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Original Article *Özgün Araştırma*

THE UTILITY OF 3T HIGH-RESOLUTION MRI IN THE DETECTION OF BRAIN HERNIATIONS INTO THE DURAL VENOUS SINUSES OR CALVARIUM

Dural Venöz Sinüsler ya da Kalvarum İçerisine Beyin Herniasyonlarının Tespitinde Yüksek Rezolüsyonlu 3T MRG Yararı

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ABSTRACT

Objective: Brain parenchyma herniation into the dural venous sinus or calvarium is considered a rare anatomical variation. The aim of this study is to evaluate the frequency, localization, and clinical and radiological findings of brain herniation into dural venous sinus and/or calvarium with high resolution 3 Tesla magnetic resonance imaging in a large group of patients.

Material and Methods: A total of 6825 cranial magnetic resonance images containing pre-contrast and post-contrast 3D T1-weighted sequences as well as conventional sequences were retrospectively evaluated. The presence of brain herniation into dural sinuses or calvarium, location and size of herniation, signal intensity of the adjacent brain parenchyma, presence of arachnoid granulation adjacent to the herniation were noted.

Results: Brain herniation into DVS/ calvarium was determined in 50 patients (0.73%). The detected brain herniations were most frequently associated with the temporal lobe parenchyma (n=37, 68.5%), and 91% (n=49) extended into the transverse sinuses. All brain herniations were detected both by 3D T1-weighted and 3D T2-weighted sequences; however, 29 (53.7%) of the 54 herniations were not detected by conventional sequences.

Conclusion: High resolution MRI sequences are superior to conventional sequences in detecting brain herniation into DVS/ calvarium. Patients with brain herniation into DVS/ calvarium may present with heterogeneous symptomatology, and the relationship between brain herniation and symptoms is controversial.

***Keywords**: meningeal herniation, arachnoid, sinus thrombosis, magnetic resonance imaging*

ÖZ

Amaç: Dural venöz sinüsler ya da kalvaryum içerisine beyin parankimi herniasyonu, nadir bir anatomik varyasyon olarak kabul edilmektedir. Bu çalışmanın amacı, geniş bir hasta rubunda, yüksek çözünürlüklü 3 Tesla Manyetik rezonans görüntüleme ile, dural venöz sinüs içerisine ve/veya kalvaryuma beyin parankimi herniasyonunun sıklığı, lokalizasyonu, klinik ve radyolojik bulgularını değerlendirmektir.

Gereç ve Yöntemler: Kontrast öncesi ve kontrast sonrası 3D T1 ağırlıklı sekansları ve aynı zamanda konvansiyonel sekansları içeren toplam 6825 beyin Manyetik rezonans görüntüleme incelemesi retrospektif olarak değerlendirildi. Dural sinüs içerisine beyin herniasyonu varlığı, herniasyonun yerleşimi ve boyutu, komşu beyin parankiminin sinyal intensitesi, herniasyon komşuluğunda araknoid granülasyon varlığı kaydedildi.

Bulgular: 50 hastada (%0.73) dural venöz sinus/kalvaryum içerisine beyin herniasyonu saptandı. Saptanan beyin herniasyonları en sık temporal lob parankimi ile ilişkili (n=37, %68,5) ve %91'i (n=49) transvers sinüs içerisine uzanım gösteriyordu. Tüm beyin herniasyonları hem 3D T1 ağırlıklı hem de 3D T2 ağırlıklı sekanslarda saptandı; buna karşın 54 herniasyonun 29'unda (%53.7) konvansiyonel sekanslarla herniasyon saptanmadı.

Sonuç: Dural venöz sinüs/kalvarum içerisine beyin parankimi herniasyonunu saptamada, yüksek çözünürlüklü MRG sekansları konvansiyonel sekanslara göre üstündür. Dural venöz sinüs/kalvarum içerisine beyin parankimi herniasyonunu hastalarda heterojen semptomatoloji ile ortaya çıkabilir ve semptomlar ile beyin parankim herniasyonu arasındaki ilişki tartışmalıdır.

***Anahtar Kelimeler**: meningeal herniasyon, araknoid, sinus trombozu, manyetik rezonans görüntüleme*

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INTRODUCTION

Brain parenchyma herniation into the dural venous sinus (DVS) or calvarium is a rare anatomical variation. Although the exact prevalence of this variation is not well known, according to two studies in adults and children, it was reported as 0.32% and 0.65%, respectively (1,2). The underlying precise etiologic mechanism has not been fully elucidated. However, some hypotheses have been proposed such as intracranial pressure, aging and erosive arachnoid granulations (3). Moreover, clinical symptoms of the patients may differ from each other (4-6). Although the most common symptom is headache in many patients, brain parenchyma herniation into the DVS or calvarium is often detected incidentally in magnetic resonance imaging (MRI) performed in the evaluation of other pathologies (1).

Nowadays, with the improvement of imaging techniques, high resolution and thin slice images can be obtained. Especially, 3D T1-weighted sequences provide higher spatial resolution and can be useful in the detection of different pathologies with more anatomic detail (2,7). Thus, both the herniated brain parenchyma and giant arachnoid granulations (AG) in different localizations can be distinguished by using thin slice images (8,9). The aim of this study was to evaluate the frequency, localization, and clinical and radiological findings of brain herniation into DVS with high resolution 3T MRI in a large group of patients.

MATERIALS AND METHODS

Ethics Approval: This retrospective study was approved by our institutional ethics committee (İstanbul University Cerrahpasa, Cerrahpasa Medical Faculty Ethics Committe of Clinical Research, date: 06.11.2020, issue number:146359) and carried out according to the requirements of the Declaration of Helsinki. Informed consent of each patient in the study group was obtained.

Patient Selection: The MR images of all patients (n=6946) who underwent cranial MRI between February 2019 and April 2020 were examined in this retrospective study. The cranial MR examinations consisted of pre-contrast and post-contrast 3D T1W sequences as well as conventional sequences. Exclusion criteria were MRI examinations with motion and other artefacts that were not suitable for evaluation (n=97), and patients with dural sinus thrombosis and history of prior dural sinus surgery (n=24). Figure 1 shows the flowchart of the study population.

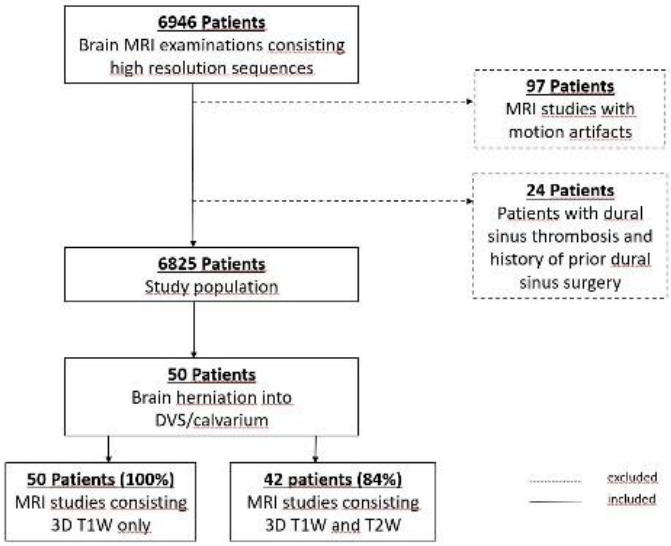

Figure 1: Flowchart of the study

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MRI Technique: MRI examinations were performed on 3T MR system (Ingenia; Philips Healthcare, Best, Netherlands) using a 16 or 32-channel head coil. The standard imaging protocol included conventional sequences (localizer, sagittal TSE T2, coronal TSE T2, axial T1 SE, axial fluid attenuation inversion recovery (FLAIR)) and thin slice 3D T1 TFE (FOV 24-26 cm, slice thickness=1 mm, echo time/repetition time=26/6.2ms, flip angle=25°, matrix=256x256) sequences. In 5904 (84.9%) cases, 3DT2 Brain VIEW was also available.

Intravenous gadobutrol (Gadovist; Bayer Schering Pharma, Berlin, Germany) with a dose of 0.1 mmol / kg was used for the post-contrast T1 TFE sequence.

MRI Evaluation and Clinical Findings: MRI images were independently reviewed by two neuroradiologists with 11 and 24 years of experience in neuroimaging (BK, OK); respectively, using a PACS workstation (Carestream PACS, version 1.4; Kodak, Rochester, NY). Conventional T1 weighted, T2 weighted sequences and high-resolution 3D T1W sequences (pre and post-contrast) were evaluated for each patient. If available, 3D T2 Brain VIEW was also evaluated. Multiplanar reconstruction (MPR) technique was used to obtain certain different plane images (coronal/sagittal). All 3D T1 and T2 images were evaluated separately in axial, sagittal and coronal planes for dural sinus herniation by two neuroradiologists independently. Any discrepancies were resolved by consensus.

Herniation location into the DVS and/or calvarium [1], herniated brain parenchyma site [2], size of the hernia sac [3], size and signal intensity of the brain parenchyma projecting to it [4], presence of arachnoid granulation (AG) adjacent to the herniation [5] and presence and number of AG/giant AG within other DVS [6] were recorded. All MRI examinations were also evaluated for mass effect and MRI features of idiopathic intracranial hypertension (IIH) (enlarged arachnoid outpouchings, distension of the perioptic subarachnoid space, vertical optic nerve tortuosity etc.) which are associated with elevated intracranial pressure (10,11).

Symptoms and / or clinical indications were obtained from the hospital database in patients with brain herniation into DVS.

Statistical Analysis: Statistical analyses were performed using SPSS version 21.0 software (SPSS Inc., Chicago IL, USA). Percentages (%) were used for categorical data and median values were used for continuous data in descriptive statistics. Pearson $\chi 2$ test or Fischer exact test were performed for categorical variables. Cohen's kappa coefficient was calculated to measure inter-observer agreement for the detection of brain herniation into DVS in high resolution sequences (3D T1W and 3D T2W).

RESULTS

6825 brain MRI studies were evaluated retrospectively and brain herniation into DVS/ calvarium (BHVSC) was determined in 50 patients (0.73%). Of these 50 patients, the mean age was 43.7±17.8 (range 1-76 years) and 6% (n=3) of the patients were in the pediatric age group (<18 years). While 70% (n=35) of the patients were female, the remaining 15 were male. The prevalence of brain herniation into dural sinus was higher in females and it is found to be statistically significant ($p<0.05$).

The most common clinical manifestation was headache (n=21, 42%) and 4 of 50 patients (8%) were asymptomatic. 26% of patients had brain lesions associated with mass effect and 10% of patients had features of IIH in MRI. Detailed clinical and imaging findings in the patients BHVSC are depicted in Table 1.

54 herniations were observed in 50 patients. The locations of the herniations were left transvers sinus (n=33), right transvers sinus (n=16), torcular herophili (torcula) (n=3) and, occipital bone (n=2) (Figure 2). The most common location for herniated brain parenchyma was temporal lobe (n=37, 68.5%). The signal intensity and structure of herniated parenchyma was the same as

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the normal brain parenchyma except in 2 cases, who had headache in clinical presentation (Figure 3). Mean maximum diameter of the herniated sac and brain parenchyma were7.04 ±2.12 mm (range 4-13.5 mm) and 5.03 ±1.66 mm (range 2-9 mm), respectively. The features of brain herniations are shown in Table 2. In all BHVSC patients, brain herniation was accompanied by AG at the same localization. Moreover, 44 (88%) of 50 patients had AG in other locations and 5 of them were giant AGs.

All patients in the study group with BHSVC had conventional MRI sequences and 3D T1 FFE whereas 42 of 50 patients (84%) had 3D T2 Brain VIEW sequence. All brain herniations were detected both by 3D T1W and 3D T2W sequences. However, 29 (53.7%) of 54 herniations, which were observed by 3D T1 FFE sequence, were not detected by conventional sequences. There was a strong correlation in the detection of brain herniation in both 3D T1 FFE and 3D T2 BrainVIEW sequences (Cohen k: 0.86; CI, 0.79-0.95 and 0.84; CI, 0.67-1.01 respectively).

Table 1: Clinical and magnetic resonance imaging findings of the patients with brain herniation into dural venous sinuses/ calvarium

Clinical Manifestations	**n %**
Headache	21 (42%)
Seizure	6 (12%)
Altered consciousness/Syncope	6 (12%)
Focal Neurologic Deficit	5 (10%)
Vertigo	3 (6%)
Lhermitte sign	2 (4%)
Visual loss	1 (2%)
Hearing loss	1 (2%)
Ataxia	1 (2%)
Asymptomatic	4 (8%)
Concomitant MRI findings	
Mass lesion	13 (26%)
Diffuse astrocytic/ oligodendroglial tumours	3 (6%)
	3 (6%)
Meningioma	5 (10%)
Brain metastases	2 (4%)
Arachnoid cyst	
IIH features	5 (10%)
Empty or partially empty sella	5 (10%)
Tortuous optic nerves	2 (4%)
Dilated optic nerve sheaths	2 (4%)
Hydrocephalus	2 (4%)

MRI: magnetic resonance imaging, IIH: Idiopathic intracranial hypertension

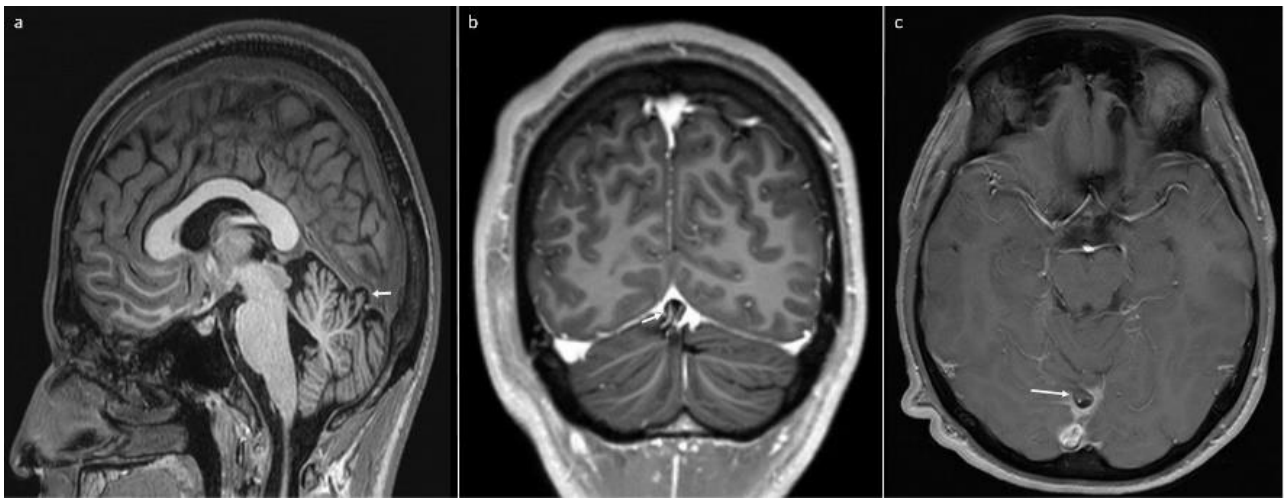

Figure 2: 24-year-old-man with seizure. a. Sagittal 3D T1 FFE image shows left cerebellar parenchymal herniation into the torcula (arrow). b, c. Contrast-enhanced 3D T1-weighted GRE coronal and contrast-enhanced T1-weighted FFE axial MR images also depict cerebellar herniation into the torcula (*FFE: Fast field echo, GRE: Gradient echo, MR: Magnetic resonance)*

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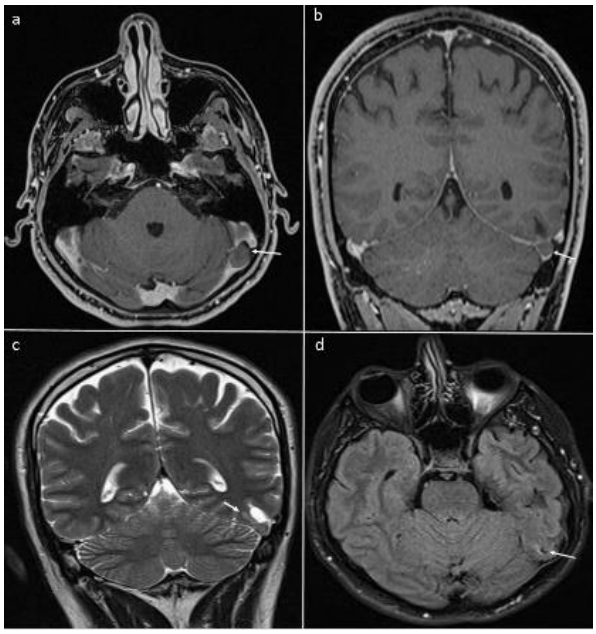

Figure 3: 38-year-old man with headache. a, b. Contrast-enhanced 3D T1-weighted GRE axial and coronal MR images show herniation of left temporal lobe parenchyma into the left TS. c, d. There are high signal intensity and mild atrophy within the herniated brain parenchyma on coronal T2W and axial FLAIR MR images. *(GRE: Gradient echo, MR: Magnetic resonance, FLAIR: Fluid-attenuated inversion recovery)*

Table 2: Features of brain herniations into DVS/calvarium

Feature	Total (n=54)
Locations of brain herniations	
Left TS	33 (61.1%)
Right TS	16 (29.6%)
Torcula	3 (5.6%)
Occipital Bone	2 (3.2%)
Brain parenchyma within herniations	
Temporal lobe	37 (68.5%)
Cerebellar hemisphere	11 (20.4%)
Occipital lobe	6 (11.1%)
Maximum diameter of the herniated sac*	7.04 ±2.12 mm
Maximum diameter of the brain parenchyma*	5.03 ±1.66 mm

DVS: dural venous sinus, TS: transvers sinus, Torcula: Torcular herophili, *Mean±standard deviation

DISCUSSION

In this study, it was aimed to evaluate the detection frequency, localization, clinical and radiological findings of brain herniation with high resolution 3T MRI in a large patient group. Brain herniations into the dural sinuses has been known to be a rare condition; however, with the increasing use of 3D MR imaging methods, the frequency of detection has been increasing recently. In our study, it was shown that BHVSC is rare but more common than previously reported (1,2). In a study conducted by Battal et.al with a similar number of patients, the frequency of brain herniation was found less than half of that in present study (1). Sade et al. reported a prevalence of 0.65%, but the study group included only pediatric patients (2). Moreover, our study confirms that BHVSC is significantly more common in females and it shows gender predilection as in some previous studies (2,3).

BHVSC is usually detected in the posteroinferior parts of the brain parenchyma and the cerebellum. In previous studies and most of the case series, the most common BHVSC locations were transverse sinuses (TS) and the occipital bone, while the herniated brain parenchyma was reported as the temporal and occipital lobe or cerebellar hemisphere, similar to our study (1,9,12-14). The frequency of these locations is thought to be possibly due to the previously hypothesized close association of BHVSC with arachnoid granulations (3,15).

Factors such as cerebrospinal fluid (CSF) pulsations and dural defect, which cause the growth of arachnoid granulations and their invagination into the dura, allow 'herniation' of the brain parenchyma from the same dural opening with a similar mechanism (3,16). In early imaging studies, most of the detected AG and giant arachnoid granulations (GAGs) were located in TS and its surroundings. Furthermore, in several studies, nonvascular gray matter isointensities were identified within some arachnoid granulations which may

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represent stromal collagenous tissue, hypertrophic arachnoid mesangial cell proliferation, or invaginated brain tissue (16-18). Therefore, it can be argued that pre-existing AG is the precursor to the development of BHSVSC, and the definition of brain herniation into arachnoid granulation (BHAG) is more reasonable in describing this finding (2,9,15). This study also supports this aspect and all BHVSCs are accompanied by AG and in 88% of the patients, AGs were detected among other venous sinuses without herniation.

One of the important points investigated regarding BHVSC (or BHAG) is whether it causes neurological symptoms. In most of the studies conducted to date, the most common symptom is headache (1,2,9,15). Other common clinical associations are with symptoms such as vertigo, seizures and syncope (2,4-6,13). Although various findings were found with BHAG in most studies, in their study, Liebo et al, observed no symptoms in most of the BHAG cases (15). In our study, the symptomatology is similar to that of the literature in terms of headache and other neurological findings. In addition, 4 patients (8%) were asymptomatic. In conclusion, BHVSC is an imaging finding presenting with heterogeneous symptomatology, and the relationship between brain herniation and symptoms is controversial. In addition, the fact that it can be found in asymptomatic cases supports the opinion that this finding is possibly incidental (1,15).

The observed radiologic or pathologic evidence for an association between BHAG and intracranial hypertension (IH) highlights the possible clinical significance of this imaging finding (2,3,15,19). Liebo et al. found clinical / radiological findings or associated conditions (mass lesions, meningitis) secondary to the increase in intracranial pressure (ICP) in 63% of BHAG cases (15). Also, Malekzadehlashkariani et. al. observed IIH findings in 4 of 38 patients and Sade et.al. observed in 3 of 15 patients, in their studies with BHAG cases (2,3). In our study, 26% (n=13) of patients had intracranial mass, 10% (n=5) had IIH findings, so 36% of the patients in total had increased ICP findings. In addition, hydrocephalus was observed in 2 patients. For the relationship between BHAG and IH, it is thought that herniation into the venous sinus may cause an increase in ICP by preventing venous flow, especially in patients with IIH (pseudotumor cerebri) (3). Another hypothesis is that herniation into the DVS develops as a result of a compensatory mechanism secondary to increased intracranial pressure, as in GAG growth and development (20). However, in the published literature, the cause-effect relationship has only been tested with follow-up studies in very few cases (3,15). Therefore, future prospective and systematic studies with large population are needed to test both the effect of intracranial hypertension (especially IIH) on the development and growth of AG and BHAG, as well as possible intra-DVS venous flow obstruction that may be caused by these findings.

High resolution MRI sequences are superior to conventional sequences in detecting BHVSC and demonstrating the structural features of herniated parenchyma. BHVS can be easily distinguished from thrombus or giant arachnoid granulations with thin-section 3D MRI images (7,9). In our study, all BHVSCs were detected with high resolution T1W and T2W sequences. However, only 2 patients had signal changes in the herniated brain parenchyma.

Study Limitations

Our study has a number of limitations. First of all, this study has the limitations of all retrospective studies. Secondly, the patient group evaluated is relatively small. In addition, although some clinical findings associated with brain herniations were described, clinical-radiological correlation was not evaluated. Finally, only 86.5% of patients have high resolution 3D T2W images.

This study shows that brain herniations into DVS may be more common than previously reported and that there is gender preference in these cases. Patients with this radiological finding may or may not have different

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neurological symptoms or ICP as an association. More than one BHAG can be detected in a patient and some localizations are typical for it. Thin section high-resolution MRI images are advantageous in recognizing this finding, which is generally considered incidental. Prospective studies including baseline and follow-up MRI examinations in the future may allow clear determination of the etiopathological relationship with IIH.

Conflict of Interest: The authors have no conflicts of interest to declare.

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Researchers' Contribution Rate Statement: Concept-Design: BK, AKK, SA, OK, BG; Supervision - SA, OK; Resources: OB, GMA, AKK, BG; Materials - OB, GMA, BG; Data Collection and/or Processing - AKK, GMA, OB, BG; Analysis and/or Interpretation: BK, SA, GMA, OB; Literature Search: AKK, BG; Writing Manuscript: BK, AKK, OK; Critical Review: SA, OK, BG.

Ethics Committe Aproval: Cerrahpasa Medical Faculty Ethics Committe of Clinical Research, date: 06.11.2020, issue number: 06/11/2020-14659

REFERENCES

1. Battal B, Hamcan S, Akgun V, Sari S, Oz O, Tasar M et al. Brain herniations into the dural venous sinus or calvarium: MRI findings, possible causes and clinical significance. Eur Radiol. 2016;26(6):1723-31.
2. Sade R, Ogul H, Polat G, Pirimoglu B, Kantarcı M. Brain herniation into the transverse sinuses' arachnoid granulations in the pediatric population investigated with 3 T MRI. Acta Neurol Belg. 2019;119(2):225–31.
3. Malekzadehlashkariani S, Wanke I, Rüfenacht DA, San Millán D. Brain herniations into arachnoid granulations: about 68 cases in 38 patients and review of the literature. Neuroradiology. 2016;58(5):443–57.
4. Çoban G, Yıldırım E, Horasanlı B, Çifçi BE, Ağıldere M. Unusual cause of dizziness: occult temporal lobe encephalocele into transverse sinus. Clin Neurol Neurosurg. 2013;115(9):1911-3.
5. Karatag O, Cosar M, Kizildag B, Sen HM. Dural sinus filling defect: intrasigmoid encephalocele. BMJ Case Rep. 2013;5;2013:bcr2013201616.
6. Kakisaka Y, Sato S, Takayanagi M, Nakasato N. Epilepsy case with focal cerebral herniation into the sigmoid sinus. Neurol Sci. 2016;37(3):487–8.
7. Battal B, Castillo M. Brain herniations into the dural venous sinuses or calvarium: MRI of a recently recognized entity. Neuroradiol J. 2014;27(1):55–62.
8. Ogul H, Guven F, Izgi E, Kantarci M. Evaluation of giant arachnoid granulations with high-resolution 3D-volumetric MR sequences at 3T. Eur J Radiol. 2019;121:108722.
9. Gozgec E, Ogul H, Izgi E, Kantarci M. Tissue damage in herniated brain parenchyma into giant arachnoid granulations: demonstration with high resolution MRI. Acta Radiol. 2021;62(6):799-806
10. Suzuki H, Takanashi J, Kobayashi K, Nagasawa K, Tashima K, Kohno Y. MR Imaging of idiopathic intracranial hypertension. Am J Neuroradiol. 2001;22(1):196-9.
11. Leach JL, Fortuna RB, Jones B V, Gaskill-Shipley MF. Imaging of cerebral venous thrombosis: current techniques, spectrum of findings, and diagnostic pitfalls. RadioGraphics 2006;26(suppl_1):S19-41.
12. Chan WC, Lai V, Wong YC, Poon WL. Focal brain herniation into giant arachnoid granulation: A rare occurrence. Eur J Radiol Extra. 2011;78(2):e111-3.

KÜ Tıp Fak Derg 2022;24(2):254-261
Doi: 10.24938/kutfd.1019408

13. Asadi H, Morokoff A, Gaillard F. Occult temporal lobe encephalocoele into the transverse sinus. J Clin Neurosci 2015;1;22(7):1202-4.
14. Kocyigit A, Herek D, Balci YI. Focal herniation of cerebral parenchyma into transverse sinus. J Neuroradiol 2015;42(2):126-7.
15. Liebo GB, Lane JJI, Van Gompel JJ, Eckel LJ, Schwartz KM, Lehman VT. Brain herniation into arachnoid granulations: clinical and neuroimaging features. J Neuroimaging. 2016;26(6):592-8.
16. Leach JL, Jones B V, Tomsick TA, Stewart CA, Balko MG. Normal appearance of arachnoid granulations on contrast-enhanced CT and MR of the brain: differentiation from dural sinus disease. Am J Neuroradiol. 1996;17(8):1523-32.
17. Trimble CR, Harnsberger HR, Castillo M, Brant-Zawadzki M, Osborn AG. "Giant" arachnoid granulations just like CSF?: NOT!! Am J Neuroradiol. 2010; 31(9):1724-8.
18. Liang L, Korogi Y, Sugahara T, Ikushima I, Shigematsu Y, Takahashi M et al. Normal structures in the intracranial dural sinuses: delineation with 3D contrast-enhanced magnetization prepared rapid acquisition gradient-echo imaging sequence. Am J Neuroradiol. 2002;1;23(10):1739–46.
19. Wolbach SB. Multiple Hernias of the Cerebrum and Cerebellum, due to intracranial Pressure. J Med Res 1908;19(1):153-74.
20. Watane GV, Patel B, Brown D, Taheri MR. The Significance of Arachnoid Granulation in Patients With Idiopathic Intracranial Hypertension. J Comput Assist Tomogr. 2018;42(2):282-5.