Internal Jugular Vein Geometry Under Multiple Inclination Angles with 3D Low-Field MRI in Healthy Volunteers

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Background: Cerebral venous pathways are subjected to geometrical and patency changes due to body position. The internal jugular veins (IJVs) are the main venous drainage pathway in supine position. Their patency and geometry should be evaluated under different body inclination angles over a three-dimensional (3D) volume in the healthy situation to better understand pathological cases.

Purpose: To investigate whether positional changes in the body can affect the geometrical properties and patency of the venous system.

Study Type: Prospective.

Population: 15 healthy volunteers, of which seven males and median age 22 years in a range of 19–59.

Field Strength/Sequence: A 0.25-T tiltable MRI system was used to scan volunteers in 90°/C14 (sitting position), 69°, 45°, 21°, and 0° (supine position) in the transverse plane with the top at vertebra C2. A gradient echo sequence was used.

Assessment: Three observers assessed IJVs on patency and created automatic centerlines from which diameter and patency were analysed perpendicular to the vessel at every 4 mm starting at the level of C2.

Statistical Tests: A Student’s t test was used to find statistical difference (p < 0.05) in average IJV diameters per inclination angle.

Results: The amount of fully collapsed IJVs increased from 33% to 93% (left IJV) and 14% to 80% (right IJV) when increasing the inclination angle from 0° to 90°. In both IJVs, the mean diameter (±SD) of the open vessels was significantly higher at 0° than 90° with 6.3 ± 0.5 mm vs. 4.4 ± 0.1 mm (left IJV) and 6.6 ± 0.6 mm vs. 4.3 ± 0.4 mm (right IJV).

Data Conclusion: Tiltable low-field MRI can be used to assess IJV geometry and its associated venous pathways in 3D under multiple inclination angles. Next to a higher amount of collapsed vessels, the average diameter of noncollapsed vessels decreases with increasing inclination angles for both left and right IJVs.

Level of Evidence: 2

Technical Efficacy Stage: 1

Chronic cerebrospinal venous insufficiency (CCSVI) is a condition characterized by anomalies in the veins draining the central nervous system (CNS) that disturbs the normal outflow of blood from the CNS to the heart. CCSVI is linked to several CNS disorders, such as idiopathic intracranial hypertension, traumatic brain injury, senile dementia, and hydrocephalus. Previous studies have shown that the cerebral venous pathways depend on the body position: in supine position, the cerebral venous drainage through the internal jugular vein (IJV) is increased compared to an upright position. In upright position, the IJVs collapse and the blood goes primarily through the paravertebral venous plexus. Primarily, cerebral venous pathways are imaged in supine position, while humans spend most of the time in the upright position.

Ultrasound (US) can be used to visualize extracranial veins such as the IJVs and with additional doppler technique the flow velocity inside the veins can be measured. US is noninvasive and can be performed in both supine and upright position.
position. However, robust three-dimensional (3D) imaging over a longer trajectory with low interobserver agreement is challenging in clinical practice.\(^\text{11}\)

Potentially, with a robust 3D imaging method, the trajectory and patency of the IJVs can be studied in more detail. Because US studies usually perform imaging in a two-dimensional (2D) plane, a longer trajectory has not been investigated yet under multiple angles. Tilted low-field MRI opens up possibilities to investigate the postural changes of the extracranial venous pathways in 3D under different inclination angles.\(^\text{12}\) Information on 3D geometry in multiple inclination angles may lead to a better understanding of the normal variation in the healthy situation and how this should be translated to abnormal cases. Ideally, this imaging method can be applied and used in pathological cases like CCSVI. This research aims to contribute to a better understanding of venous geometrical changes and patency in the IJVs affected by different body inclination angles.

**Materials and Methods**

**Data Acquisition**

This study was approved by the local institutional review board, and informed consent was obtained from all subjects. The inclusion criterion was that subjects should be healthy (no known abnormalities of the cervical veins) and 18 years or older. The exclusion criteria were 1) subject length > 200 cm, and 2) not eligible for MRI in response to the MRI safety checklist. All healthy volunteers were scanned with an open 0.25-T MRI system (G-scan Brio, Esaote SpA, Genoa, Italy), as shown in Fig. 1. Subjects were first imaged in sitting position (90°/C14) positioned in a dual phased array coil designed for cervical spine examinations. After that, the same imaging protocol was applied at 69°/C14, 45°/C14, 21°/C14, and 0°/C14 inclination angle, which corresponds to a supine position. For each scan, the field of view (FOV) was positioned with its upper boundary just inferior to the second cervical vertebra (C2) level. The transverse imaging plane was selected perpendicular to C2.

A gradient echo sequence was used to acquire transverse slices with a saturation band inferior to the FOV to eliminate pulsation artifacts from the carotid arteries. The parameters used were repetition time (TR) of 90 msec, echo time of 10 msec, flip angle of 75°, FOV of 26 × 26 × 8 cm\(^3\), imaging matrix of 192 × 128, and slice thickness of 4 mm with no gap. Odd and even scans were acquired in an interleaved fashion. Twenty slices were acquired for a total IJV length of 80 mm. The total acquisition time per inclination angle was 2 minutes and 8 seconds.

**Analysis**

Data were analyzed with dedicated software (Aquarius iNtuition Ver.4.4.13, TeraRecon, San Mateo, CA, USA). Semiautomatic centerlines through the IJVs were created by J.V.Z. (6 years of experience), K.K. (1 years of experience), and C.S. (25 years of experience) through selecting consecutive points from the IJVs to obtain perpendicular views through the vessels. The centerline was manually adjusted in slices with insufficient contrast between IJV and surrounding tissue. In cases where side branches were visible, centerlines were made only through the IJV. An automatically created vessel outline based on the contrast between vessel lumen and surroundings was used for measurements of the average diameter for every 4 mm along the centerline starting at the level of C2.

Each of the 20 points along the centerline was labeled based on lumen visibility as assessed by three independent reviewers (J.V. Z., K.K., and C.S.). Discrepancies were resolved by discussion. Therefore, in all IJVs that were assessed, there was a distinction between 1) fully open, 2) partially collapsed, and 3) fully collapsed vessels. Collapse of the IJV was accepted when there was not enough signal for centerline extraction. Additionally, parts of vessels or entire

![FIGURE 1: (a) A healthy volunteer sitting in the MRI scanner at 90° inclination angle. (b) Schematic overview of relevant extracranial veins in this study. The bold red lines are depicting the upper and lower boundaries of the field of view, where the thin red lines represent the orientation and a number of the slices that were scanned. Adapted from smart.servier.com.](image-url)
vessels that could not be assessed because of low scan quality were labeled as 4) technically excluded.

Clear signal intensity in the vessel lumen indicated blood flow, which was based on the used time-of-flight sequence. A visually correct vessel outline was considered as an open lumen. If no signal in the IJV was present, the centerline point was labeled as anatomically collapsed. If more than 10 points of a single centerline were technically excluded, the entire centerline was discarded. The diameters of fully collapsed and technically excluded vessels were not considered for analysis.

Average vessel diameters were calculated based on the cross-sectional area inside the automatically generated outlines, assuming that the vessels had a perfect circular shape. Diameters for each vessel were analyzed as function of the height with respect to C2. For each inclination angle, the average diameters were normalized with respect to the supine position (0°) to compare relative changes between subjects. Again, fully collapsed veins or centerline points where the vein was collapsed were not taken into account. To analyze the change in diameter per inclination angle, vessel diameters at each angle were averaged for each left and right IJV of all subjects.

**Statistical Analysis**

Mean and SDs were used to describe the different vessel diameters over a distance inferior to C2. A Student’s t test was used to find statistical difference in average IJV diameters per inclination angle. Statistical significance was defined as $P < 0.05$.

**Results**

Demographics of the subjects are given in Table 1. Fifteen healthy volunteers were included of which seven males (47%) and the median age was 22 years (in the range of 19–59). Examples of transverse MRI data and centerlines together with vessel outlines are shown in Figs 2 and 3, respectively. Depending on the trajectory of the IJV, the number of centerline points located 4 mm apart from each other ranged between 17 and 23 points. All vessels fell in one of these categories based on the number of centerline points labeled as open, where >15 open assessed points were fully open, between 5 and 15 were partially collapsed, and <5 points were fully collapsed. Often, a part of the IJV had clear signal inside the lumen and was thus considered open (eg, before or

| TABLE 1. Demographics of the Healthy Volunteers Who Participated in This Study |
|-----------------------------|---------|
| Volunteers ($n$)            | 15      |
| Height, cm (mean ± SD)      | 178 ± 10|
| Weight, kg (mean ± SD)      | 71.9 ± 13.7|
| BMI, kg/m² (mean ± SD)      | 22.5 ± 3.2|

**FIGURE 2:** Example of transverse MRI of a participant at inclination angles ranging from 0° to 90°. Arrows indicate examples of relevant findings in the scans. Red = internal jugular vein; Yellow = facial vein. The open arrows indicate an anatomical collapse for 69° and 90°.
after side branches), whereas higher or lower parts were lacking signal intensity. An example of such a vessel can be seen in Fig. 3c and d.

Figure 4 shows the distribution for the left and right IJV that were fully open, partially collapsed, fully collapsed, and technically excluded. A total of 8 (53%) left IJVs and...
9 (60%) right IJVs were fully open at 0°, which decreased to, respectively, 0 and 2 (13%) open IJVs at 90°. At an inclination angle of 0°, 5 (33%) left and 2 (14%) right IJVs were anatomically collapsed, which increased to 14 (93%) left and 12 (80%) right IJVs at 90°. In all slices where the IJV was assessed as collapsed, an alternative venous pathway was visible as flow in the facial vein, anterior jugular vein, external jugular vein, or even in the paravertebral venous plexus. From the 150 (15 subjects × 5 inclination angles × 2 sides) potential IJVs, 2 (1.3%) were technically excluded by the reviewers.

Vessel diameters as function of the distance inferior to C2 at 0° and 90° are shown in Fig. 5. For the left IJV, the mean diameter (±SD) was significantly higher at 0° than 90° with 6.3 ± 0.5 mm vs. 4.4 ± 0.1 mm. It should be noted that at 90° there was only one left IJV partially collapsed. In the right IJV, a significant difference was found between average diameters of 6.6 ± 0.6 mm at 0° and 4.3 ± 0.4 mm at 90°. The maximal difference in average diameter over the whole length was only 1.2 mm for the left IJV at 0°, and 2.0 mm and 1.6 mm for the right IJV at 0° and 90°. Thus, the average diameter varied minimally as function of the height with respect to C2, which also applied to IJVs with less included centerline points at 90° inclination angle. At 21°, 45°, and 69° inclination angles, the mean diameter ± SD were, respectively, 5.3 ± 0.3 mm, 4.0 ± 0.5 mm, and 3.6 ± 0.1 mm for the left IJVs, and 5.7 ± 0.5 mm, 5.3 ± 0.4 mm, and 4.5 ± 0.5 mm for the right IJVs. The difference between minimal and maximal diameters of the right IJV was smaller at 90° than at 0° due to the smaller amount of vessels that were opened.

Figure 6 shows for the noncollapsed IJVs the average change in normalized diameter as function of inclination angle. Vessels of which the centerline at 0° could not be measured due to technical exclusion or collapse at this point were not considered in this result. Likewise, there was a single vessel partially open for the left IJV at 90° that showed a full collapse at 69°. This resulted in a single point at 90° and a sudden increase at the end of this graph, since no data existed for that vessel at 69°. Based on the vessels that did not fully collapse, the relative average vessel diameter decreased consecutively to 0.82, 0.74, 0.53, and 0.94 times the diameter at 0°.
for the left IJV and 0.88, 0.82, 0.73, and 0.70 times for the right IJV. Diameters and vessel patency information of all the centerline points from all volunteers are provided in the supplementary materials.

**Discussion**

This study was designed to assess IJV geometry and patency assessment over a long trajectory in multiple inclination angles using a tiltable MRI. From the 150 vessels that were measured only a small part was excluded due to technical issues. The remaining vessels were assessed over a length of 80 mm and there was no indication that the IJV varies in diameter in cranial-caudal direction. There was a shift observable toward partially open and fully collapsed vessels with increasing inclination angle for both left and right IJVs. This research confirmed that tiltable MRI was able to measure basic geometric characteristics and patency of the IJVs over a long trajectory under multiple inclination angles.

Whereas US studies typically investigate IJV geometry in a single 2D plane, with this study 3D imaging over an 80-mm trajectory was performed under five inclination angles. It was shown that the IJVs could also partially collapse, consisting of flow in higher or lower parts of the IJV and flow in collateral veins (eg, the paravertebral plexus) in case of collapse. Where the interaction between IJVs and paravertebral venous plexus in relation to inclination angle has been studied before, this research suggests that variation in venous drainage patterns is more complex and involves multiple venous pathways in the cervical region. However, it should be noted that alternative pathways could only be visually observed in this study, but not sufficiently analysed in terms of geometry due to gradient limitations on the MR system that was used. The MRI protocol should be further optimized in terms of resolution and efficient flow imaging to emphasize the role of smaller venous pathways under inclinations. Therefore, subsequent studies that focus on venous cervical pathways should focus on the simultaneous visualization of multiple venous pathways to make sure that all possible routes are included. Although in this study there was a small variation in diameter over the measured IJV trajectory, the patency of the IJVs suggest that in all cases the blood flow follows alternative paths. This study showed that a combination of more than two possible venous pathways is clearly possible.

There were some vessels and centerline points in this study that could not be properly imaged or assessed. The reasons for these technical exclusions vary from a reduced inflow effect because of low blood velocity, multislice failure, or subject movement in between slices. Due to a large variation in flow and geometry between subjects, there were cases where flow was too low to obtain positive contrast in the gradient echo sequence. For these subjects, shorter TR or larger slice thickness should improve inflow effect and yield adequate

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**FIGURE 6: Average diameter for all open internal jugular veins (IJVs) as function of the inclination angle of the subjects relative to the individual diameter at 0° inclination. The range of maximum and minimum relative diameter change is depicted with the shaded bands.**
When investigating patients
In this study, it was shown that tiltable low-
venous drainage exists in the healthy population. In
the pathological situation, it is beneficial for patients to have
alternative pathways for cerebral venous drainage in the case of
obstructions. Furthermore, the awareness of the variety in
venous drainage patterns should also be considered when per-
forming flow and modeling studies, like performed by Müller
et al. In this study, it was shown that tiltable low-field MR
imaging under different inclination angles could contribute to
comprehensive analysis of these venous pathways. Adequate
tiltable imaging of venous drainage is even more relevant con-
sidering that humans have a supine to upright ratio over the
day of 1:2 based on daily activities. Based on this study, it
would be relevant to obtain more insight in the complexity of
other venous pathways than the IJVs and paravertebral plexus
under multiple inclination angles.

Limitations
For this study, volunteers from a small population were
scanned in a single center. Although only 15 volunteers were
studied, the amount of IJVs under different inclination angles
was large enough for this feasibility study to emphasize the
variation in IJV patency and diameter. Further limitations of
the study include the use of a single field strength and a single
vendor which is caused by the fact that tiltable MRI systems
are not widely available.

Conclusion
Tiltable low-field MRI can be used to assess IJV geometry and its associated venous pathways in 3D under multiple
inclination angles. When the IJVs in healthy subjects are not
fully open or partially collapsed, different smaller venous veins
and pathways are activated to drain cervical blood when the
human body is put at an inclination angle. The amount of
IJVs that are fully collapsed increases for both left and right

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