in a patient with viral nasal inflammation. In that case, early appearance of the nasal mucosa led to rapid contrast filling of the superior ophthalmic vein and CS, preceding the opacification of the LS.

Embryological hypothesis

According to Padget (1956), connections between the CS and the SMCV are usually not established before birth. During fetal life, the CS only receives blood from the superior ophthalmic vein, while cortical blood from the SMCV drains directly into the transverse sinus via the primitive tentorial sinus (of Padget). Secondary anastomoses between these two embryologically distinct systems will eventually allow cortical venous drainage towards the CS. However, connections seem to occur earlier in the fetal period, at the time of formation of the CS lateral wall. Hakuba et al (1996) have shown that the lateral wall of the CS is formed around the 8^{th} week of gestation by combination of an outer layer, the dura propria of the temporal lobe, and an inner layer, the dural sheaths of the III, IV and V cranial nerves. The expansion of the temporal lobe is thought to be responsible for the medial bulging of its dural covering which comes to overly and fuse with the pre-existing dural layer of the III, IV and V cranial nerves, thus forming the CS lateral wall. It is conceivable that the same process produces a medial migration of the primitive tentorial sinus as well, bringing it close to the CS. The early formation of anastomoses between the superficial middle cerebral venous system and the CS is confirmed by the study of Knosp and co-workers (1987). Investigating human fetuses between the 17^{th} and 40^{th} weeks of gestation, these authors observed connections between the SMCV and the CS in 20% of cases. These connections resulted either from a direct termination of the SMCV into the CS, or from connections between a primitive tentorial sinus and the CS. It thus seems that the SMCV drainage pattern reaches its adult configuration during the fetal period, although further modifications such as secondary anastomoses to the CS may occur after birth. In summary, we think that the primitive tentorial sinus (of Padget), which drains cortical blood coming from the SMCV, migrates medially towards the CS region at the time of formation of the CS lateral wall, around the 8^{th} week of gestation. Depending upon the extent of migration, initial location in the MCF, and subsequent formation of anastomoses between the tentorial sinus and the CS, three adult SMCV drainage patterns may result: i) persistence of a primitive tentorial sinus, coursing laterally in the temporal fossa and taking the name of PCS in the adult, ii) presence of a LCS within the lateral wall of the CS, with or without secondary connections with the CS itself, and iii) direct termination of the SMCV into the CS, the classically described but less often observed pattern anatomically and angiographically (Figure 18).

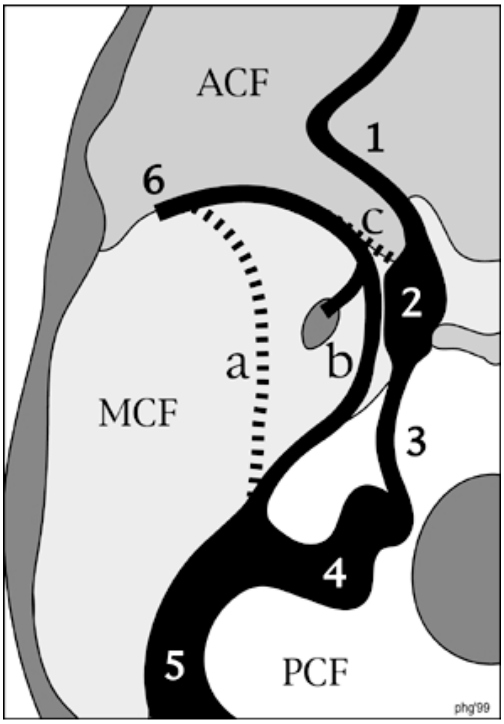


Figure 18 : Schematic representation of the three anatomically basic drainage pathways of the SMCV (6), depending upon the extent of migration, initial location in the MCF, and subsequent formation of anastomoses between the tentorial sinus and the CS (2). The three adult SMCV drainage patterns that may result are: i) persistence of a primitive tentorial sinus, coursing laterally in the temporal fossa and taking the name of PCS (a) in the adult, ii) presence of a LCS (b) within the lateral wall of the CS, with or without secondary connections with the CS itself, and iii) direct termination of the SMCV(c) into the CS, the classically described but less often observed pattern anatomically and angiographically . Anterior, middle, and posterior cranial fossa, ACF, MCF, and PCF, respectively. 1, SOV; 3, IPS; 4, SS; 5, TS.

Clinical implications of the laterocavernous sinus

Recognizing a LCS during workup MRA or DSA studies is essential for a good understanding of the various pathologies involving the laterosellar region. Treatment modalities of dural arteriovenous fistulae (DAVF) involving the laterosellar region will vary depending on the anatomy of venous structures involved in the arterio-venous connection. The usual endovascular approach, that is through the ophthalmic vein or inferior petrosal sinus, may not allow access to the fistulous point is located on LCS. For instance, in the cases where fistula situated on a LCS that is not connected to the CS, feasibility of an endovascular approach would rely on possible access routes to the LCS through a superior petrosal sinus or by way of the pterygoid plexus and emissary veins of the base of the skull. In such cases, a direct surgical approach, could be preferred in high grade fistulas, or alternatively radiosurgery could be envisaged with low grade fistulas. In cases where the DAVF involves a LCS that is connected to the CS, an endovascular access to the LCS could prove challenging or impossible, given that such connection are often very small. Again, a neurosurgical approach, or alternatively treatment by radiosurgery could be envisaged depending on the grade of the fistula.

The sphenoparietal sinus of Breschet, the meningeal, and the diploic veins

Introduction

The term sphenoparietal sinus (SphS) was introduced in the early 19th century by Gilbert Breschet in an atlas of the venous system (Breschet G 1829). If the SphS was clearly depicted and labelled in the anatomic drawings illustrating the atlas, the manuscript itself was, however, incompletely published, and no reference to the SphS is found in the accompanying text. Cruveilhier later quoted Breschet's description of the SphS as a "sinus found within the limits of the anterior and medial portions of the base of the skull, and which occupies a transversally oriented gutter that runs inwards into the cavernous sinus. This sinus receives several branches from the skull bones, the dura mater, and the diploic vein of the temporal"[1](Cruveilhier J 1852). This account, consistent with Breschet's illustrations, corresponds to the sphenoid portion of the SphS, found under the lesser sphenoid wing (LSW) and involved in diploic and meningeal venous drainage. This is the classic definition of the SphS, which then came to be known as the sinus of Breschet (Rouvière H and Delmas A 1997).

The anatomic description became more complex and somewhat confusing when the notion was introduced that the superficial middle cerebral vein (SMCV) ended into the SphS under the lesser sphenoid wing (LSW) (Galligioni F et al 1969), or that the SMCV was at least partially equivalent to the SphS. This view, which can be traced back to Hédon's monograph on the cerebral venous system published in 1888, is commonly reproduced in the radiological, surgical, and anatomic literature. Oka and co-workers (1985) mention, for example, that the SMCV may either join the SphS or drain directly into the CS. These authors also affirm that the SphS may drain into the spheno-basal or spheno-petrosal sinuses, which are better described conjointly as the PCS. Bisaria (1985) reports that the SMCV terminates into the SphS in 68% of cases. Wolf et al (1963) mention that "in the region of the pterion, the vein [SMCV] enters the dura and runs along the lesser wing of the sphenoid to enter the anterior end of the cavernous sinus. The dural portion of this channel along the lesser wing is frequently referred to as the SphS…"(Wolf BS et al 1963). However, these authors add that "there is no significant dilution of the opaque material when the sinus [SphS] fills via the superficial sylvian vein [SMCV]". They suggest that the SphS drains exclusively the SMCV and that the term "sinus of the lesser wing of the sphenoid" should be preferred.

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[1] "un sinus situé sur la limite de la portion antérieure et de la portion moyenne de la base du crâne, sinus qui occupe une gouttière transversalement dirigée de dehors en dedans et s'abouche dans le sinus caverneux. Ce sinus reçoit plusieurs branches veineuses des os crâniens, de la dure-mère, et la veine diploïque du temporal." Author's translation. The reference given by Cruveilhier, that is "book II, plate 3" could not be found or confirmed, and does not correspond to Breschet's atlas (1).

However, we have seen above that injecting the SMCV with coloured gelatine is not followed by a concomitant filling of the middle meningeal veins (MMV). Furthermore, when the SMCV drains into the laterosellar region, it does not first constitute a dural venous sinus under the LSW, but instead directly pierces the dura mater in the superior-anterior aspect of the lateral wall of the CS after coursing freely in the subarachnoid space. In the rare cases where the SMCV courses under the LSW, it is attached to the dura mater overlying the sphenoid ridge, but maintains the macroscopic appearance of an arachnoid vein, that is, it does not become a venous sinus. These findings suggest that the SMCV and the SphS are not connected and that, if a dural venous sinus actually exists under the LSW, it is not related to the SMCV.

We performed an anatomic study based on corrosion casts and dissection of fresh cadavers following intravascular injection of an acrylic cement (see Materials and Methods) to clarify the discrepancy between our findings and the descriptions in the literature relative to the SMCV and the SphS.

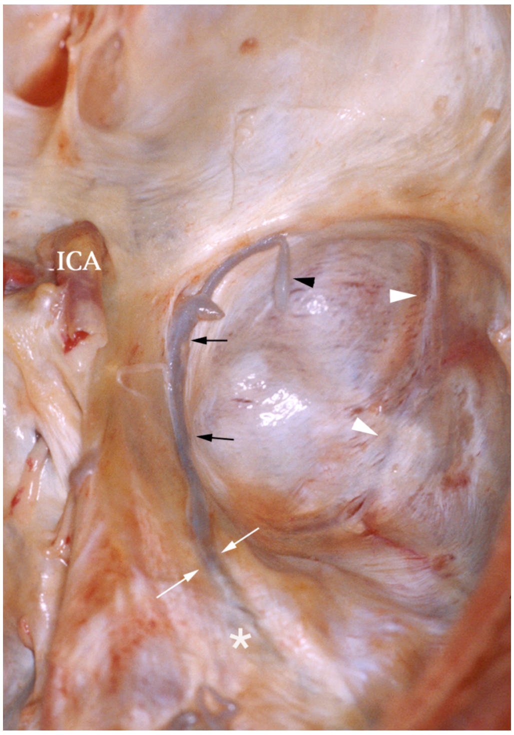
Results

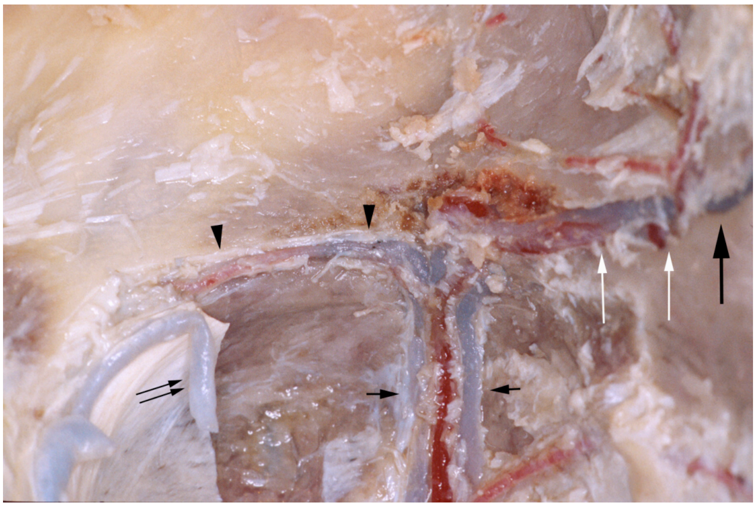
Anatomic findings

The following anatomic description is based on observations made on the 11 specimen sides with adequate vascular filling, that is, 5 sides prepared as corrosion casts and 6 sides used for standard dissection.

The major venous channels observed in the middle cranial fossa, in the LSW and laterosellar regions, and along the cranial vault in the frontoparietal region were the anterior branch of the MMV (AMMV), a dural venous sinus coursing under the LSW (thereafter called sinus of the lesser sphenoid wing, SLSW), and the termination of the SMCV.

The AMMV was composed of a sphenoid and a parietal portion. The sphenoid portion of the AMMV (Figures 19a-c) crossed the floor of the middle cranial fossa from the lateral and anterior aspect of the greater sphenoid wing to the foramen ovale or spinosum, through which it joined the PP.





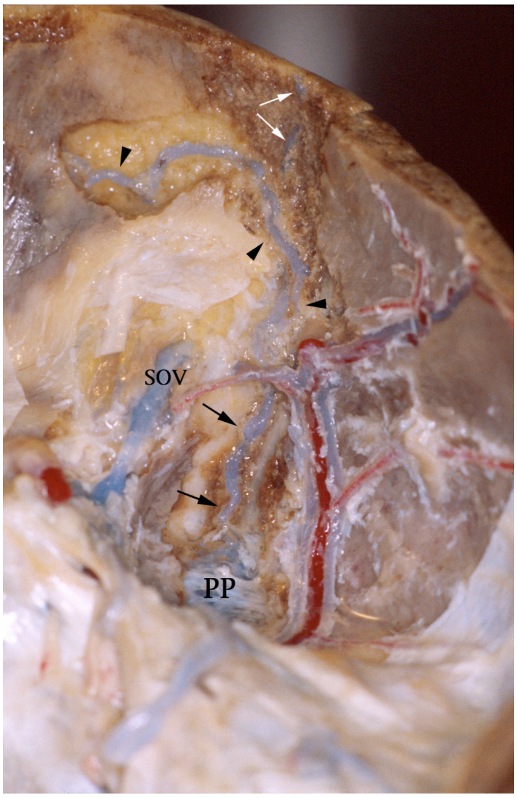


Figure 19. Serial dissection of a right of a fresh specimen. 19a).top left image. Superior topographic view of the right MCF. The brain has been removed and the bridging veins of the temporal pole, in this case a single SMCV (black arrowhead), have been sectioned close to the brain surface. The SMCV is attached to the dura mater overlying the LSW, but keeps the appearance of an “arachnoid vein”. Note the different appearance between the SMCV and the middle meningeal vessels (white arrowheads), the latter being embedded in the dura mater. The SMCV terminates into a LCS (black arrows). Note that in this case the LCS shares both “arachnoid” and dural characteristics being as translucent as the SMCV, but more greatly embedded in the dura matter. The LCS becomes a definite dural venous sinus more posteriorly (white arrows) as it drains into the superior petrosal sinus (asterisk). 19b) top right image. The dura mater of the MCF and the ridge of the LSW have been removed to reveal the sphenoid (small black arrows) and parietal (large black arrow) portions of the AMMV and the SLSW (black arrowheads). The white arrows demonstrate the location of the sphenoparietal canal (of Trolard), whose roof has been removed. The SMCV (black double arrow) has been kept in situ and no connections are demonstrated with the SLSW. The anterior branch of the middle meningeal artery is seen between the two veins that constitute the AMMV. 19c) bottom image. The inner bony plate of the frontal and sphenoid bones has been removed to expose diploic vessels. Part of the roof of the orbit has been removed to expose the superior ophthalmic vein (SOV). The diploic vein of the orbital roof (black arrowheads) is followed anteriorly and exits the skull through the supra-orbital foramen (not shown here). The diploic vein of the orbital roof connects with a frontal diploic vein (white arrows) that drains into the SLS. The diploic vein of the GSW (black arrows) drains into the pterygoid plexus (PP) extracranially.

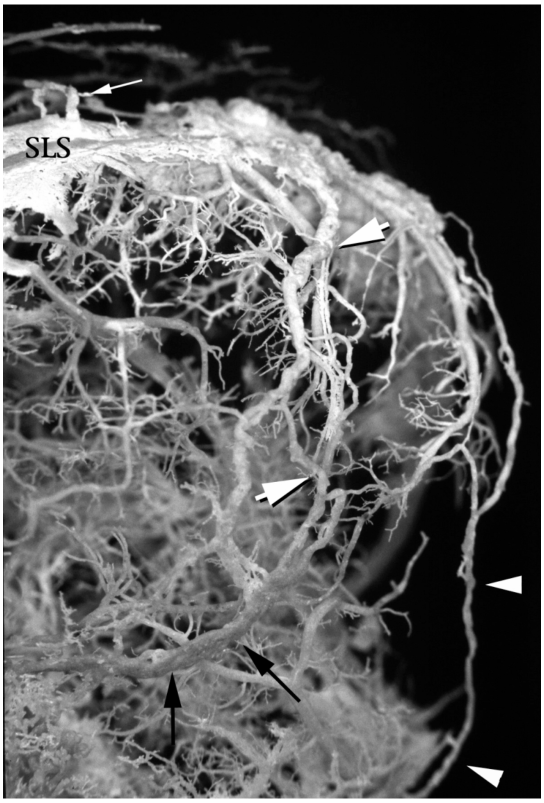


Figure 20: Anterior and lateral view of the left convexity of a corrosion cast showing the parietal portion of the AMMV. The dual meningeal and diploic nature of the parietal portion of the AMMV is demonstrated. The anterior parietal diploic vein (black arrows) and the parietal portion of the AMMV may be individualized wherever their course does not overlap. Note how diploic veins enter the venous lacunae of the SLS at a right angle (white arrow). A parieto-temporal diploic vein is demonstrated (white arrowheads), it drained into the middle third of the left transverse sinus.

This sphenoid portion was composed of two small parallel venous channels separated by the anterior branch of the middle meningeal artery. At the anterior margin of the GSW, the sphenoid portion entered a 3 to 10-mm long osseous canal identified by Trolard as the sphenoparietal canal. The parietal portion of the AMMV (Figures 19b and 20) extended from the lateral opening of the sphenoparietal canal up to the venous lakes of the superior sagittal sinus. As it emerged from the sphenoparietal canal, the parietal portion of the AMMV appeared as a single wide channel, which was larger than its two tributaries, and met the definition of an anterior parietal diploic vein. Two thin individual veins corresponding to the classic AMMV appearance were seen again for short distances wherever the anterior parietal diploic vein deviated from its more or less straight caudocranial course towards the SSS. The distinct AMMV fused with the anterior parietal diploic vein once their respective courses met again.

A SLSW was constantly observed, both in the dissected specimens and in the corrosion casts (Figures 19b-c, 21a-b).

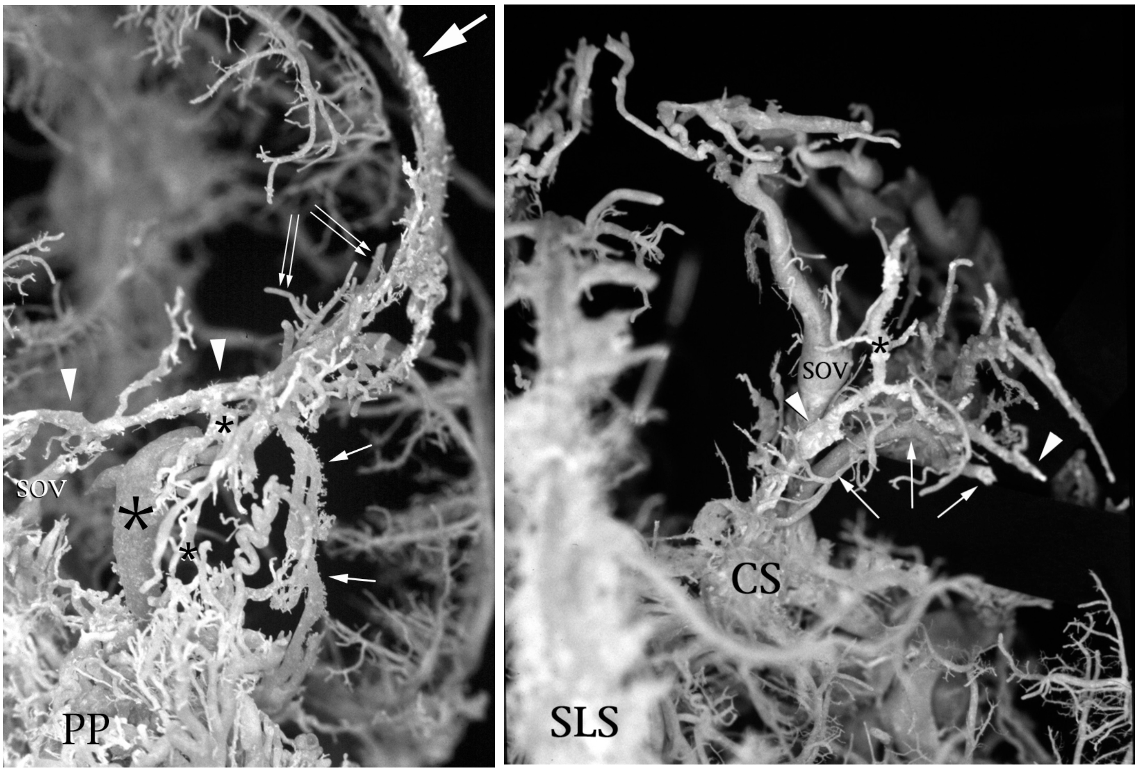


Figure 21 : 21a) left image. AP view of left side of a corrosion cast showing the SLSW (arrowheads), the parietal portion of the AMMV (large white arrow), and the sphenoid portion of the AMMV (small white arrow). Different branches of the SMCV (double arrows) are seen behind the SLSW. The SMCV drains into a PCS (large asterisk). The SLSW is seen to cross over the SOV. Only the dorsal aspect of the SOV was filled in this side. Note the different aspects of the sphenoid and parietal portions of the AMMV, in which the former offers a typical aspect of parallel meningeal channels, while the latter resembles a diploic vein. A diploic vein of the greater sphenoid wing (small asterisk) is seen to drain into the pterygoid plexus (PP). 21b) right image. Superior view of the right side of a corrosion cast in the region of the right LSW, demonstrating the SLSW, the diploic vein of the orbital roof (asterisk; the anterior portion of this vein is not filled), and the SMCV (arrow) draining into a LCS (not seen). Note how the SMCV and the SLSW are not connected and course on different anatomical planes. The SLSW typically crosses over the dorsal portion of the SOV. The AMMV was not filled in this side. CS – cavernous sinus; SLS – superior longitudinal sinus.

In the dissected specimens, this venous channel was found within the dura mater under the LSW. It was connected laterally with the sphenoid portion of the AMMV proximal to its entry into the sphenoparietal canal. Medially, the SLSW crossed over the superior ophthalmic vein (SOV) before entering the most anterior and superior aspect of the CS. The middle and lateral third of the SLSW received several branches:

i) a diploic vein that coursed within the orbital roof towards the orbital process of the frontal bone, to exit the skull through the supraorbital foramen into the supraorbital veins (5/11 sides) (Figures 19c, 21b).

ii) a diploic vein of the greater sphenoid wing coursing craniocaudally into the pterygoid plexus (7/11 sides) (Figures 19c);

iii) an orbital vein observed once in a dissected specimen. This vein was only injected over a few millimetres, and its orbital termination could not be confirmed. Its anterolateral orientation suggested, however, that it corresponded to an ophthalmo-meningeal vein (of Hyrtl) (cited by Wolf BS et al 1963).

The relation between the SMCV and the dura mater in the LSW region could only be assessed in the dissected specimens, the corrosion casts being devoid of cranial soft and osseous tissues. Out of the 6 dissected sides, the SMCV continued as a PCS once, as a LCS on 3 occasions (Figure 19a), or joined the CS on 2 occasions. In 3 of the 5 sides where it drained towards the laterosellar region, either into a LCS, or into the CS, the SMCV pierced the dura mater of the lateral wall of the CS directly. In the 2 other cases, the SMCV was superficially attached to the dura mater underlying the middle and medial third of the LSW, but kept the characteristics of an "arachnoid vein". The transition between the "arachnoid" and dural components of the SMCV occurred abruptly in all sides but one, in which the SMCV drained into a LCS. The SMCV never assumed the characteristics of a dural sinus. These findings are in accordance with the observations made during the study of the termination of the SMCV. Connections between the SMCV and the AMMV or the SLSW were not observed.

The drainage of the SMCV and its connections with other skull base venous channels were analysed in the 21 corrosion cast sides that showed complete filling of the SMCV. The SMCV drained into the CS in 7 instances. It continued as a LCS in 7 sides, and as a PCS in 5 sides. No connections between the SMCV and the AMMV, or the SLSW were documented in these 21 corrosion cast sides.

Angiographic correlation

The SMCV and its various drainage patterns, the SLSW, and the sphenoid and parietal portions of the AMMV were identified on the various venous phases of cerebral angiograms. Some examples are shown in Figures 22a to d.

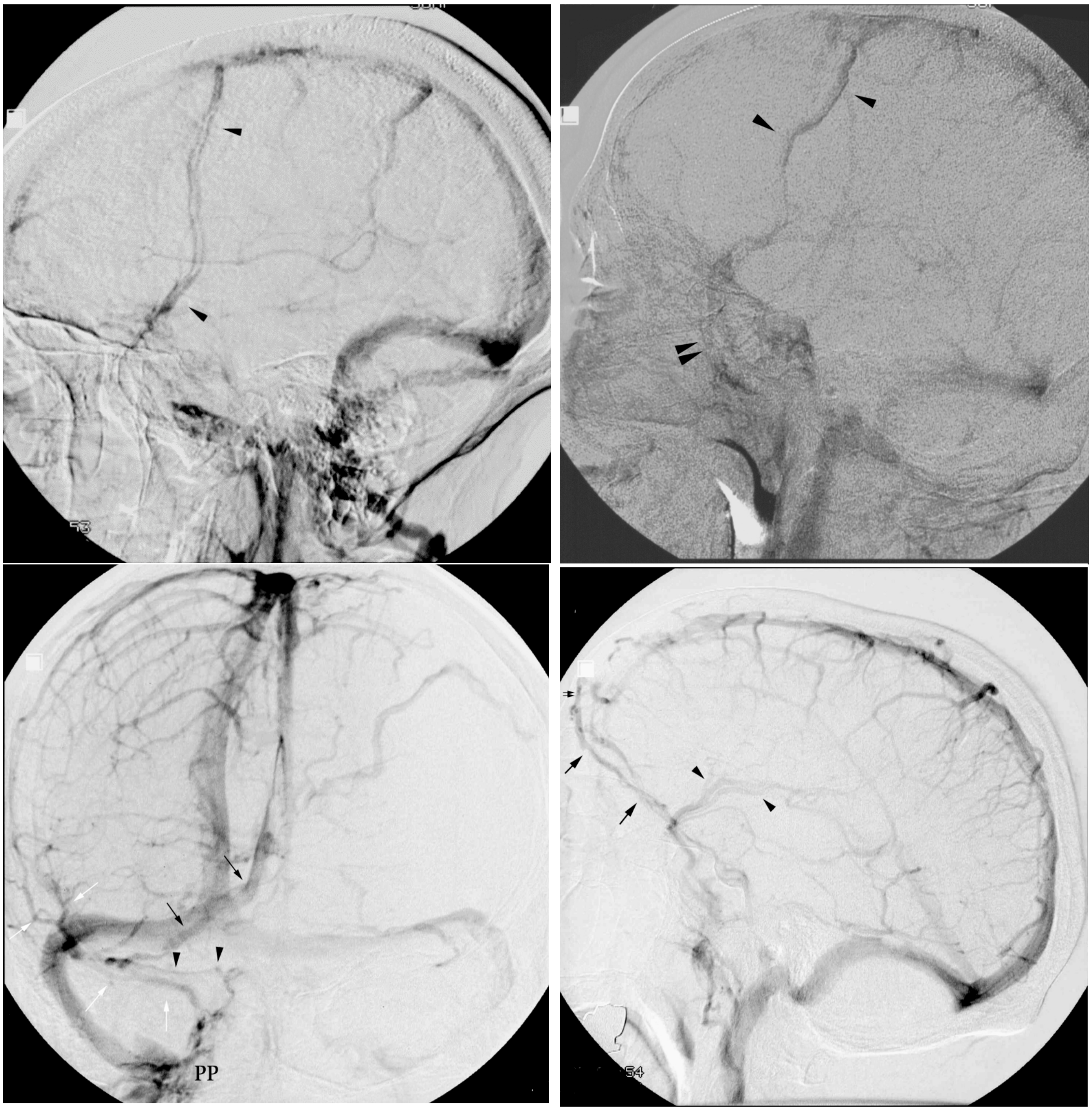


Figure 22. Various venous phases of DSA, selective ICA injections of three patients with no confirmed cerebrovascular disease. 22a) left top image. Lateral projection of a late venous phase showing the characteristic venous sinus appearance of the parietal portion of the AMMV, seen as two distinct thin channels coursing in parallel (arrowheads). 22b) right top image. Lateral projection of a late venous phase depicting both the sphenoid (double arrowhead) and parietal (single arrowheads) portions of the AMMV. The parietal portion is seen as a wide sinuous channel typical of a diploic channel. 22c) left bottom image. AP projection demonstrating simultaneously the SLSW and the SMCV. The SLSW (black arrowheads) drains medially into the CS and is connected laterally to the diploic vein of the orbital roof (black arrow). The SMCV (white arrow) is seen to drain through emissary veins of the into the pterygoid plexus (PP). 22d) right bottom image (same patient as 22c). lateral view showing the diploic vein of the orbital roof (black arrows) connecting extracranially with the supra-orbital veins (black double arrows). The SMCV (black arrowheads) is well delineated and drains into the emissary veins of the MCF.

Clinical case

A 47 year-old male presented with a long history of headache when bending his head over. There was no prior record of head trauma. The only clinical finding on examination was a pulsatile bruit upon auscultation of the right orbital region that was not subjectively perceived by the patient.

MRI and MR angiography demonstrated a possible DAVF of the LSW. DSA studies revealed a type IV[2] right dural arteriovenous fistula (DAVF) under the LSW, nourished by branches from the right middle meningeal artery and from the recurrent meningeal branch of the right ophthalmic artery (Figure 23). The fistula was directly on the right SMCV. The portion of the SMCV that coursed under the sphenoid lesser wing showed a focal saccular dilatation. Superficial and deep cerebral veins were filled in a retrograde fashion via the SMCV and the DMCV. Embolization into the recurrent meningeal branch of the ophthalmic artery followed by surgical clipping and resection of the saccular dilatation of the SMCV (performed by Prof Nicolas de Tribolet, Division of Neurosurgery, Geneva University Hospital, Geneva, Switzerland) permitted to close the fistula with a good clinical outcome.

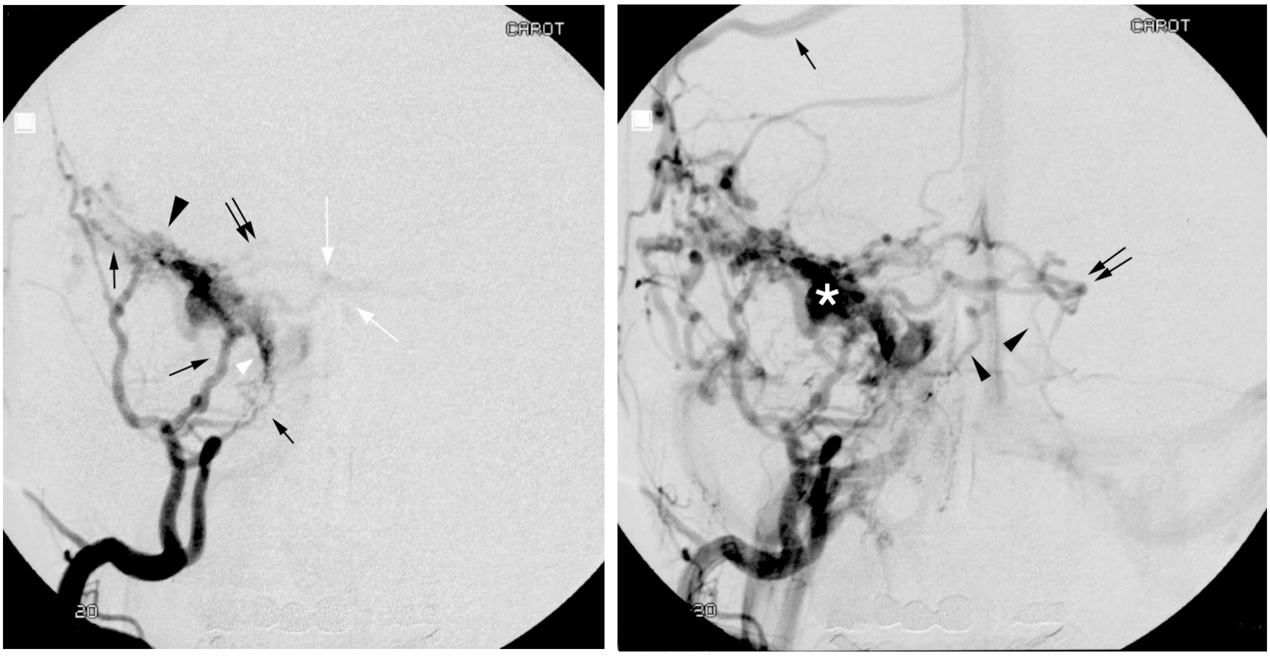


Figure 23: DAVF of the LSW. 23a) left image. Early filling of a selective right ECA injection in the AP projection. Nourishing branches from the right middle meningeal artery (black arrows) feed a dilated SMCV (black arrowhead). The SMCV drains into a LCS (white arrowhead), which is also directly involved in the DAVF and is fed by branches of the right middle meningeal artery. Early anterograde filling of the CS is observed. There is retrograde filling into the right basal vein and into the right peduncular vein, through the right DMCV. 23b) right image. Selective right ECA injection, later in the venous phase. Retrograde filling of the right superficial cortical veins (black arrow) via the right SMCV is now observed. The left basal vein (black double arrow) is now also opacified via the peduncular veins, and the straight sinus is clearly delineated. There is an infratentorial drainage of the fistula into the anterior and lateral pontomesencephalic veins (black arrowheads). The saccular dilatation of the SMCV is clearly visible (asterisk).

[2] According to Cognard et al's (1998) revision of Djinjian and Merland's classification.
Type I: DAVF draining into a sinus, with a normal antegrade flow direction; Type II: DAVF draining into a sinus. Insufficient antegrade venous drainage and reflux. Type IIa: retrograde venous drainage into sinus(es) only; Type IIb: retrograde venous drainage into cortical vein(s) only; Type IIa+b: retrograde venous drainage into sinus(es) and cortical vein(s); Type III: DAVFs draining directly into a cortical vein without venous ectasia; Type IV: DAVFs draining into a cortical vein with a venous ectasia >5 mm in diameter and three times larger than the diameter of the draining vein. Type V: DAVFs (intracranial) draining into spinal perimedullary veins

Discussion

Anatomy

The AMMV (sphenoid portion) crosses the floor of the middle cranial fossa, from the foramen ovale or spinosum to the pterion, taking the form of two parallel venous sinuses centered by the middle meningeal artery. It then progresses cranially along the anterior margin of the parietal squama to terminate into the venous lakes of the superior sagittal sinus (parietal portion). As they course under the most lateral aspect of the LSW, the AMMV and its arterial counterpart are contained for a short distance within an osseous canal, the sphenoparietal canal (of Trolard), before exiting into a sulcus of the parietal squama. This has been previously reported (Padget DH 1957, Trolard P 1890, Jones FW 1912). Before entering this osseous canal, the AMMV establishes a connection with a dural venous sinus located under the LSW, the SLSW. The SLSW is connected laterally with the sphenoid portion of the AMMV, and medially with the anterior and superior aspect of the CS. It crosses over the SOV before reaching the CS. A similar description of the SLSW was given by Trolard. Three tributaries of the SLSW were found, usually draining into its lateral portion:

i) a diploic vein of the orbital roof. It connected anteriorly and extracranially with the supraorbital veins, and sometimes laterally with frontal diploic veins that drained into the SSS. We found no mention of this diploic vein in the literature.

ii) a diploic vein located within the GSW and draining into the pterygoid plexus.

iii) an orbital vein corresponding to the ophthalmo-meningeal vein (of Hyrtl).

Connections between the SMCV and the SLSW or the AMMV were never demonstrated in this study. All the other possible terminations of the SMCV in the middle cranial fossa, that is, into a PCS, a LCS, or a CS were encountered. Our data also confirms previous reports (Bisaria 1985) showing that, whenever the SMCV drains in the laterosellar region, it generally directly pierces the dura of the lateral wall of the CS. Only rarely is the SMCV attached to the dura mater underlying the inferior aspect of the LSW. In such cases it maintains the characteristics of an “arachnoid vein”. In our material, the SMCV never assumed the characteristics of a dural sinus.

Based on their angiographic observation that opacified blood from the SMCV was not diluted under the LSW, Wolf et al. (1963) suggested that the SLSW exclusively drained the SMCV. With this assumption, they clearly, and we think erroneously, assimilated the distal portion of the SMCV to the SLSW. As early as 1890, however, Trolard had challenged the already widespread impression that the SMCV and the SLSW were connected under the LSW. This general misconception can probably be ascribed to the close topographic relationship between the SLSW and a SMCV attached to the dura mater of the LSW. Furthermore, most of the anatomic studies evaluating the termination of the SMCV have been performed on non-injected specimens, a fact that may easily explain why the SLSW was overlooked.

The fact that the meningeal and diploic veins of the middle cranial fossa are not anatomically and functionally related to the SMCV is also supported by their different developmental origins. According to Padget, the MMV arises from the primitive middle meningeal sinuses, which are lateral tributaries of the pro-otic sinus. The pro-otic sinus is also the precursor of the CS and of the superior petrosal sinus (Padget DH 1957), both of which occupy an extradural position in the adult. The primitive middle meningeal sinuses develop as extrachondrocranial vessels (around the 40-mm stage) and are involved in the vascularization of membranous bones that will form the skull vault. On the other hand, the SMCV drains, along with the deep middle cerebral veins and the primitive tributaries of the basal vein of Rosenthal, into the primitive tentorial sinus (of Padget). By the 60-mm ands 80-mm stages, with the development of the cerebral hemispheres and the subsequent caudal swing of the transverse sinus, the caudal end of the tentorial sinus migrates cranially and ventrally towards the junction between the sigmoid and transverse sinuses. As already noted by Padget, the final location of the tentorial sinus in the middle cranial fossa can vary from a medial to a lateral position. The adult remnant of the primitive tentorial sinus is, therefore, either incorporated to the CS (medial position), courses within the lateral wall of the CS as a LCS (intermediate position), or remains on the floor of the middle cranial fossa as a PCS (lateral position).

An interesting finding in our material was the observation that the AMMV became assimilated to the anterior parietal diploic vein as they came out from the sphenoparietal canal (of Trolard), only to emerge as two distinct channels wherever their respective course did not overlap. The dual diploic and meningeal nature of the AMMV has been reported by Trolard (1890) and Padget (1957). This phenomenon is probably related to aging. All the observations in our study are based on cadavers aged over 80 years on average. Diploic vessels appear postnatally concomitantly with the development of the cranial diploe and become prominent with old age (Boismoreau MEP 1904). With age, the parietal impressions that correspond to the AMMV (Jones FW 1912) become deeper and more prominent (Augier M 1932, Saban R 1984). Furthermore, there exist connections by way of small foramina between the parietal portion of the AMMV and the parietal diploic vein (Trolard P 1890, Saban R 1984). Since, with age, the AMMV becomes more deeply positioned in the inner table of the skull, it seems reasonable to assume that a secondary assimilation of the parietal portion of the AMMV to the underlying parietal diploic vein may ensue.

The parietal portion of the AMMV can be identified during the late venous phase of cerebral angiograms. When detectable, it is usually seen as two parallel, regular, and thin venous channels characteristic of meningeal veins, coursing from the pterion to the SSS. Alternatively, the parietal portion of the AMMV may appear as a wide sinuous channel typical of a diploic vein.

The sphenoid portion of the AMMV is uncommonly documented on routine cerebral angiograms, either concomitantly to the SMCV opacification, or slightly later in the venous phase. Distinction between the sphenoid portion the AMMV and a PCS, or a LCS, on the lateral projection is based on the absence of cortical afferences from the superficial or deep middle cerebral veins.

The SLSW is rarely observed angiographically. It appears concomitantly to the SMCV and can be identified in the anteroposterior projection as a thin channel coursing parallel to the inferiorly located SMCV. The diploic vein of the orbital roof may be identified angiographically and must be distinguished from an ophthalmic vein, especially on lateral projections. Non-subtracted images in the lateral projection demonstrate the position of both the SOV and the diploic vein of the orbital roof in relation to the orbital roof. In the AP projection, distinction between the diploic vein of the orbital roof and the SOV is made by identifying the characteristic inverted “S” course of the SOV and its dorsal connection with the CS.

As mentioned earlier, Breschet’s atlas of the venous system remained unfinished, and we found no written description of the SphS by Breschet himself. Trolard reached the same conclusion in 1890. Cruveilhier (1852) quoted Breschet’s definition of the SphS as a dural venous channel located under the LSW and draining meningeal and diploic blood, but the origin of this quotation could not be confirmed. In several of Breschet’s original illustrations, a venous channel, located under the LSW and apparently dural in nature, is clearly identified and labelled as a SphS (Figures 24 a and b).

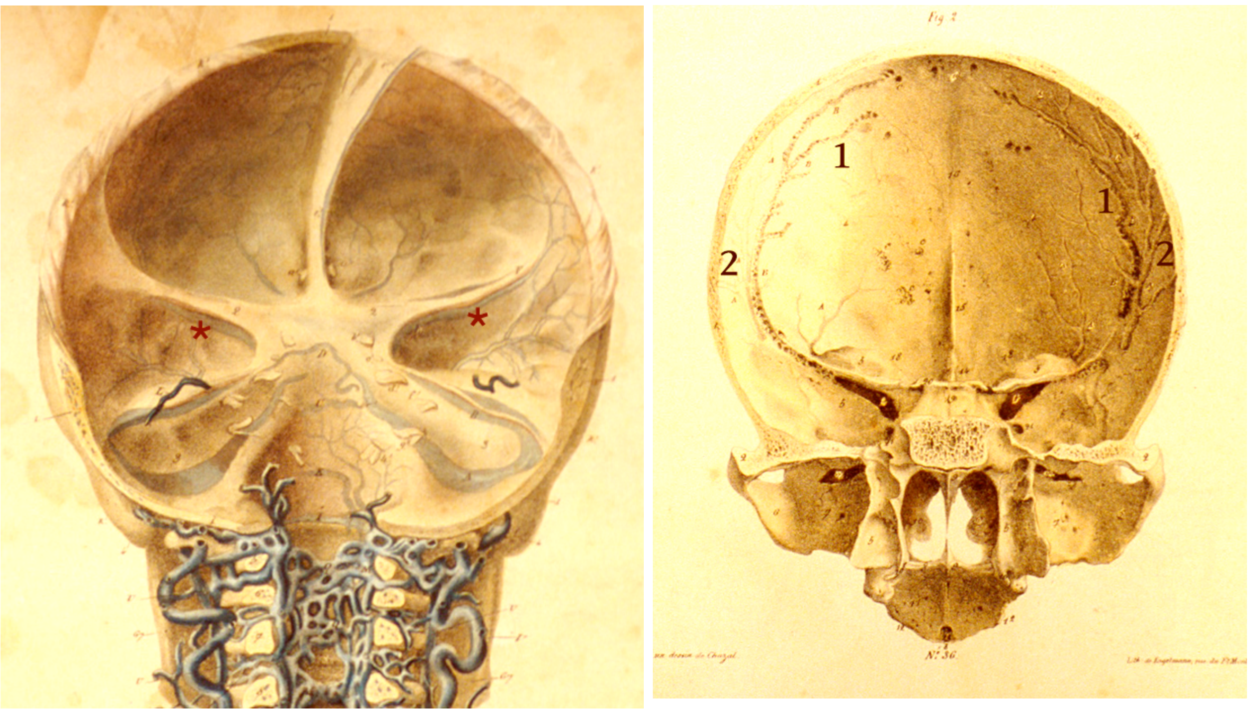


Figure 24: plates from Breschet’s atlas (courtesy of Mme B Molitor, Section Histoire de la Médecine, BIUM, Paris,

France). 24a) left image. Posterior view of the three cranial fossas. The sphenoid portion of the SphS, corresponding to the SLSW, is shown under the LSW (brown asterisk). Connections between the SphS and the AMMV are illustrated and were described in the legends of the original text. Note that the SMCV is not depicted. 224) right image. Posterior view of the anterior and middle cranial fossae, the dura mater has been removed. The parietal portion of the SphS (1), is depicted and artificially distinguished from the AMMV (2). The floor of the sulcus of the SphS is pierced by many small foramina. The legend describes these foramina, which are connections between the SphS and underlying diploic veins.

The MMV are also illustrated and the legend mentions their connection with the SphS. Nowhere in the 42 plates of Breschet's atlas does the SMCV appear to be connected with the SphS.

According to his illustrations, Breschet seems to have combined the parietal portion of the AMMV with a dural sinus located under the LSW, to create a single continuous venous entity that he named SphS. We think, along with Trolard, that the parietal portion of Breschet's SphS is in fact the parietal prolongation of the AMMV. The sphenoid portion of the SphS, on the other hand, appears to be a distinct dural venous sinus coursing under the LSW, with its own set of tributaries and secondary anastomoses. This venous structure is, in our opinion, adequately described by the term of "sinus of the lesser sphenoid wing" proposed by Wolf et al (1963).

It thus appears that the name of SphS does not describe an actual anatomic entity, but rather corresponds to the arbitrary assimilation of two independent meningeal vessels. Furthermore, the frequent and incorrect assimilation made in the anatomic, radiological, and surgical literature of the so-called SphS with the termination of the SMCV, generates further confusion. For these reasons the term of SphS should be abandoned.

Clinical implications

DAVF in the region of the sphenoid lesser wing are rare findings; there is usually a history of previous head trauma or prior surgery (Bitoh S et al 1980, Tsutsumi et al (1990). We present a case of type IV DAVF under the LSW (Figure 23). This fistula involved the SMCV and not a SLSW. Distinction between the two was possible by recognizing a retrograde filling into the deep and superficial cerebral venous system, the presence of a saccular dilatation more typical of a vein than a venous sinus, and the demonstration of a LCS, which as mentioned earlier, when present, drains the SMCV and / or the DMCV.

Development of a DAVF on a SMCV is rendered possible by its occasional attachment to the dura mater overlying the LSW. This distinction is clinically relevant as cerebral venous hypertension and related complications are only likely to result from a high grade fistula involving a SMCV. Bitoh et al (1980) reported a case of DAVF of the SLSW presenting with a three-month history of exophthalmia and chemosis due to venous hypertension in the SOV, which necessitated a surgical correction. However, in general, asymptomatic DAVF's of the SLSW probably do not require any correction. This is supported by a case reported by Tsutsumi et al (1990) of a spontaneous resolution of a DAVF of the SLSW that had appeared post-operatively.

The petrosquamosal sinus

Introduction

In humans, the anatomy and embryology of the PSS and the PGF have been extensively documented, mostly in post-mortem anatomical studies, since the early descriptions attributed to Rathke and Luschka (Rathke cited by Butler H 1957 and 1967, Luschka H 1859, Streeter GL 1915, Fisher MH 1926, Boyd GI 1936, Waltner JG 1944, Padget DH 1957, Butler H 1957 and 1967, Conroy G 1982, Wisocky J 2002). Their importance in evolutionary phylogenetics has been suggested by several authors (Butler H1957 and 1967, Conroy G 1982). Recently, the description of the PSS has been added to the radiological literature by Marsot-Dupuch et al (2001), who suggested that the persistence of a PSS in adults was more frequent in patients harbouring a malformation of the base of the skull. Other reports in humans have focused on the potential role of the PSS as an alternative venous drainage pathway for the posterior fossa towards the EJV system, on its potential clinical significance during surgical otological approaches, or on its implication in the potential spread of septic thrombosis in the otological sphere (Cheatle AH 1899, Furstenberg AC 1937).

This section provides a comprehensive review of the PSS in humans, based on the literature and on our observations from corrosion cast studies of the cranial venous system, and from two radiological observations in patients. Particular weight will be given to the description and illustration of the clinical cases, and in particular the second one, in which a complex anomaly of the encephalic venous drainage pathways is encountered. Clinical implications are advanced in light of these anatomical findings.

Materials and methods

Postmortem study

Corrosion casts of the cranial venous system were prepared from 13 non-fixed human specimens (8 females, 5 males, average age of 81 years) as described in Post-mortem study / General Materials and Methods section (an extra corrosion cast had been obtained by the time the petrosquamosal sinus study was undertaken).

Minimum and maximum diameters of the PSS on the corrosion casts was measured for all cases with a small ruler with markings for every millimetre.

Computed tomography with three-dimensional reconstruction was obtained for two corrosion casts, allowing for virtual dissection of the zones of interest on a post-processing workstation (Vitrea, Vital Images, Minnesota, USA).

Clinical imaging cases

Images from two routine clinical radiological investigations were selected as illustration of the variable anatomical presentation of the PSS. In the first case, high resolution CT was employed to study the temporal bone. In the second case, the patient underwent high resolution CT angiography, MRI and MR phlebography, and digital subtraction angiography (DSA) of the head and neck.

Results

Postmortem study

The results presented here were partially discussed in a previous brief communication (San Millán Ruíz D, Fasel JH, and Gailloud P 2002). A PSS was present in 5 out of the 26 corrosion cast sides. A connection with the TS was found in all cases. This connection was located on the lateral and superior surface of the TS at its junction with the sigmoid sinus (SS). In all cases, the PSS coursed anteriorly and then medially towards the region of the foramen ovale. A connection with the emissary veins of the foramen ovale could be documented in 2 out of 5 cases. In one case, the anterior portion of the PSS gave rise to two branches, the medial branch just described, and a lateral branch which was connected extracranially with a deep temporal vein (Figure 25). In the same case, the dorsal portion of the PSS received a posterior temporal diploic vein. In three instances, the contour of the PSS was irregular and its course tortuous in the manner of a diploic vein. The contour was smooth and the course less tortuous in keeping with a meningeal vessel in the two remaining cases. The diameter of the PSS measured in the corrosion casts did not exceed three millimeters (average 2.6, minimum 2 mmm; maximum 3 mm).

Figure 25. 3D images after reconstruction of a CT of a corrosion cast of the cranial venous system on a Vitrea workstation (Vital Images, Minnesota, USA) (0.8 mm slices, every 0.4 mm. Philips MX 8000 IDT 16 channel-multirow detector, Philips Medical Systems, Best, The Netherlands). The cortical veins have been virtually dissected. **25a**. right lateral view showing a petrosquamosal sinus (PSS) (1), the transverse sinus (2), the sigmoid sinus (3), the cavernous sinus (CS), a temporoparietal diploic vein (4), the internal jugular vein (IJV), the pterygoid plexus (PP), and the superior ophthalmic vein (sov). The PSS is connected to the transverse sinus/sigmoid sinus junction (asterisk). Close to this point, the PSS receives a posterior temporoparietal diploic vein. The single arrow points at a deep temporal vein. The double arrow represents the sphenoparietal sinus, which drained a large anterior parietal diploic vein into the cavernous sinus. **25b**. superior view of the right middle cranial fossa. Same legend as **25a**. The connection of the PSS with the emissary veins of the middle cranial fossa (foramen ovale) is marked by an arrowhead. The double arrowhead indicates the connection with the deep temporal vein through the postglenoid foramen (PGF). The sphenoparietal sinus (double arrow) courses over the superior ophthalmic vein (sov) and joins the anterior superior aspect of the cavernous sinus (CS).

Clinical imaging cases

Case 1

A 29-year-old woman was admitted to the emergency department for severe headache following an occipital trauma. Initial clinical examination was normal. Head CT was performed, which revealed a longitudinal linear fracture of the occipital squama on the right side. High resolution CT showed no other fractures, but revealed osseous canals compatible with a PSS (Figure 26). The diameters of the osseous canals containing the PSS were comparable to those observed in the corrosion casts, and did not exceed two millimeters.

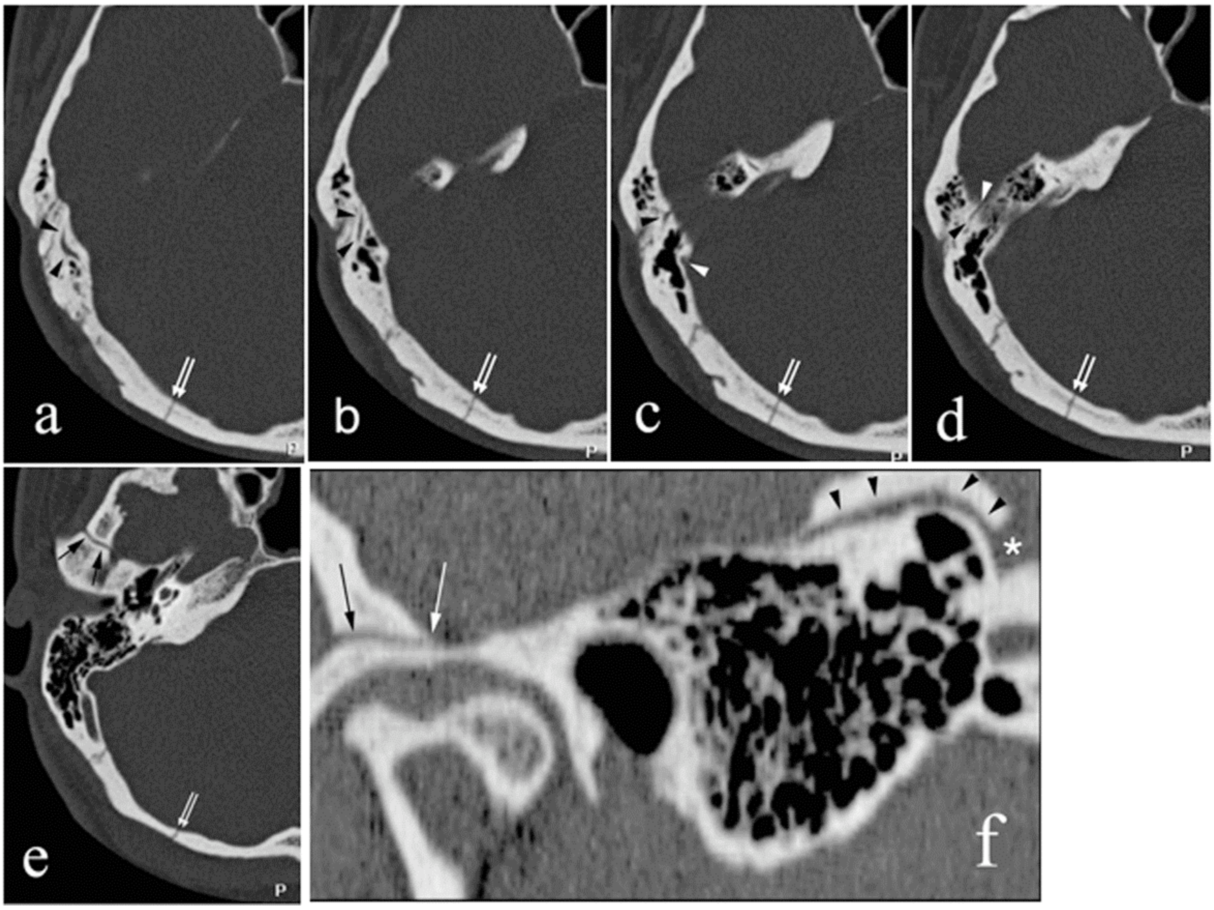


Figure 26. Case 1. High resolution CT with bone algorithm of the right temporal bone (Philips MX 8000 IDT 16 channel-multirow detector,Philips Medical Systems, Best, The Netherlands). **26a-e** are axial source images following the course of the PSS cranio-caudally. The proximal and dorsal portion of the PSS is contained within a petrous bony canal (arrowheads) that is parallel to the petrosquamosal suture and follows the roof of the left petrous bone (**26a-d**). Proximally, the petrous bony canal opens into the superior and lateral aspect of the distal transverse sinus (white arrowhead, **26c**) Distally, it opens into the middle cranial fossa, where the PSS likely shifts from a diploic to a dural position (white arrowhead, **26d**). A bony canal in the temporal squama containing the anterior and lateral branch of the PSS is depicted in **26e** (black arrows). This temporal canal is anterior to the root of the zygomatic process and cranial to the glenoid cavity of the temporomandibular joint. Its opening into the temporal fossa corresponds to the PGF. Thus, in this case, the portion of the PSS coursing on the floor of the middle cranial fossa is intradural and not intraosseous, while its proximal (dorsal) and distal (ventral) extremities are contained in the petrous and temporal squama, respectively. A linear fracture of the occipital squama is seen on all images (white double arrow). **26f** shows a curved MPR reconstruction of the osseous canals containing the PSS. The arrowheads indicate the petrous canal containing the proximal PSS; the arrows point at the temporal canal containing the medial and anterior branch of the PSS.

Case 2

A 7-year-old girl treated for left sided cluster headaches since age 3, consulted for the new onset of severe constant, posture-dependent headaches. Cerebral MRI suggested an anomalous encephalic drainage pattern and a possible arteriovenous shunt, which was then ruled out by CTA and digital subtraction angiography (DSA). Lumbar puncture showed no increase in the opening cerebrospinal fluid pressure. Anatomical findings obtained from the three imaging modalities are described in detail in Figures 27-29.

On the left side, the SS and the IJV were absent. Drainage of the TS occurred through a large PSS. The PSS provided a connection with the EJV system by way of its anterior-lateral and anterior-medial branches, which communicated with a deep temporal vein and the emissary veins of the middle cranial fossa, respectively. The anterior-lateral branch of the PSS exited the skull through a PGF found in the temporal squama, which measured 4.5 mm in diameter at its outer orifice. Its connections with the EJV and with a “hybrid jugular vein” are described in Figure 27. On the right side, the TS drained into an anomalous SS, which communicated exclusively with a posterior condylar emissary vein. No right IJV was found.

High resolution CT disclosed severe bilateral hypoplasia of the pars vascularis of the jugular foramen consistent with the absence of IJV, bilateral absence of the mastoid emissary foramina, and absence of the left posterior condylar canal.

Considering the restricted encephalic venous outflow pathways of the posterior cranial fossa, Doppler sonography of the neck vessels was performed in order to evaluate postural drainage variations. Doppler sonography confirmed the absence of the right IJV. No postural variations in diameter or flow were observed in the vertebral artery venous plexus on either side, in the EJV, or in the “hybrid jugular vein” on the left when going from the prone to the upright position.

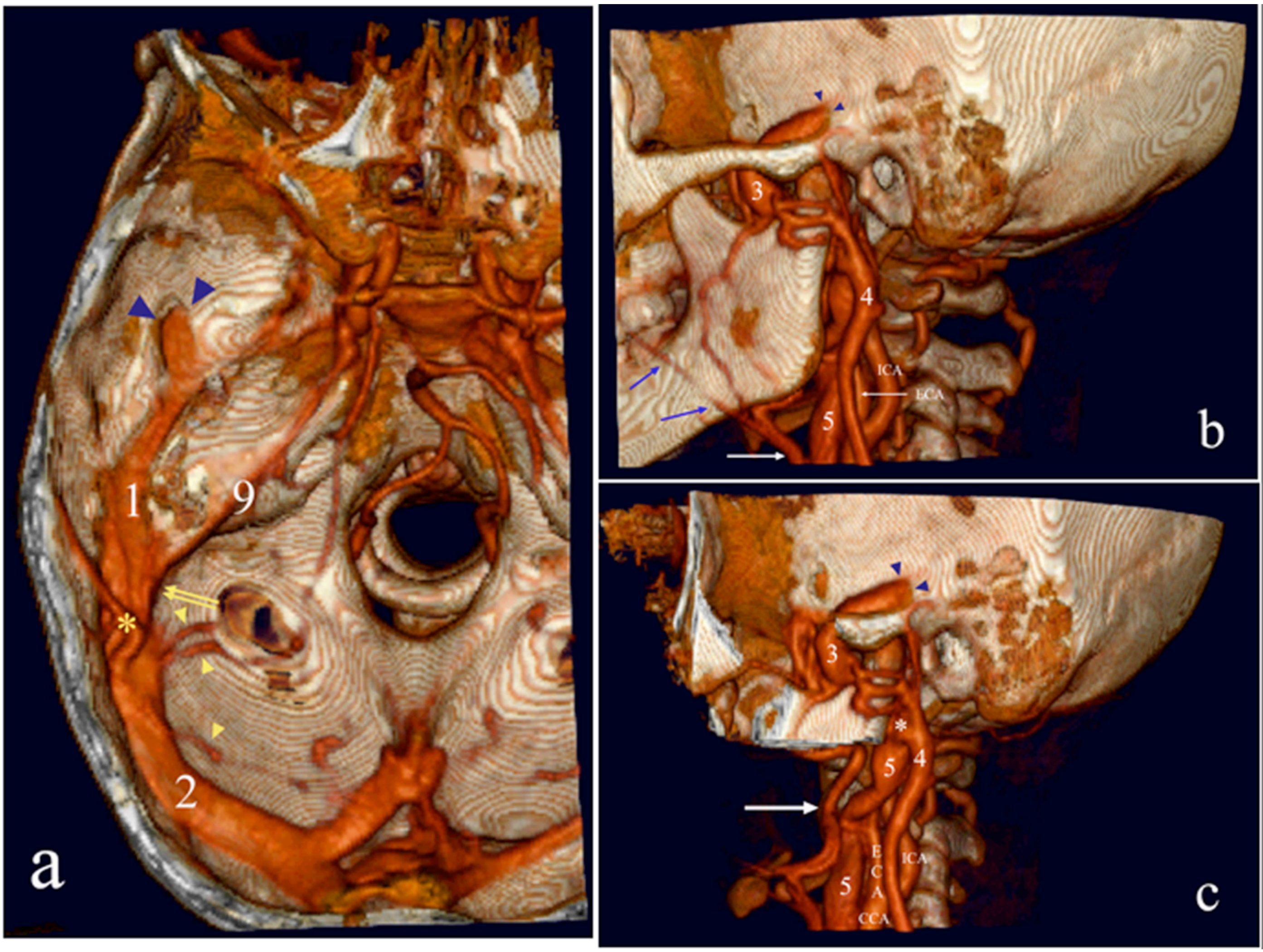


Figure 27. Case 2. 3D reconstruction of angio-CT images (Philips MX 8000 IDT 16 channel-multirow detector,Philips Medical Systems, Best, The Netherlands) obtained on Vitrea workstation (Vital Images, Minnesota, USA). **27a.** superior view of the left cranial fossa showing the left transverse sinus (2) draining anteriorly through a large PSS (1). The anterior-lateral branch of the PSS exits the middle cranial fossa through a PGF (blue arrowheads). The size of the PSS is identical to the transverse sinus. No left sigmoid sinus is observed. The transverse sinus receives several infratentorial veins (yellow arrowheads), and a lateral temporal vein (yellow asterisk). The superior petrosal sinus (9) joins the stem of the PSS (double yellow arrows). **27b and c.** left lateral view centered on the external auditory canal before (**26b**) and after virtual dissection of the left zygomatic process and ramus of the mandible (**27c**) . The PSS opens into enlarged deep temporal veins (2) via the PGF (blue arrowheads). The deep temporal veins communicate with the external jugular vein (EJV) (4), and with a "hybrid jugular vein" (5) [3]. This vessel originates behind the ramus of the mandible at the cervical level of C1. It then courses within the carotid sheath for a short distance, after which it crosses over the anterior border of the left sternocleidomastoid muscle, and comes to lie superficial to the infrahyoid muscles, in the manner of an anterior jugular vein. At the level of the jugular incisura, it crosses the midline to join the right subclavian vein. Relation to the internal and external carotid arteries (ICA and ECA) is shown. A deep facial vein draining the pterygoid plexus is joined by a superficial facial vein (blued arrows) and forms a common facial vein (white arrow). The point at which the deep temporal veins join the EJV and the "hybrid jugular vein" is marked by a white asterisk. Note venous branches from the deep temporal veins going around the condyle of

[3] An explanation of the embryological significance of this "hybrid jugular vein" is beyond the scope of the present communication. However, the course of the middle portion of the "hybrid jugular vein" within the carotid sheath and its relation to the ICA and CCA, suggest that it is in fact an IJV whose cranial and caudal thirds are absent. This hypothesis is further supported by the termination, in the middle portion of the "hybrid jugular vein", of the common facial vein, which corresponds to the primitive linguo-facial vein, an early tributary of the primitive IJV (anterior cardinal vein) as stated by Padget (1957) and Lewis (1909).

the mandible and forming a venous arch. The white arrow shows a left common facial vein, which was seen to drain caudally into the middle portion of the “hybrid jugular vein” (see **29a**). CCA stands for common carotid artery.

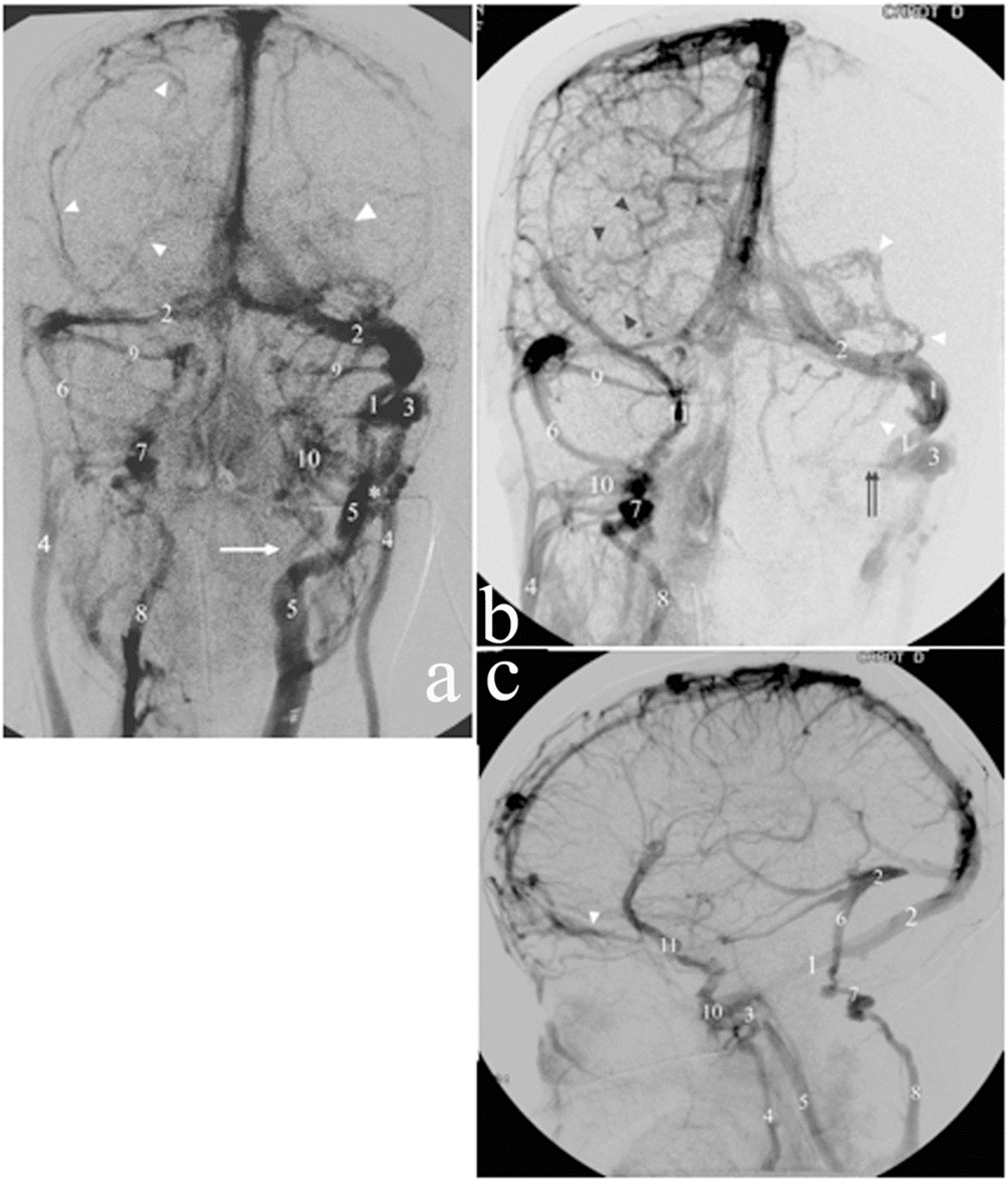


Figure 28a-c. Case 2. DSA (BN3000, Philips, Best, The Netherlands). Aside from confirming the CTA findings, DSA disclosed signs of venous hypertension, partial obstruction of the superior sagittal sinus draining cortical veins from the left convexity (not shown), and compensatory collateral drainage through an enlarged system of diploic veins on both sides **28a.** late venous phase obtained after injection of contrast agent into the ascending aorta, anteroposterior view. Same legend as in previous figures. The absence of the left sigmoid sinus is confirmed. The right transverse sinus is hypoplastic compared to the left and drains into a sigmoid sinus (6). Drainage of the right sigmoid sinus occurs through a posterior condylar emissary vein (7) into a deep cervical vein (8). Note the absence of a right IJV. The left pterygoid plexus (10) is prominent and drains into a large deep facial vein, which ultimately becomes a common facial vein (white arrow). Cortical veins have washed out at this stage and only a few prominent diploic veins are recognized (white arrowheads) on both sides, compatible with collateral venous flow. **28b.** early venous phase after right ICA injection, anteropostarerior view. There is simultaneous opacification of the transverse sinuses.

Controlateral drainage into the PSS is conspicuous. The anterior-medial connection of the PSS with the middle meningeal veins (not seen here) is faintly opacified (double black arrow). A right laterocavernous sinus (11) (San Millán Ruíz et al. 1999, Gailloud et al. 2000) receives a prominent superficial middle cerebral vein and drains into a voluminous pterygoid plexus (10). This drainage pattern was also seen on the left side (not shown). The cortical veins (black arrowheads) on the right display a "corkscrew" appearance suggesting a certain degree of venous hypertension. Note that prominent diploic veins have already appeared on the left (white arrowheads). **28c.** lateral view, right ICA injection, slightly earlier venous phase than **28b** confirming the absence of left sigmoid sinus. The prominent left diploic veins seen in **28b** are within the frontal bone and drain into the supraorbital veins by way of a large orbital diploic vein (arrowhead). The cavernous sinuses were never observed, but there were no signs in favour of a cavernous sinus thrombosis in any of the imaging modalities used during the investigation. No inferior petrosal sinuses were demonstrated on either side.

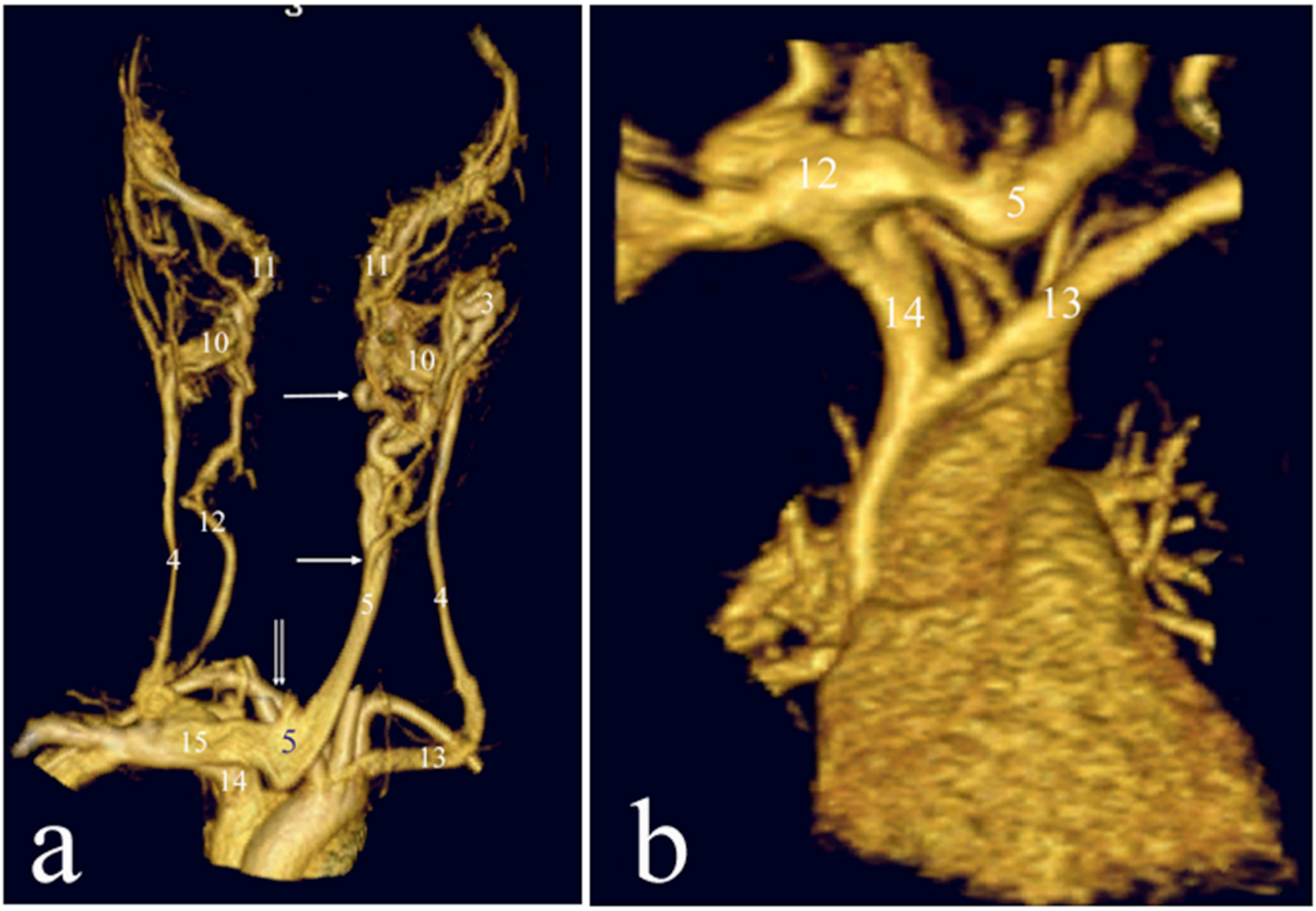


Figure 29a and b. Case 2. 3D reconstructions obtained from MR phlebography with bolus-tracking (Philips Intera 1.5 The, Philips Medical Systems, Best, The Netherlands; 18 seconds acquisition in echo gradient T1 consisting of 85 slices, 1,3 mm thickness after reconstruction of 2.6 mm slices on acquisition; FOV 350 mm with matrix of 160x256; flip angle 40°; TE 1ms, TR 4ms; AP phase encoding; 2 bolus injections of gadobutrolum (Gadovist ® 1.0, Shering (Schweiz) AG) one in arterial time, and a second in venous phase). The neck arteries have been virtually removed. There is no IJV is seen on the right. A prominent right anterior jugular vein (12) drains the pterygoid plexus and joins the subclavian vein (15) with the EJV (4). The subclavian vein receives the "hybrid jugular vein" (5) from the left, and continues as an anomalous brachiocephalic vein (14). The left EJV (4) joins the left axillary vein and forms an anomalous subclavian vein that drains into the anomalous brachiocephalic vein to form the superior vena cava. The left common facial vein (white arrow) joins the "hybrid jugular vein" in its middle third (within the carotid sheath). The white double arrow points at a right aberrant subclavian artery.

Discussion

In adult mammals, the major cerebral venous outflow pathways are the EJV, the IJV, and the vertebral venous system (VVS). The relative development of these three venous systems varies between species. The dominance of the IJV system over the EJV system for the cerebral drainage appears late in evolution (Conroy G 1982). The IJV system and the VVS are the main cerebral drainage pathways in humans, with dominance of the IJV in the supine position and transfer of the IJV outflow to the VVS when standing upright (Epstein HM et al. 1970, Eckenhoff J 1970, Théron J and Moret J 1978, Valdueza J et al. 2000). In humans, the EJV system drains the viscero- and neurocranium, and offers only a small participation to the cerebral venous drainage, mainly as an effluent of the pterygoid plexus. This pattern is shared by most catarrhine primates[4], and some non-primate mammals including cats and pigs (Wysocki J 2002, Conroy G1982, Hegedus SA and Shackelford RT 1965). The EJV system represents the major cerebral outflow pathway with variable degrees of participation of the VVS in Strepsirrhines[5] and in most non-primate mammals such as dogs, sheep, rabbits, and horses.

The development of the PSS and its connections to the EJV seem to be a constant feature in the early development of all mammalian embryos (Butler H 1967). The degree of subsequent involution of the PSS is correlated to the growing dominance of the IJV over the EJV, which itself seems to be determined by the relative development of the brain over the face (Padget DH 1957). Conroy (1982) corroborated this view suggesting that the development of the telencephalon and its caudal expansion over the cerebellum, observed in catarrhine primates (including humans), is at the origin of the modifications taking place in the dural venous sinuses of the posterior and middle cranial fossas. The TS is, in the early human embryo as in most mammals, vertically oriented and follows a craniocaudal course. At this stage, the SS and the PSS have similar diameters. The caudal expansion of the telencephalon over the cerebellum will later displace the TS from a vertical to a horizontal position. Conroy (1982) has suggested that this reorientation leads to the regression of the PSS, with the SS then becoming the major outflow pathway of the transverse sinus. Inversely, in animals with a lesser telencephalic development and persistent verticality of the TS, the PSS is likely to be retained as the major outflow pathway of the TS. The crossroad in embryological development during which the growth of the hemispheres will modify the orientation of the TS begins around stage 6 (embryos in horizons XX, XXI, 18-26 mm stage) (Padget DH 1957). This is

[4] The superfamily of Catarrhini includes the Cercopithecidae (Old World monkeys), Hominidae (humans, gorilla, chimpanzee, bonobo, orangutan) and Hylobatidae (gibbons) (Classification phylogénétique du vivant. Eds Le Guyader H and Lecointre G.Paris: Belin 2001)

[5] The suborder Strepsirrhini includes the lemurs and lorises (Classification phylogénétique du vivant. Eds Le Guyader H and Lecointre G.Paris: Belin 2001)

concomitant to the development of the definite EJV, which not only begins to drain the PSS, but also takes over, to a variable degree, the primitive facial tributaries of the IJV.

The PSS is not a rare finding in the human adult. Knott (1882) found 19 unilateral and 7 bilateral PSS in 44 adult cadavers. Cheatle (1899) stated that it was "the rule rather than the exception for remains of the sinus [the PSS] to be present in some form or another all through life". In human adults, only the connections of the PSS with the middle meningeal veins and the transverse sinus usually persist, while the lateral connection with the deep temporal veins is lost. The rare observation of temporal foramina in human skulls, reported in 8 out of 1500 dry skulls (0.53%) by Boyd (1939) and in 23 out of 2585 (0.88%) by Cheatle (1899), is in accordance with the loss of the connection between the PSS and the deep temporal veins. In adults, the remnants of the PSS can drain a posterior temporal diploic vein and superior tympanic veins (Cheatle AH 1899, Padget DH 1957), and are also likely involved in the meningeal venous drainage of the middle cranial fossa. Our corrosion cast findings with 5 PSS present unilaterally in 13 heads, are consistent with statements that the PSS is not rare in adults. Only one of the identified PSS had retained a connection with the veins of the temporal fossa and drained a posterior temporal diploic vein, though this may be an underestimation due to imperfect venous filling in the remaining corrosion casts.

Radiological demonstration of the PSS is possible and usually relies on identifying a bony canal along the petrosquamosal suture or within the temporal squama on high resolution CT (HRCT) of the temporal bone. However, the proximity of the PSS to bone and its small size make its detection by CTA, MRA, or even DSA difficult, explaining the discrepancy in the detection of a PSS observed between post-mortem and imaging examinations, as was reflected in the present study as well as in other reports (Marsot-Dupuch K et al 2001, Koesling S et al 2005). The PSS is likely amenable to identification by imaging techniques only when it persists as a large channel, or when it is contained within a bony canal. Marsot-Dupuch et al. (2001) recently gave, to our knowledge, the first radiological description of the PSS associated with a PGF in four cases, using HRCT in all cases, complemented by MR venography in three. Interestingly, these authors suggested that a PSS was most frequently found in patients with congenital malformations of the skull base associated with venous and middle ear anomalies. Koesling et al. (2005) also described the PSS on HRCT studies, and found six unilateral PSS in 233 cases, without mentioning an association with skull base malformations. Our series of corrosion cast provide no information about potential middle ear malformations. It offers, on the other hand, a detailed appreciation of the venous anatomy, which failed to demonstrate venous anomalies in the cases where a PSS was observed. These findings are consistent with the fact that the persistence of a small PSS is probably a normal feature of the adult venous system, while a larger, more readily identifiable channel might represent a collateral drainage pathway associated with a venous or skull base anomaly.

In humans, the venous drainage of the posterior fossa follows highly asymmetric patterns with frequent anatomic variations, in keeping with the independent development of its constituents, in particular of the transverse and sigmoid sinuses (Padget DH 1957, Butler H 1957 and 1967). The latter are subject to lateral dominance, the right side being frequently more developed than the left side, but also to segmental variations of the transverse and sigmoid sinuses, with greater anatomical constancy found in the SS (Huang YP et al 1984). The most frequently encountered segmental variation is isolated hypoplasia of the proximal portion of the TS. Hypoplasia of the SS in the presence of a normal TS is rare, and it is generally coupled with compensatory rerouting of venous blood into prominent mastoid emissary or posterior condylar emissary vein (Knott JF 1882, Laff HJ 1939, Valdueza J 2000, Furstenberg AC 1937). Alternatively, an occipital sinus may convey venous blood from the torcular herophili to the bulb of the IJV, in association with either normal, hypoplastic, or absent transverse and sigmoid sinuses (Woodhall B 1936, Rollins N et al 2005, Widjaja E and Griffiths PD 2004). In any case, most variations involving the transverse and sigmoid sinuses in humans allow conservation of the IJV and VVS as their major outflow pathways for encephalic drainage.

Only rarely, when the SS is absent or severely hypoplastic, may a PSS represent the major or only drainage pathway of the transverse sinus, directing the venous blood to the EJV system. Furstenberg described a case of surgically proven “aseptic thrombus which could be traced for a considerable distance and removed from a persistent PSS of large proportions” in the absence of a SS (Furstengerg AC 1937). Marsot-Dupuch et al. (2001) documented a case with HRCT and MR phlebograhy in which the TS drained anteriorly into the EJV system by way of a PSS. Their case showed severe hypoplasia of the jugular foramen in keeping with the absence of a SS similar to the one observed bilaterally in our second case. They also mentioned the presence of a malformation of the craniocervical junction, the type of which was not specified.

In our second case, the PSS was present in its complete form, that is, with all its constituents and embryological connections having persisted, likely as a compensatory response to the loss of the right SS and IJV. The diameter of the PSS was equal to that of the TS, confirming it as the principal if not only outflow pathway of the TS. The posterior stem of the PSS in proximity of the TS received the superior petrosal sinus medially, consistent with the primitive disposition and tributaries of the PSS at 80 mm stage of fetal development (Padget DH 1957). Anteriorly, the PSS showed a medial connection with the middle meningeal veins at the foramen ovale, and a lateral connection with the veins of the temporal fossa and EJV system through the PGF. Thus, the venous blood reaching the left TS was redirected towards tributaries of the EJV by the anterior-medial and anterior-lateral connections of the PSS.

The skull base and jugular venous anomalies described here must have occurred at a simultaneous developmental period, likely during the late embryonic and early foetal periods between stages 6 and 7 (20-80 mm) (Padget DH 1957). During this relatively long period from a developmental standpoint, the EJV appear as a definite structure and partially or completely absorbs the original tributaries of the primitive IJV (Lewis FT 1909), and the PSS develops as a potential anastomosis between the TS and the EJV system. The development of the cranial venous system is characterized by circulatory adjustments including the total obliteration of pre-existing channels following the formation of new replacement channels, a process described by Streeter as "spontaneous migration" (Streeter GL 1915). In humans, the IJV is favoured over the EJV as the major outflow pathway of encephalic drainage, corresponding to the primitive embryological drainage plan or "anlage" where the IJV is the main drainage vessel of the head. In case 2, a disruption in venous drainage through the SS and the IJV, speculatively secondary to a venous thrombosis, could have lead to the anomalous redirection of venous drainage from the TS towards the EJV system through the PSS. A similar situation, but sparing the SS, would explain the venous disposition encountered on the right side where the right SS drained into the VVS by way of a posterior condylar emissary vein.

The pattern of venous drainage of the posterior fossa encountered in case 2 represents a situation of extreme anatomical variation in which normal outflow pathways of encephalic venous drainage are severely restricted. Schematically, two drainage pathways are normally encountered on each side, a direct route through the IJV, and a more indirect route involving emissary veins of the PCF into the VVS (Arnautovic KI et al 1997, San Millán Ruíz D et al 2002). In case 2, neither of these drainage pathways were possible on the left side as both the SS and the IJV were absent, with the bulk of the venous blood entering the TS being rerouted towards the EJV system. On the right side, drainage occurred exclusively into the VVS. This anomalous anatomic disposition does not allow for the normal postural variations of the encephalic venous outflow pathways, as was confirmed by Doppler-ultrasound which demonstrated the absence of normal variations in diameter and blood flow in the jugular veins and VVS in response to changing from a supine to an upright position (Valdueza J et al 2000). Whether these anatomical and hemodynamic findings have a cause to effect relationship with our patient's headaches, is difficult to ascertain and remains speculative given the absence of both an increased CSF pressure on lumbar puncture and of a delayed venous passage on DSA. However, DSA also demonstrated a "corkscrew" appearance of cortical veins, an abnormal opacification of the superior sagittal sinus during left ICA injection, and an abnormally developed collateral diploic venous circulation, all of which are suggestive of a intracranial venous hypertension.

Conclusion

The venous drainage pathways of the middle cranial fossa are complex, and may be schematically divided into three systems: a system draining the orbit; a system draining the SMCV, and a system draining the neurocranium. Current anatomical descriptions of this venous system needs to be revised in light of the results presented in this study.

The gross and radiological anatomic findings reported here are consistent with the concept that the laterosellar blood spaces should be divided into two embryologically, morphologically and functionally independent systems with eventual secondary connections i) a medial system made of the superior ophthalmic vein, the CS and the inferior petrosal sinus, and ii) a lateral system draining the cortical blood of the cerebral convexity through the SMCV towards the PP and/or the transverse sinus. The latter pathway may take the form of a PS, a LCS or a classic termination into the anterosuperior aspect of the CS, in decreasing order of frequency. Although sometimes difficult to identify on DSA due to its close topographic relationship with the CS, the LCS is an independent anatomic entity with characteristic angiographic features. Better knowledge of its course and connection pattern should allow to recognize LCS more frequently on angiographic studies and evaluate their potential clinical implications. Moreover, recognition of a LCS is essential for understanding DAVF of the laterosellar region, as it will be determinant in deciding on the feasibility of an endovascular treatment.

The SphS corresponds to the artificial combination of two venous structures, the parietal portion of the AMMV and a dural channel located under the LSW, the SLSW. The classic notion that the SMCV drains into or is partially equivalent to the SphS is erroneous. These structures are independent and the SMCV are never connected to the AMMV or the SLSW. Our findings indicate that the term SphS should better be abandoned for the sake of anatomic precision and consistency. Knowledge of the venous anatomy in the region of the LSW is of clinical importance, for instance, in the diagnosis, classification and therapeutic considerations of DAVF's in this region.

The PSS is not a rare or abnormal finding in humans, though only parts of its embryological constituents usually persist into adult life. Rarely, the PSS may become a major outflow pathway of the TS when the SS is insufficiently developed or absent, in which case it persists as a conspicuous vessel. On such occasions, the EJV system becomes the major encephalic outflow pathway in the affected side, a drainage pattern observed in most mammals. Modern imaging techniques allow for in vivo recognition of the PSS, which, especially when large, may be of clinical importance as it may represent a hemorrhagic hazard during surgical procedures of the petrous and mastoid regions. Furthermore, in the eventuality that a PSS represents the main outflow pathway of the TS, particular care should be taken during surgical procedures, as the sacrifice of this outflow pathway could lead to catastrophic venous ischemic and hemorrhagic consequences. Knowledge of the anatomy of the PSS and its various forms of persistence in adult humans is therefore relevant for anatomists and clinicians.

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Part III : Venous systems in the posterior fossa and cranio-cervical junction

Introduction

We have seen above that the cerebral venous territory of the SMCV ultimately drains through the emissary veins of the MCF in a large proportion of cases. However, the bulk of the encephalic venous drainage reaches the dural venous sinuses of the PCF from which connections are established with the outflow pathways of neck at the cranio-cervical junction. These outflow pathways consist of the IJVs and the VVS (Breschet G 1929, Clemens H 1961, Batson O 1957, Groan RJ et al 1997). The postural variations of encephalic venous drainage, with a preferential drainage into the IJV or VVS in the supine or upright position respectively, have been described earlier (Valdueza J et al 2000, Théron J and Moret J 1972, Epstein HM et al 1970, Eckenhoff J 1970). Whereas the pathway from the dural sinuses of the PCF into the IJVs is anatomically obvious through the jugular foramen, connections with the VVS are numerous and complex. Several authors have stressed the importance of the emissary veins of the PCF (Zouaoui A et al 1987, Braun JP et al 1977), in particular the anterior and posterior condylar, and mastoid emissary veins.

Arnautovic et al (1997) studied the microsurgical anatomy of the venous plexus surrounding the horizontal portion of the third segment of the vertebral artery, which they named the suboccipital cavernous sinus. In their study, the authors emphasized the importance of the internal and external vertebral venous plexus in the cerebral drainage and in particular the role played by the suboccipital cavernous sinus in connecting indirectly the internal vertebral venous plexus IVVP to the dural venous sinuses of the base of the skull.

As previously mentioned, classical anatomical dissections of the cranio-cervical region are hindered by the difficult access to the base of the skull. Angiographic studies may fail to demonstrate certain tributaries because of countercurrent blood flows (Théron J 1972), and because they are only performed in the supine position. These technical limitations may explain why the current descriptions of the venous anatomy of the cranio-cervical region often remain fragmentary and incomplete. For instance, the radiological and surgical literature does not mention, to our knowledge, the anterior condylar confluent (ACC). This venous confluent is located extracranially in front of the aperture of the hypoglossal canal and was described by Trolard as far back as 1868.

The cranio-cervical venous anatomy was studied in the light of these physiologic considerations, giving particular attention to the venous channels that connect the dural venous sinuses of the PCF with the cervical venous outflow tracts. Findings are based on the study of 12 corrosion casts and the 3 fresh specimens injected with PMMA, though only the corrosion casts were used for the statistical analysis. Nine out of the twelve corrosion casts (18 sides) showed filling of the entire intracranial venous system, that is the cerebral and neuro-cranial veins, and cervical venous system. The three remaining casts only showed filling of the neuro-cranial and cervical venous system which we set out to study. X-rays of certain corrosion casts were performed to demonstrate the ideal angiographic anatomy. A phlebo MRI correlation was also obtained on a normal volunteer.

Results[6]

Dural sinuses

The TS and SS didn't display any anomaly and were present in all casts (24 sides). An occipital sinus was noted in one case (Figure 30). The marginal sinus was noted in ten casts (83.3 % of the cases), and was not completely circular in seven of these cases, most likely due to incomplete filling. The marginal sinus connected anteriorly with the anterior condylar vein in all cases, and on one occasion, it bridged the anterior condylar vein with a sub-occipital vein.

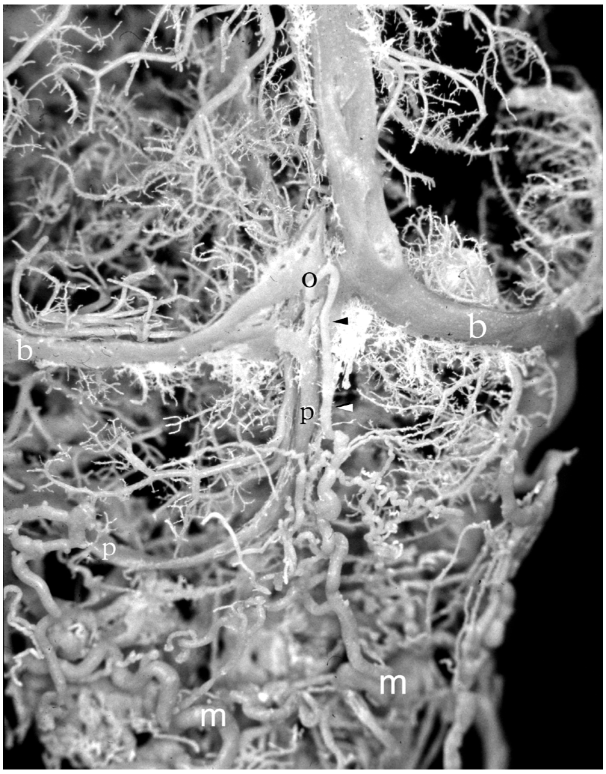

Figure 30: Posterior view of a corrosion cast demonstrating an occipital emissary vein (o) draining into the deep cervical veins, and a left occipital sinus (p). Black and white arrowheads: extracranial connection of the occipital emissary vein. Occipital sinuses usually regress in adult life, where they may be observed with either normal, hypoplastic, or absent transverse and sigmoid sinuses. At birth and in young children, occipital sinuses are prominent and sometimes represent the major drainage pathway in the posterior fossa. Special care must be taken during suboccipital approaches of the PCF in children, as a lesion and interruption of an occipital sinus could have catastrophic ischemic and hemorrhagic consequences.

[6] **Figures 30-37** : General legend: a) superior jugular bulb; b) transverse sinus c) sigmoid sinus; d) cavernous sinus; e) inferior petrosal sinus; f) anterior condylar vein; g) posterior condylar vein; h) lateral condylar vein; i) anterior internal vertebral venous plexus (anterior IVVP); j) vertebral artery venous plexus (VAVP); k) anastomosis between anterior IVVP and VAVP; l) internal carotid artery venous plexus of Rektorzik (VPR); m) deep cervical vein; n) mastoid emissary vein; o) occipital emissary vein; p) occipital sinus; q) occipital sinus; r) middle meningeal veins; s) emissary vein of the foramen ovale; t) intervertebral veins (including inter atlanto-occipital vein; u) internal jugular vein v); pterigoid plexus; w) marginal sinus; asterisk - ACC.

The anterior IVVP was present in all the cases and was particularly developed at C1 and C2 vertebral levels (Figures 30a, 32a-b). It displayed communications with the vertebral artery venous plexus laterally (see below), and the anterior condylar vein cranially in all the cases studied. It also demonstrated connections to the basilar plexus on nine occasions (37.5% of the sides) (Figure 31a). The posterior IVVP was only observed in one case and it extended over the C2-C3 vertebral region. It was less developed than its anterior homologue.

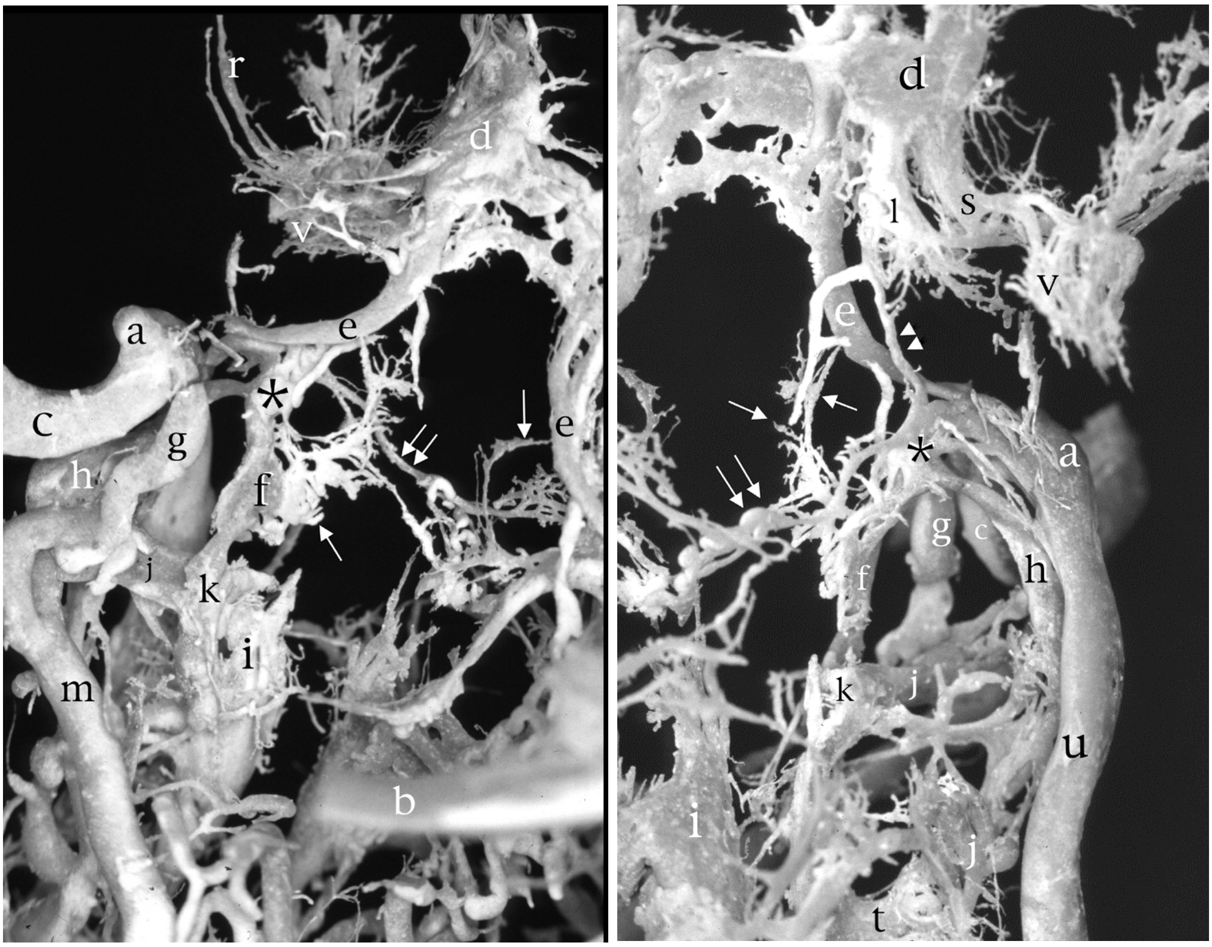

Figure 31: posterior (left image) and anterior (right image) views the left jugular bulb region in a corrosion cast. The ACC (*) and its connections with surrounding veins are demonstrated. The proximal portion of both transverse sinuses and confluens sinuum have been removed for better visualization. Arrowhead - branch between IPS and ACC; double arrowhead – inferior petro-occipital vein; arrow - basilar plexus; double arrow - branch to prevertebral venous plexus

Figure 32a-b: MRV of the cranio-cervical region (2D, TOF, Gradient Echo images with magnetization transfer; TE 7; TR 40; Fov 18; Flip 35; resolution 220 / 256; slice thickness of 1.5 mm with 0.5 mm overlap, 256x256 matrix) in overview (left image) and focused on the right superior jugular bulb (right image). The ACC (asterisk), anterior, posterior, and lateral condylar veins (f,g,h) are demonstrated.

Vertebral veins

The vertebral veins were present in all cases and the term used by Arnautovic et al., vertebral artery venous plexus (VAVP) seemed appropriate for this venous plexus surrounding the vertebral artery (Figure 33). The initial horizontal portion of the VAVP was found in the atlanto-occipital space and constantly connected with the proximal portion of the anterior IVVP, in the manner of an intervertebral vein (Figures 35a-b). The initial horizontal portion of the VAVP seems to correspond to Arnautovic's suboccipital cavernous sinus.

The deep cervical veins were completely filled in 22 sides (92% of the sides) and displayed prominent diameters in most cases (Figures 34 and 35). They showed multiple anastomoses with cervical soft tissue veins such as the suboccipital venous plexus, and with the horizontal portion of the VAVP.

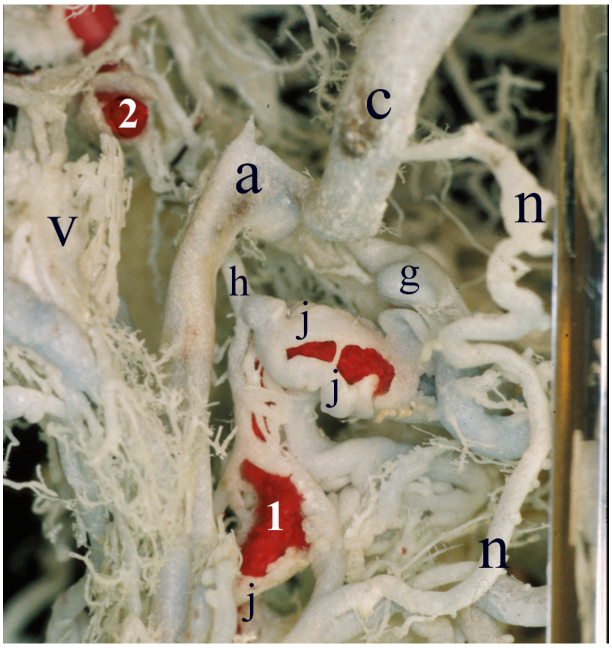

Figure 33: Left lateral view of sigmoid sinus / jugular bulb junction. The mastoid emissary vein (n) and lateral (h) and posterior (g) condylar veins are demonstrated. The plexiform nature of the vertebral artery venous plexus (j), here around the horizontal portion of V3 (1), is well demonstrated. ICA – 2.

Anterior, posterior, and lateral condylar veins, and other emissary veins

The posterior condylar vein – condylar emissary vein in the actual international anatomical nomenclature (FCAT, 1998) - was present in 19 out of 24 sides (79% of the sides) and its diameter was usually larger than that of the anterior condylar vein (Figures 31a-b, 32a-b-36). It generally took its origin from the superior bulb of the internal jugular vein, though it was seen to arise from the medial side of the distal portion of the sigmoid sinus in one occasion. It drained into the deep cervical vein, and also communicated with the horizontal portion of the VAVP.

The anterior condylar vein – venous plexus of the hypoglossal nerve in the actual international anatomical nomenclature (FCAT, 1998) - was present in all but one side (96% of the sides) (Figures 31a-b, 32a-b-35). It appeared as a plexiform connection of the anterior IVVP with the ACC. On occasions, it was traversed longitudinally by a channel for the hypoglossal nerve. In six sides, small plexiform anastomoses were observed with the basilar plexus (25% of the sides) (Figures 31a-b).

The lateral condylar vein (Arnautovic KI et al 1997), connecting with the VAVP was observed in 19 sides (79 %). Its origin was generally found on an anastomotic branch between the ACC and the IJV, and not directly on the IJV as in the cases described by Arnautovic et al (Figures 31b, 32a, and 33). According to Trolard, the proximal portion of the lateral condylar vein may sometimes be found within an osseous canal in front of the condyle.

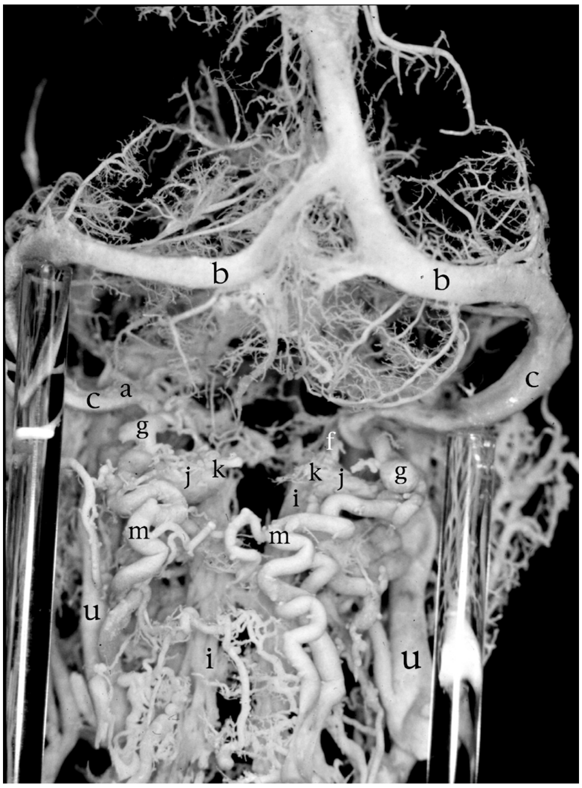

Figure 34: Posterior overview of the cranio-cervical junction in a venous corrosion cast. Note prominent deep cervical veins bilaterally (m). The left posterior condylar vein (g) is clearly seen to drain both into the horizontal portion of the left vertebral artery venous plexus at C1 level (J) and into the left deep cervical vein (m).

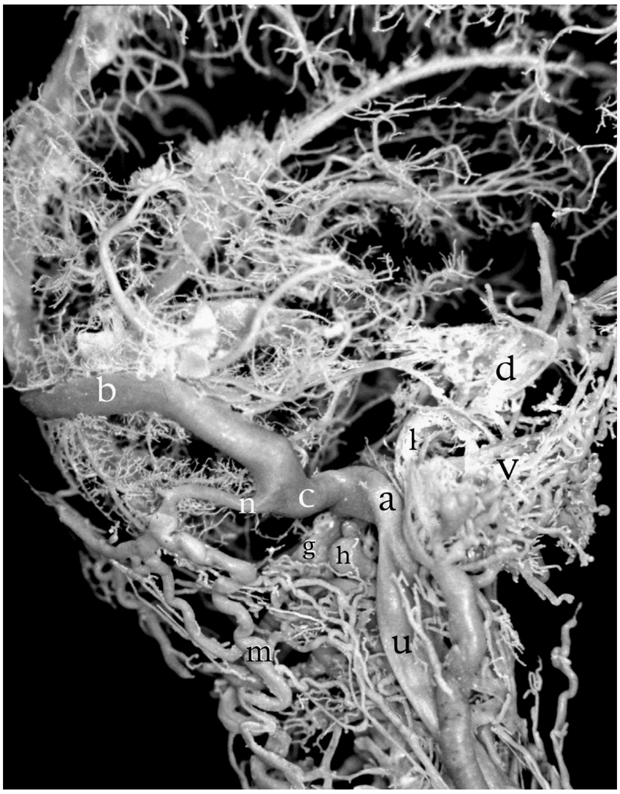

Figure 35: Right lateral view of the cranio-cervical junction in a venous corrosion cast. Note the presence of a prominent mastoid emissary vein (n) connecting to a deep cervical vein (m). The carotid artery venous plexus is clearly visible (l).

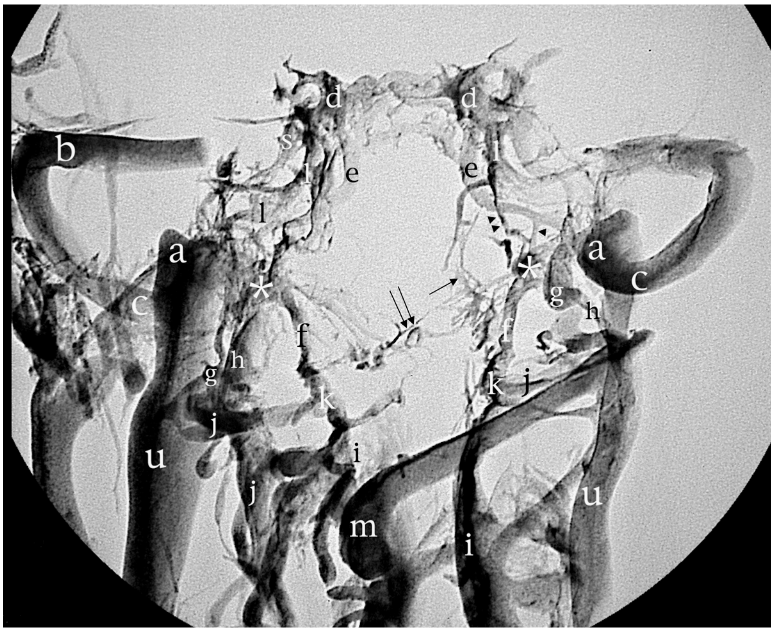

Figure 36 Standard radiographic picture of the corrosion cast from Figure 21 in the antero-posterior projection, showing the ACC and its relation with surrounding veins. The proximal portions of the transverse sinus, confluens sinuum, straight and superior longitudinal sinuses have been removed for better visualization. Arrowhead - branch between IPS and ACC; double arrowhead – inferior petro-occipital vein; arrow - basilar plexus; double arrow - branch to prevertebral venous plexus.
a, bulb of IJV; b, TS; c, SS; d, CS; e, IPS; f, anterior condylar vein; g, posterior condylar vein; h, lateral condylar vein; i, anterior IVVP; j, VAVP; k, anastomosis between anterior IVVP and VAVP; l, carotid artery venous plexus of Rektorzik; m, deep cervical vein; u, IJV.

An occipital emissary vein was observed on one cast, and was seen to join the confluens sinuum region or torcular and an occipital vein (Figure 30). A mastoid emissary vein was noted on 15 sides (63%). It arose from the middle portion of the SS and joined either a posterior auricular vein, an occipital vein, or the deep cervical vein (Figures 33 and 35).

The anterior condylar confluent of Trolard (ACC)

A venous confluent which responded to Trolard's description (Trolard P 1868) of the ACC was found in all cases (Figures 31a-b, 32a-b, 33). The ACC was located extracranially in front of the aperture of the hypoglossal canal. The size of the ACC was between 3 to 5 mm in an anterior view, and about 2 mm in its ventro-dorsal extension. The following veins regularly contributed in forming the ACC: i) the anterior condylar vein; ii) one or several branches from the IJVor its bulb; iii) the lateral condylar vein, sometimes arising from ii); iv) anastomoses with the inferior petrosal sinus, at a variable distance from its termination into the IJV; v) branches from the internal carotid artery venous plexus of Rektorzik (Figures 31b, 35), corresponding to Trolard's inferior petro-occipital vein (Trolard P 1868) found coursing extracranially along the petro-occipital suture; vi) branches from the prevertebral venous plexus found on the anterior atlanto-occipital membrane (Figures 31a-b). A graphic synopsis of these veins is provided in Figure 37.

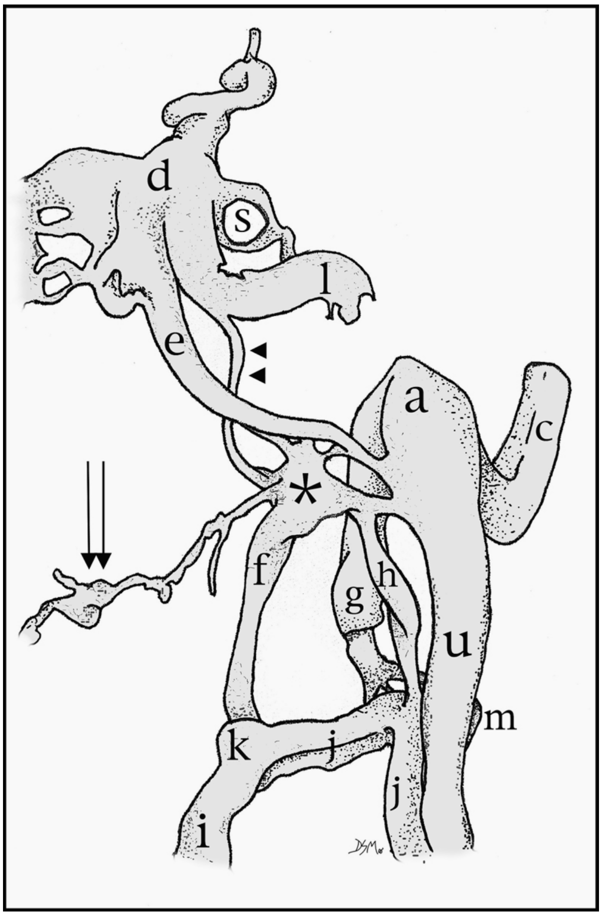

Figure 37: Schematic representation of anterior view of ACC and its connections. Note the six main contributions, from the anterior condylar vein (f), the lateral condylar vein (h), the internal jugular vein (u), the inferior petrosal sinus (e), the VPR by way of the internal petro-occipital vein of Trolard (double arrowhead), and prevertebral venous plexus (double arrow).

a, bulb of IJV; b, TS; c, SS; b, CS; f, anterior condylar vein; g, posterior condylar vein; i, anterior IVVP; j, VAVP; k, anastomosis between anterior IVVP and VAVP; l, carotid artery venous plexus of Rektorzik; m, deep cervical vein.

The anatomical dissections of the injected specimens allowed for recognition of all the cervical outflow pathways and in particular the ACC. The anatomical relationship between the ACC, its tributaries, and the surrounding anatomical structures such as cranial nerves IX-XII was readily identified.

The optimal angiographic anatomy of the venous elements described above are demonstrated on Figure 36. Figures 32a-b demonstrate the normal venous anatomy of the cranio-cervical junction observed in the living by a phlebo MRI study. All the major tributaries of the ACC and outflow pathways of the cerebral venous system were demonstrated on the phlebo MRI sequences.

Discussion

The corrosion cast findings in the present study confirm the complexity of the venous network in the cranio-cervical junction. Schematically, two descending cerebral venous outflow tracks can be distinguished: anteriorly the IJV, and posteriorly the VVS. The latter is composed of the EVVP and IVVP, which are anastomosed by way of the intervertebral and basivertebral veins (Breschet G 1829, Clemens H 1961, Batson O 1957, Groen RJ et al 1997). In the cervical region, the vertebral venous system is mainly represented by the anterior IVVP, the VAVP and the deep cervical veins.

As far as this posterior outflow track is concerned, our findings suggest that the anterior, posterior, and lateral condylar veins and the ACC represent the most important connections between the intracranial cerebral venous circulation and the VVSs, in terms of diameters (size) and frequency of occurrence. All the venous elements were readily demonstrated using 2D MRV imaging. Standard radiographic analysis of the corrosion casts provided correlation to the angiographic anatomy of the cranio-cervical junction venous system. Although not all the vessels are demonstrated simultaneously in the venous phase during routine cerebral DSA studies, isolated emissary veins do appear and need to be identified.

The posterior and lateral condylar veins allow for connections with the EVVP, while the anterior condylar veins are predominantly related to the IVVP. It is noteworthy that even though the diameters of the anterior and lateral condylar veins were important, they were connected to the IJV only by a small anastomosis between the jugular bulb or internal jugular vein and the ACC. However, phlebography studies on live monkeys and humans clearly illustrate that not only the vertebral artery venous plexuses, but also the anterior IVVP are demonstrated in the upright position and during compression manoeuvres of the IJVs (Théron J and Moret J 1978, Epstein HM et al 1970). This observation suggests that venous flow from the jugular bulb through the anterior condylar vein and into the anterior IVVP occurs efficaciously by way of the ACC regardless of how indirect this pathway may seem. It is, therefore, difficult to predict functional importance of a connecting vein involved in the outflow of cerebral blood flow based uniquely on size and on directness of the route.

The ACC appeared as an anatomical constant whose major tributaries, size-wise, were the anterior and lateral condylar veins, inferior petrosal sinus, and IJV. The ACC was also connected to the carotid artery venous plexus by the inferior petro-occipital vein and to the prevertebral venous plexus. The numerous anastomoses of the ACC make it a crossroad between the cavernous sinus, dural venous sinuses of the posterior fossa and the posterior cervical outflow tracks.

Much literature has been devoted to the anatomy of the outflow pathways of the cavernous sinus and the region around the jugular foramen in relation to skull base surgery and endovascular inferior petrosal sinus sampling (Saleh E et al 1995, Rhoton AL et al 1975, Doppman JL et al 1985, Kveton JF et al 1988, Shiu PC et al 1968, Miller DL et al 1993, Gailloud P et al 1997). The ACC has not been specifically mentioned though it has been demonstrated by several reports. Saleh et al. (Saleh E et al 1995), in a microsurgical anatomical study of the skull base, mention the presence of a venous confluence receiving the anterior condylar vein (plexus) and connecting with the jugular bulb and inferior petrosal sinus in one out of 45 specimens. Miller et al 1993) studied the phlebographic anatomy of the junction of the inferior petrosal sinus and IJV and refined Shiu's classification (Shiu PC et al 1968) on the termination of the inferior petrosal sinus. Their illustrations of retrograde inferior petrosal sinus phlebograms demonstrate the ACC but not all its tributaries. Aubin et al (1974) clearly demonstrate the ACC on several retrograde inferior petrosal sinus phlebograms and describe it as a “common canal” of the inferior petrosal sinus and the anterior condylar vein.

Anatomical knowledge of the ACC allows for a good understanding of the various types of IPS termination described by Miller et al (1993), which is essential when performing retrograde inferior petrosal phlebography or when accessing the cavernous sinus posteriorly. Though, the condylar emissary veins are variably present, we have always encountered connections both between the inferior petrosal sinus and the IJV and between the inferior petrosal sinus and the internal and external VVP (anterior or lateral condylar vein). Miller et al's failure to demonstrate these connections could be explained by the phlebograms being performed in the supine position only, whereas both the supine and upright positions are probably necessary to demonstrate all the major connections of the ACC.

From a physiological point of view, one should also consider that the same postural influences affecting cerebral venous drainage, may redirect the circulation of the VVSs. For instance, the cranial (as opposed to caudal) connections of the anterior IVVP with the anterior condylar vein could offer a cranial escape route for thoracic and abdominal venous return when thoracic and abdominal pressure are increased concomitantly. One could even consider venous blood from the anterior IVVP draining into the superior ophthalmic vein and cavernous sinus through the basilar plexus and inferior petrosal sinuses, and thus terminally into the pterygoid plexus and the EJV system. Parkinson (2000) has recently described the extradural neural axis compartment (ENAC). The ENAC contains a continuum of veins that extends from the ophthalmic to the coccygeal veins and offers numerous longitudinal and transverse venous anastomoses. In the cranio-cervical region, the basilar plexus, inferior petrosal sinuses and the anterior condylar veins represent the venous elements of this extradural neural axis compartment. This venous continuum finds its clinical significance in pathological situations such as dural arteriovenous fistulas of the anterior condylar vein, which retrogradely fill the inferior petrosal and cavernous sinuses and clinically manifest with chemosis and proptosis (Ernst R et al 1999).

Conclusion

The anterior, lateral, and posterior condylar veins and occipital and mastoid emissary veins provide connections between the PCF sinuses / IJV system with the cervical VVS. These emissary veins allow for encephalic blood to drain into the cervical internal and external vertebral venous plexus, which represent the major outflow tract for encephalic drainage in the upright position. The anterior condylar confluent, a venous entity ignored since Trolard described it in 1868, represents a major venous crossroad of the base of the skull. Thorough anatomical knowledge of the venous system of the cranio-cervical region is necessary to understand not only the physiology of cranio-cervical venous drainage, but also when attempting selective retrograde venous catheterization, or when interpreting venous imaging studies such as MRV that readily demonstrate the major emissary veins. Emissary veins must no longer be considered as of secondary physiologic importance, mainly acting as a safety venous outlet routes, but as obligatory outflow pathways for encephalic drainage in the upright position. The constant presence of emissary veins and the size proportionality relation they exhibit strongly suggests their major functional importance.

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