

Intracranial Aneurysm Detection with 3T Magnetic Resonance Angiography

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Abstract

Introduction: The new 3 Tesla (T) magnetic resonance (MR) scanners yield improved signal-to-noise ratio and spatial resolution with superior background suppression compared to lower field strength systems. This is advantageous for MR angiograms. The purpose of our study was to compare unenhanced three-dimensional time-of-flight magnetic resonance angiography (3D TOF MRA) at 3T with catheter digital subtraction angiography (DSA) in detecting unruptured intracranial aneurysms. **Materials and Methods:** Out of 1375 consecutive patients who underwent unenhanced 3D TOF MRA at 3T, 15 patients with unruptured intracranial aneurysms were retrospectively identified. Nine of these 15 patients had DSA as the reference standard for comparison. Aneurysm size, location and morphology were independently assessed on both MRA and DSA by 2 radiologists. **Results:** Seventeen aneurysms ranging in size from 1 mm to 24 mm were identified in 15 patients on MRA. DSA confirmed the aneurysms in 9 patients with good anatomical correlation compared with the MRA findings. **Conclusions:** 3D TOF MRA at 3T has good correlation with DSA and aneurysms as small as 1 mm in size can be detected. This can be a promising, non-invasive method for aneurysm surveillance.

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Introduction

The recent advent of 3 Tesla (T) very high field magnetic resonance (MR) systems into clinical practice has enabled a variety of exciting developments in both clinical and research applications. The main advantage of 3T MR imaging is increased signal-to-noise ratio (SNR), which increases in an approximately linear fashion with field strength in the range of 1.5T to 3.0T.¹ This increased SNR improves spatial resolution and potentially enables MR angiography (MRA) at 3T to rival catheter digital subtraction angiography (DSA), traditionally regarded as the gold standard, for the evaluation of intracranial vascular disease. Apart from the improved SNR, there is superior background suppression and excellent fat suppression at 3T, resulting in improved visualisation of the intracranial vessels. The purpose of our study was to compare unenhanced three-dimensional time-of-flight magnetic resonance angiography (3D TOF MRA) at 3T with DSA in detecting unruptured intracranial aneurysms.

Materials and Methods

Out of 1375 consecutive patients who underwent unenhanced 3D TOF MRA evaluation [TR/TE/flip angle/

number of acquisition: 18/3.3/20/1, 168 slices of 0.5 mm slice thickness using multichunk technique, field of view 20 cm x 20 cm, matrix 512 x 254, scan duration 4 minutes (with sensitivity encoding {SENSE} factor 2) to 7 minutes 42 seconds (without SENSE) on our 3T clinical MR scanner (Gyrosan Intera, Philips Medical System, Eindhoven, The Netherlands)], 15 patients with small unruptured intracranial aneurysms were retrospectively identified. All patients also had axial T2-weighted imaging (WI) (TR/TE 4000/100, echo train length 16, 2 excitations, matrix size 320 x 224) and single-shot spin-echo echo-planar imaging (EPI) diffusion-weighted imaging (DWI) (TR/TE 5000/90, 4 mm slice thickness, matrix size 256 x 256, 1 excitation, FOV 24 cm, EPI factor 89) performed as part of our institution's stroke imaging protocol. The reformatted maximum intensity projection (MIP) 3D TOF MRA images were independently evaluated by 2 experienced radiologists on a visual analogue scale, with further review of the MRA source data. The reviewers were blinded to the diagnosis of the presence of an aneurysm except in patients with known aneurysms on follow-up. In the patients on follow-up for aneurysms, the reviewers were blinded to the location and

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characteristics of the aneurysms.

In 9 patients, DSA correlation was available. DSA was performed after MRA for confirmatory diagnosis of the aneurysm in 5 patients, with the DSA done 2 days to 3 weeks after the MRA. For 4 patients (patients 5, 6, 10 and 15) with conservative management of previously diagnosed aneurysms, the DSA had been done 2 months to 2 years prior to MRA in 3 patients, while for 1 patient on annual follow-up for a small 1 mm siphon aneurysm (patient 5), the DSA had been done 5 years prior, with intervening annual MRA follow-up at 1.5T.

The location of the aneurysm, its size and its morphology were assessed separately on both MRA and DSA, and comparison made between the modalities when available. For aneurysm measurements made on DSA, this was performed by comparing against the average of two 1-cm diameter radio-opaque rings that had been placed on opposing sides of the patient's head (perpendicular to the X-ray beam) during the angiogram. Measurements were carried out on 2 orthogonal views (e.g., in the anteroposterior and lateral projections). Where 3D rotational spin angiography was available, measurements were made on the independent workstation using the standard calibrated software (Advantage Windows 4.0, GE Medical Systems, Wisconsin, MI).

Results

The patients' biodata, indications for MRI scanning, and the MR as well as the DSA findings are presented in Table 1. The clinical indications for the MRI included stroke-like symptoms (dysarthria, hemiparesis, numbness and giddiness), migraine and follow-up of previously diagnosed aneurysms. There were 9 male and 6 female patients, with an age range of 26 to 75 years. Seventeen aneurysms ranging from 1 mm to 24 mm in size were detected on the reformatted maximum intensity projection (MIP) 3D TOF MRA images. There were 11 cavernous carotid aneurysms, 3 vertebral artery aneurysms, 2 posterior communicating (PCOM) aneurysms and 1 right M1 segment aneurysm. Eight of the aneurysms were on the right while 9 were on the left. There was a 100% concordance rate in the diagnosis and analysis of the detected aneurysms between the 2 readers.

The cavernous carotid aneurysms ranged from 1 to 10 mm in size and most were situated in the para-ophthalmic region, with 6 arising just before, 2 at the level of, and 2 just after the ophthalmic artery origin (Fig. 1). One of the vertebral artery aneurysms was a dissecting aneurysm with involvement of the origin of the posterior inferior cerebellar artery (PICA). One distal vertebral aneurysm, just proximal to the origin of the PICA was thrombosed with localised mass effect on the brainstem while another vertebral

aneurysm did not have significant effect on the brainstem despite lateral side outpouchings. A solitary right M1 segment aneurysm arose just after the M1 origin.

In 9 patients with 10 aneurysms that were angiographically proven, there was good anatomical correlation between the DSA and 3D TOF MRA findings (Fig. 2). The sizes of 7 aneurysms were identical in 6 patients. Size correlation between MRA and DSA was not possible in the case of the thrombosed vertebral aneurysm (patient 8). In 2 patients with vertebral aneurysms (patients 9 and 10), the diameters of the patent lumen of the aneurysms were fairly comparable.

There were 5 patients in whom the MRA revealed other abnormalities apart from the aneurysms. Four of these 5 patients (patients 3, 5, 12 and 14) had atherosclerotic disease with corresponding infarcts in the territories supplied by the affected arteries while 1 patient (patient 7) had a normal brain MRI scan despite atherosclerotic changes on the MRA.

Discussion

The incidence of intracranial aneurysm in routine autopsies is 5% and the rupture rate is 12/100,000 population/year, mostly in the 5th, and 6th decades.² The common sites of aneurysms have also been well established, with 30% to 35% arising from the anterior communicating artery, 30% to 35% at the posterior communicating artery and 20% to 25% at the middle cerebral artery bifurcation.³ These aneurysms constitute most of the cases of atraumatic subarachnoid haemorrhage.^{4,5} Those situated in the carotid siphon or cavernous part of the internal carotid artery are rare^{6,7} and usually do not rupture or cause haemorrhage.⁸

The natural history of unruptured intracranial aneurysms is unclear but is influenced by many factors, including previous subarachnoid haemorrhage, patient's age, coexisting medical conditions and aneurysm characteristics such as size, location and morphology.⁹ While the aneurysms originating from the circle of Willis are prone to rupture and haemorrhage, cavernous aneurysms are known to have a benign course and do not rupture.¹⁰ However, there have been reports of clinical progression of these aneurysms giving rise to ophthalmoplegia¹¹ as well as cavernous sinus syndrome.¹² Spontaneous remission of such symptoms has also been observed.¹³

Results comparing MRA performed at 0.5T and 1.5T have shown that the sensitivity in the detection of intracranial aneurysms was lower at 0.5T than at 1.5T^{14,15} while 3.0T TOF MRA has been shown to be significantly better for visualisation of aneurysms ($P < 0.001$).¹⁶ In a recent report, dynamic 3D contrast-enhanced T1-weighted MRA at 1.5 T detected all 23 cases of aneurysms (2 to 21 mm) shown on DSA.¹⁷

Most of our patients presented with stroke-like symptoms

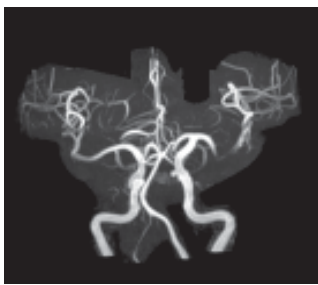


Fig. 1a.

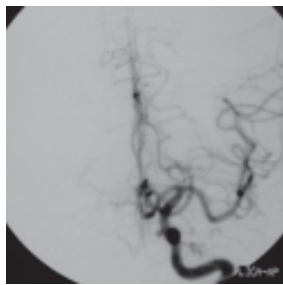


Fig. 1b.

Fig. 1. A 63 year old female (patient 5) on follow-up for aneurysm since 1998. (a) MRA at 3T demonstrates a small 1 mm left cavernous carotid aneurysm, (b) left ICA digital subtraction angiogram confirms the size, location and morphology of the aneurysm.

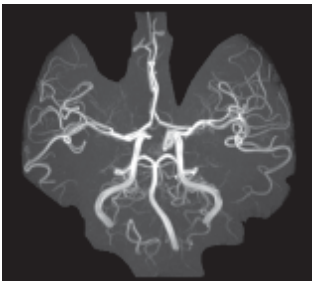


Fig. 2a.

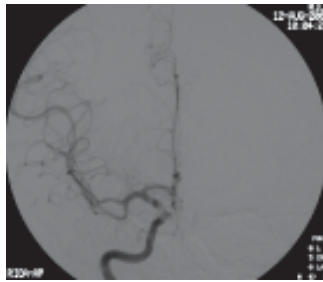


Fig. 2b.

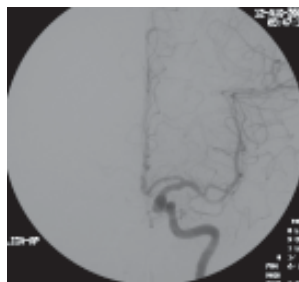


Fig. 2c.



Fig. 2d.

Fig. 2. A 44 year old female (patient 6) with bilateral cavernous aneurysms (a) MRA at 3T demonstrates bilateral cavernous carotid aneurysms with the right measuring 3 mm and the left 9 x 4 mm in size, (b) right ICA DSA confirms right cavernous carotid aneurysm, (c) left ICA DSA confirms left cavernous carotid aneurysm, (d) reconstructed 3D spin angiogram of left cavernous aneurysm.

and underwent the institution's stroke study protocol consisting of T2 WI, DWI and unenhanced 3D TOF MRA. TOF technique is based on the contrast provided by flow-related enhancement when fully magnetised unsaturated blood enters the imaging slice where the magnetism of the stationary tissue has been saturated. 3D TOF MRA is more sensitive than 3D phase contrast (PC) MRA in detecting stenotic lesions in the workup of patients with cerebrovascular disease and has a higher negative predictive value.¹⁸ TOF MRA is also generally preferred over PC MRA as it has the advantage of good resolution and superior SNR, requiring only half the scan time required for a PC MRA. Although PC MRA is able to evaluate flow velocity and direction without the inplane saturation effects or "Venetian blind artifacts" of TOF, its long acquisition time and the technically demanding aspect of selecting the appropriate velocity encoding gradient puts it at a relative disadvantage in the routine clinical MR evaluation protocol. While dynamic contrast-enhanced T1-weighted MRA at 1.5T provides better depiction of the aneurysm,¹⁷ being less prone to signal intensity losses due to turbulence or flow saturation, it is more invasive, requiring a fast bolus injection of intravenous contrast.

Although detection rates of 90% have been reported for aneurysms more than 3 mm to 4 mm in size, smaller aneurysms may also be diagnosed on unenhanced 3D TOF MRA, with intracranial aneurysms as small as 1.5 mm in

size having been detected^{19,20} at 1.5T MR scanning. The aneurysms most likely to be missed are those in the carotid siphon,²¹ because of flow turbulence and the complicated anatomy in this region.¹⁵ Our results with unenhanced 3D TOF MRA at 3T suggests that with careful evaluation of the reformatted MIP images, small aneurysms as small as 1 mm in size can be reliably detected without the use of intravenous contrast. These aneurysms can be further confirmed by reviewing the MRA source images, which has been shown to both increase the detection rate of internal carotid artery aneurysms²² and aid in understanding the topography of paraclinoid carotid artery aneurysms.²³ The detection of such tiny aneurysms may or may not be clinically significant, depending on their location and the cause of these aneurysms. The incidence of aneurysms detected in our series approximates 1% (15 out of 1375 patients scanned). This incidence is lower compared to the reported incidence of 5% in routine autopsies, probably because autopsies reflect the total prevalence of a disease, both symptomatic and asymptomatic, while the study cohort sampled was that of a relatively well, albeit mildly symptomatic subgroup. Patients who presented acutely and catastrophically with subarachnoid haemorrhage were not subjected to an MRA examination and hence excluded from the study.

With the superior background suppression, improved SNR and excellent fat suppression at 3T, there is

Table 1. Summary of Patient's Biodata and Imaging Findings

Patient	Age (y)	Gender	Indication for scan	3T MRI findings	DSA findings
1	75	Female	R hemiparesis	2 x 3 mm cavernous aneurysm, points medially Chronic infarct R caudate	
2	26	Female	Migraine	2 mm cavernous aneurysm, points laterally Brain normal	2 mm aneurysm just after L ophthalmic artery, points laterally DSA done 2.5 weeks after MRA
3	69	Female	No past medical history Vertiginous giddiness, dysarthria	1 mm aneurysm R M1 segment, points posteriorly Atherosclerotic changes R PCA and both M1 segments Acute L pontomedullary and chronic L corona radiata infarcts	
4	46	Male	R hand numbness 2 weeks	4 mm cavernous aneurysm, points medially Brain normal	
5	63	Female	Polycythaemia rubra vera On follow-up for small aneurysm since 1998	1 mm cavernous aneurysm, pointing medially, stable since 1998 Latest MR showed occluded L PCA with corresponding acute infarcts	DSA 98 – 1 mm aneurysm L carotid siphon, points medially
6	44	Female	Incidental bilateral aneurysms on MRI in another radiology centre	Bilateral distal ICA aneurysms distal to cavernous segments R 3 mm, points medially L 9 x 4 mm, points posteriorly Brain normal	Bilateral distal ICA aneurysms R 3 mm, points medial L 9 x 4 mm, points posterior DSA done 2 months before MRA
7	53	Male	To exclude vertebrobasilar insufficiency	2 mm L carotid siphon aneurysm, points medially Atherosclerotic changes proximal L M1 and L A1 segments Brain normal	2 mm aneurysm supraclinoid para-ophthalmic L ICA pointing medially DSA done 3 weeks after MRA
8	46	Male	Giddiness and numbness of R upper limb for 2 months	18 x 16 x 19 mm distal R vertebral aneurysm, thrombosed, localised mass effect on brainstem	Thrombosed R vertebral artery aneurysm DSA done 1 week after MRA
9	54	Male	Giddiness for 1 month	Fusiform L vertebral artery dissecting aneurysm 11 mm length and 9 mm in maximum diameter Origin of L PICA from aneurysm Brain normal	16 mm (length) x 10 mm (diameter) fusiform aneurysm L vertebral artery involving L PICA DSA done 2 days after MRA
10	61	Male	R vertebral aneurysm for pre-embolisation assessment	24 x 22 x 17 mm partially thrombosed R vertebral aneurysm with patent lumen diameter of 11 mm Gliosis R frontal lobe	Fusiform aneurysm R vertebral artery with prominent side outpouchings, lumen 12 mm diameter DSA done 5 months before MRA
11	75	Male	Transient failure of R eye adduction post cardiac angiogram Suspected cerebellar stroke	Bilateral PCOM aneurysms: 3 mm on R, points medially, 5 mm on L, points laterally Acute L cerebellar and vermian infarcts with haemorrhagic conversion	

Table 1. Contd.

Patient	Age (y)	Gender	Indication for scan	3T MRI findings	DSA findings
12	67	Male	Dysarthria, R ptosis and Horner's Suspected medullary infarction	10 x 4 mm L ICA siphon aneurysm, bulging medially Atherosclerotic changes in intracranial arteries especially L M1 segment and cavernous L ICA Acute on chronic L MCA territory infarcts	
13	64	Male	Giddiness	2 mm L cavernous aneurysm, pointing medially Old R cerebellar infarcts, previous haemorrhage L hemipons	
14	62	Female	R choreoathetosis with suspected L thalamic infarct	3 mm R paraclinoid aneurysm, points superiorly narrowed L MCA subacute L thalamic infarct	3 mm R carotid siphon aneurysm DSA done 2 weeks after MRA
15	55	Male	Intracavernous aneurysm on follow-up Initially presented with TIA	3 mm R cavernous aneurysm, points posteriorly Brain normal	3 mm R carotid siphon aneurysm DSA done 2 years before MRA

ICA: internal carotid artery; L: left; MCA: middle cerebral artery; MRA: magnetic resonance angiography; PCA: posterior cerebral artery; PCOM: posterior communicating artery; PICA: posterior inferior cerebellar artery; R: right; TIA: transient ischaemic attack

improvement in visualisation of the distal intracranial vessels.²⁴ Smaller and more peripheral vessels beyond the circle of Willis can routinely be visualised on unenhanced 3D TOF at 3T. This includes the ophthalmic artery, perforating lenticulostriate vessels, and third-order branches of the middle cerebral artery. Such small vessels are often not demonstrated on routine unenhanced MRA protocols at lower field strengths, including the 1.5T scanners. The improved visualisation and clarity beyond the circle of Willis at 3T MRA allows more distal vascular pathology such as mycotic or distal aneurysms to be assessed non-invasively. The relationship between the aneurysm and adjacent small vessels may also be better depicted.

Superior SNR at 3T may also translate to shorter scan time compared to an equivalent protocol at lower field strength.¹ It has also been shown that the image quality of intracranial aneurysms depicted is better with 3T TOF MRA compared to that at 1.5T.²⁵ To the best of our knowledge, there has thus far been no published study comparing non-invasive unenhanced 3D TOF MRA at 3T with the reference standard of invasive DSA procedure.

Our results showed good correlation of the location of the aneurysms, their size and morphology on the unenhanced 3D TOF 3T MRA with the DSA examination. Despite background atheromatous changes in some patients, aneurysms as small as 1 mm were evident on the MRA source images. Hence, unenhanced 3D TOF MRA at 3T appears to be a suitable, non-invasive, non-ionising and relatively quick method of monitoring patients with incidentally detected small aneurysms on conservative

management, including those that are intracavernous; and for non-invasive evaluation of patients and their relatives with positive familial history of aneurysms. In the near future, it may have a role to play in the follow-up of patients post-Guglielmi detachable coil (GDC) coiling,^{26,27} provided the MR safety issues at 3T pertaining to such coils have been established. It is also, in general, a cheaper alternative to a full DSA study.

Potential pitfalls with MRA on a 3T scanner includes increased specific absorption rate (SAR) and T2* dephasing but the latter is thought not to be substantially more problematic than at 1.5T,¹⁶ and SAR limitations do not generally limit the use of TOF, PC or even contrast-enhanced MR angiographic techniques at 3.0T.¹ Flow-related artefacts are a potential problem in the carotid siphon and has been seen at all field strengths¹⁵ but was not a significant problem in our patients.

Conclusion

Our experience suggests that with careful visualisation of 3D TOF MRA on a 3T MR scanner, even without intravenous contrast, aneurysms as small as 1 mm in size can be detected on the reformatted images with confirmation provided by the source images. Its good correlation with DSA, the current gold standard, allows it to be a suitable non-invasive method of monitoring patients with conservatively treated aneurysms, including incidentally detected intracavernous aneurysms, and for non-invasive evaluation of cases with familial history. In future, it may have a role to play in the follow-up of patients post-GDC coiling.

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