ORIGINAL RESEARCH

MR and MR Angiographic Appearance of Arachnoid Granulations in the Venous Sinuses

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ABSTRACT
Purpose: To study the imaging pattern, location, prevalence, and multiplicity of arachnoid granulations in cerebral venous sinuses. **Methods**: We retrospectively reviewed 100 contrast-enhanced Brain MR studies, investigating the venous sinuses for discrete filling defects. After reviewing the imaging findings, we tried relating with clinical symptoms. **Results**: MR images show these entities as largely hypointense as compared to cerebrospinal fluid in T1and hyperintense in T2 sequences, isointense on FLAIR, hypointense on DWI and seen as filling defect in BRAVO sequence. Septations were seen as linear variations of signal intensity within the granulations. Altered MR signal intensity was occasionally noted, when calcifications were present. The granulations appear as filling defects at MR angiography. Due to elliptical shape on oblique MR angiographic images, they could be mistaken for thrombus. No clinical significance could be given to the existence of any of these arachnoid granulations. They occur in 0.3 to 1 of 100 adults in the population. **Conclusion**: On thin cross sectional imaging, arachnoid granulations in the venous sinuses are observed incidentally and are usually of no clinical significance. However, differentiation with intra sinus thrombus and tumor should be made. Index terms: Anatomy, Arachnoid Granulations, Dural venous sinuses, Thrombosis.
Keywords: MR, Arachnoid, Granulations, Venous Sinuses

INTRODUCTION
Extensions of the arachnoid membrane into the dural venous sinuses, are called as Arachnoid Granulations (AG) and they drain the cerebrospinal fluid (CSF) from the subarachnoid space into the venous system [1]. They are part of normal anatomy, and can be frequently demonstrated on imaging. AG contain adjacent blood vessels, which invaginate into the granulations [2]. Most common location found for arachnoid granulations include superior sagittal sinus and transverse sinus. Commonly adjacent superficial draining cortical vein is seen abutting [3]. Their incidence is seen to increase with age. Incidentally giant arachnoid granulation (>10mm) are mistaken for other pathologies, as they appear as sharp osteolyticlucency on X-ray and CT , or venous sinus filling defect [4]. They should be differentiated from recanalised venous sinus thrombi, deep venous thrombosis, isolated cortical venous thrombosis, idiopathic intracranial hypertension , hemorrhage[5]. Less common conditions include intrasinus septa, fenestrations asymmetric superior sagittal sinus bifurcation [6] and duplications [7].

MATERIALS AND METHODS
We selected 100 patients randomly who underwent contrast enchanced MRI at our institution, and evaluated them for appearance, frequency and distribution of arachnoid granulations. MR examination was done on 3T machine.
Focal areas with well defined margins showing signal void projecting into sinus lumen were recorded at superior sagittal sinus, middle to lateral transverse sinus, transverse sinus-sigmoid sinus junction, sigmoid sinuses and torcularHerophili. They are most commonly seen at the junction between the middle and lateral thirds of the transverse sinuses near the entry sites of the superficial veins [8]. Aforementioned differentials and artefacts due to sluggish or turbulent flow were differentiated by; visibility on all pulse and imaging

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planes sequences with maintained definite intra sinus position and circumferential surrounding of contrast.

RESULTS

AG appeared as hypointense relative to the brain on T1WI, hyperintense relative to the brain on T2WI, showing complete suppression on fluid-attenuated inversion recovery sequences(FLAIR), associated lower signal, most likely representing collagenous connective tissue maintained venous flow around the lesion was observed. Incidentally hypoplasic sinus or veins were documented. Focal, well-defined areas of nonflow signal protruding into the sinus lumen, producing defects in the contrast column, were identified in 13 (13%) of the 100 randomly selected contrast- enhanced MR examinations. A total of 14 intrasinus foci were identified. Twelve were located in the middle to lateral transverse sinus(12%), one was located in the transverse sinus–sigmoid sinus junction(1%), and one was located in the superior sagittal sinus(1%). Of the 13 defects seen in the transverse sinus, 11 (85%) were directly adjacent to vein entry sites. The foci exhibited isointense to hypointense signal relative to brain parenchyma on T1-weighted images (13 were hypointense, one was isointense) (Fig 3B and E), and hyperintense signal on T2-weighted images. The foci were more variable in signal on proton density–weighted images. Three were hypointense, six were hyperintense, two were isointense, and three were hyperintense peripherally, with a hypointense center. No contrast enhancement was identified in any case. The focal defects were seen best on the T2-weighted images, but could be confirmed on all pulse sequences and imaging planes. The mean size of the foci was 5.2 6 mm base dimension (range, 2 to 10 mm) and 5.3 6intraluminal dimension (range, 3 to 10 mm). The mean linear distance from midline (transverse sinus foci) was 40 6 mm (range, 23 to 55 mm). The defects appeared as focal impressions into the sinus lumen, with surrounding flow signal on MR venograms. No difference in sex distribution was noted between the patients with filling defects and those without. As a group, patients in whom filling defects were identified were older than patients who had no filling defects. The mean age of the group with defects was 46 years (range, 10 months to 86 years), whereas the mean age of the group with no defects was 40 years (range, 1 month to 92 years) (P 5 .005, Student's two-tailed t test). No protuberances were identified within the straight sinus, sigmoid sinuses, or distal superior sagittal sinus. Most of the protuberances within the transverse sinus projected from the anterior inferior aspect of the sinus directly into the sinus lumen. As on imaging, the protuberances were often closely associated with cortical venous entrance sites into the sinus. On HPE evaluation, the protuberant masses were composed of a mixture of variably dense fibrous connective tissue containing numerous fibroblasts, scattered arachnoid cell nests, and an irregular network of small vessels and delicate endothelium-lined spaces, most prominent in the basal regions. Trabeculated channels with attenuated endothelial lining were often seen in the core of the granulations. The protuberances projected through the portion of the dura comprising the sinus walls and into the lumen, where the structure was covered by an endothelial cell layer continuous with the sinus lining. Proximity to venous entrance sites was again noted, as seen on gross examination. Smaller granulations exhibited a characteristic architecture with an irregular, loose fibrous connective tissue core and a more peripheral, dense, hyalinized connective tissue layer. Most small granulations exhibited a simple, smooth surface contour. The larger granulations were more complex and contained an admixture of both dense and loose connective tissue within the core. The gross and microscopic appearance of these structures compare closely with previous descriptions of arachnoid granulations (13, 14).

DISCUSSION

Tufts of arachnoid villi invaginating into the dural sinuses are called Arachnoid granulations, through which cerebrospinal fluid (CSF) enters the venous system [1]. Occasional hypertrophy of arachnoid villi in response to increasing CSF volume and pressure, forms macroscopic lobulated AG. We have shown that focal filling defects are present in the dural sinuses in 24% of randomly selected contrast-enhanced CT examinations. These defects are well circumscribed, hypodense to isodense relative to brain parenchyma, and predominantly located in the lateral transverse sinuses. Comparison with MR findings showed the defects to be hypointense on T1- weighted images, variable in signal on proton density–weighted images, and hyperintense on T2-weighted images. Randomly selected MR examinations of the brain revealed focal signal alterations in the dural sinuses in 13% of cases, matching the defect distribution seen on CT scans It is possible that some of the filling defects seen in our study could have been caused by processes other than arachnoid granulations. Intrasinus septa, venous sinus duplications (7), partial volume averaging of adjacent brain or dura, or normal variations in sinus contrast density on CT scans (with delayed scanning) (8) could all produce relative defects or signal alterations within the dural sinuses. The focal distribution, well-defined morphology, and circumferential contrast around the defects seen in this study makes these possibilities unlikely. All the evaluated contrast-enhanced CT scans in this study were obtained immediately after bolus contrast administration and during drip contrast infusion. Inflow of unopacified blood can produce

apparent intrasinus filling defects on angiograms (22); however, these defects would not be expected on contrast-enhanced CT or MR examinations. Slow or turbulent flow can cause unusual signal within the dural sinuses on MR images (4); however, these signals are rarely focal and would not be present on contrastenhanced CT scans in the same location, as they were in many of our cases. Arachnoid granulations are normally occurring focal protuberances of the leptomeninges into the dural venous sinus lumen (13, 16). Arachnoid granulations and arachnoid villi differ primarily in size and complexity of structure. Arachnoid granulations are visible to the unaided eye, whereas arachnoid villi are microscopic structures (13, 14, 16, 17). Besides being larger, granulations exhibit more extensive collagenous deposition and hyalinization (14, 18). There have been few dedicated anatomic studies of arachnoid granulations within the transverse sinuses. Most anatomic studies have evaluated arachnoid granulations within the superior sagittal sinus. Browder et al (18, 24) described 33 smooth-surfaced nodules projecting into the dural sinuses within 32 of 380 cadavers. In their studies, the nodules ranged in size from 3 to 24 mm in maximum dimension; 26 of the 33 were identified within the left transverse sinus. As in our study, the nodules were commonly associated with venous entry sites into the sinus, particularly the vein of Labbe´ . Two of the 33 nodules were found in the right transverse sinus and two large nodules were seen within the distal superior sagittal sinus. This distribution coincides with our observations on imaging studies and anatomic dissections, with the exception of the more striking left-sided distribution in their study. Our study revealed a higher prevalence of arachnoid granulations, most likely caused by the inclusion of smaller protuberances (mean, 2 mm). A few reports have described the imaging appearance of arachnoid granulations. Grossman and Potts (10) described their appearance on angiograms and plain radiographs. Impressions in the skull from arachnoid granulations were identified in 46% of 400 randomly selected skull films, increasing in prevalence with age. The majority were found in the anterior parietal region, close to the midline. Angiographically, arachnoid granulations appeared as filling defects within the lacunae laterales (and in one case within the lumen of the superior sagittal sinus), usually closely related to cortical veins. No arachnoid granulation relating to the lumen of the transverse sinus was seen at angiographyThe appearance of arachnoid granulations on contrast-enhanced CT scans was described by Tokiguchi et al (9), who described a 2 3 3-mm hypodense filling defect within the left transverse sinus, similar in appearance to the granulations seen in our study. This was subsequently proved histologically to represent an arachnoid granulation with an appearance that was

identical to that in our cases. Cure´ et al, in a review of normal dural sinus anatomy (1), described two cases of large filling defects within the superior sagittal sinus and transverse sinus on CT and MR studies. These were hypodense on contrast-enhanced CT scans and hypointense to isointense on T1- weighted MR images. No description of their appearance on T2-weighted MR images or information on contrast enhancement was provided. These also appeared as focal filling defects on MR venograms and standard angiograms. Mamourian and Towfighi (11) described a large arachnoid granulation within the superior sagittal sinus on MR images, MR venograms, and CT scans. The mass was focal, isointense to hypointense on T1-weighted images, hyperintense on T2-weighted images, and showed minimal heterogeneous contrast enhancement. No cases of contrast enhancement were found in our series, even in the largest granulations. The contrast enhancement seen in their study may be related to adjacent intraluminal enhancement or easier identification owing to larger granulation size. They performed a limited autopsy study of 10 cases and found three granulations in two cases. Two were present in the transverse sinuses and one in the superior sagittal sinus. The prevalence of arachnoid granulations in our anatomic study was much greater; again most likely because we identified much smaller granulations (mean size, 2 mm). Roche and Warner, in a recent imaging study (12), described filling defects identical to those seen in our study and estimated a frequency of occurrence of between 0.3 and 1 in 100 adult patients. Their CT scans were obtained with 3-mm sections at 5-mm intervals through the posterior fossa, instead of the 3-mm or 5-mm contiguous scans used in our study, which probably underestimated the true frequency. They reviewed 200 T1-weighted MR studies obtained with 2-mm adjacent sections through the transverse sinuses and found two granulations. No contrast material was used. As documented in our study, arachnoid granulations are optimally identified on T2-weighted images or on contrast-enhanced T1-weighted images. Arachnoid granulations within the distal superior sagittal sinus, transverse sinuses, and sigmoid sinuses are common, occurring in 66% of cases in our careful anatomic study. The underestimation of the true prevalence on imaging examinations is most likely due to partial volume averaging effects relating to section thickness and section-selection parameters. Despite the common finding of arachnoid granulations within the superior sagittal sinus in previous anatomic studies (15–17), the vast majority of the filling defects seen on CT or MR examinations in our study and in the literature are present within the transverse sinuses. One reason for this is that most arachnoid granulations in the anterior superior sagittal sinus actually protrude into the lacunae laterales and not into the sinus lumen (10, 14–16).

Arachnoid granulations, producing calvarial impressions, occur between 13 and 15 mm lateral to midline in this region (10). These would not present as focal intrasinus filling defects, and would not be confused with thrombosis on imaging studies. The axial imaging plane of the CT examinations in this study affords poor visibility of the proximal superior sagittal sinus, and some defects in this region could have been missed. MR examinations, however, allowed imaging in three planes, and no proximal superior sagittal sinus intraluminal foci were identified. The CT density of granulations in this study, and in the literature, varied from being like cerebrospinal fluid to being isodense with brain. Despite the potential for psammomatous calcification in arachnoid granulations (12, 14), no calcifications were seen on the CT examinations or anatomic specimens in our study. MR signal intensity is more variable; however, almost all granulations appeared hyperintense on long repetition- time/echo-time sequences. The variable CT density and MR signal intensity most likely represents the variable amounts of connective tissue and cerebrospinal fluid within the granulation as well as partial volume effects from the adjacent contrast-filled dural sinus.   Arachnoid granulations can be easily distinguished from thrombosis. Thrombosis usually involves an entire segment of sinus or multiple sinuses, and can extend into cortical veins (2– 5). Arachnoid granulations produce focal, welldefined defects or signal foci. The density and signal of arachnoid granulations are also different from those seen with thrombosis. Usually, with acute thrombosis, hyperdensity is seen within the sinus lumen on CT scans, and variable signal intensity (usually T1 hyperintensity) is seen on MR images (depending on the age of the thrombus and the pulse sequence) (2, 4). Arachnoid granulations were never hyperdense or T1-hyperintense in our cases. Abnormal flow is usually seen distal to a thrombosed segment of sinus. Normal sinus contrast opacification on CT scans, flow void on MR images, and intrasinus signal on MR venograms are seen both proximally and distally to arachnoid granulations. The characteristic distribution of arachnoid granulations (lateral transverse sinus associated with venous entrance sites) also helps to identify and differentiate these entities from thrombosis. No secondary signs of thrombosis or venous hypertension (collateral veins, dural enhancement, brain swelling) were noted, even with the largest filling defects. We have not encountered a case ourselves, or in the literature, in which arachnoid granulations (within the dural sinus) have been solely responsible for a patient's symptoms. Roche and Warner (12) reviewed the clinical history of 32 patients with arachnoid granulations within the transverse sinuses and found no convincing evidence of related symptoms. It stands to reason, however, that large granulations could produce relative luminal compromise and lead to a pressure gradient or disturbed flow. This could lead, in turn, to venous hypertension (if the superior sagittal sinus or dominant transverse sinus were involved) or to thrombosis (if flow were sufficiently slow or in hypercoagulable states). In summary, focal filling defects within the dural venous sinuses, consistent with arachnoid granulations, are seen on 24% of contrast-enhanced CT scans and on 13% of contrastenhanced MR examinations of the brain. They are typically located within the transverse sinuses, adjacent to venous entrance sites. They can be differentiated from thrombosis and intrasinus tumor by their characteristic location, well-defined morphology, density, and signal characteristics.

CONCLUSION

In the majority of cases, the identification of AGs can be facilitated by their characteristic appearances: rounded or oval shaped, well-defined outlines and homogenous density and signal intensity. The presence of an adjacent cortical vein can be considered as an additional supportive element.

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