European Journal of Radiology 121 (2019) 108722

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Research article

Evaluation of giant arachnoid granulations with high-resolution 3D-volumetric MR sequences at 3T

Hayri Ogul*, Fadime Guven, Emine Izgi, Mecit Kantarci

Department of Radiology, Medical Faculty, Ataturk University, Erzurum, Turkey

ARTICLE INFO

Keywords:
Magnetic resonance imaging
Brain
Cerebrospinal fluid

ABSTRACT

Purpose: To evaluate the contribution to the diagnosis of the giant arachnoid granulations (AGs) of three-dimensional (3D) high-resolution magnetic resonance (MR) imaging sequences such as T2-weighted sampling perfection with application optimized contrasts using different flip-angle evolution (SPACE) and post-contrast T1-weighted magnetization prepared rapid gradient echo (MPRAGE).

Materials and Methods: Patients with 45 giant AGs were included in this retrospective study. All the patients were performed 3D T2-weighted SPACE and contrast enhanced MR venography sequences, as well as conventional cerebral MR imaging sequences. Post-contrast T1 weighted MPRAGE sequence were performed on 38/45 patients. All cerebral MR examinations were reviewed by the 2 neuroradiologists. Each GA was evaluated carefully to assess location and mean diameter.

Results: The most common location for giant AGs was at both transverse sinuses. Fluid signal feature within the giant AGs was not isointense to CSF on SE T1 and FLAIR MR imaging in 32 of 45 giant AGs. There were cerebral herniation into AG in 10 (22.2 %) of 45 giant AGs. 33 (73.3 %) of 45 giant AGs had central vein finding into AG in contrast enhanced MR venography. Signal void phenomenon into AG in 3D T2-weighted SPACE MR sequence was identified in 28 (62.2 %) of 45 giant AGs.

Conclusions: Fluid within giant AGs had no completely CSF-like signal intensity on conventional and 3D high-resolution MR imaging sequences. Majority of CSF-incongruent fluid within giant AGs on conventional sequences is mostly due to intra-AG CSF flow.

1. Introduction

Arachnoid granulations (AGs) are pseudopodial anatomic structures that protrude into the lumen of the venous sinuses [1]. These structures are filled with cerebrospinal fluid (CSF) and surrounded by pia-arachnoid membranes [1,2]. Intra-sinusoidal AGs are typically a few millimeters in diameter. Occasionally, they can be larger than 1 cm in the case of giant AGs [3,4]. Giant AGs may obliterate the venous sinuses or expand the internal table of the calvarium [3–5]. In this instance, they can mimic dural sinus thrombosis or neoplastic processes such as cavernous hemangioma and meningioma [6–8]. It is important to distinguish giant AGs from other serious venous sinus pathologies to avoid unnecessary surgical or radiological invasive procedures.

Classically, AGs are demonstrated as structures that have the same density or signal intensity as CSF and protrude into the lumen of the venous sinuses in routine computed tomography (CT) and magnetic resonance (MR) imaging [2,3]. However, recent studies with MR imaging examinations revealed that giant AGs are complex structures that have content non-identical to CSF [4]. Through advances in MR imaging technology, the complex content of giant AGs can now be successfully demonstrated with three-dimensional (3D) high-resolution volumetric MR images. In this context, multi-planar reformation (MPR) visualization after single-plane acquisition is the most important feature of 3D MR imaging sequences. These sequences are a potential new method for evaluating the detailed anatomy and pathology [9].

3D-sampling perfection with the application of optimized contrasts using different flip-angle evolution (SPACE) sequences (Siemens) is a recently developed sequence that is fast, efficacious, and equivalent to the VISTA (GE) or Cube (Philips) sequences [9,10]. Because the 3D T2-weighted SPACE technique is a flow-sensitive sequence, it has been successfully used in the diagnosis of patients with CSF leaks and hydrocephalus [9,11]. Recent studies have demonstrated MR images of the content of giant AGs protruding into the venous sinus or calvarium [3–5]. However, to the best of our knowledge, there has been no descriptive study on 3D high-resolution MR imaging concerning the presence of CSF flow into giant AGs. The objective of this retrospective

* Corresponding author at: Kazım Karabekir Mah., Terminal Cad., Site Polat Apt. B Blok, Kat 1, No 2, Erzurum, Turkey.
E-mail address: hogul7@yahoo.com (H. Ogul).

https://doi.org/10.1016/j.ejrad.2019.108722
Received 5 July 2019; Received in revised form 17 August 2019; Accepted 20 October 2019

study was to analyze the 3D T2-weighted SPACE MR imaging features of patients with 45 giant AGs. We also aimed to determine the contribution to the diagnosis of the intra-arachnoid flow void phenomenon.

2. Materials and methods

2.1. Patients

In this retrospective study, we included all consecutive patients referred to our hospital for cerebral MR imaging between January 2017 and December 2018. All of these patients also had 3D high-resolution volumetric MR images [3D T2-SPACE sequence and 3D T1-magnetization prepared rapid gradient echo (MPRAGE)] in addition to conventional cerebral MR sequences. Approval for this study was obtained from our institutional review board. Written informed consent was not required for this retrospective review of medical records and imaging studies.

A list of all the cerebral MR images taken over a 2-year period was obtained from the database of our radiology unit at a single institution. We only selected those patients with arachnoid granulation in the report who had a complete imaging workup including 3D T2-SPACE and T1-MPRAGE MR images in addition to conventional cerebral MR sequences. All the reports were examined for MR imaging findings suggestive of giant AG. All cerebral MR examinations that were retrieved by this general search were reviewed by two neuroradiologists, one with 12 years of experience and the other with 10 years of experience. All of cases with giant AGs were evaluated by two radiologists (F.G. and H.O.) by using the following criteria: 1- size > 1 cm, 2- location within a dural venous sinus, and 3- exclusion of other pathology according to standard diagnostic criteria, including ovoid/round shape, lack of solid contrast enhancement, and absence of blooming on susceptibility weighted imaging (SWI) or gradient echo (GRE) sequences. Most of the patients who were retrieved had also clinic records of the headache and blurred vision. The exclusion criteria were dural venous sinus thrombosis, neoplasms, previous cranial surgery, and artefacts obscuring cerebral dural venous structures.

2.2. MR imaging technique

Cerebral MR imaging examinations were performed with a 3 T MR system (Magnetom Skyra; Siemens Healthcare, Erlangen, Germany) using a standard head coil. All imaging studies included conventional axial spin-echo (SE) T1, coronal and sagittal turbo spin-echo (TSE) T2, axial fluid-attenuated inversion recovery (FLAIR), pre-contrast 3-D T1 MPRAGE, post-gadolinium (0.1 mmol/kg) 3-D T1 acquisitions, and sagittal plane 3-D T2 SPACE sequences. In some patients, constructive interference in steady state (CISS), contrast-enhanced MR venography (CE-MRV), and susceptibility weighted imaging (SWI) acquisitions were also available. The routine cranial MR imaging protocols are summarized in Table 1.

2.3. Imaging analysis

All available cerebral MR images were reviewed on high-resolution monitors using a picture-archiving and communication system (Syngo Via console, software v. 2.0; Siemens Medical Solutions, Erlangen, Germany). Consensual analysis of all MR images was performed by two neuroradiologists. All patients with giant AG protruding into the dural venous sinus were included in this study. Each case was evaluated carefully to assess the location, mean diameter, and content of giant AGs. The origin and location of the brain herniation into the giant AG were recorded. Signal changes of giant AGs in conventional and 3D high-resolution MR sequences were noted. The presence or absence of the flow void phenomenon into giant AGs in 3-D T2 SPACE images was examined carefully for each patient. Images were evaluated according to whether vascular structures entered into the giant AGs using post-contrast 3-D T1-weighted MPRAGE or dynamic MR venography.

Table 2
Locations of giant AGs.

Location	Patient (%)
SSS	6 (13.3)
Straight sinus	5 (11.1)
Right TS	16 (35.6)
Left TS	14 (31.1)
Left SS	4 (8.9)
Total	45 (100)

SSS = superior sagittal sinus.
TS = transverse sinus.
SS = sigmoid sinus.

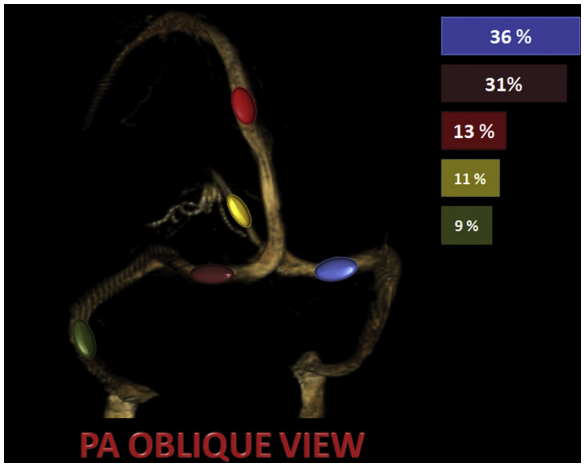

Fig. 1. Diagram of the venous sinuses showing frequency and location of the giant AGs.

2.4. Statistical analysis

Percentages were used for discrete data and median values were used for continuous data in descriptive statistics. The chi-squared and Mann–Whitney U tests were used to compare the differences between the groups for categorical and continuous data, respectively. The chi-squared test was also performed to determine the prevalence of giant AGs in male and female patients and their distribution in each age group. The statistical analyses were performed using SPSS software version 20 (SPSS for Windows; SPSS, Chicago, IL, USA). A p-value of ≤

Table 1
3-Tesla MR scanner MR imaging sequence parameters.

Sequence	TR/TE (ms)	Inversion time (ms)	Flip angle (degrees)	Slice thickness (mm)	FOV (mm)
SE T1	450/8	–	–	4	256 × 182
TSE T2	3100/90	–	–	4	256 × 182
FLAIR	10 000/120	2000	–	4	256 × 182
3-D T1 MPRAGE	15/8	300	15	1.25	256 × 256
3-D T2 SPACE	3200/400	–	Variable	1	256 × 256

Table 3
MR imaging features of giant AGs.

MR sequence	Brain herniation into giant AG	Venous structure into giant AG	CSF flow into giant AG	Septation in giant AG	Stromal structure within giant AG	Giant AG signal intensity according to CSF
SE T1	7	27	–	3	–	Isointense(15/45) Hyperintense(30/45)
FLAIR	8	29	–	3	–	Isointense(3/45) Hyperintense(42/45)
TSE T2	8	30	–	3	–	Isointense(14/45) Hypointense(31/45)
Contrast Enhanced MR Venography	–	33	–	–	–	–
Pre-conrast T1 MPRAGE	10	31	–	3	–	Isointense(19/45) Hyperintense(26/45)
Post-conrast T1 MPRAGE	10	33	–	3	–	–
3D T2 SPACE	10	33	28	3	–	Isointense(7/45) Mild hypointense(38/45)

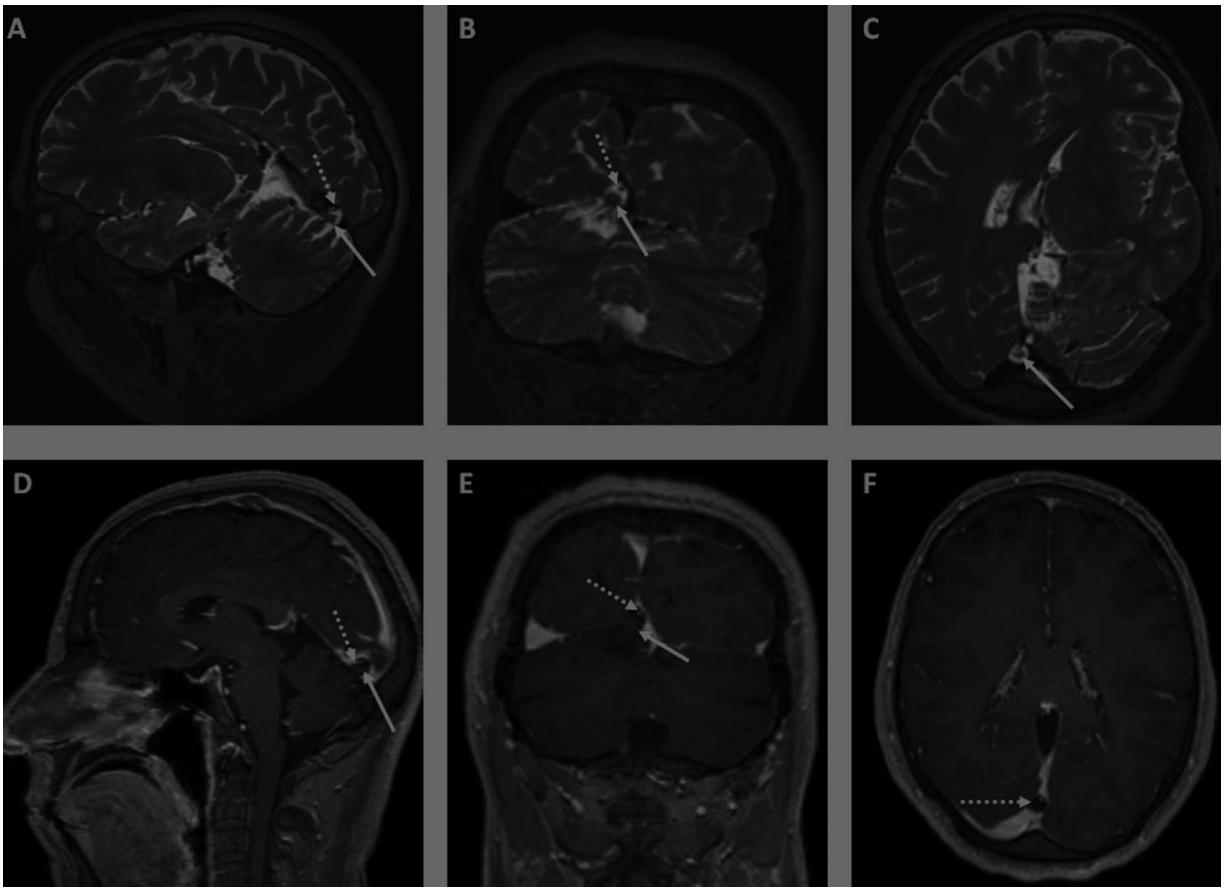

Fig. 2. 28-year-old man with headache. (**a-c**) Sagittal, coronal, and axial oblique 3D T2-weighted SPACE MR sequences show a giant AG in the right transverse sinus. There are cerebellar herniation (solid arrow) and vascular flow void (dashed arrow) within the giant AG. (**d-f**) Post-contrast sagittal, coronal, and axial 3D T1-weighted MPRAGE MR sequences reveal cerebellar herniation (solid arrow) and vascular structure (dashed arrow) within the giant AG.

0.05 was considered significant.

3. Results

The study included 45 patients [26 females (57.8%), 19 males (42.2%)] with a mean ± SD age of 28.3 ± 18.6 years (range 6–69 years) and 45 giant AGs. All 45 patients underwent conventional cerebral MR imaging and also had 3D T2 weighted SPACE and pre-contrast T1 weighted MPRAGE sequences. Post-contrast T1 weighted MPRAGE sequences were performed on 41 of the 45 patients. Since the patients were referred for diagnosis for venous sinus thrombosis, all of them had any of the contrast-enhanced dynamic MR venography or post-contrast T1 weighted MPRAGE sequences.

The most common location for giant AGs was both the left and right transverse sinuses [30 (66.7%) of 45 giant AGs]. The frequencies and locations of giant AGs are summarized in Table 2 and Fig. 1. There was no significant difference between male and female patients regarding the locations of the giant AGs ($p = 0.49$). No patients had multiple giant AGs. AGs greater than 1 cm in diameter were accepted as giant AGs. The mean lengths of the giant AGs along the long and short axes were 17.1 ± 7.1 mm (range 10–42 mm) and 8.9 ± 2.7 mm (range 5–19 mm), respectively. There was no significant difference between male and female patients regarding the dimensions of the giant AGs ($p = 0.22$ for the long axis and $p = 0.59$ for the short axis).

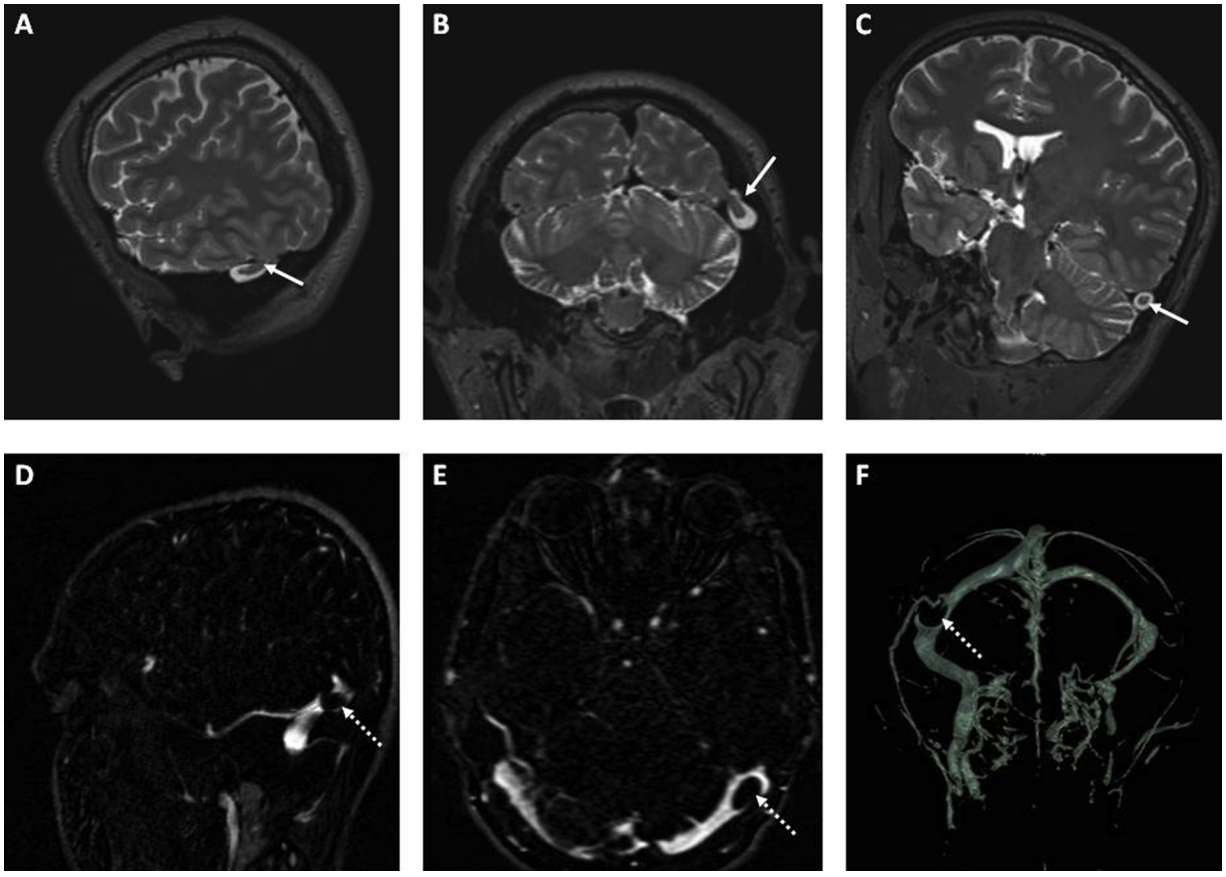

Fig. 3. 27-year-old woman with severe headache. (**a-c**) Sagittal, axial, and coronal oblique 3D T2-weighted SPACE MR sequences show a giant AG in the left transverse sinus. There is cerebral gyrus herniation (solid arrow) into the giant AG. (**d-f**) Sagittal, axial, and 3D reformat CE-MRV also reveal contrast filling defect within the AG.

Giant GAs were evaluated according to their characteristics, such as parenchymal herniation into giant AG, the CSF flow void phenomenon into the giant AG in 3D T2-weighted SPACE sequence, vascular structure within the giant AG in contrast enhanced dynamic MR venography or post-contrast T1-weighted MPRAGE sequence, signal features of the fluid within giant AG in conventional MR sequences, and intra-AG septations (Table 3). There were intra-arachnoid septations in only 3 of the 45 giant AGs. The fluid signal feature within the giant AGs in conventional T1, T2, and T2 FLAIR MR imaging sequences was not isointense to CSF in most patients. On 3D T2-SPACE sequences there was a higher rate of CSF-incongruent signal than on conventional MRI sequences, or something similar.

There was parenchymal herniation into 10 (22.2 %) of the 45 giant AGs (Figs. 2A-F and 3 A-F). There was no significant difference between genders regarding intra-arachnoid parenchymal herniation ($P = 0.72$). There were vessels within 33 (73.3 %) of the 45 giant AGs in contrast-enhanced dynamic MR venography or post-contrast T1-weighted MRAGE sequences (Fig. 4A-F). Intra-AG vein findings were demonstrated in 22 (84.6 %) of the 26 female patients by dynamic MR venography. This finding was significantly more common in females than males ($P = 0.04$).

We identified the signal void phenomenon in 28 (62.2 %) of the 45 giant AGs in the 3D T2-weighted SPACE MR sequence (Figs. 5A-F and 6 A-C). The intra-AG signal void phenomenon indicating CSF flow was significantly more frequent in females [20 (76.9 %) of 26 female patients] than males ($P = 0.01$).

4. Discussion

We have described a reliablediagnostic finding in giant AGs with 3D high-resolution MR sequences in 3 T MR. Because previous studies did not performed high-resolution MR imaging sequences (1-mm sections) for GAs, this finding has not been described clearly. Our results showed that the 3D T2-weighted SPACE sequence could reveal the intra-arachnoid signal void phenomenon as a finding of CSF flow into a giant AG.

The 3D T2-weighted SPACE sequence (Siemens Healthcare, Erlangen, Germany) is a relatively new TSE MR imaging technique introduced by Mugler et al. in 2000 [12]. The T2 SPACE technique with multiplanar reconstruction capability offers images with high spatial resolution. Because of its high motion sensitivity [13], the sequence has been successfully used in the demonstration of CSF flow dynamics [14]. For this purpose, recent studies have performed the T2 SPACE sequence for the detection of cerebellar tonsillar motion in Chiari I malformation, the demonstration of craniocervical pseudomeningocele in the neck, the assessment of third ventriculostomy patency, the evaluation of cervical spine MR imaging anatomy, the determination of the etiology of non-communicating hydrocephalus, and localization of spinal dural arteriovenous fistula [9–11,15–17]. However, to the best of our knowledge, no study has shown the presence of CSF flow into giant AGs with the 3D T2 SPACE technique.

Haroun et al. [18] examined the features of AGs in the dural sinuses using conventional cerebral MR imaging and contrast-enhanced 3D MR venography. They noted intermediate signal intensity in the MR images with reconstruction in one-third of patients with AGs. There were even very small AGs in their series. Therefore, they postulated that the intermediate signal intensity may be due to a partial volume effect. In another MR imaging study, Leach et al. [3] demonstrated the features of large AGs in the superior sagittal sinuses in 12 patients using conventional MR imaging and MR venography. They observed insufficient

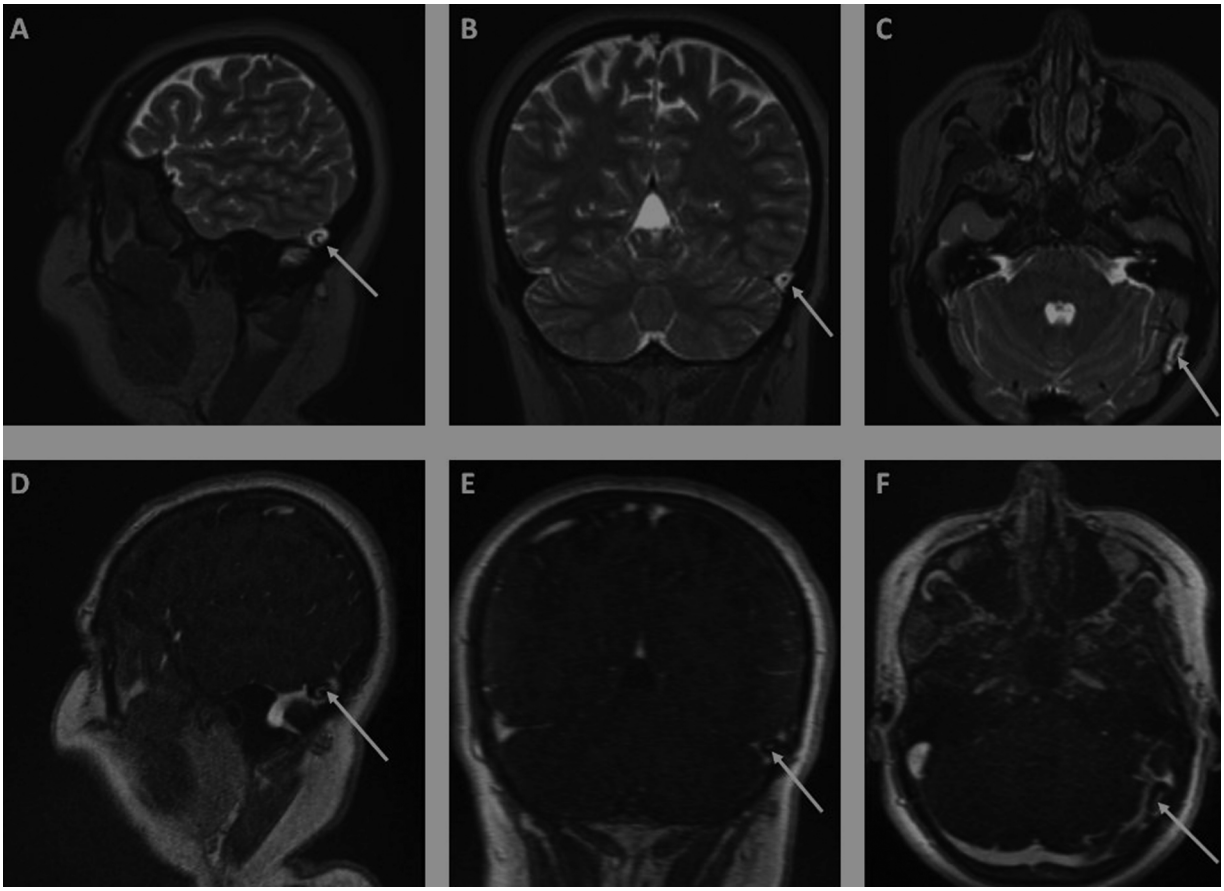

Fig. 4. 24-year-old woman with headache. (**a-c**) Sagittal, coronal, and axial 3D T2-weighted SPACE MR sequences show a vascular signal void (solid arrow) within the giant AG in the left transverse sinus. (**d-f**) Sagittal, coronal, and axial CE-MRV also reveal vascular structure (solid arrow) within the AG.

suppression of the content of AGs in most patients in FLAIR images. They also demonstrated that some AGs were not isointense to CSF in T1-weighted MR images. The absence of a CSF-like signal intensity in large AGs in FLAIR sequences may be due to the pulsation effect from the adjacent venous sinus and differing CSF flow motion characteristics within the AG. Alternatively, it may be due to slow flowing CSF in the AG as compared to adjacent dural sinus.

In a recent study, Trimble et al. [4] characterized the content of giant AGs with conventional MR imaging sequences in 17 patients. They demonstrated that intra-AG fluid did not parallel CSF in 8 out of 8 giant AGs with FLAIR imaging, in 13 of 19 giant AGs with T2-weighted imaging, and in 7 of 10 giant AGs with T1-weighted imaging. This represents the largest data set on this group of patients thus far. They listed the following possible causes for the CSF-incongruent signal intensity within giant AGs in MR images:

a Spin dephasing due to disordered flow
b The presence of stromal tissue in giant AGs
c The presence of non-communicating fluid within multi-loculated giant AGs

Unlike these two previous studies, our study had a large patient population. Moreover, in addition to the conventional cerebral MR imaging sequences, we also performed 3D high-resolution MR sequences in 3 T MR. Our conventional MR imaging findings about giant AGs were similar to the results of previous research. However, we did not observe any stromal tissue in giant AGs. There were multi-loculated giant AGs in only 3 cases. We explained below the possible causes of CSF-incongruent signal intensity within giant AGs in conventional MR images with the 3D T2 SPACE sequence. In our series, 38 of 45 giant AGs had lower signal intensity than CSF in the 3D T2-weighted SPACE sequence. We observed the intra-AG signal void phenomenon in 28 of these 38 patients and cerebral gyrus herniation into the giant AG in 10 of the 38 patients. We assert that the majority of CSF-incongruent signal intensities within giant AGs in conventional MR images are due to turbulent and jet CSF flow into the AG. The intra-AG signal void phenomenon in the 3D T2-weighted SPACE sequence may be help for the diagnosis of giant AGs. Moreover, in conjunction with other sequences e.g. SWI/ GRE the sequence may be performed to make sure it's not thrombus and so on.

The penetration of cortical or dural veins within giant AGs has commonly been described in previous studies [3,4,18,19]. Intrinsic veins within giant AGs were demonstrated as linear signal void areas in all conventional MR sequences. The presence of the vascular signal void can be better shown by 3D high-resolution MR sequences than conventional MR sequences, as in our series. However, contrast-enhanced high-resolution MR or CT images and digital subtraction angiography (DSA) are the best imaging modalities for this purpose. Compared with small AGs, there is a higher probability of the presence of internal veins within giant AGs [3,4]. Cortical veins may be present in the periphery or center of AGs. Haroun et al. [18] commonly found cortical veins in the center of large AGs. In our series, cortical veins were eccentrically located in patients with parenchymal herniation within AGs and centrally located in most of the remaining patients.

Battal et al. [20] performed an MR imaging study with a relatively large series in 2016 and reported a prevalence of 0.32% for brain herniation into AGs in the dural sinus or calvarium. In our study, we investigated only giant AGs within dural venous sinuses and found brain herniation into AGs in 22% (10/45) of our patients. Intra-AG brain herniations can occur secondary to increased intracranial

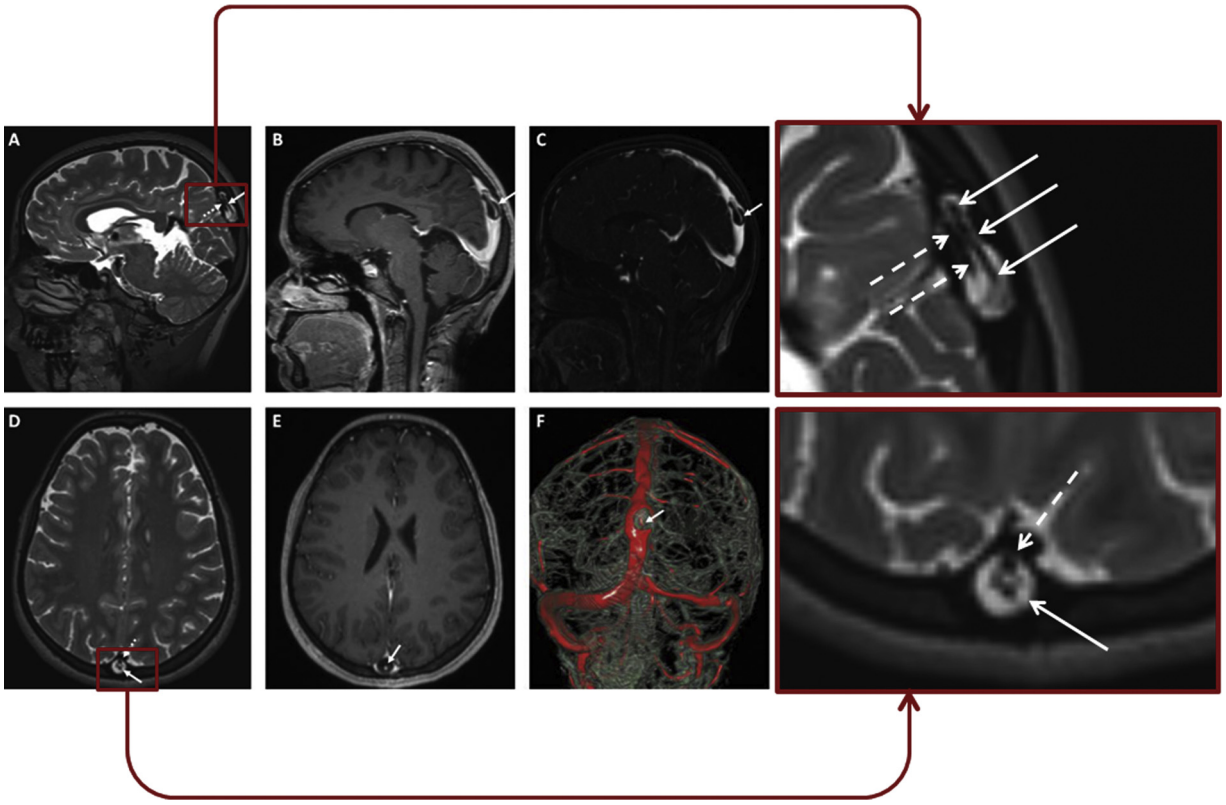

Fig. 5. 19-year-old woman with headache. (**a** and **d**) Sagittal and axial T2-weighted SPACE MR sequences show a giant AG in the superior sagittal sinus. There are two different signal void as CSF flow void (dashed arrow) and vascular flow void (solid arrow) within giant AG. (**b** and **e**) Post-contrast sagittal and axial T1-weighted MPRAGE MR sequences reveal venous structure (solid arrow) within giant AG. (**c** and **f**) Sagittal and 3D reformat CE-MRV also reveal intra-AG venous structure.

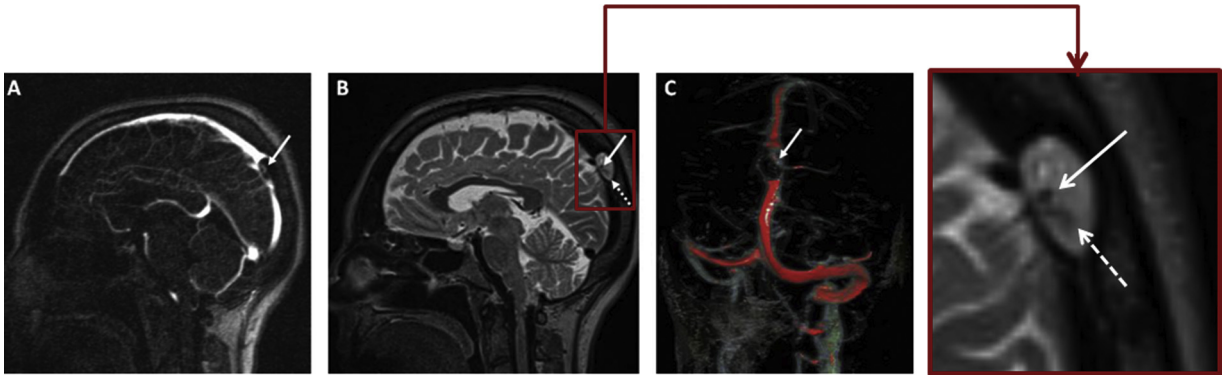

Fig. 6. 51-year-old woman with headache. (**a** and **c**) Sagittal and 3D reformat CE-MRV images show a venous structure (solid arrow) within the giant AG in the sigmoid sinus. (**b**) Sagittal 3D T2-weighted SPACE MR sequence reveals both venous structure (solid arrow) and CSF flow void (dashed arrow) within the giant AG in the sigmoid sinus.

pressure or spontaneously [20,21]. Liebo et al. studied the neuroimaging features of intra-AG brain herniations [21]. They performed conventional MR imaging sequences to demonstrate the content of AGs. They reported that the signal intensity of the adjacent fluid within AGs with parenchymal herniation was parallel to that of CSF.

In our study, we evaluated all the details of the content of giant AGs using high-resolution volumetric MR sequences. We observed the signal void phenomenon secondarily to CSF flow within giant AGs without parenchymal herniation in 3D T2 SPACE sequence, but we did not observe the phenomenon within giant AGs with parenchymal herniation. Therefore, intra-AG fluid in patients with parenchymal herniation was clear and was isointense to CSF. Furthermore, some patients had only cerebral parenchyma without adjacent fluid within the giant AG. We postulate that because parenchymal herniation probably obstructs the dural hiatus, there is no signal void phenomenon in giant AGs with parenchymal herniation in the 3D T2 SPACE sequence.

There were several potential limitations in our study. The main limitation was the retrospective design. Thus, clinical features of patients were obtained from MR imaging indications and patient records. Additionally, the lack of histopathologic correlations is one obvious weakness of the study. Despite these limitations, our results are still valuable because all of our patients had high-resolution volumetric T1 and T2-weighted MR sequences. Moreover, it is not possible to prove the presence of CSF jet flow into a giant AG with other techniques. CT or MR cisternography after injecting contrast material intrathecally can demonstrate intra-AG contrast leaks. However, these techniques cannot evaluate the flow dynamics into AGs.

5. Conclusion

The morphology and flow dynamics of CSF-containing spaces such as giant AGs are better demonstrated with the volumetric 3D T2-weighted SPACE technique than conventional MR imaging sequences. Our study demonstrated that this technique is valuable for the precise description of giant AGs. Our results also indicated that some of the AGs had incongruent signal but in some of them the CSF signal was isointense. We think that the probable cause of the CSF-incongruent signal within giant AGs in conventional sequences is mostly CSF flow. We also assert that the signal void phenomenon suggesting intra-AG CSF flow in 3D T2-weighted SPACE sequences can be used as strong supporting evidence for the diagnosis of giant AGs.

Ethical approval

"All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards."

Informed consent

"Informed consent was obtained from all individual participants included in the study."

Funding

None.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgment

None.

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