EXTRAJUGULAR PATHWAYS OF HUMAN CEREBRAL VENOUS BLOOD DRAINAGE - ASSESSED BY DUPLEX ULTRASOUND

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Abstract

Cerebral venous drainage in man is thought to be ensured mainly via the internal jugular veins (IJVs). However, anatomical, angiographic and ultrasound studies suggest that the vertebral venous system serves as an important alternative drainage route. We assessed venous blood volume flow (vBVF) in vertebral veins (VVs) and IJVs of 12 healthy volunteers using duplex ultrasound. Measurements were performed at rest, during a transient bilateral IJV and a circular neck compression. Total vBVF at rest was 766±226 ml/min (IJVs: 720±232, VVs: 47±33). During bilateral IJV compression VV flow increased to 128±64 ml/min. Circular neck compression, causing an additional deep cervical vein obstruction led to a further rise in VV volume flow (186±70 ml/min). As the observed flow increase did not compensate for IJV flow cessation, other parts of the vertebral venous system like the intraspinal epidural veins and the deep cervical veins have to be considered as additional alternative drainage pathways.
Introduction

The internal jugular veins (IJVs) are thought to represent the main outflow pathway for cerebral venous blood in humans. However, the clinical observation that bilateral resection of the IJV is usually well tolerated suggests the presence of alternative, non jugular pathways (9). Such a route exists in form of the anatomically complex vertebral venous system (1, 7, 8, 16). Part of this system are the vertebral veins (VVs) which have been shown to serve as venous collaterals in cases of jugular flow obstruction (5, 9). A recent ultrasound study of healthy volunteers demonstrated, that the pattern of cerebral venous drainage changes even under physiological conditions, depending on the body position (23). While flow in the IJVs dominated in the supine position, a marked jugular flow reduction and a concomitant flow rise in the VVs was seen when changing into the erect body position. However, the magnitude of flow increase in the VVs did not match the decrease, measured in the IJVs. The authors therefore posed the hypothesis, that alternative pathways, like the spinal epidural veins as a part of the internal vertebral venous system might have been the reason for the observed difference (23). In addition, the deep cervical veins, and other ultrasound inaccessible parts of the external vertebral venous system have to be considered (1, 4). To study the potential role of the deep neck veins, venous blood volume flow (VBVF) was measured by duplex ultrasound in both VVs during bilateral IJV and during circular neck compression.
Materials and Methods

The study was conducted in 12 volunteers (3 females, 9 males, mean age ± SD, 29 ± 6 years), free of cardiovascular disease. All subjects gave informed consent. Color-coded duplex sonography was performed using a 3 - 11 MHz linear transducer (HP Sonos 5500, Hewlett Packard). Insonation was carried out in a head straight and supine body position at a midcervical level during normal breathing of the probands. VBVF was calculated as described previously (13, 14, 19, 23) by multiplication of vessel area and time averaged velocity (TAV = mean of all frequencies over 2 - 3 heart cycles) using the HP Sonos 5500 software (Fig.1). In case of marked respiratory variations of TAV and vessel cross sectional area (CSA), measurements were performed during brief apnea after a normal expiration. The CSA of the IJV was measured in the horizontal plane using the B-mode image while VV-CSA was calculated from VV diameters, obtained in the sagittal plane assuming a circular vessel shape. VBVF at rest was assessed in both IJVs and VVs. Additional VBVF measurements were then carried out in the VVs during a transient complete blood flow obstruction of both IJV, lasting approximately 1 - 2 min. Flow cessation - confirmed by duplex ultrasound - was achieved by applying a constant manual pressure on both IJVs at the submandibular level. A third VV flow analysis was performed during circular neck compression at the same level, using an elastic band. This procedure also led to IJV flow cessation. For statistical analysis nonparametric repeated measures ANOVA (Friedman test) and Dunn’s multiple comparison post test were performed. A p-value of < 0.05 was considered significant.

Two volunteers (No. 6 and 7) were additionally studied by venous MR-angiography (Magnetom Vision, 1.5 Tesla, Siemens, Germany) during manual jugular vein compression to analyze, if flow changes in the non-jugular venous system could be visualized. For data acquisition a saturated FLASH 2D sequence was used (TR/TE 33/9 msec, one signal acquired, 3 mm slice thickness, 260-mm field of view, 192x256 pixel matrix).
Results

All vessels were successfully insonated at rest and during the two modes of venous compression (Fig. 1). Compression tests were well tolerated with subjects mainly noticing the applied neck pressure and some degree of facial swelling but no other side effects like headaches or visual disturbances. IJV flow cessation during circular neck compression was achieved by a mean neck circumference reduction of 4.5 cm (range 3 to 7 cm). Mean total venous outflow, calculated as the sum of VV and IJV volume flow at rest was 766 ± 226 ml/min, ranging from 390 to 1130 ml/min. The IJVs contributed 94% (720 ± 232 ml/min) and the VVs 6% (47 ± 33 ml/min) of total VBVF (Table). The following compression tests led to a significant VV flow increase (p < 0.0001). Bilateral manual IJV compression resulted in a VV flow of 128 ± 64 ml/min (p < 0.05), comprising now 17% of the total VBVF. The circular compression led to a further non-significant mean flow rise (186 ± 70 ml/min, p > 0.05, 24% of total VBVF). This increase however, was only seen in 7 of the 12 subjects.
Discussion

Although the extracranial portion of the arterial cerebral inflow has been investigated in detail by different modalities, only little attention has been paid to the venous drainage of the brain. The IJVs have been considered to present the most important pathway for venous blood returning from the brain. This assumption was based on angiographic studies and CBF analyses with nitrous oxide, labeled erythrocytes and thermodilution techniques (12, 21, 15, 25) which were all performed in a supine body position. However, anatomical investigations as well as clinical observations in patients after bilateral radical neck dissection suggest coexisting IJV independent alternative venous drainage pathways (9).

Venous anatomy

The main jugular blood drainage pathway leads from the superior sagittal and the transverse sinuses via the sigmoid sinuses into the IJVs, which meet the superior cava vein via the brachiocephalic vein. Competent valves usually impede retrograde flow in the IJV. In contrast, the vertebral venous system forms a freely communicating, valveless “network” of longitudinal and transverse venous vessels. It consists of an internal part, the intraspinal epidural venous plexus, and an external paravertebral part, both continuing throughout the entire length of the spinal column. The system communicates with deep thoracic and lumbar veins, intercostal veins, azygos and hemiazygos veins as well as with the inferior vena cava (6, 7, 1). The VVs represent the main longitudinal part of the external vertebral venous system. VVs and the deep cervical veins, which are located within the muscle layers of the nape, receive inflow from the marginal and sigmoid sinuses via condylar veins and emissaries and from the venous plexus surrounding the foramen magnum (2, 10, 16, 24). In addition, there are several, frequently segmental connections between the internal and external parts of the vertebral venous system. VVs, deep cervical veins and the external jugular vein (EJV) finally join the brachiocephalic vein. The cross-sectional area (CSA) of the internal vertebral venous system at skull base level has
been estimated to reach up to 1/4\textsuperscript{th} of the combined jugular CSA, while the total CSA of the vertebral venous system might even surpass that of both IJVs (3, 4).

**Ultrasound assessment of VBVF**

In the mid-cervical region IJVs and VVs are easily accessible by duplex ultrasound (13, 14, 11, 23). The presented VBVF measurements are in good agreement with previously obtained ultrasound data. Different research groups found a combined mean IJV flow of 740 ± 209 ml/min and 700 ± 270 ml/min (13,23) and a mean VV flow of 40 ± 20 ml/min (23) in the supine body position. The accessible total mean venous outflow of 766 ± 226 ml/min in our group of healthy volunteers corresponds well with ultrasound assessed global arterial inflow which has been reported within the range of approximately 500 - 950 ml/min (19, 20, 17) and with a mean value of 727 ± 102 ml/min for subjects aged 20 - 39 (18). Therefore the IJVs have to be considered the main outflow pathways in the supine position. This however, was shown to change completely when turning into the upright position as IJV flow fell from 700 ± 270 to 70 ± 100 ml/min in a group of volunteers while VV rose from 40 ± 20 to 210 ± 120 ml/min, leaving an unexplained remaining mean difference of about 450 ml/min (23). In our study, a complete IJV flow cessation was assured by bilateral manual compression. This indeed, caused the expected VV increase (mean 82 ± 57 ml/min). Interestingly, individual values varied greatly from 220 ml/min (No. 6) to one subject without a detectable flow rise (No. 7). Venous MR angiography in subject No. 6 showed bilateral prominent IJVs at rest, and a noticeable signal increase in both VV as well as the deep cervical veins during IJV compression (Fig. 2). In contrast, subject No. 7 demonstrated multiple cervical veins at rest which showed a pronounced signal increase during compression. These veins probably explain, why no ultrasonographic VV flow increase could be detected during the bilateral IJV compression. However, circular neck compression in this subject did result in a VV flow increase of 100 ml/min, confirming the predominating non-jugular pathway via the deep cervical veins. In contrast, non-jugular drainage patterns in subject No. 6 seem to mainly follow the VVs as fewer deep cervical
veins could be visualized. Combined with a deeper location of the cervical veins, predominantly surrounding the splenius capiti muscles, circular neck compression probably did not result in any significant flow obstruction, explaining the absent VV flow rise. Overall the additional cervical vein obstruction led to a further VV flow increase of 58 ± 53 ml/min (range: -10 to 140) yielding VV flow values compensating 19% (1/5th) of the jugular drainage capacity. A similar VV capacity of 26% (1/4th of jugular venous flow) was seen within the upright body position (23).

For interpretation of these data a number of technical limitations as well as anatomical specific characteristics of the insonated vessels have to be considered. An unintentional concomitant carotid artery compression could for instance lead to a reduced arterial inflow and subsequent overestimation of the diverted venous flow. However, this seems very unlikely as the applied jugular pressure was low and B-mode insonation of the carotid CSA during compression did not show vessel deformation. In our VBVF measurements a circular shaped VV was postulated for flow calculations while real vessel CSA at rest is probably non-circular in most cases, changing into a more circular shape due to an intraluminal pressure rise during the compression tests (Fig. 2). This might have led to an under- or overestimation of VV flow, especially at rest. Furthermore, known venous anatomical variations, like the doubling of VVs might have been overlooked or missed in our approach. However, even considering these potential systematic errors, more than 50% of jugular blood flow seems to follow other routes, so that the VVs are unlikely to be the main non-jugular drainage pathway. Our results suggest, that the deep cervical veins represent one of the relevant additional alternative pathways, particularly as they turned out to be the most prominent veins besides the VVs on our MRI scans, all together probably extending the CSA of the VV. The only moderate further VV flow increase during circular neck compression (8% of total jugular flow) is probably due to a limited compression effect on deep cervical veins caused by their anatomical location (Fig. 2). This hypothesis is further supported by case reports of patients in whom intraspinal pressure studies were performed by lumbar puncture after bilateral radical neck dissection (22).
Under application of bilateral manual pressure to the cervical muscle bed the registered pressure in two patients rose from 22 and 25 cm/H$_2$O to 65 and 60 cm/H$_2$O, respectively (22).

Finally, the intraspinal epidural system, already demonstrating a flow increase during IJV compression on MRI has to be considered. The distribution between these two compartments remains unclear, as no validated technique exists to directly assess blood flow within these regions.

In conclusion, we have shown in a group of young healthy volunteers, that powerful additional venous pathways besides the IJVs exist and may compensate for IJV flow cessation. The VVs as important parts of the vertebral venous system are probably not the main non-jugular drainage pathway. Instead the variably developed deep cervical veins as well as the intraspinal epidural venous system have to be considered. Knowledge of the individual venous drainage patterns might be of clinical relevance in patients undergoing IJV resection or patients suffering from raised intracranial pressure.
Acknowledgement

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References


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Figure 1:
Example of blood volume flow measurements in one subject - right and left vertebral vein (VV) at rest, during bilateral jugular vein compression (comp 1) and during circular neck compression (comp 2).
Figure 2:

Subjects No. 6 and 7: MR sagittal slice at the submandibular level. A and C - resting condition, B and D - manual bilateral IJV compression. Internal jugular veins (IJVs) - black arrows, external jugular veins (EJVs) - grey arrows, vertebral veins (VVs) - small full arrows, deep cervical veins - small empty arrows, intraspinal vertebral system - small grey arrows. Note the differently developed deep neck veins between A and C at rest and under compression.
Tables

Table: Total internal jugular vein (IJV) and vertebral vein (VV) blood volume flow at rest. VV flow changes during bilateral manual IJV compression (comp 1) and circular neck compression (comp 2).

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<th>total VV comp 1 (ml/min)</th>
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m = male, f = female, SD = standard deviation