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Comparative evaluation of dural venous sinuses and cerebral veins using contrast-enhanced spoiled gradient recalled echo and time-of-flight magnetic resonance venography

Dural venöz sinüsler ve serebral venlerin kontrastlı spoiled gradient recalled echo ve time-of-flight manyetik rezonans venografiler ile karşılaştırmalı değerlendirilmesi

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Abstract

Introduction: In the present study, dural venous sinuses and cerebral veins were examined using contrast-enhanced spoiled gradient recalled echo (3D SPGR MRV) and time-of-flight magnetic resonance venography (2D TOF MRV). These methods were compared in terms of detectability of venous structures and their diameters.

Methods: A total of 110 patients (66 female and 44 male) who had contrast-enhanced 3D SPGR MRV and 2D TOF MRV examinations using a 1.5 T MRI machine in May 2008-June 2011 period were included in the present study. Diameters of dural venous sinuses and veins were measured at three different planes at a position 1cm distal to the site they drained into, and average values were used. Both MRV methods were compared to reveal whether the diameters calculated were different in age groups and between genders.

Results: Superior sagittal sinus (SSS), bilateral transverse sinuses (TS), right sigmoid sinus, Galen vein and bilateral internal cerebral veins (ICV) all could be determined using 3D SPGR MRV. Not all dural venous sinuses and veins (excluded right sigmoid sinus) could be visualized in all patients on 2D TOF MRV. There were significant differences between the two examinations for SSS and inferior sagittal sinus, bilateral TS and sigmoid sinuses, straight sinus, bilateral Labbe and ICV and Galen vein diameters ($p<0.05$) Diameters of dural venous sinuses and cortical veins were generally measured larger by 3D SPGR MRV compared to 2D TOF MRV.

Discussion and Conclusion: In conclusion, differences could be observed between the two MRV examinations for detectability and diameters of intracranial venous structures. Evaluation of intracranial venous structures should not be carried out using only 2D TOF MRV.

Keywords: Cerebral veins; contrast-enhanced angiography; dural venous sinuses; magnetic resonance venography; time-of-flight angiography.

Özet

Amaç: Bu çalışmada dural venöz sinüsler ve serebral venler kontrastlı spoiled gradient recalled echo (3B SPGR MRV) ve time-of-flight manyetik rezonans venografi (2B TOF MRV) ile incelenerek tetkikler arasında venöz yapıların saptanabilirliği ve çapları açısından farklılık olup olmadığı değerlendirildi.

Gereç ve Yöntem: Çalışmaya, Mayıs 2008–Haziran 2011 tarihleri arasında 1.5 T MRI cihazı ile kontrastlı 3B SPGR MRV ve 2B TOF MRV tetkiki yapılan 110 (66 female, 44 male) hasta dahil edildi. Dural venöz sinüsler ve venlerin çapları drene oldukları bölgeden 1 cm distalde üç farklı planda ölçülerek ortalama çapları alındı. Her iki MRV tetkiki arasında çap farklılığı ile yaş ve cinsiyete göre değişkenlik olup olmadığı incelendi.

Bulgular: Süperior sagittal sinüsler (SSS), bilateral transvers sinüsler (TS), sağ sigmoid sinüs, Galen veni ve bilateral internal serebral venler (İSV)'in hepsi 3B SPGR MRV'de saptanabildi. 2B TOF MRV ile sağ sigmoid sinüs haricindeki dural venöz sinüs ve venlerin hepsi hastaların tümünde vizüalize edilemedi. SSS ve inferior sagittal sinüsler, bilateral TS ve sigmoid sinüsler, straight sinüsler, bilateral Labbe ve İSV ile Galen venlerinin çaplarında, iki tetkik arasında anlamlı farklılık saptandı ($p<0,05$). Dural venöz sinüs ve kortikal venlerin çapları çoğunlukla 3B SPGR MRV'de 2B TOF MRV'ye göre daha geniş bulundu.

Sonuç: Sonuç olarak her iki MRV tetkiki ile yapılan incelemelerde intrakraniyal venöz yapıların saptanabilirliğinde ve çaplarında farklılık görülebilmektedir. Bu nedenle intrakraniyal venöz yapıların değerlendirilmesinde sadece 2B TOF MRV ile yetinilmemeli mümkünse 3B SPGR MRV gibi kontrastlı MRV sekansları uygulanmalıdır.

Anahtar Sözcükler: Serebral venler; kontrastlı anjiyografi; dural venöz sinüsler; manyetik rezonans venografi; time-of-flight anjiyografisi.

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Intracranial venous system consists of two major constituents: dural venous sinuses and cerebral veins.[1,2] In many intracranial pathologies, especially ones involving increased intracranial pressure, changes could arise in the sizes of venous structures.[1–4] Computed tomography venography (CTV) and magnetic resonance venography (MRV) are the methods of choice for the radiological visualization of intracranial venous system.[2,5,6] Cerebral venous system could be non-invasively visualized using MR angiography methods such as time-of-flight (TOF) and phase-contrast angiography without using contrast agent and taking radiation risk. In addition, it could also be examined using any of magnetic resonance venography (MRV) methods with contrast agent.[7,8] Since TOF MRV is prone to artifacts due to some technical reasons, it could give misleading findings in radiological evaluations.[8–10]

The aims of the present study were to compare three-dimensional Spoiled Gradient Recalled Echo (3D SPGR) MRV and two-dimensional (2D) TOF MRV techniques for detectability of dural venous sinuses and cerebral veins and for measuring their diameters.

Materials and Method

The present study included 110 patients (66 females and 44 males) who had contrast-enhanced 3D SPGR MRV and 2D TOF MRV examinations using a 1.5 T MRI machine due to neurological complaints in May 2008-June 2011 period. Only patients who did not have any pathologies that could suppress or expand the venous structures in these examinations were included. Five patients (arteriovenous malformation, mass, dural venous thrombosis, etc.) were excluded from the study.

The study was carried out retrospectively using images in PACS system of our department after acquiring the approval of the local ethics committee (B.30.2.GOÜ.0.01.00.00/67).

The MRI examinations were carried out on a 1.5 T machine (Signa excite HD; GE Healthcare, Milwaukee, WI, USA, 2005) using an 8-channel neuro-vascular coil. 3D SPGR sequence parameters were: TR/TE, 6.88/2.48 ms; matrix, 288–160; field of view, 22 cm; slice thickness, 4 mm; slice spacing, 2 mm. 3D SPGR MRV images were taken in axial, coronal and/or sagittal planes.

Contrast agent was administered into antecubital vein through an automatic injector (Nemoto Sonic Shot 50, Tokyo-Japan) with 22g cannula at a dose of 0.1 mmol/kg and 1.5 ml/s rate. As contrast agent, gadobenat dimeglumin (Multihance R-0.5 mol/L; Bracco, Milan, Italy) or gadodiamid (Omniscan 0.5 mol/L; GE Healthcare Bio-Sciences) was used.

2D TOF MRV parameters were: TR/TE, 23.7/8.8 ms; matrix, 256–224; field of view, 24 cm; slice thickness, 2 mm; slice spacing, 2 mm. 2D TOF MRV images were obtained in coronal plane. Inferior saturation band was used to eliminate signals from arterial structures.

Source images in 3D SPGR sequences, 2D TOF MRV and 3D images created by maximum intensity projection algorithms were obtained and evaluated using "Volume Viewer" software of "GE Advantage Windows Workstation 4.2".

MRV images of the patients were randomly selected and evaluated. MRV images (3D SPGR and 2D TOF MRV) of the same patient were evaluated consecutively. Diameters of superior sagittal sinus (SSS), transverse (TS) and straight sinuses (SS) were measured 1–2 cm distal to torcular Herophili

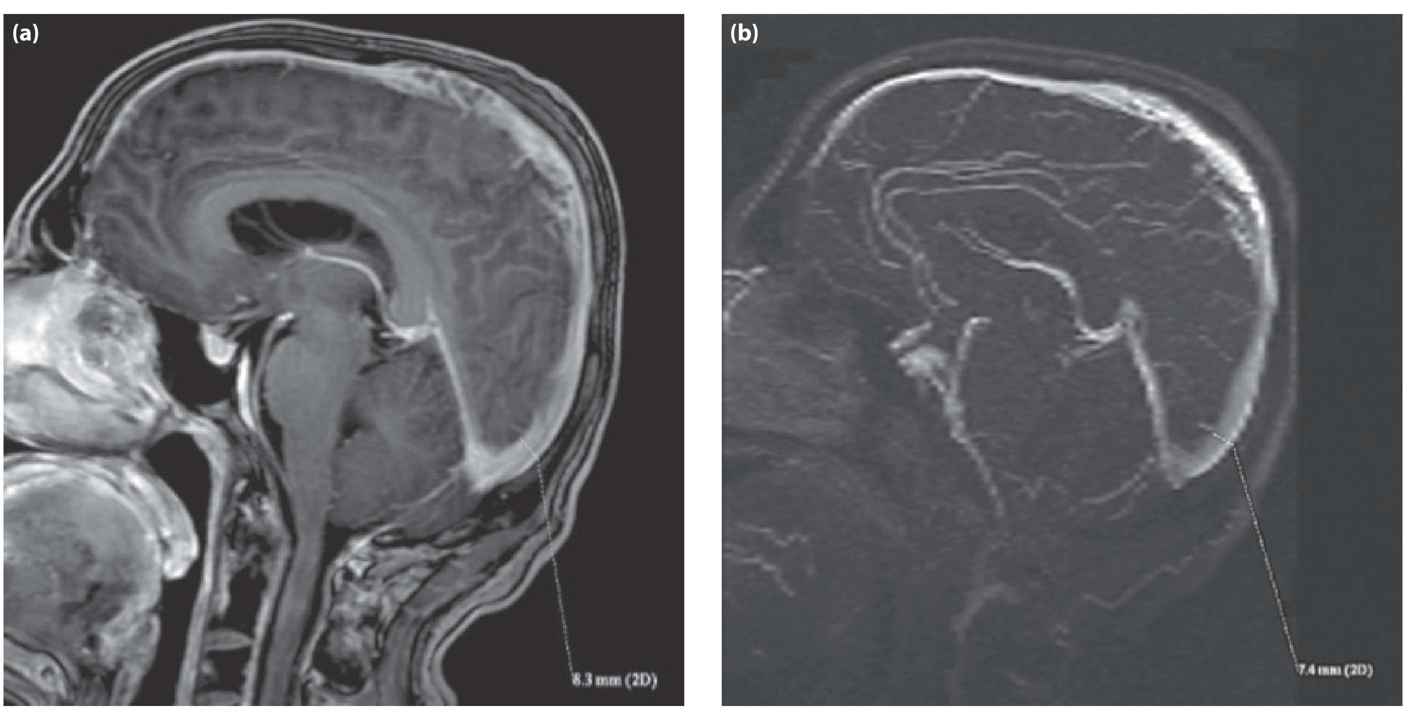

Figure 1. Measuring the diameter of superior sagittal sinus in sagittal plane in the same patient. **(a)** 3D SPGR MRV image. **(b)** 2D TOF MRV image.

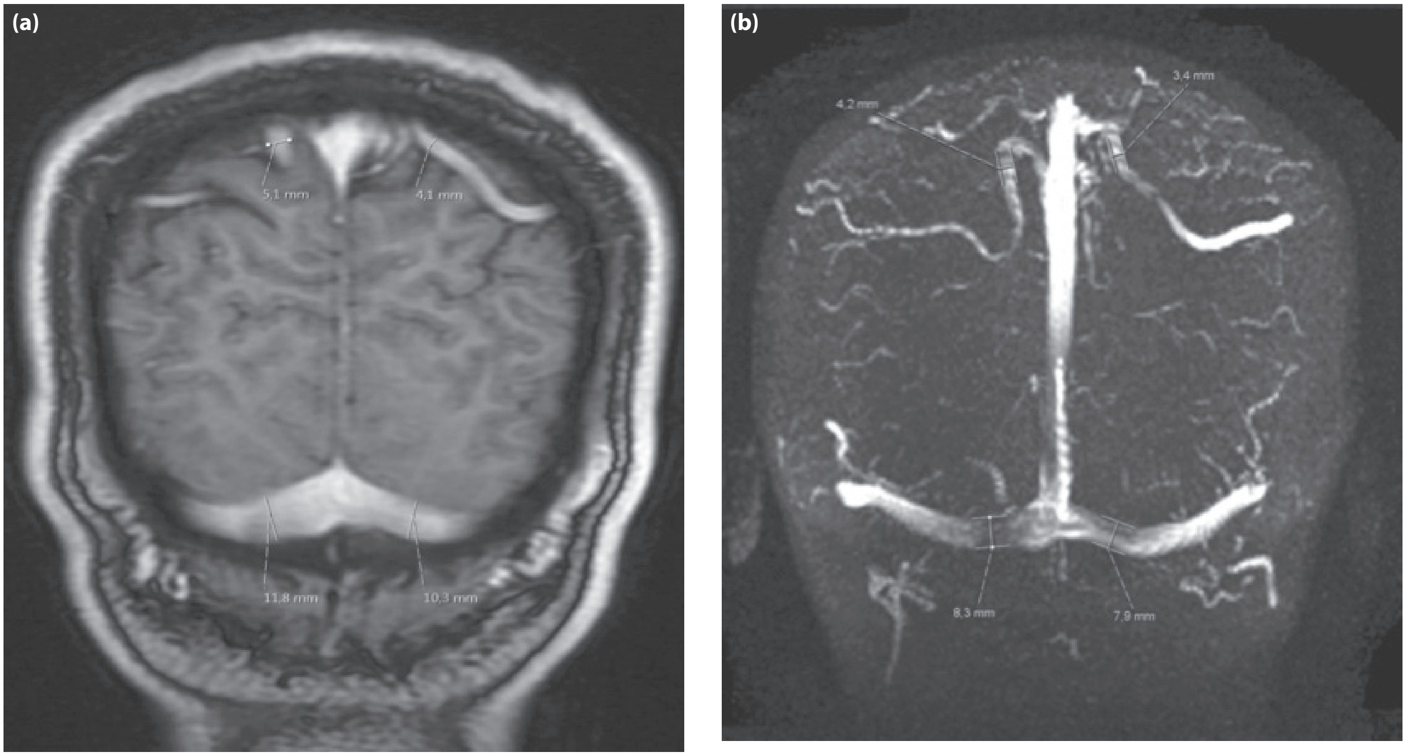

Figure 2. Measuring the diameters of bilateral trolard veins and transverse sinuses in coronal plane in the same patient. **(a)** 3D SPGR MRV image. **(b)** 2D TOF MRV image.

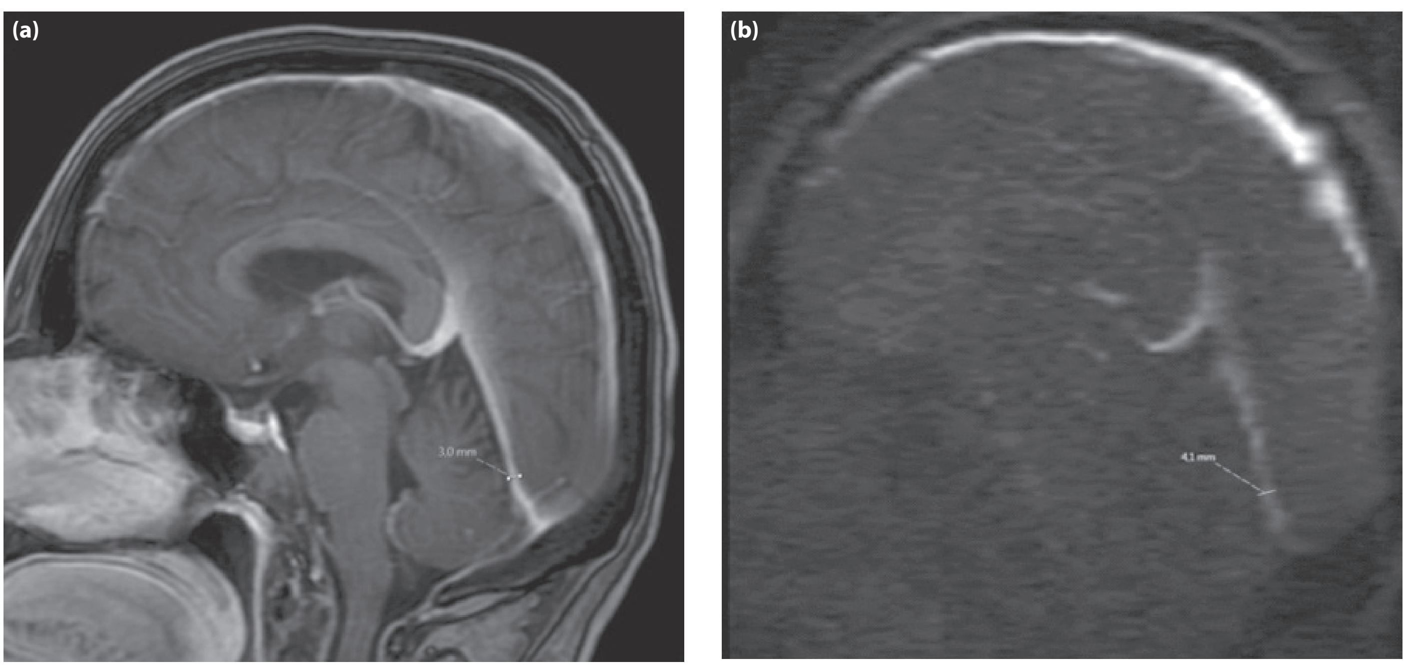

Figure 3. Measuring the diameters of straight sinus in sagittal plane in the same patient. **(a)** 3D SPGR MRV image. **(b)** 2D TOF MRV image.

while cortical vein diameters were measured about 1 cm distal to sinus into which they drain in places where no focal ectasia or narrowness was present. The diameters of dural venous sinuses and cerebral veins were measured by measuring the outermost boundaries of the contrast medium filling the lumen. Diameters of internal cerebral veins (ISV) and basal veins of Rosenthal (BVR), on the other hand, were measured in rostral area at least 1 cm distal to Galen vein. ISS diameters were measured at SS junction, whereas sigmoid sinus diameters were measured 1 cm distal to TS junction (Figures 1–3).

Dural venous sinuses and cerebral vein diameters were mea-

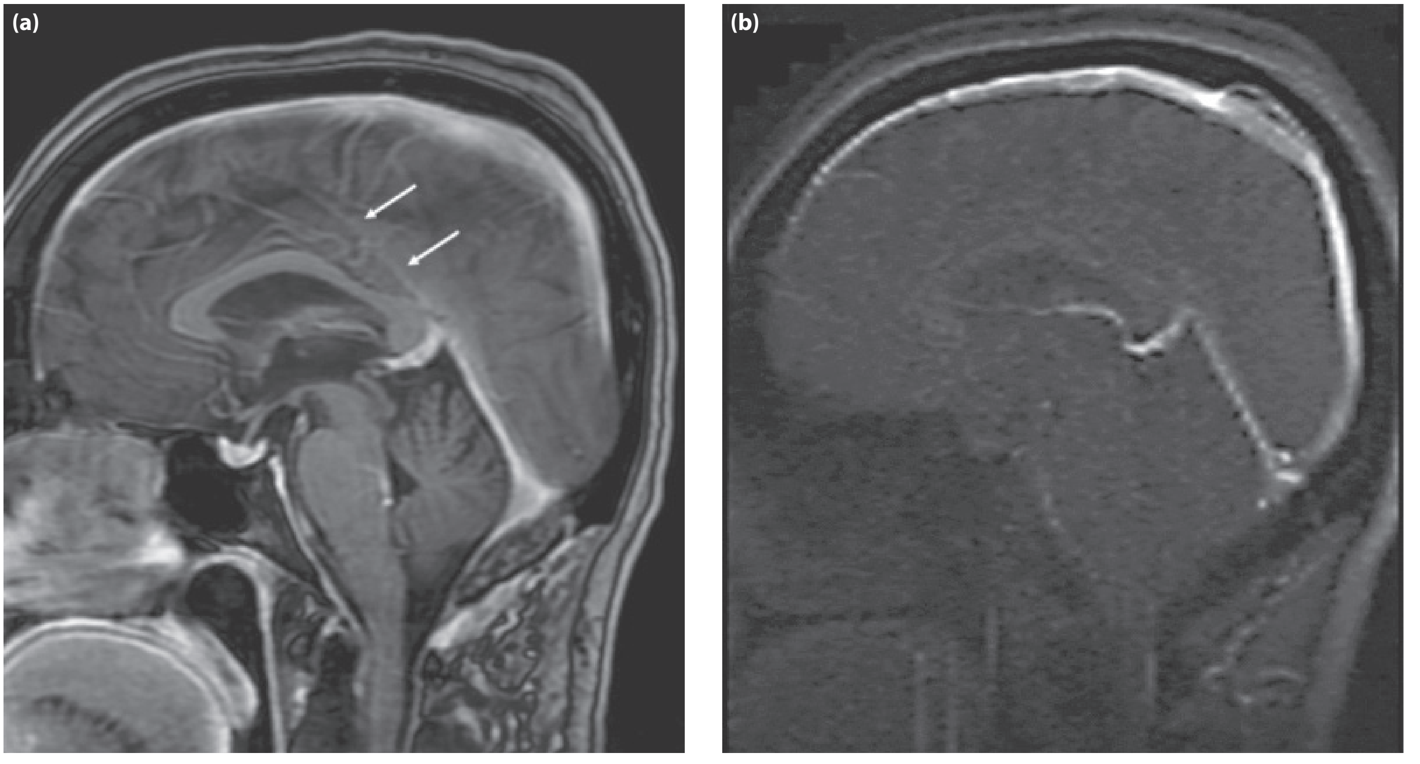

Figure 4. In 53 years old woman patient **(a)** inferior sagittal sinus is visualized by 3D SPGR MRV. **(b)** Inferior sagittal sinus cannot be visualized by 2D TOF MRV.

sured with both techniques in axial, sagittal and/or coronal planes on reformat images. Evaluations were made simultaneously by two radiologists (Ç.D. and E.G.). Age- and gender-based differences between 3D SPGR MRV and 2D TOF MRV for diameter measurements of dural venous sinuses and cerebral veins were investigated.

The patients were divided into ≤19, 20-39, 40-59 and ≥60 age groups. Chi-square tests were used to evaluate categorical variables. Continuous variables were expressed as arithmetic mean (mean) and standard deviation (SD) while categorical variables were given as numbers (n) and percentages (%). p values less than 0.05 were considered statistically significant. Statistical analyses were carried out using SPSS statistical software (IBM SPSS Statistics 19, SPSS Inc. an IBM Co, Somers, NY).

Results

Age of the patients varied from 7 to 81 (average 42.57±17.81). Only right sigmoid sinus could be detected in all patients (100%) by both MRV examinations. SSS, bilateral TS, Galen vein and bilateral ISV could be observed in all patients (100%) on 3D SPGR MRV. Observability of dural venous sinuses and veins except for right sigmoid sinus with 2B TOF MRV varied from 38.19 to 99.09%. In all sinuses and veins except for right sigmoid sinus, detectability of venous structures with 2D TOF MRV was lower compared to 3D SPGR MRV (Figure 4). Number and frequency of dural venous sinuses which can be detected by the two MRV sequences were given in Table 1.

Table 1. Detectability of dural venous sinuses and cerebral veins with 3D SPGR MRV and 2D TOF MRV sequences

Dural venous sinuses or veins	3D SPGR MRV		2D TOF MRV	
	n	%	n	%
Superior sagittal sinus	110	100	109	99.09
Inferior sagittal sinus	82	74.55	63	57.27
Right transverse sinus	110	100	109	99.09
Left transverse sinus	110	100	103	93.64
Right sigmoid sinus	110	100	110	100
Left sigmoid sinus	109	99.09	108	98.18
Straight sinus	110	100	108	98.18
Galen vein	110	100	108	98.18
Right internal cerebral vein	110	100	109	99.09
Left internal cerebral vein	110	100	109	99.09
Right basal veins of rosenthal	108	98.18	99	90.00
Left basal veins of rosenthal	106	96.36	99	90.00
Right trolard vein	44	40.00	42	38.18
Left trolard vein	45	40.91	42	38.18
Right labbe vein	106	96.36	104	94.55
Left labbe vein	107	97.27	106	96.36

SPGR: Spoiled gradient recalled; MRV: Magnetic resonance venography; TOF: time-of-flight.

There were significant differences between the two imaging methods for the diameters of SSS and ISS, bilateral TS and

Table 2. Diameters of dural venous sinuses and veins detected by 3B SPGR MRV and 2B TOF MRV

Dural venous sinuses or veins	Sinus diameters (mm)±SD		
	3D SPGR MRV	2D TOF MRV	p
SSS	7.75±1.19	7.10±1.34	**<0.001**
ISS	1.60±1.16	1.05±0. 99	**<0.001**
SS	3.76±1.09	4.04±0.64	**0.003**
R Transverse S	6.81±1.59	6.61±1.63	0.062
L Transverse S	5.97±2.10	5.52±2.25	**<0.001**
R Sigmoid S	7.47±1.55	7.10±1.84	**0.001**
L Sigmoid S	6.65±1.75	6.10±1.71	**<0.001**
R Trolard	1.18±1.59	1.16±1.58	0.909
L Trolard	1.19±1.59	1.22±1.64	0.367
R Labbe	2.12±0.57	1.98±0.69	**0.005**
L Labbe	2.26±0.51	2.05±0.57	**<0.001**
R BVR	1.58±0.37	1.51±0.62	0.584
L BVR	1.56±0.42	1.64±1.17	0.584
R ICV	2.13±0.30	2.00±0.34	**0.003**
L ICV	2.14±0.40	2.00±0.33	**0.004**
Galen Vein	4.39±0.80	4.04±0.86	**<0.001**

SPGR: Spoiled gradient recalled; MRV: Magnetic resonance venography; TOF: time-of-flight; SD: Standard deviation; SSS: Superior sagittal sinus; ISS: Inferior sagittal sinus; SS: Straight sinus; BVR: Basal veins of Rosenthal; ICV: Internal cerebral vein.

sigmoid sinuses, SS, bilateral Labbe and ISV and Galen veins (p<0.05). Diameters of dural venous sinuses and cortical veins except for straight sinus were larger in 3D SPGR MRV measurements compared to those of 2D TOF MRV. There was no significant difference between the two MRV imaging methods for diameter of right TS. Diameter measurements of venous sinuses and cerebral veins by the two MRV methods and statistical information regarding the diameter differences were given in Table 2.

Gender difference was statistically significant for the diameters of SSS, bilateral internal cerebral veins and Galen vein measured by 3D SPGR MRV (p<0.05) (Table 3). On the other hand, SSS and right Labbe vein diameters measurements by 2D TOF MRV were significantly different among age groups (p<0.05) (Table 4).

Discussion

Cerebral venous system could be visualized using digital subtraction angiography (DSA), CTV and MRV, DSA still being reference modality for visualization of intracranial venous system.[2,5,6] Considering DSA as the gold standard, Liang et al.[11] compared 2D TOF and 3D magnetization prepared rapid gradient echo (MP-RAGE) MRV, a contrast-enhanced MRV sequence, for detection of normal venous anatomy and venous diseases, and concluded that 3D MP-RAGE MRV is superior to 2D TOF MRV and conventional spin echo sequences. Lee et al.[12] carried out 3D contrast-enhancement (CE) MRV for 40 patients, 2D TOF MRV for 25 patients and DSA for 10 patients. They compared these examinations in terms of detection of dural venous sinuses and cerebral veins and concluded that 3D CE MRV was superior to 2D TOF MRV.[12] Lee et al.[12] reported that contrast-enhanced 3D SPGR MRV could be useful in preoperative evaluation of sinus occlusion and cortical drainage veins. The investigators found detectability rates of ISS, basal vein of Rosenthal and superficial cortical veins as 92.5, 90 and 100% with 3D CE MRV, respectively, which were 40, 48 and 0% with 2D TOF MRV, respectively.[12] Detectability rates of all other dural venous sinuses were 100% with both examinations. Detectability rates of ISS, BVR and superficial cortical veins were found higher in the present study com-

Table 3. Association of gender with diameters of superior sagittal sinus, internal cerebral veins and Galen vein measured by 3D SPGR MRV

3D SPGR MRV	n	Sinus diameter (mm)±SD	p
SSS			
Female	66	7.45±1.01	**0.001**
Male	44	8.20±1.30	
R Internal cerebral vein			
Female	66	2.08±0.27	**0.018**
Male	44	2.20±0.33	
L Internal cerebral vein			
Female	66	2.12±0.45	**0.028**
Male	44	2.18±0.29	
Galen vein			
Female	66	4.22±0.78	**0.009**
Men	44	4.63±0.78	

SPGR: Spoiled gradient recalled; MRV: Magnetic resonance venography; SD: Standard deviation; SSS: Superior sagittal sinus.

Table 4.Association of age with diameters of SSS and right Labbe vein measured with 2D TOF MRV

2D TOF MRV	n	Sinus diameter (mm)±SD	p
SSS age groups			
≤19	11	7.72±0.95	**0.045**
20–39	40	7.40±1.41	
40–59	40	6.71±1.46	
≥60	19	6.93±0.84	
Right labbe vein groups			
≤19	11	2.40±0.62	**0.021**
20–39	40	2.09±0.61	
40–59	40	1.91±0.63	
≥60	19	1.65±0.87	

TOF: time-of-flight; MRV: Magnetic resonance venography; SD: Standard deviation; SSS: Superior sagittal sinus.

pared to those reported by Lee et al.[12] These differences could be due to examination parameters and study population.In their studies with 10 cadavers and 10 patients, Kiliç et al.[13] found that detectability rates of basal veins of Rosenthal were 100, 90 and 60% with DSA and 2D TOF MRV, while they were 100, 100 and 90% for internal cerebral veins. Ahmed et al.[14] evaluated cerebral venous system of 204 patients with 2D TOF MRV, and found that SSS was detected in 100% of the patients while ISS was detected only in 86.05%. Using 2D TOF MRV, Ayanzen et al.[10] were able to detect SSS and SS in all patients, but ISS was visualized in only 52% of the patients. In the present study, 3D SPGR MRV could visualize ISS in 74.54% of the patients. On the other hand, similar to what was reported by Ayanzen et al.,[10] 2D TOF MRV was able to detect ISS only in 57.2%. In parallel with the previous findings in literature, our results showed the superiority of contrast-enhanced MRV sequences over 2D TOF MRV for the detectability of dural venous sinuses and cerebral veins.

Caliber and hemodynamics of dural venous sinuses could vary based on orthostatic or supine position and on many intracranial and neurological events (e.g. intracranial hypertension or hypotension, arteriovenous malformations, dural venous sinus or vein thrombosis, intracranial masses, hemorrhages, etc.).[4,15] Diameters in cerebral venous drainage have regional differences.[16] Veins drained into SSS enlarge especially in posterior frontal and parietal regions and increase in number. In addition, lacunary morphologies become prominent and SSS becomes enlarged here.[2,16] It was revealed that in brain centers involving motion, feeling, danger protection, hearing, speaking and reproduction, number and diameters of veins could increase.[16,17] Using axial T2 weighted MR images of 24 patients (17 with intracranial hypertension and 7 healthy controls), Rohr et al.[3] measured SSS sectional area at a 1 cm distance to torcular Herophili at the initial examinations and found that sectional area was 34.7±5.9 mm^2 in hypertensive patients and 34.3±4.6 mm^2 in healthy control group. Post-treatment follow-up examinations showed that SSS sectional area increased in patients with intracranial hypertension (mean: 40.7±5.5 mm^2). Diameters of intracranial venous structures are considerably affected by drainage pattern. Diameters of transverse sinus and jugular veins are directly associated with drainage pattern of SSS. Diameters of TS and IJV are larger at the side into which SSS is dominantly drained.[18] Right TS and left TS dominance percentages were reported to be 33-59 and 8-36%, while reported codominance varied from 8 to 49%.[5,10,19–23] Similar to many studies in the literature, TS diameters determined by 3D SPGR MRV were dominant on the right in 42.72% of the cases, on the left in 19.09% and codominant in 38.18% of the cases in the present study. Diameter differences in transverse sinuses could lead to difficulties and even to misdiagnoses in intracranial pathologies especially in dural venous sinus thrombosis.[24] In studies dealing with SSS drainage pattern in the torcular Herophili, it was shown that individual differences could be observed. It was also difficult to distinguish normal blood flow from thrombosis or occlusion when the images pointed a thin flow. It is important to note in dural venous sinuses diseases such as sinus thrombosis that each sinus has a certain tendency for drainage pattern, which is not the same in different patients.[18] Therefore, for the evaluation of venous system dimensions in various pathologies, average diameters of venous system in normal population should be known. Sayhan et al.[25] measured SSS diameters in six cadavers before lambdoid, coronal suture and confluence sinuum drainage areas and reported diameters of 13.1, 14.4 and 12.2 mm. SSS measured in the 1-2 cm segment before confluence of sinus drainage and average diameter was 7.75 mm with 3D SPGR MRV and 7.10 mm with 2D TOF MRV. The diameter differences between the study by Sayhan et al.[25] and in the present study could be due to different measuring sites and measuring techniques employed (measuring from wall to wall or measuring just the lumen width) and due to the fact that they used cadavers while we used living individuals.

Significant differences were found in the present study between sinus diameter measurements using 3D SPGR MRV and 2D TOF MRV of right TS, SSS, ISS, SS, left SS, right SigS, left SigS, right Labbe, left Labbe, right ISV, left ISV and Galen veins. Measurements with the two examination methods were not different for other sinuses. In their studies, Gökçe et al.[26] also mentioned that ISS had less caliber in 2D TOF MRV measurements and could be visualized more weakly compared to 3D SPGR MRV. In the present study, gender differences for diameters of SSS, right ISV, left ISV and Galen vein were significant in 3D SPGR MRV measurements. These sinuses and veins were larger in men. SSS and right Labbe diameters measured by 2D TOF MRV were significantly different in different age intervals. SSS and Labbe vein diameters were narrower in older age groups. Diameters of dural venous sinuses and venous structures except for straight sinus and left BVR were of less caliber in 2D TOF MRV measurements compared to 3D SPGR MRV measurements. Larger diameter measurements observed in straight sinus and left BVR by 2D TOF MRV could be due to imaging parameters of 2D TOF MRV and causes associated with the method itself. 2D TOF MRV has some limitations due to the artifacts arising from slow blood flow, mostly saturated in-plane flows and turbulent and/or pulsatile flows. Vessel calibers could be misinterpreted and stenosis or thrombosis misdiagnoses could be made due to the saturation of slow flows. In addition, calcification, stents, or other metallic medical devices could also lead to artifacts which need to be taken into account during the diagnosis.[8,10]

In their studies on bridging veins and cortical cerebral veins of 30 adult cadavers and 76 living patients, Han et al.[6] found that average diameter of Labbe veins at their entrance to TS was 2.8 mm in cadaveric measurements using DSA, CTV and 2D TOF MRV. In the present study, on the other hand, average Labbe vein diameter was 1.98-2.26 mm based on MRV examinations. Slightly narrow calibers of Labbe veins observed in the present study compared to those reported by Han et al.[6] could be a result of the fact that measurements in the present study were performed about 1 cm distal to sinuses where veins drained into.

In terms of the limitations of the present study, single point measurements for diameters of dural venous sinuses and veins could constitute a limitation. Venous structures enlarge from distal to proximal direction. Since veins and sinuses could exhibit focal enlargement in opening localizations in places where they drain into, we decided to perform measurements at a 1 cm distal point. In addition, because of apparent sensitivity of venous structures to hemodynamic changes, vein calibers could have instant changes. Therefore, measurements give approximate rather than absolute values. Another limitation was that although patients with pathologies that could compress or expand venous structures were radiologically excluded from the study, other diseases that could affect venous system in the included patients could not be exactly eliminated.

In conclusion, detectability and diameters of intracranial venous structures by the two MRV examinations could be different. Therefore, evaluation of intracranial venous structures should not be carried out using only 2D TOF MRV, and contrast-enhanced MRV sequences such as 3D SPGR MRV should also be employed when possible. Since there has been no study in the literature comparing the two MRV techniques for the measurement of venous sinuses and vein diameters, the present study could be extended with additional studies to larger series.

Conflict of interest: There are no relevant conflicts of interest to disclose.

References

1. Osborn AG. Venous anatomy and occlusions. In: Osborn's brain: imaging, pathology, and anatomy. 1st ed. Manitoba, Canada: Amirsys; 2013. pp. 215.
2. Cure JK, Van Tassel P, Smith MT. Normal and variant anatomy of the dural venous sinuses. Semin Ultrasound CT MR 1994;15:499–519.
3. Rohr A, Bindeballe J, Riedel C, van Baalen A, Bartsch T, Doerner L, Jansen O. The entire dural sinus tree is compressed in patients with idiopathic intracranial hypertension: a longitudinal, volumetric magnetic resonance imaging study. Neuroradiology. 2012;54(1):25–33. doi: 10.1007/s00234-011-0850-6.
4. Beggs CB. Venous hemodynamics in neurological disorders: an analytical review with hydrodynamic analysis. BMC Med. 2013;31(11):142. doi: 10.1186/1741-7015-11-142.
5. Widjaja E, Griffiths PD. Intracranial MR venography in children: normal anatomy and variations. AJNR Am J Neuroradiol 2004;25:1557–1562.
6. Han H, Yao Z, Wang H, Deng X, Yu Fong AH, Zhang M. Dural entrance of the bridging vein into the transverse sinus provides a reliable measure for preoperative planning: an anatomic comparison between cadavers and neuroimages. Neurosurgery. 2008;62 (5 Suppl2): ONS289-95;discussionONS295-6. doi: 10.1227/01.neu.0000326009.46197.ab.
7. MacDonald ME, Frayne R. Cerebrovascular MRI: a review of state-of-the-art approaches, methods and techniques. NMR Biomed. 2015;28(7):767–91. doi: 10.1002/nbm.3322.
8. Paoletti M, Germani G, De Icco R, Asteggiano C, Zamboni P, Bastianello S.Intra- and Extracranial MR Venography: Technical Notes, Clinical Application, and Imaging Development. Behav Neurol. 2016;2016:2694504. doi: 10.1155/2016/2694504.
9. Widjaja E, Shroff M, Blaser S, Laughlin S, Raybaud C. 2D time-of-flight MR venography in neonates: anatomy and pitfalls. AJNR Am J Neuroradiol. 2006;27(9):1913–8.
10. Ayanzen RH, Bird CR, Keller PJ, McCully FJ, Theobald MR, Heiserman JE. Cerebral MR venography: normal anatomy and potential diagnostic pitfalls. AJNR Am J Neuroradiol. 2000;21(1):74–8.
11. Liang L, Korogi Y, Sugahara T, Onomichi M, Shigematsu Y, Yang D, Kitajima M, Hiai Y, Takahashi M. Evaluation of the intracranial dural sinuses with a 3D contrast-enhanced MP-RAGE sequence: prospective comparison with 2D-TOF MR venography and digital subtraction angiography. AJNR Am J Neuroradiol. 2001;22(3):481–92.
12. Lee JM, Jung S, Moon KS, Seo JJ, Kim IY, Jung TY, Lee JK, Kang SS.Preoperative evaluation of venous systems with 3-dimensional contrast-enhanced magnetic resonance venography in brain tumors: comparison with time-of-flight magnetic resonance venography and digital subtraction angiography. Surg Neurol. 2005;64(2):128–33; discussion 133–4.
13. Kiliç T, Ozduman K, Cavdar S, Ozek MM, Pamir MN.The galenic venous system: surgical anatomy and its angiographic and magnetic resonance venographic correlations. Eur J Radiol. 2005;56(2):212–9.
14. Ahmed MS, Imtiaz S, Shazlee MK, Ali M, Iqbal J, Usman R. Normal variations in cerebral venous anatomy and their potential pitfalls on 2D TOF MRV examination: Results from a private tertiary care hospital in Karachi. J Pak Med Assoc. 2018;68(7):1009–1013.
15. Prada F, Del Bene M, Mauri G, Lamperti M, Vailati D, Richetta C, Saini M, Santuari D, Kalani MYS, DiMeco F. Dynamic assessment of venous anatomy and function in neurosurgery with real-time intraoperative multimodal ultrasound: technical note.Neurosurg Focus. 2018 Jul; 45(1):E6. doi: 10.3171/2018.4.FOCUS18101.
16. Rhoton AL Jr. The cerebral veins. Neurosurgery. 2002;51(4 Suppl):S159–205.
17. Hua J, Liu P, Kim T, Donahue M, Rane S, Chen JJ, Qin Q, Kim SG. MRI techniques to measure arterial and venous cerebral blood volume. Neuroimage. 2018;16. pii: S1053-8119(18)30115–0. doi: 10.1016/j.neuroimage.2018.02.027
18. Saiki K, Tsurumoto T, Okamoto K, Wakebe T. Relation between bilateral differences in internal jugular vein caliber and flow patterns of dural venous sinuses. AnatSci Int. 2013;88(3):141–50. doi: 10.1007/s12565-013-0176-z.
19. Kaplan HA, Browder J, Knightly JJ, Rush BF, Jr. Browder A. Variations of the cerebral dural sinuses at the torcularHerophili. Importance in radical neck dissection. Am J Surg, 1972;124 (4), 456–461.
20. Durgun B, Ilgıt ET, Cizmeli MO, Atasever A.Evaluation by angiography of the lateral dominance of the drainage of the dural venous sinuses. SurgRadiol Anat. 1993;15(2):125–30.
21. Singh M, Nagashima M, Inoue Y. Anatomical variations of occipital bone impressions for dural venous sinuses around the torcularHerophili, with special reference to the consideration of clinical significance. SurgRadiol Anat. 2004;26(6):480–7.
22. Alper F, Kantarci M, Dane S, Gumustekin K, Onbas O, Durur I. Importance of anatomical asymmetries of transverse sinuses: an MR venographic study. Cerebrovasc Dis. 2004;18(3):236–9.
23. Kopuz C, Aydin ME, Kale A, Demir MT, Corumlu U, Kaya AH. The termination of superior sagittal sinus and drainage patterns of

the lateral, occipital at confluenssinuum in newborns: clinical and embryological implications. SurgRadiol Anat. 2010;32(9):827–33. doi: 10.1007/s00276-010-0628-2.
24. Provenzale JM, Kranz PG. Dural sinus thrombosis: sources of error in image interpretation. AJR 2011;196:23–31.
25. Sayhan S, Guvencer M, Ozer E, Arda MN.Morphometric evaluation of parasagittal venous anatomy for intracranial approaches: a cadaveric study. Turk Neurosurg. 2012;22(5):540–6. doi: 10.5137/1019-5149.JTN.4086-11.3.
26. Gökçe E, Pınarbaşılı T, Acu B, Fırat MM, Erkorkmaz Ü. TorcularHerophili classification and evaluation of dural venous sinus variations using digital subtraction angiography and magnetic resonance venographies. SurgRadiol Anat. 2014;36(6):527–36. doi: 10.1007/s00276-013-1223-0.