Intraoperative color-coded duplex sonography of the superior sagittal sinus in parasagittal meningiomas

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Summary
Background: Patency of the superior sagittal sinus (SSS) is a key factor in surgery of parasagittal meningiomas (PSM). The main and least invasive method of evaluation of the SSS is magnetic resonance venography (MR venography). However the efficacy of this method is limited in some cases especially in slow flow velocities.

Objective: Determine potentials of intraoperative color-coded duplex sonography (CCDS) for evaluation of the SSS in PSM comparing them with MR venography.

Methods: CCDS was conducted in 30 adult patients with PSM using linear ultrasound probe i12L-RS (Vivid E, GE) placed on the superior wall of the SSS after craniotomy. Intraoperative CCDS findings were compared with 2D time-of-flight MR venography.

Results: False-positive results of complete occlusion of the SSS by MR venography in our series were obtained in 7 out of 16 cases (for the anterior third of the SSS — 5 out of 6; middle third — 1 out of 8; posterior third — 1 out of 2). CCDS determined the degree of SSS invasion and differentiated invasion from compression or thrombosis of the SSS, which MR venography could not.

Conclusion: Intraoperative CCDS is safe and allows evaluation of SSS patency as well as venous lacunae, bridging veins and inferior sagittal sinus, classification according to degree of SSS invasion, and being more precise than MR venography it can be used to determine surgical strategy.

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Background

Patency of the superior sagittal sinus (SSS) is a key factor in surgery of parasagittal meningiomas (PSM) and, therefore, its determination is the standard of preoperative work-up [1]. Up to 50% of PSM invade the SSS lumen [2]. It is generally accepted that totally invaded SSS should be resected en bloc, but if the invasion is partial the SSS should be reserved even in cases with residual flow in it [3]. There are three methods of evaluation of the SSS — digital subtraction angiography (DSA), computed tomography (CT) and magnetic resonance venography (MR venography). DSA is the “gold standard” of cerebral angiography and cerebral venography in particular. It gives the most precise information about SSS patency, but it is invasive and costly, therefore its usage gradually declines. CT is believed to be slightly more accurate than MR venography in verification of SSS patency [4]. CT is less invasive than DSA yet requires irradiation and iodine contrast medium. MR venography is presently the method of choice for evaluation of SSS patency in patients with PSM due to its noninvasiveness [5].
are three kinds of MR venography: 2D time-of-flight (TOF), phase-contrast and MR venography with contrast medium. They all differ by the method of revealing flowing blood [6]. 2D TOF MR venography is the most simple of all its three kinds, sensitive to slow flow (which is typical for venous blood flow) and does not even require contrast medium. Though 2D TOF MR venography is less precise than MR venography with contrast medium, it is widely used in pre-operative evaluation of the SSS in patients with PSM [6–9]. However, the efficacy of this method is limited in low blood flow velocities that occur in substantial invasion and/or compression of the SSS by PSM [9]. As a result there is a dilemma — the more precise method we use the more it is invasive. Search of the altogether noninvasive and precise method leads us to sonography, but transcranial sonography is impossible for investigation of the SSS because of deep location and an inappropriate angle [10,11]. The method of intraoperative color-coded duplex sonography (CCDS) is known but information about it is scant and ambiguous, so we decided to study this method ourselves.

**Objective**

Determine potentials of CCDS for intraoperative evaluation of SSS patency in PSM and compare them with MR venography.

**Methods**

30 patients (20–67 years, mean age 55) with PSM were studied. Intraoperative CCDS (anterior third of the SSS — 7 patients; middle third — 20; posterior third — 3) was conducted with linear ultrasound probe 112L—RS (Vivid E, GE, USA) placed on the superior wall of the SSS after craniotomy. Intraoperative CCDS findings were compared with 2D time-of-flight MR venography (Signa Infinity, GE, USA).

There are some important points that we want to mention. First, the superior wall of the SSS should be free from bone. This can be achieved by bilateral craniotomy or unilateral craniotomy with additional resection of overlying bone with rongeurs. Our attempts to evaluate the SSS through its lateral wall were not successful. Second, hemostatic materials (Surgicel, collagen sponge) should not be used during sonography of the SSS as they hinder propagation of the ultrasound and therefore the quality of the image will be significantly worse. Small bleedings from the SSS were stopped by cauterization, while more significant ones were terminated by applying hemostatic material and then removing it before CCDS. The probe was placed on the superior wall of the SSS and CCDS was performed in two planes — frontal (transverse) and sagittal. In B-mode in the frontal plane the presence, location and degree of intraluminal invasion was evaluated. We used color flow Doppler in the frontal plane only to confirm the presence of flow. In the sagittal plane we used color-mode only, because B-mode is not informative. We do not recommend to evaluate invasion of the SSS only in the sagittal plane since artifact from the lateral wall of the SSS may occur. Thus, in the sagittal plane we determined Doppler Spectrum, direction of flow and its quantitative characteristics — TAMEAN (time-averaged mean velocity) and TAMAX (time-averaged maximum velocity).

We performed CCDS of the SSS and the adjacent venous structures (lacunae, bridging veins) within the craniotomy window both before and after removal of PSM. It is important to apply on the SSS as little pressure as possible (up to the appearance of artifact due to air between the SSS and the probe) since the SSS is very easy to compress and blood flow velocity significantly increases.

**Results**

MR venography showed absence of blood flow in the SSS in 16 out of 30 cases, which was confirmed by intraoperative CCDS in 9 cases only (complete invasion in 7 cases, thrombosis in 2 cases). In the remaining 7 cases the SSS was patent (blood flow velocity in the SSS was 5–29 cm/s and flow index reached 40 ml/min). In 14 out of 30 patients MR venography revealed flow in the SSS and it was confirmed by CCDS. Thus, false-positive results of complete occlusion of the SSS according to MR venography in our series were obtained in 7 out of 16 cases (for the anterior third of the SSS — 5 out of 6; middle third — 1 out of 8; posterior third — 1 out of 2). CCDS additionally evaluated the degree of SSS invasion/compression with its hemodynamics and differentiated invasion from compression of the SSS. Examples of different types of SSS invasion by PSM obtained intraoperatively by CCDS, where consistency (Fig. 1) and discrepancy (Fig. S1 — to view the figure, please visit the online supplementary file in ScienceDirect) between CCDS and preoperative MR venography are presented.

B-mode in the frontal (transverse) plane allows verification of compression, partial invasion and complete invasion of the SSS. It helps to determine the limits of completely invaded SSS in order to resect it en bloc (Fig. S2 — to view the figure, please visit the online supplementary file in ScienceDirect). This data allows to classify PSM according to degree of SSS invasion according to classification by Sindou and Alvernia [3], which is the mostly widely used (Fig. 2). Nowadays CCDS seems to be the only method that allows doing this noninvasively (without excision of the SSS). However, this classification is not ideal and could not encompass all the cases we had like in Fig. S3 (to view the figure, please visit the online supplementary file in ScienceDirect), where all three walls of the SSS are invaded but the latter is still patent. B-mode can also visualize intrasinal structures like septum (Fig. S4 — to view the figure, please visit the online supplementary file in ScienceDirect). It should be noted that arachnoid granulations may mimic invasion of the SSS angle.

CCDS may also be used to visualize venous lacunae, bridging veins (Fig. S5 — to view the figure, please visit the online supplementary file in ScienceDirect) and inferior sagittal sinus (Fig. S6 — to view the figure, please visit the online supplementary file in ScienceDirect), which can be of significant help during operation. Inferior sagittal sinus usually becomes seen when the SSS is totally invaded and serves as collateral venous channel. Therefore visualization of the inferior sagittal sinus in order to preserve it may be important when PSM is large and encompasses the sinus.
Discussion

Intraoperative sonography was first described by the American neurosurgeon B.W. Brawley in the Journal of Neurosurgery in 1969 [12]. There was a case with a 43-year-old female patient with PSM, in whom X-ray angiography (at that time it was the only method of preoperative evaluation of SSS patency) gave uncertain result and intraoperatively the SSS was evaluated with Doppler sonography revealing its patency. The PSM was therefore subtotally resected with SSS preserved.

It is obvious that since that time medical sonography has become much more sophisticated. Nowadays transcranial Doppler is considered to be the best noninvasive method
of quantitative evaluation of intracranial vessels. However, it is impossible to use it in adults for evaluation of the SSS. When the temporal window is used the angle of insonation is more than 60° and thus inappropriate [10]. It is possible to detect the posterior third of the SSS through the occipital window, but the detection rate is not more than 55% and even 38% for patients older than 60 years. In this case the flow velocity is 6—10 cm/s [11].

It is little known about the blood flow in the SSS. Aside from almost useless transcranial Doppler, there is phase-contrast MR venography, which allows quantitative evaluation of the SSS hemodynamics in patients with PSM. This method revealed that mean blood flow velocity in the SSS is 10—15 cm/s [13]. This method is rather approximate since it is operator dependent and based on several assumptions. There are no more methods of quantitative evaluation of blood flow velocity in the SSS in patients without cerebral pathology.

2D TOF MR venography due to its noninvasiveness (no irradiation, no contrast material) and simplicity and sensitivity to slow flow is the first-line method of preoperative evaluation of the SSS patency at our Institute and in many other clinics. However, this method has limitations, for example, artifactual signal loss resulting from in-plane vascular flow. To overcome this artifact, it is desirable to orient the acquisition plane perpendicular to the long axis of the vessel being imaged [9]. As a standard, frontal acquisition plane is used for SSS evaluation, therefore signal loss may occur in anterior and posterior parts of the SSS as these segments gradually become coplanar with the imaging plane. That is why in our study the rate of false-positive results of complete occlusion of the SSS according to 2D TOF MR venography is very high (83%) in anterior third of the SSS, and relatively low in its middle third (13%). According to the general opinion, anterior third of the SSS is not functionally significant and may be resected even if patent, 83% of false-positive results of complete occlusion do not discredit 2D TOF MR venography, but indicate that the method is useless for anterior third of the SSS. We would like to mention, that due to limited time of intraoperative study we did not use power Doppler, which is more sensitive to slow flow than color flow Doppler and could give even more accurate information about SSS patency.

CCDS is not invasive but requires removal of bone overlying the SSS which is not adequate in some cases like in small PSM. CCDS consumes little time (3—10 min) and is safe since neither one of our 30 patients had infectious or any other related complications.

Conclusion

Thus, intraoperative CCDS is safe and allows evaluation of SSS patency as well as venous lacunae, bridging veins and inferior sagittal sinus, classification according to degree of SSS invasion, and being more precise than MR venography it can be used to determine surgical strategy. The most rate of false-positive results of complete occlusion according to our study was observed in the anterior third of the SSS.

Appendix A. Supplementary data


References