Malaysian Journal of Medical Sciences, Vol. 10, No. 1, Jan 2003 (37-42)

ORIGINAL ARTICLE

COMPARISON BETWEEN 3D TOF MAGNETIC RESONANCE ANGIOGRAPHY AND INTRAARTERIAL DIGITAL SUBTRACTION ANGIOGRAPHY IN IMAGING THE CIRCLE OF WILLIS

Rozita Mohd Ghazali and Ibrahim Lutfi Shuaib.

Department of Radiology,
School of Medical Sciences, Universiti Sains Malaysia
16150 Kubang Kerian, Kelantan, Malaysia

This study was done compare the accuracy of non-contrast enhanced 3D time of flight magnetic resonance angiography (3D TOF MRA) with intraarterial digital subtraction angiography (IADSA) in depicting the arterial segments of the circle of Willis. 398 arterial segments were analysed from 38 patients who underwent both non-contrast enhanced 3D TOF MRA and IADSA examinations in Hospital Universiti Sains Malaysia from November 1998 to December 2000. Two observers performed blinded retrospective analysis of the IADSA images and Maximum Intensity Projection display of the 3D TOF MRA of the circle of Willis on separate sessions. Non-contrast enhanced 3D TOF MRA was sensitive and specific in depicting the A1, A2, M1, P1 and Anterior Communicating segments of the circle of Willis with a sensitivity ranging from 94.5% to 100% and specificity ranging from 90.5% to 100%. However it was poor in depicting the Posterior Communicating segments with a sensitivity of 21.4%. MIP display of the non-contrast enhanced 3D TOF MRA is sensitive in depicting the anatomy of the circle of Willis except for the PCOM segment. It is thus a reliable method for screening of this arterial circle.

Key words *: 3D TOF MRA, IADSA, circle of Willis.*

Submitted-25.5.2002, Revised-15.12.2002, Accepted-30.12.2002

Introduction

IADSA is currently the gold standard in assessing the intracranial arteries, however it is invasive and carries multiple risks to the patient. MRA technique has been introduced to look at its feasibility in assessing the intracranial arteries. This technique is non-invasive, does not use iodinated contrast material and there is no ionising radiation involved. It also has the capacity to provide multiple projections of anatomically complex vascular territory with a single data acquisition.

There are two fundamental magnetic resonance acquisition techniques that are used in MRA. They are time of flight (TOF) and phase contrast angiography (PCA) (1). The TOF technique is based on the difference in signal intensity between static tissue and flowing blood while the PCA technique is based on the fact that flowing blood will interact with a special type of magnetic gradient (1). The technique currently used in Hospital Universiti Sains Malaysia is 3D time of flight magnetic resonance angiography (3D TOF MRA) without administration of intravenous gadolinium.

The purpose of this study is to compare the accuracy of the magnetic resonance angiography with intra-arterial digital subtraction angiography in depicting the arterial segments of the circle of Willis.

Materials and Methods

38 patients who had undergone both non-contrast enhanced 3D TOF MRA and IADSA investigations of the intracranial arteries from the period of November 1998 to December 2000 were included in this study. Two observers consisting of a radiology

Table 1 *: Comparison of the demonstration of arterial segmentsbetween IADSA and MRA by observer 1.*

Arterial segment	IADSA			3D TOF MRA		
	Normal	Small	Absent	Normal	Small	Absent
Right A1 (n=38)	32	6	0	31	6	1
Left A1 (n=35)	32	2	0	33	2	1
Right A2 (n=38)	36	0	0	36	2	0
Left A2 (n=35)	34	1	0	33	2	0
Right M1 (n=38)	38	0	0	38	0	0
Left M1 (n=35)	35	0	0	35	0	0
Right P1 (n=35)	31	2	0	28	5	0
Left P1 (n=32)	31	1	0	30	2	0

IADSA = intraarterial digital subtraction angiography
3D TOF MRA = 3 dimensional time of flight magnetic resonance angiography
A1 = A1 segment of the anterior cerebral artery
A2 = A2 segment of the anterior cerebral artery
M1 = M1 segment of the middle cerebral artery
P1 = P1 segment of the posterior cerebral artery

trainee (observer 1) and a consultant radiologist (observer 2) performed analysis of the non-contrast enhanced 3D TOF MRA and IADSA images of the circle of Willis. The observers were blinded to the clinical information about the patients. The image analysis of these two different techniques for each patient was done on two separate sessions so as to prevent bias in the interpretation.

Imaging Modalities

1) For the non-contrast enhanced 3D TOF MRA, studies were performed with a 1.0T strength Signa Horizon LX GE Medical Systems equipment. The parameters used were: a) 31 / 4 (repetition time, TR in milliseconds / echo time, TE in milliseconds). b) 20° flip angle. c) 220 x 160 mm field of view (FOV). d) 384 x 192 matrix. e) 1.2 mm section thickness and 0.6 mm overlap of sections (i.e. gap of –0.6mm). The total imaging time was approximately 4 minutes 53 seconds.

2) For the IADSA, studies were performed with Advantx LCA / LCV + / LC + GE Medical Systems equipment. For this technique, the routine views were: a) AP and lateral views for the internal carotid artery run. b) Towne and lateral views for the vertebral artery run. Additional views such as the oblique views and cross compression views were done whenever necessary.

Images from the non-contrast enhanced 3D TOF MRA acquisition were post processed using a maximum intensity projection (MIP) algorithm to create an angiogram like image. These reconstructed images were then analysed to depict the arterial segments of the Circle of Willis.

Table 2: Comparison of visualization of ACOM, right PCOM and leftPCOM between IADSA and MRA by observer 1.

Arterial segment	IADSA			3D TOF MRA		
	Functional	Patent	Not visualised	Functional	Patent	Not visualised
ACOM	1	16	21	5	17	16
Right PCOM	1	35	2	1	8	29
Left PCOM	0	34	1	0	9	26

Table 3: Comparison of visualization of ACOM, right PCOM and leftPCOM between IADSA and MRA by observer 2.

Arterial segment	IADSA			3D TOF MRA		
	Functional	Patent	Not visualised	Functional	Patent	Not visualised
ACOM	4	17	17	1	18	19
Right PCOM	1	35	2	1	7	30
Left PCOM	0	34	1	0	7	28

IADSA = intraarterial digital subtraction angiography,
3D TOF MRA = 3 dimensional time of flight magnetic resonance angiography.
ACOM = anterior communicating artery,
PCOM = posterior communicating artery

For the IADSA all the available images were reviewed. Due to some technical difficulties, the vertebral artery was not cannulatedin 5 out of 38 patients, and in 3 out of the 38 patients, the left internal carotid artery was not cannulated and these vessels were excluded.

Image Analysis

The parameters assessed were: Right and left A1 segment of the anterior cerebral artery (ACA); right and left A2 segment of the ACA; right and left M1 segment of the middle cerebral artery (MCA); right and left P1 segment of the posterior cerebral artery (PCA); right and left posterior communicating

Table 4: Comparison of the demonstration of arterial segments between IADSA and MRA by observer 2.

Arterial segment	IADSA			3D TOF MRA		
	Normal	Small	Absent	Normal	Small	Absent
Right A1 (n=38)	31	7	0	32	6	0
Left A1 (n=35)	32	3	0	33	2	0
Right A2 (n=38)	38	0	0	36	2	0
Left A2 (n=35)	34	1	0	33	0	0
Right M1 (n=38)	38	0	0	38	0	0
Left M1 (n=35)	35	0	0	35	0	0
Right P1 (n=33)	32	1	0	29	3	1
Left P1 (n=32)	32	0	0	31	1	0

IADSA = intraarterial digital subtraction angiography
3D TOF MRA = 3 dimensional time of flight magnetic resonance angiography
A1 = A1 segment of the anterior cerebral artery
A2 = A2 segment of the anterior cerebral artery
M1 = M1 segment of the middle cerebral artery
P1 = P1 segment of the posterior cerebral artery

artery (PCOM) and the anterior communicating artery (ACOM).

For the non-contrast enhanced 3D TOF MRA technique, the arterial segments were graded according to whether it is normal, small or absent for the A1, A2, M1 and P1 segments; patent, functional or not visualised for the communicating segments.

The A1, A2, M1 and P1 segments of the arterial Circle of Willis are considered as: (a) Normal when the diameter of the vessel is more than or equal to 1mm. (b) Small when the diameter is less than 1mm. This could be due to hypoplastic vessel or vessel spasm. (c) Absent when the vessel is not visualised. This could be due to congenital absence, thrombosis or vessel spasm.

The patency of the ACOM and PCOM were established when the arteries were visible. The ACOM was considered functional when the two A2 segments showed identical signal intensities with a single A1 segment while the contra lateral A1 segment is absent or hardly visible. The PCOM was considered functional if it has the same diameter and signal intensities as the P2 segment while the P1 segment is absent or hardly visible (2). Failure to identify the communicating arteries could be related to non-patency (atresia, thrombosis or vessel spasm); an absence of significant flow in the baseline conditions i.e. equilibrium between its two arterial feeders (2).

The depiction of the A1, A2, M1 and P1 segments of the arterial circle of Willis on the IADSA technique is similar as with the non-contrast enhanced 3D TOF MRA technique and the vessels were graded similarly. For the communicating arteries, i.e. the ACOM, the right and left PCOMs, they are considered: (a) Patent if opacified. (b)Functional if both the vessels it connected are opacified via injection into one of them. (c)Non-visualised if the vessels are not seen. This could be due to congenital absence, thrombosis or spasm (2). For these two techniques, abnormalities of the arterial segments of the circle of Willis were also noted if present.

Data and Statistical Analysis

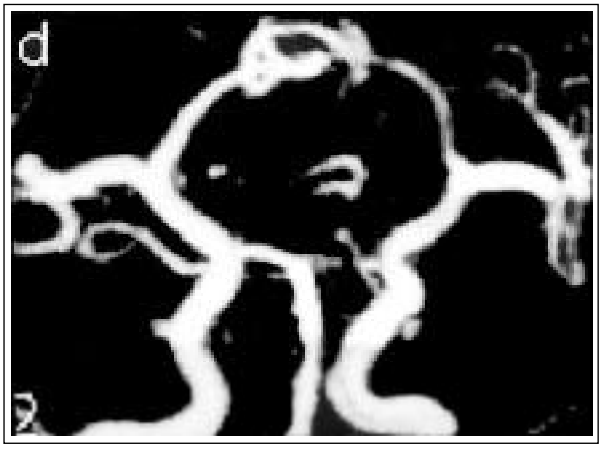
For the data analysis, the intraarterial digital subtraction angiography (IADSA) was taken as the gold standard. There was complete agreement between observers 1 and 2 in depiction of the presence of each of the arterial segments for this technique. The arterial segments of the circle of Willis were compared between the two techniques

Table 5: Sensitivity, specificity and predictive values of non-contrast enhanced 3D TOF MRA compared to IADSA in detection of the segments of the Circle Of Willis.

Arterial segment	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Accuracy
A1	(63/65) 100%	(8/8) 100%	(63/65) 100%	(8/8) 100%	(73/73) 100%
A2	(68/72) 94.5%	(1/1) 100%	(68/68) 100%	(1/4) 25%	(70/73) 95.9%
M1	(73/73) 100%	-	(73/73) 100%	-	(73/73) 100%
P1	(60/62) 96.8%	(3/3) 100%	(60/60) 100%	(3/5) 60%	(63/65) 96.9%
ACOM	(17/17) 100%	(19/21) 90.5%	(13/19) 89.5%	(19/19) 100%	(36/38) 94.7%
PCOM	(15/70) 21.4%	(3/3) 100%	(15/15) 100%	(3/58) 5.2%	(18/73) 24.66%

A1 = A1 segment of the anterior cerebral artery
A2 = A2 segment of the anterior cerebral artery
M1 = M1 segment of the middle cerebral artery
P1 = P1 segment of the posterior cerebral artery
ACOM = anterior communicating artery
PCOM = posterior communicating artery

Figure 1: Magnetic resonance angiography of the circle of Willis showing splaying of the arterial segments (arrows) due to presence of a space occupying lesion. In addition, there is narrowing of the left P1 and A1 segments most likely secondary to the mass effect.



by both observers on separate occasion. In addition, comparison of depiction of the arterial segments between the 2 observers using the non-contrast enhanced 3D TOF MRA technique was also performed. Statistical analysis was done by using SPSS for Windows Version 9.0 software program.

The accuracy of the non-contrast enhanced 3D TOF MRA technique as compared to the IADSA technique was analysed statistically in terms of its sensitivity, specificity and predictive values. Measure of the agreement between the non-contrast enhanced 3D TOF MRA and the gold standard IADSA was determined by using the kappa statistics. The agreement can be interpreted as k £ 0.20 as slight, 0.21 – 0.40 fair, 0.41 – 0.60 moderate, 0.61 – 0.80 substantial and 0.81 – 1.00 as perfect. Measure of agreement between the two observers in depicting the arterial segments of the Circle of Willis was also determined by using the Kappa statistics.

Results

A total of 398 arterial segments were compared and analysed (73 A1 segments, 73 A2 segments, 73 M1 segments, 65 P1 segments, 38 ACOM segments and 73 PCOM segments). The duration between the non-contrast enhanced 3D TOF MRA and the intraarterial DSA range from 1 to 30 days with mean of 9.3 days.

Comparisons of the depiction of the arterial segments between these two techniques by the two observers were done quantitatively (tables 1 – 4). The measures of agreement between these two techniques were than analysed statistically using the kappa method. The kappa coefficients between IADSA and non-contrast enhanced 3D TOF MRA in detecting the arterial segments of the Circle of Willis by observers 1 and 2 are: A1 (0.88, 0.87); A2 (0.39, 0.39); P1 (0.57, 0.42); ACOM (0.41, 0.89); right PCOM (0.07, 0.03) and left PCOM (-0.06, 0.02) respectively. The measures of agreement by the 2 observers were also calculated, giving kappa coefficient values of 0.89 (A1), 1.00(A2), 0.89(P1), 0.96(ACOM), 0.93(right PCOM) and 0.86(left PCOM).

Our study has shown that non-contrast enhanced 3D TOF MRA technique is highly accurate in depicting the segments of the circle of Willis, excluding the PCOM segment. It is sensitive in depicting the A1, A2, M1, P1 and ACOM segments of the Circle of Willis (table 5). It was 100% sensitive for depiction of the A1, M1 and the ACOM segments; 96.8% and 94.5% for the P1 and the A2

Figure 2: Magnetic resonance angiography showing presence of an aneurysm arising from the right anterior cerebral artery which is confirmed by intraarterial digital subtraction angiography study.

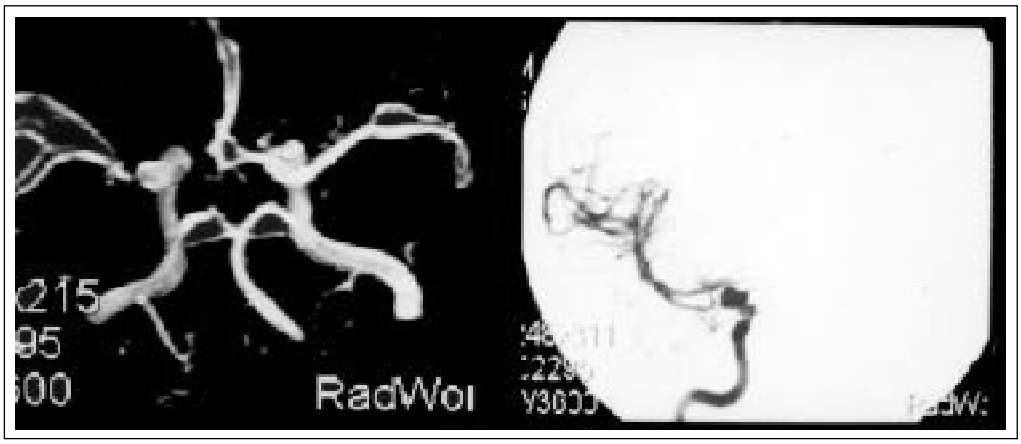
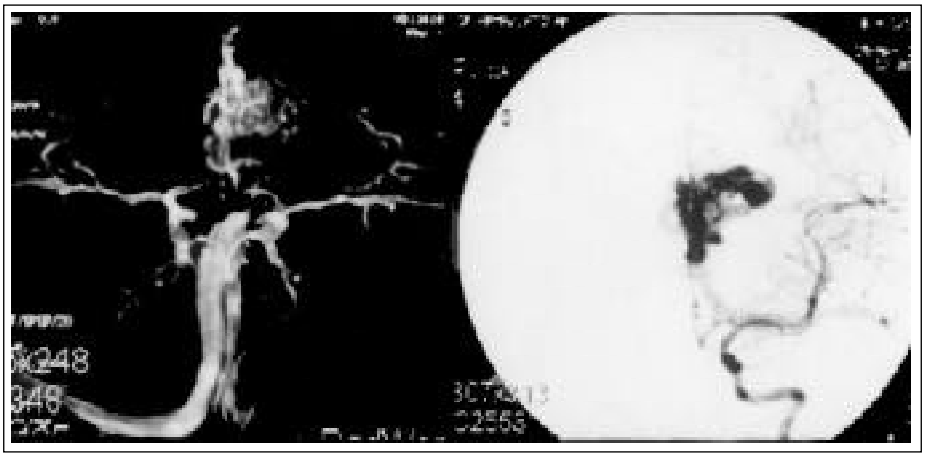


Figure 3: Magnetic resonance angiography showed an arteriovenous malformation at the left parasagittal region which is confirmed by the left internal carotid artery run of the intraarterial digital subtraction angiography study.



segments respectively. In addition, it is also highly specific, with a specificity of 100% for the A1, A2, P1 and PCOM segments and specificity of 90.5 % for the ACOM segments. There were no false negative findings for A1, M1 and ACOM and the false negative findings for A2 was 3 out of 4 patients and for P1 it was two out of five patients. The depiction of the PCOM segment was however very poor with a sensitivity of 21.4%. The false negative findings for this vessel was 53 out of 58 patients. There were no false positive results for the A1, A2, M1 and P1 segments. However, two false positives out of 19 patients were found for the ACOM segment.

The non-contrast enhanced 3D TOF MRA technique also correctly depicted 9 cases of splaying and stretching of the arterial segments of the circle of Willis due to presence of space occupying lesions. An example of vascular splaying due to a space occupying lesion is demonstrated in figure 1. Out of these 9 cases, 5 of them demonstrated presence of tumour blush on the IADSA technique, but only 2 of the tumour blush were detected on the non-contrast enhanced 3D TOF MRA technique.

Detection of vascular lesions was also possible, where one aneurysm at the tip of the basilar artery, one aneurysm arising from the internal carotid artery (figure 2) and an arteriovenous malformation at the left parasagittal region (figure 3) were also correctly identified. However, the non-contrast enhanced 3D TOF MRA did not detect the presence of a posterior fossa AVM found on the IADSA technique.

Discussion

MIP display of the non-contrast enhanced 3D TOF MRA technique is a reliable and accurate method for anatomical depiction of most of the arterial segments of the Circle of Willis except for the PCOM segment. Observer agreement of the two techniques is fair to perfect except for the PCOM segment where the agreement is only slight, stressing the point that the non-contrast enhanced 3D TOF MRA technique is not reliable for the assessment of the PCOM segment.

There is perfect agreement between the two observers in depicting the arterial segments of the Circle of Willis using the non-contrast enhanced 3D TOF MRA technique.

The false negative findings for the A2, P1 and PCOM segments in our patients could be due to either problems of saturation effects of slow flowing blood or due to limits of resolution of this technique and its MIP post-processing images (3-5). The MIP processing technique contributes to the problem because it ignores low signal intensities that fall less than a certain threshold. The MIP algorithm generally requires the vessel to be at least two standard deviations above the background to allow the ray tracing technique to work successfully for visualisation of the vessels (3, 4). If the vessel intensity were less than this value, the vessel would not be demonstrated in the MIP images. Another reason for the poor depiction of the PCOM segment is that in certain cases, this segment is smaller than the MRA section widths and run parallel to the

axially acquired sections. This made the depiction of the segment to be limited by volume averaging.

The false positive findings of the ACOM segment could be explained by two possibilities: (i) a patent vessel was not seen with IADSA because compression manoeuvres were not routinely performed. If flow within the ACOM segment is in equilibrium with the segments that it connected it would not be opacified (4). (ii) presence of bright objects on T1WI e.g. fat or subacute haemorrhage could also give false impression that the ACOM segment is present.

Conclusion

MIP display of the non-contrast enhanced 3D TOF MRA is an accurate and reliable method for anatomical depiction of the arterial segments of the circle of Willis except for the PCOM segment. However further studies need to be done to assess the reliability of this technique for assessment of pathological changes of the arterial segments.

Correspondence:

Dr. Rozita Mohd Ghazali, MBBS (Adelaide), MMed. Radiology, (USM).
Hospital Ipoh,
30990 Ipoh,
Perak.

References

1. Sheppard, S. Basic concepts in magnetic resonance angiography.*Radiologic Clinics of North America* 1995; **33**(1), 91–113.
2. Patrux, B., Laissy, J.P., Jouini, S., Kawiecki, W., Coty, P., Thiebot, J. Magnetic resonance angiography (MRA) of the circle of Willis: a prospective comparison with conventional angiography in 54 subjects. *Neuroradiology* 1994; **36**, 193–197.
3. Katz, D.A., Marks, M.P., Napel, S.A., Bracci, P.M., Roberts, S.L. Circle of Willis: evaluation with spiral CT angiography, MR angiography, and conventional angiography. *Radiology* 1995 **195**, 445–449.
4. Stock, K.W., Wetzel, S., Kirsch, E., Bongartz, G., Steinbrich, W., Radue, E.W. Anatomic evaluation of the circle of Willis: MR angiography versus intraarterial digital subtraction angiography. *Am J Neroradiol* 1996 **17**, 1495 –1499.
5. Krabbe-Hartkamp, M.J., Grond, J., Leeuw, F., Groot, J., Algra, A., Hillen, B., Breteler, M., Mali, P. Circle of Willis: Morphologic variation on three-dimensional time-of-flight MR angiograms. Radiology 1998; **207**: 103-111.