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Review Article

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A cadaveric review of the variations in anatomy in the junction between the great cerebral vein and the straight sinus

Abstract

The human brain is an area that anatomists have been exploring for centuries, and one which has been a mystery to science for much of this time. Even today the human brain is not fully understood in its entirety. Since the early works of Paul Broca in the mid eighteenth century, cited in Finger[1] and Clark,[2] research has been constantly evolving to explore the human brain and the many intrinsic factors that make it work. The cerebral venous system is an area of anatomy which has been explored using varying methods of anatomical research; these have included MRI, CT, ultrasonic's, comparative human anatomy and cadaveric studies. This review study will explore the cerebral venous system, primarily focusing on the junction located between the great cerebral vein (GCV) and the straight sinus (Ss). Previous research into the junction between the GCV and the Ss will be examined, compared and critiqued in order to further develop an understanding of the location of this junction and the anatomical variations that have been previously identified there. This review study will consider the following anatomical research techniques: sonography, cadaveric and gender comparative anatomy incorporating haemodynamic perspectives of the venous system through the approach of ultrasonic's – a method used to measure velocities of flow through vessels by using high-intensity acoustic energy to produce visible imagery. Several methodologies are used so that broader comparisons and contrasts can be made between research methods; this then allows for more exact data analysis.

Keywords: dural venous drainage, great cerebral vein, straight sinus

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Abbreviations: GCV, great cerebral vein; SS, straight sinus; SS-S, superior sagittal sinus; CoS, confluence of sinuses; IS-S, inferior sagittal sinus; VoG, vein of galen; TCC-DS, transcranial colour-coded duplex sonography; ICV, internal cerebral vein; BV, basal vein

Introduction

The objectives of this study are to examine why variations may be present; how these variants may have formed in the junction between the GCV and the Ss; and to explore the potential correlation between these formations and the haemodynamic processes of the cerebral venous system in the human body. In order to attempt to find some answers to the questions put forward by this research, a number of scientific methods will be examined, and these, where possible, will be amalgamated to form an understanding of how different techniques used in anatomical science can be used to explore an area of interest to the researcher. Variations of scientific principles used to interpret data will be examined and scrutinized in order to explore several anatomical research methods. This is an important objective, since cadaveric studies alone will not produce as much comparable data as other research methodologies such as Transoccipital Power-Based Colour-Coded Duplex Sonography. This is a method used to view real-time flow rates and patterns within the venous system of the living brain by using a combination of acoustic imagery (sonar), combined with computer colour mapping to interpret rates and patterns within a desired location of interest. Parameters may vary within the cerebral vascular system and this may be influenced by an array of physical and physiological factors, including the diameters of vessels; the density of red blood cells; blood pressure; age; gender; ethnicity; oxygen/carbon dioxide; rate of perfusion; and other pathologies and anatomical variations in structure.[3] It has been suggested that anatomical variations within the cerebral venous system can be formed from the earliest stages of development and that this may alter anatomical architecture, and, with that, velocities through the system,[4] This in turn can further influence cerebral venous architecture through the process of remodelling.[3] This is thought to occur via variation in circulation volumes and velocities through the cerebral venous system, resulting in the creation of diversities in structure due to the nature of the variant pressures throughout the venous system.[3] Alternatively, variation in volumes and velocities may have connections to every single point of cerebral venous anatomy, as variants in structure in the cerebral venous system may in turn influence forces and pressures through the system.[5] The process known as remodelling can reshape cerebral venous anatomy and this can be dependent on the need for collateral flow, which may result in hugely diverse variation from person to person. This is potentially dependent on an array of complex variants which may be a result of age, gender, ethnicity and diet.[6] In this review study, haemodynamics will be examined in relation to variants in the cerebral venous anatomy between the GCV and Ss, and consideration given as to whether potentially remodelling could play a part in anatomical architecture between the GCV and the Ss, and how and why this might occur. The focus will be on the cerebral venous system; the arterial system, which is beyond the scope of the review study, will not be considered. Cerebral venous return is a process which can be separated into two areas, the superficial and the deep. The anatomy of the superficial system contains dural venous sinuses;

these venous sinuses have a wall composed of dura mater lined with endothelium.[7] The dural sinuses are found in the surface of the cerebellum. The superior sagittal sinus (SS-S) is the most prominent of the sinuses and flows in the sagittal plane under the midline of the cerebral vault, both posteriorly and inferiorly to the torcula, which then forms the confluence of sinuses (Figure 1).[8]

The cerebral venous drainage tracks through the confluence of sinuses (CoS) where the superficial drainage links with the sinus and primarily drains the deep venous system.[9] Two transverse sinuses bifurcate and travel laterally and inferiorly in an S-shaped curve that forms the sigmoid sinuses (S-S), and this then goes on to form two jugular veins in the neck; the jugular veins parallel the upward course of the carotid arteries and drain blood into the superior vena cava.[10] The anatomical architecture of the deep venous drainage system is principally comprised of conventional veins inside the deep structures of the brain, which join behind the midbrain to form the Vein of Galen (VoG) (not illustrated in Figure 1). The VoG fuses with the inferior sagittal sinus (IS-S) to form the straight sinus (Ss), which then joins the superficial venous system at the confluence of sinuses (CoS).[4] Baumgartner et al.[11] carried out a research project into the hemodynamic mechanism of the cerebral venous system. Sonography was the chosen method for investigation, with the intention of viewing the haemodynamics of the cerebral sinuses and veins in living participants. Hennerici & Heusler[12] suggest that the use of sonography in the clinical diagnosis of pathological variants in the cerebral venous system is a unique way of viewing haemodynamics in the living, and that even though some age groups and ethnicities are more varied in the actual imaging process, additional ultrasound phase contrast imaging can allow for better quality results. Ultrasound phase contrast imaging can be identified in this work as a process of using colour mapping to view the images created by acoustic energy imaging to highlight venous flow. The methodology of Baumgartner et al.[11] was to use Transcranial Colour-Coded Duplex Sonography (TCC-DS), a technique widely used for the detection of abnormal or variant cerebral venous flow. Transcranial Colour-Coded Duplex Sonography (TCC-DS) is a method that uses a probe moved around the posterior aspect of the cranium – around the point of the external occipital protuberance and around the sides of the parietal and temporal aspect of the skull – to produce colour imagery of the underlying haemodynamics in the vessels through acoustic resonance. However Baumgartner et al.[11] suggested that it is best suited for the measurement and or detection of slow cerebral venous velocities, thus allowing an actual proportional mapping of volumes and velocities across the cerebral venous system. The detection of slow velocities allows for comparative imagery, which highlights an overall mapping of function within vessels, but the question of what the result of fast cerebral venous velocities would have on the results of imagery was not speculated upon. Hennerici & Heusler[12] also used TCC-DS and suggested that the use of Sonography for viewing haemodynamics is an unparalleled method for real time mapping of flow patterns and velocities within the living brain; and an area which may in future be a reliable resource for diagnostic assessment of pathological conditions. The sample selected and used for the research by Baumgartner et al.[11] was comprised of 120 healthy volunteers, 60 men and 60 women, with an age range of 20-79years. The sample was stated to be of Caucasian descent with no medical history of cerebrovascular and cardiopulmonary disease. Forty of the sample were aged between 20 and 39years; 40 were aged between 40 and 59years; and 40 were aged 60-79years. The chosen method of Sonography involved using an Acuson 128 XP/10 device equipped with a 2.0- to 2.5-MHz 90° sector scan. A process of transoccipital insonation was performed on the subjects, who were placed in a sitting position with the head bent slightly forward. The transducer was positioned approximately 1cm above the external occipital protuberance. Sagittal scanning planes were the preferential measurement. The Ss, IS-S, GCV, internal cerebral vein (ICV), and basal veins (BV) were insonated. All anatomical locations were identified according to the direction of the flow patterns and the volume and velocity.

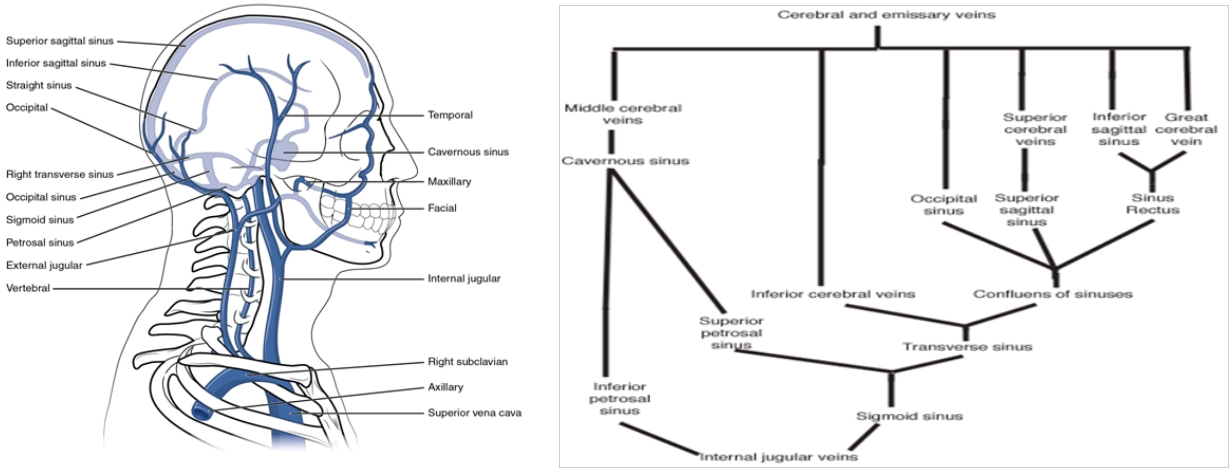

Figure 1 and Diagram 1: Shows the stages of dural venous return Sources: Dissector [8,17].

Results of the research suggested that gender may be a factor to be considered in relation to possible anatomical variants. The research showed that out of the subject groups, more women than men showed positive traces in the insonated images, thus indicating increased flow rates which allowed better images for comparisons on haemodynamic velocity between genders. James suggest that the variant anatomy between the cerebral venous system of men and woman may be due to factors relating to variations in cerebral pressure through the system, and suggests that women aged between 20 and 35years are at higher risk of cerebral sinus thrombosis because of these variations in velocity. Hennerici & Heusler[12] also speculated that because velocities and volumes differ between genders, this may affect the ability to view the cerebral venous haemodynamic patterns in men and women equally, as velocity may alter measurable imagery. Baumgartner et al.[11] suggested that by viewing cerebral venous volumes and velocities through the process of sonography, trends

in volume and velocity patterns could be identified. They identified through their research that the highest velocities were seen in the Ss, slower in the GCV, and slowest in internal cerebral veins (ICV). The concept that there are variations in the volumes and velocities around the cerebral venous system is interesting, as it may have some further relevance to the variations in the anatomy between the GCV and the SS. Baumgartner et al.[11] suggested the SS as having the highest velocities and the GCV as having a slower velocity, so there could be a correlation between volumes and velocities over time remodelling parts of the cerebral venous anatomy. If this is so, how does it manifest itself, and would higher or lower velocities and or volumes increase or decrease variations within the junction between the GCV and the SS? Baumgartner et al.[11] identified that cerebral venous velocities show trends of decreasing with age. This view was held by Kvetan & Dantzker,[13] who also suggested that velocities may decrease with age, but will increase if vessel diameter is decreased. Therefore variation and function will directly affect each other. Overall, the research of Baumgartner et al.[11] makes interesting points on the anatomical variant velocities in the cerebral venous system, and has raised further questions with reference to potential anatomical remodelling through cerebral venous hemodynamics. Kvetan & Dantzker[13] suggest that variants in anatomy may increase or decrease velocities and volumes in the cerebral venous system; and therefore where, when and how these variants in anatomy come to pass is an area for exploration. The suggestion from Baumgartner et al.[11] and Kvetan and Dantzker[13] that age and variation in anatomy may alter cerebral venous haemodynamics was an interesting concept and one that needed further investigation. Stolz et al.[14] carried out a research project using a sample of 130 healthy volunteers, with an age range of between 14 and 77years. The methodology they adopted was similar to that used in the research project of Baumgartner et al.[11] but the equipment used was slightly different. A Phased-Array Ultrasound System (PAUS) (Hewlett Packard, Sonos 1000 and 2000) equipped with a 2.0- and 2.5-MHz 90° sector transducer was used.

The subjects for the research were examined in the supine position, in contrast to the sitting position with the head bent slightly forward, as had been carried out by Baumgartner et al.[11] Cottrell & Smith[15] suggest that the sitting with head down position may alter the cerebral blood transfusion via gravity in a non-beneficial direction, and therefore varied results may be shown with regard to velocities recorded. Stolz et al.[14] chose to use the trans-temporal acoustic bone to monitor cerebral venous haemodynamics. Albright et al.[16] suggest that the prone position is standard neurosurgical approach to view cerebral venous drainage, as gravity helps the process of drainage in this position and this allows for more contrast in imaging. Stolz et al.[14] concurred with previous works that age seemed to decrease velocity of blood flow through the cerebral venous system within the subject group. They speculated that the method of haemodynamic studies on velocities across the system can provide information on cerebral venous haemodynamics in normal subjects and pathological cases;. They felt, however, that further research would be needed to investigate more detailed patterns of cerebral venous volumes and velocities, including further and more comparable data on age, gender and ethnical variations. Stolz et al.[14] made it clear in the research that all of the participants had been screened for pathologies relating to the cerebral venous system, and that all participants who took part in the research were classed as healthy subjects or as not having any cerebral venous pathologies. Interestingly, the research of Baumgartner et al.[11] and Stolz et al.[14] highlights velocities through the venous system, and suggests that velocities may potentially be altered over the period of life. As mentioned by Kvetan & Dantzker[13] who suggested that reduced venous diameter may increase velocities and volumes across the cerebral venous system, this may in turn be a result of related pathological conditions that may remodel anatomical areas. This may occur if during the life cycle the cerebral venous system is influenced by an array of precursors such as varied venous construction through pathologies; diet; ethnicity; gender and age. Any or all of these variables may indeed hold a reason for variant cerebral venous anatomy between the GCV and the Ss. In order to further explore anatomical variants between the GCV and the Ss, a cadaveric study by Ghali et al.[17] was examined and critiqued. The methodology for the cadaveric study was to look for variations in the cerebral venous anatomy between the GCV and the Ss. Ghali et al.[17] used a sample of 20 human cadaveric brain dissections to determine if variant anatomy could be seen in a relatively small sample size. Twenty human cadavers were used for the anatomical study, 15 procured from the dissecting room, and five from the post mortem room at the Ain-Shams University Faculty of Medicine. The specimens from the dissecting room were divided into three groups of five totalling 15 specimens. The first group of five specimens were cut along the median sagittal plane to open and examine the Ss. The second group of five specimens were cut along the parasagittal plane and the angle between the GCV and the Ss was measured and the pattern of the junction was recorded. The third group of five specimens had the cerebellum dissected free to examine the inferior surface of the tentorium cerebella with its contained Ss. The other five specimens from the post-mortem room were dissected to examine the junction between the GCV, the IS-S and the Ss. These specimens were fixed in 10% formal saline, orientated in paraffin blocks and from this 12cm sections were cut. Sections were stained with haematoxylin and eosin and Masson's trichrome stains. The macroscopic study identified the presence of a posterior elevation that had been previously identified by Clark and Le Gros[18] who named the elevation the suprapineal arachnoid body.

The suprapineal arachnoid body is also described by Dagain et al.[19] in later research which named the cerebral venous variant, the posterior elevation. During the examination of the Ss a small elevation was found in its floor at its junction with the GCV. The variant elevation was described as having a smooth surface that was convex in an upwards direction. Ghali et al.[17] described the elevation as having dimensions ranging between 3.5–4.5mm in length and 2.5–3mm in width. Microscopic study identified that the elevation had more or less the same amount of dense fibrous tissue lined with vascular endothelium as in the wall of the Ss, suggesting the construction was consistent with that of the Ss and not an elevation that had been created from another material. Histological sections that had been taken from the anterior end of the Ss identified the presence of a smooth elevation with an empty cavity underlying it. Ghali et al.[17] describe the wall of the Ss as being formed of dense fibrous tissue arranged in laminae of collagen bundles which they suggest run parallel to each other, and are lined by vascular endothelium in the same pattern as that of the Ss. This potentially may suggest that the variant posterior elevation could have been formed through the process of remodelling caused by the haemodynamic flow and the velocities and volumes through the Ss, as it had the same structure. A disadvantage of the research is that the sample size is very small, as initially 20 human cadaveric brain dissections were used. These were sub divided into groups of five, which then had varied scientific procedures performed; this could be compromizing as the sample is so small, and therefore comparatives within the sample could be cross referenced with other larger similar studies in order to gain significant statistical data. Ghali et al.[17] did not explicitly quantify other research projections, and therefore it was hard to compare this work with previous cadaveric studies with regard

to sample size and the anatomical method of dissection that was used. In order to further investigate the work of Ghali et al.[17] other relevant cadaveric studies were examined and contrasted within the context of variant anatomy. The research of Dagain et al.[19] Sought to investigate the anatomical variant as described by Ghali et al.[17] and Clark and Le Gros.[18] Dagain et al.[19] used an Anatomical, Immunohistochemical and Ultra-structural methodology to examine the junction between the GCV and the Ss, using 25 human cadaveric brain dissections from the University of Bordeaux anatomy laboratory. The venous junctions with the Ss were examined using an operating microscope. Two of the brains were injected with blue and red latex post separation from the trunk and 48 hour post mortem; 18 of the brains were examined after total body embalming in a 10% formol solution; five junctions were examined under operating microscope; and 18 junctions were examined using smooth muscular actin immunohistochemical staining, the fixed pieces were embedded with paraffin. Each piece was cut with a microtome to obtain a series of sections of 4mm thickness. The-4mm sections were secondarily spread out on super frost slides and unparaffinated in a drying oven at 540 C for six hours. In order to gain a more precise location of the junction, hematoxylin eosin staining was used on the slides.

Dagain et al.[19] noted three anatomical variants within the cadaveric study (Figure 2). These were identified as: a posterior elevation that was found in 14 of the specimens, an outgrowth from the floor of the SS with a semi-circular form, [found in 7 specimens] and a posterior intra- luminal nodule, which was found in 4 of the specimens. The research by Dagain et al.[19] explained in some detail the process of anatomization of the specimens, something that had not been hdone in the work of Ghali et al.[17] The method of dissection was described in the work as a bi-parietal occipital craniotomy with the dura-mater being cut along the lateral edges of the superior sagittal sinus (SS-S) and the superior edges of the transverse sinuses (TSs). This was described as being performed on all specimens. The explanation of the dissection technique seems to be of significant relevance as variations of technique could potentially alter specimens and thus provide varied results. The process of bi-parietal occipital craniotomy is described in many anatomical articles as being the most preferred method of removal of the brain, and in autopsy practice is the common method used.[20] Dagain et al.[19] presented the research data in a way that overlapped diagrams with text to clearly explain the three anatomical variations within the junction. This was very helpful at showing how these variants may have formed in the cerebral venous system, and how these variants may have links to hemodynamics through the cerebral venous system. When compared and contrasted with the previous work of Ghali et al.[17] it seemed that the sample size of 25 was also a small sample to gain significant data, however the variations in scientific technique employed by Dagain et al.[19] for the preservation of the specimens seem slightly obscure, as 18 had total embalming, whereas five were dissected without preservation and 24hours post mortem, with the remaining two being injected with latex. The variation in the method between fresh cadaveric specimens and preserved specimens may potentially show different results due to the very process of the preservation method which may alter anatomical features. If that is so, should protocols in measurement be derived for different specimen subgroups? By looking at both haemodynamic research and cadaveric studies, a greater insight has been gained into variant forms of anatomy in the cerebral venous system of the junction between the GCV and the Ss and how these may become prevalent throughout the life cycle. The haemodynamic sonography studies by Baumgartner et al.[11] and Stolz et al.[14] presented a foundational point for considering cerebral venous anatomy through the on-going process of development throughout the human life cycle. The relevance of where, when and how changes in the cerebral venous system may form, seem to allow for a base understanding of how potentially volumes and velocities through the junction between the GCV and Ss may alter anatomical configuration through the process of remodelling.[21] If, as suggested by Kvetan and Dantzker,[13] decreases in diameter of the venous system do occur due to age, gender or pathological conditions, and this potentially alters velocities through the system, does this in turn give a broader understanding of cadaveric variants seen in the junction between the GCV and the Ss– as discussed by Ghali et al.[17] and Dagain et al.[19] In order to gain more data for a study such as this, further larger cadaveric and sonographic studies with a broader diversity of ethnicity, age and gender may increase the understanding of how variant anatomy and hemodynamics interlink. To further adapt and improve upon research in this area, all research methods should attempt to have some common shared base element or measurement, so that a valid comparable measurement across various research methodologies can be achieved.

Conclusion

In conclusion, the haemodynamic research investigated in this work has used similar methodologies to investigate a common question. However the gap that seems to be missing is a uniform approach in the understanding of the anatomical variations and why they may occur. Ideas and speculations on gender, age and ethnicity have all been considered, but they have been confined to groups of individual research papers. The nature of the haemodynamic process is unsurprisingly complex and therefore it is an ongoing question that will need further research and different research methods in order to better understand the very fundamentals of anatomical design within the cerebral venous system.

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Conflict of interest

Author declares that there is no conflict of interest.

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