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The petrosquamosal sinus in humans

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Abstract

This article provides a comprehensive description of the morphology of the human petrosquamosal sinus (PSS) derived from original observations made on 13 corrosion casts of the cranial venous system combined with routine clinical imaging studies in two patients. The PSS is not a rare finding in the adult human. In particular, continuous developments in imaging techniques have made radiologists become increasingly aware of this anatomical entity in recent years. The role of the PSS as a major encephalic drainage pathway and its potential implication in pathological conditions such as intracranial venous hypertension are discussed.
Key words anatomy; encephalic venous drainage pathways; internal and external jugular veins; petrosquamosal sinus; postglenoid foramen; venous hypertension.

Introduction

In humans, most of the cerebral venous drainage reaches the posterior fossa before being directed primarily towards the internal jugular veins (IJV) or the vertebral venous system (VVS). The external jugular veins (EJV) are primarily involved in venous drainage of the viscerocranium and neurocranium, with a variable, but generally limited, participation in the cerebral venous drainage itself. There are two possible pathways connecting the cerebral drainage to the EJV system. The most common pathway involves drainage of the superficial and deep middle cerebral veins (SMCVs and DMCVs) into the pterygoid plexus by way of the cavernous sinus and/or the emissary veins of the middle cranial fossa (Hacker, 1974). The second pathway involves a connection between the rostral portion of the transverse sinus and the veins of the temporal fossa through a petrosquamosal sinus (PSS) (Cheatle, 1899; Butler, 1957, 1967; Padget, 1957). This pathway normally regresses during fetal and early postnatal life and may be absent in the human adult. The PSS courses along the petrosquamosal suture, either within an osseous groove or a complete canal referred to as the temporal canal of Vergi (Wysocki, 2002), and exits the temporal squama through an emissary foramen named the postglenoid foramen (PGF) or the spurious jugular foramen (Cheatle, 1899; Boyd, 1939; Butler, 1957, 1967; Padget, 1957; Conroy, 1982; Wysocki, 2002). Although this drainage pathway is prominent in most mammals where it constitutes the major route of cerebral venous drainage, it is rarely of functional significance in humans, in which the IJV and VVS represent the major outflow pathways.

Since the early descriptions attributed to Rathke and Luschka, the embryology and morphology of the PSS and PGF have been extensively documented in humans, mostly in post-mortem anatomical studies (Rathke, cited by Luschka, 1859; Streeter, 1915; Fischer, 1926; Boyd, 1939; Waltner, 1944; Butler, 1957, 1967; Padget, 1957; Conroy, 1982; Wysocki, 2002). Their important phylogenetic role has been suggested by several authors (Butler, 1967; Conroy, 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 with a skull base malformation. Other reports have focused on the potential role of the PSS in humans

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as an alternative venous drainage pathway for the posterior fossa towards the EJV system, on its potential clinical significance during otological surgical approaches, or on its implication in the potential spread of septic thrombosis in the otological sphere (Cheatle, 1899; Furstenberg, 1937).

This article provides a comprehensive description of the morphology of the human PSS derived from original observations made on corrosion casts of the cranial venous system combined with routine clinical imaging studies.

Materials and methods

Post-mortem study

Corrosion casts of the cranial venous system were prepared from 13 non-fixed human specimens (eight females, five males, average age 81 years). In each case, the IJV were carefully dissected in the neck and cannulated 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 IJV 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.

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 (CT) 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).

In vivo study

Images from two routine clinical radiological investigations were selected as illustrations 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 (CTA), magnetic resonance imaging (MRI) and magnetic resonance phlebography, and digital subtraction angiography (DSA) of the head and neck.

Results

Post-mortem study

The results presented here were partially discussed in a previous brief communication (San Millán Ruíz et al. 2002a). A PSS was present in five of the 26 corrosion cast sides. A connection with the transverse sinus was found in all cases. This connection was located on the lateral and superior surface of the transverse sinus at its junction with the sigmoid sinus. 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 two of five cases. In one case, the anterior portion of the PSS gave rise to two branches, the medial branch as described above, and a lateral branch connected extracranially with a deep temporal vein (Fig. 1). 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 3 mm (average 2.6 mm, minimum 2 mm, maximum 3 mm).

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. A CT scan of the head 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 (Fig. 2). The diameters of the osseous canals containing the PSS were similar to those observed in the corrosion casts, and did not exceed 2 mm.

Case 2

A 7-year-old girl, treated for left-sided cluster headaches since age 3, presented with 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 DSA. Lumbar puncture showed

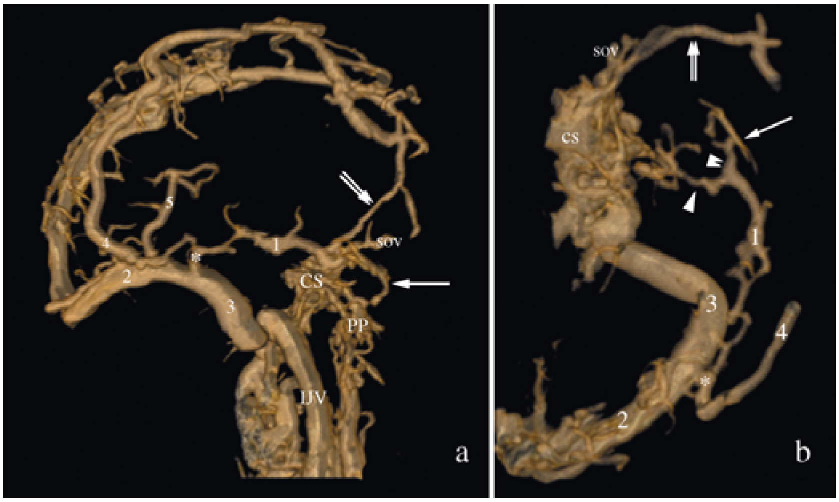

Fig. 1 Three-dimensional images after CT reconstruction of a corrosion cast of the cranial venous system on a Vitrea workstation (Vital Images, Minnesota, USA) (0.8-mm slices, every 0.4 mm; Philips MX 8000 IDT 16-channel multirow detector, Philips Medical Systems, Best, The Netherlands). The cortical veins have been virtually dissected. (a) 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 to a deep temporal vein. The double arrow represents the sphenoparietal sinus, which drained a large anterior parietal diploic vein into the cavernous sinus. (b) Superior view of the right middle cranial fossa. Details as in (a). 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).

no increase in cerebrospinal fluid pressure. Anatomical findings obtained from the three imaging modalities are shown in detail in Figs 3–5.

On the left side, the sigmoid sinus and the IJV were absent. Drainage of the transverse sinus 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 shown in Fig. 3. On the right side, the transverse sinus drained into an anomalous sigmoid sinus, which communicated exclusively with a posterior condylar emissary vein. No right IJV was found.

High-resolution CT revealed 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.

Given 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 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.

Discussion

In adult mammals, the major cerebral venous outflow pathways are the EJV the IJV and the VVS. The relative development of these three venous systems varies between species. The dominance of the IJV system over the EJV system for cerebral drainage appears late in evolution (Conroy, 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 (Eckenhoff, 1970; Epstein et al. 1970; Théron & Moret, 1978; Valdueza et al. 2000). In humans, the EJV system drains the viscerocranium 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,

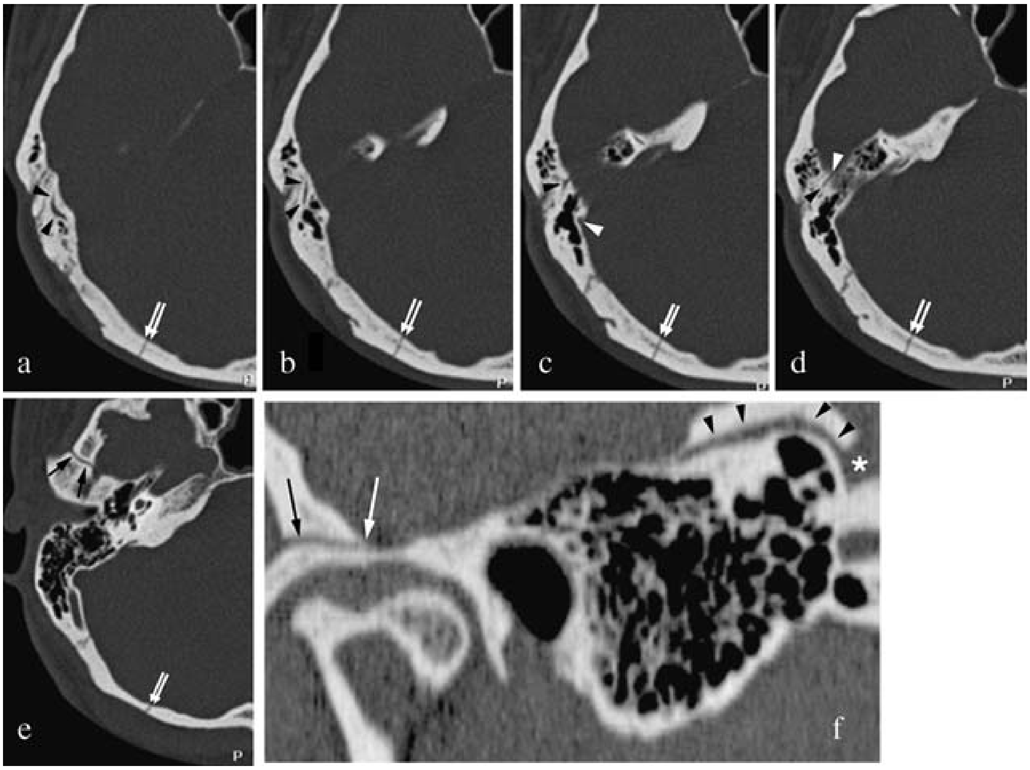

Fig. 2 Case 1. High-resolution CT with bone algorithm of the right temporal bone (Philips MX 8000 IDT 16-channel multirow detector,Philips Medical Systems, Best, The Netherlands). (a)–(e) Axial source images following the course of the PSS cranio-caudally. The proximal and dorsal portion of the PSS is contained within a petrous bony canal (arrowheads) that is parallel to the petrosquamosal suture and follows the roof of the left petrous bone (a–d). Proximally, the petrous bony canal opens into the superior and lateral aspect of the distal transverse sinus (white arrowhead, c). Distally, it opens into the middle cranial fossa, where the PSS probably shifts from a diploic to a dural position (white arrowhead, d). A bony canal in the temporal squama containing the anterior and lateral branch of the PSS is depicted in (e) (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 bone and temporal squama, respectively. A linear fracture of the occipital squama is seen on all images (white double arrow). (f) A curved MPR reconstruction of the osseous canals containing the PSS. The arrowheads indicate the petrous canal containing the proximal PSS; the arrows point to the temporal canal containing the medial and anterior branch of the PSS.

and some non-primate mammals including cats and pigs (Hegedus & Shackelford, 1965; Conroy, 1982; Wysocki, 2002). [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, Lecointre G). Paris: Belin. 2001).] The EJV system represents the major cerebral outflow pathway with variable degrees of participation of the VVS in Strepsirrhines and in most non-primate mammals such as dogs, sheep, rabbits and horses. [The suborder Strepsirrhini includes the lemurs and lorises (*Classification phylogénétique du vivant* (eds Le Guyader H, Lecointre G). Paris: Belin, 2001).]

The development of the PSS and its connections to the EJV system seem to be a constant feature in the early development of all mammalian embryos (Butler, 1967). The degree of subsequent involution of the PSS is correlated with 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, 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 transverse sinus is, in the early human embryo as in most mammals, vertically orientated and follows a craniocaudal course. At this stage, the sigmoid sinus and the PSS have similar diameters. The caudal expansion of the telencephalon over the cerebellum will later

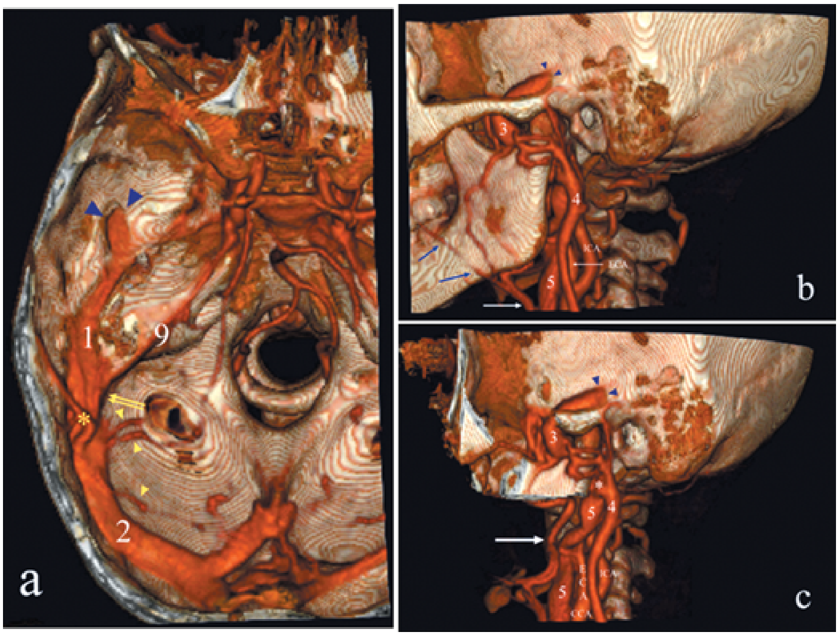

Fig. 3 Case 2. Three-dimensional reconstruction of angio-CT images (Philips MX 8000 IDT 16-channel multirow detector, Philips Medical Systems, Best, The Netherlands) obtained on a Vitrea workstation (Vital Images, Minnesota, USA). (a) Superior view of the left cranial fossa showing the left transverse 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 that of 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). (b,c) Left lateral view centred on the external auditory canal before (b) and after virtual dissection of the left zygomatic process and ramus of the mandible (c). 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). [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).] 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 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 Fig. 5a). CCA stands for common carotid artery.

displace the transverse sinus from a vertical to a horizontal position. Conroy (1982) has suggested that this reorientation leads to the regression of the PSS, with the sigmoid sinus then becoming the major outflow pathway of the transverse sinus. By contrast, in animals with a lesser telencephalic development and persistent verticality of the transverse sinus, the PSS is likely to be retained as the major outflow pathway of the transverse sinus. The crossroads in embryological development during which the growth of the hemispheres will modify the orientation of the transverse sinus begins around stage 6 (embryos in horizons XX, XXI, 18–26 mm stage) (Padget, 1957). This is concomitant with 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 adult human. Knott (1882) found 19 unilateral and seven 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

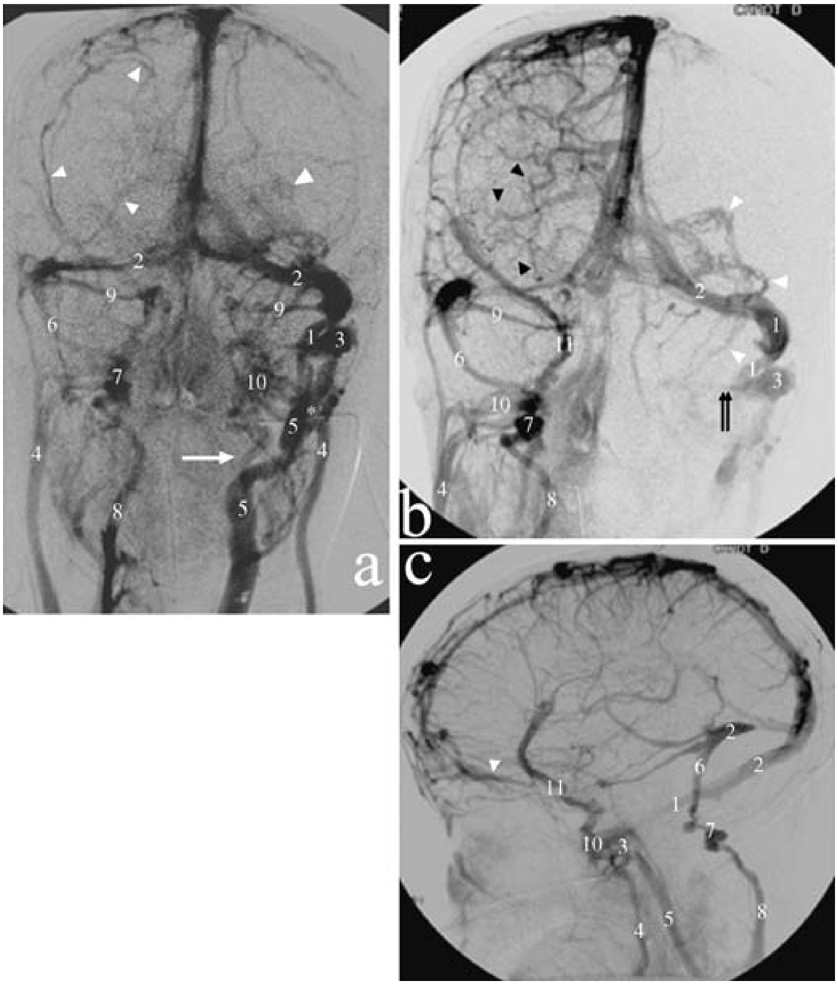

Fig. 4 Case 2. DSA (BN3000, Philips, Best, The Netherlands). Aside from confirming the CTA findings, DSA disclosed signs of venous hypertension, partial obstruction of the superior sagittal sinus draining cortical veins from the left convexity (not shown), and compensatory collateral drainage through an enlarged system of diploic veins on both sides. (a) Late venous phase obtained after injection of contrast agent into the ascending aorta, anteroposterior view. Details 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. (b) Early venous phase after right ICA injection, anteroposterior 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). (c) Lateral view, right ICA injection, slightly earlier venous phase than (b) confirming the absence of left sigmoid sinus. The prominent left diploic veins seen in (b) 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.

connection with the deep temporal veins is lost. The rare observation of temporal foramina in human skulls, reported in eight of 1500 dry skulls (0.53%) by Boyd (1939) and in 23 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, 1899; Padget, 1957), and are probably also involved in the meningeal venous drainage of the middle cranial

Fig. 5 (a,b) Case 2. Three-dimensional reconstructions obtained from MR phlebography with bolus-tracking [Philips Intera 1.5 The, Philips Medical Systems, Best, The Netherlands; 18-s 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 160 × 256; flip angle 40°; TE 1 ms, TR 4 ms; 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 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 indicates a right aberrant subclavian artery.

fossa. Our corrosion cast findings with five 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 owing 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 et al. 2001; Koesling et al. 2005). The PSS is probably 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 casts provide no information about potential middle ear malformations. It does offer, however, a detailed appreciation of the venous anatomy, which failed to demonstrate venous anomalies in those 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, whereas 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 anatomical variations, in keeping with the independent development of its constituents, in particular of the transverse and sigmoid sinuses (Butler, 1957, 1967; Padget, 1957). 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 sigmoid sinus (Huang et al. 1984). The most frequently encountered segmental variation is isolated hypoplasia of the proximal portion of the transverse sinus. Hypoplasia of the sigmoid sinus in the presence of a normal transverse sinus is rare, and it is generally coupled with compensatory re-routing of venous blood into the prominent mastoid emissary or posterior condylar emissary vein (Knott, 1882; Furstenberg, 1937; Laff, 1939; Valdueza et al. 2000). 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, 1936; Widjaja & Griffiths, 2004; Rollins et al. 2005). Regardless, most variations involving the lateral sinus in humans allow conservation of the IJV and VVS as their major outflow pathways for encephalic drainage.

Only rarely, when the sigmoid sinus is absent or severely hypoplastic, may a petrosquamosal sinus represent the major or only drainage pathway of the transverse sinus, directing the venous blood to the EJV system. Furstenberg (1937) 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 sigmoid sinus. Marsot-Dupuch et al. (2001) documented a case via HRCT and MR phlebography in which the transverse sinus 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 sigmoid sinus 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, i.e. with all its constituents and embryological connections having persisted, probably as a compensatory response to the loss of the right sigmoid sinus and IJV. The diameter of the PSS was equal to that of the transverse sinus, confirming it as the principal if not only outflow pathway of the transverse sinus. The posterior stem of the PSS in proximity to the transverse sinus received the superior petrosal sinus medially, consistent with the primitive disposition and tributaries of the PSS at 80-mm stage of fetal development (Padget, 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 transverse sinus 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, probably during the late embryonic and early fetal periods between stages 6 and 7 (20–80 mm) (Padget, 1957). During this relatively long period from a developmental standpoint, the EJV appear as a definite structure and partially or completely absorb the original tributaries of the primitive IJV (Lewis, 1909), and the PSS develops as a potential anastomosis between the transverse sinus and the EJV system. The development of the cranial venous system is characterised by circulatory adjustments including the total obliteration of pre-existing channels following the formation of new replacement channels, a process described by Streeter (1915) as 'spontaneous migration'. 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 sigmoid sinus and the IJV, speculatively secondary to a venous thrombosis, could have led to the anomalous redirection of venous drainage from the transverse sinus towards the EJV system through the PSS. A similar situation, but sparing the sigmoid sinus, would explain the venous disposition encountered on the right side where the right sigmoid sinus 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 posterior cranial fossa into the VVS (Arnautovic et al. 1997; San Millán Ruíz et al. 2002b). In case 2, neither of these drainage pathways was possible on the left side as both the sigmoid sinus and the IJV were absent, with the bulk of the venous blood entering the transverse sinus being re-routed towards the EJV system. On the right side, drainage occurred exclusively into the VVS. This anomalous anatomical 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 et al. 2000). Whether these anatomical and haemodynamic findings have a cause–effect relationship with our patient's headaches is difficult to ascertain and remains speculative given the absence of both an increased cerebrospinal 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 internal cartoid artery (ICA) injection, and an abnormally developed collateral diploic venous circulation, all of which are suggestive of a intracranial venous hypertension.

In conclusion, the PSS is not a rare or abnormal finding in humans, although only parts of its embryological constituents usually persist into adult life. Rarely, the PSS may become a major outflow pathway of the transverse sinus when the sigmoid sinus 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 haemorrhagic hazard during surgical procedures of the petrous and mastoid regions. Furthermore, in the eventuality that a PSS represents the main outflow pathway of the transverse sinus, particular care should be taken during surgical procedures, as the sacrifice of this outflow pathway could lead to catastrophic venous ischaemic and haemorrhagic consequences. Knowledge of the anatomy of the PSS and its various forms of persistence in adult humans is therefore relevant for anatomists and clinicians.

References

Arnautovic KI, al-Mefty O, Pait TG, et al. (1997) The suboccipital cavernous sinus. *J Neurosurg* **86**, 252–262.

Boyd GI (1939) The emissary foramina in the cranium of man and anthropoids. *J Anat* **65**, 108–121.

Butler H (1957) The development of certain human dural venous sinuses. *J Anat* **91**, 510–526.

Butler H (1967) The development of mammalian dural venous sinuses with special reference to the post-glenoid foramen. *J Anat* **102**, 33–52.

Cheatle AH (1899) On the anatomy and pathological importance of the petrosquamosal sinus. *Lancet* **II**, 611–612.

Conroy G (1982) A study of the cerebral vascular evolution in primates. In *Primate Brain Evolution* (eds Armstrong E, Falk D), pp. 247–261. New York: Plenum Press.

Eckenhoff J (1970) The physiologic significance of the vertebral venous plexus. *Surg Gynecol Obstet* **131**, 72–78.

Epstein HM, Linde HW, Crampton AR, et al. (1970) The vertebral venous plexus as a major cerebral venous outflow tract. *Anesthesiology* **32**, 332–337.

Fischer MH (1926) Le sinus pétro-squameux chez l'homme: un cas de communication de la veine jugulaire externe avec le sinus latéral. *L'Assoc Des Anat (Paris)* **1**, 210–211.

Furstenberg AC (1937) Septic thrombophlebitis of the sigmoid sinus. *Trans Am Acad Ophthalmol* **42**, 424–431.

Gailloud P, San Millán Ruíz D, Muster M, et al. (2000) Angiographic anatomy of the laterocavernous sinus. *Am J Neuroradiol* **21**, 1923–1929.

Hacker H (1974) Superficial supratentorial veins and dural sinuses. In *Radiology of the Skull and Brain*, Vol. 2 Book 3 (eds Newton DG, Potts NT), pp. 1851–1877. St Louis: C.V. Mosby.

Hegedus SA, Shackelford RT (1965) A comparative-anatomical study of the cranio-cevical venous systems in mammals, with special reference to the dog: relationship of anatomy to measurements of cerebral blood flow. *Am J Anat* **116**, 375–386.

Huang YP, Okudera T, Ohta T, et al. (1984) Anatomy of the dural venous sinuses. In *The Cerebral Venous System and its Disorders* (eds Kapp JP, Schmideck HH), pp. 109–167. Orlando: Grune & Stratton.

Knott JF (1882) On the cerebral sinuses and their variations. *J Anat* **16**, 27–42.

Koesling S, Kunkel P, Schull T (2005) Vascular anomalies, sutures and small canals of the temporal bone on axial CT. *Eur J Radiol* **54**, 335–343.

Laff HJ (1939) Unilateral absence of sigmoid sinus. *Arch Otolaryng* **11**, 151–157.

Lewis FT (1909) On the cervical veins and lymphatics in four human embryos, with an interpretation of anomalies of the subclavian and jugular veins in the adult. *Am J Anat* **9**, 33–42.

Luschka H (1859) Das foramen jugulare spurium and des Sulcus petrosquamosus des Menschen. *Zeitschr Rat Med* **3**, 72–81.

Marsot-Dupuch K, Gayet-Delacroix M, Elmaleh-Berges M, et al. (2001) The petrosquamosal sinus: CT and MR findings of a rare emissary vein. *Am J Neuroradiol* **22**, 1186–1193.

Padget DH (1957) Development of the cranial venous system in man, from a viewpoint of comparative anatomy. *Contrib Embryol* **36**, 79–140.

Rollins N, Ison C, Booth T, et al. (2005) MR venography in the pediatric patient. *Am J Neuroradiol* **26**, 50–55.

San Millán Ruíz D, Gailloud P, de Miquel Miquel MA, et al. (1999) Laterocavernous sinus. *Anat Rec* **254**, 7–12.

San Millán Ruíz D, Fasel JH, Gailloud P (2002a) The petrosquamosal venous channel. *Am J Neuroradiol* **23**, 739–740.

San Millán Ruíz D, Gailloud P, Rufenacht DA, et al. (2002b) The craniocervical venous system in relation to cerebral venous drainage. *Am J Neuroradiol* **23**, 1500–1508.

Streeter GL (1915) The development of the venous sinuses of the dura mater in the human embryo. *Am J Anat* **18**, 145–178.

Théron J, Moret J (1978) *Spinal Phlebography (Lumbar and Cervical Techniques)*, 1st edn, pp. 3–7. Berlin: Springer.

Valdueza JM, von Munster T, Hoffman O, et al. (2000) Postural dependency of the cerebral venous outflow. *Lancet* **355**, 200–201.

Waltner JG (1944) Anatomic variations of the lateral and sigmoid sinus. *Arch Otolaryngol* **39**, 307–312.

Widjaja E, Griffiths PD (2004) Intracranial MR venography in children: normal anatomy and variations. *Am J Neuroradiol* **25**, 1557–1562.

Woodhall B (1936) Variations of the cranial venous sinuses in the region of the torcular herophili. *Arch Surg* **33**, 297–309.

Wysocki J (2002) Morphology of the temporal canal and postglenoid foramen with reference to the size of the jugular foramen in man and selected species of animals. *Folia Morph (Warsz)* **61**, 199–208.