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Research article

# Magnetic Resonance Angiography and Cisternography fused images in acute ischemic stroke may save time during endovascular procedure revealing vessel anatomy

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ABSTRACT

*Background and purpose:* Endovascular treatment (EVT) is a time-dependent procedure that aims to remove the arterial blood flow obstruction in brain vessels in acute ischemic stroke. In our center, the MRI patient selection protocol in acute ischemic stroke is performed with DWI, FLAIR, MR angiography (MRA) and MR cisternography (MRC) sequences. MRA and MRC are promptly and automatically fused in order to have a clear detection of vessel anatomy, before and during EVT.

Our study aim is to evaluate if the fusion process between MRA and MRC could be considered time-safe and could influence EVT duration or outcome.

*Materials and methods:* 45 patients were retrospectively selected for the study and divided into 2 groups according to the presence of MRC sequence fused with MRA (Group 1) or not (Group 2 - controls).

*Results:* MRA and MRC fusion was able to depict vessel anatomy in all subjects of Group 1 (22 patients, 12 females; age 75.59 years ± 10.87). Group 1 presented EVT time reduction ($p < 0.05$; $p = 0.040$) (51.59 min ± 30.94) when compared to Group 2 (23 patients, 13 females; age 75.04 years ± 12.12) (71.96 min ± 34.55) of 20.37 min average. No differences between groups were detected evaluating: NIHSS at admission ($p = 0.49$) and discharge ($p = 0.67$), pre-stroke mRS ($p = 0.89$), mRS at 90 days ($p = 0.62$), ASPECT ($p = 0.98$) and ASPECT-DWI scores ($p = 0.93$), time from symptom onset to groin puncture ($p = 0.80$), thromboaspiration vs combined technique ($p = 0.67$), EVT success ($p = 0.63$).

*Conclusion:* Fusion of MRA and MRC is a safe and promising technique in promptly revealing vascular anatomy beyond vessel obstruction, and can play a role in EVT duration reduction.

## 1. Introduction

Acute ischemic stroke (AIS) is a cerebrovascular disease with a striking occurrence of 1 patient on average every 40 s (in the US population according to the American Heart Association) [1]. The estimated incidence of AIS is of around 216/100,000/year, though this statistic may slightly vary according to the population sampled [2].

A successful endovascular treatment (EVT) of AIS is able to reduce mortality and morbidity with a level 1a evidence, by removing the obstruction to the arterial cerebral blood flow and allowing a timely reperfusion [3, 4]. In anterior circulation AIS, EVT was judged beneficial even when performed 24 h after the onset of symptoms, if some assumptions are met [5, 6].

Patient selection for endovascular reperfusion is a crucial point to obtain favorable outcomes; in this context computed tomography angiography (CTA) or magnetic resonance imaging (MRI) plays a pivotal role [7]. EVT patient selection with CTA or MRI may vary among different centers and stroke units. The modality of choice often depends on different structural and organizational solutions, with both approaches presenting inherent advantages and disadvantages [7, 8, 9].

Recent studies described how difficult anatomies could influence recanalization success, increasing radiation exposure, EVT duration, and

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the risk of complications and poor outcomes [10, 11, 12, 13, 14, 15]. To perform a more efficient EVT approach, it would be advisable - before the procedure - to have as thorough a knowledge as possible about the vascular anatomy ahead of the thrombus, the exact location of vessel obstruction, and the anatomy beyond the obstruction. MRI could play a pivotal role in this scenario due to the possibility to use different sequences that might be able to show all the above-mentioned anatomical patterns. As recently reported, MRI can clearly show and depict the anatomy beyond the vessel obstruction in anterior circulation AIS, potentially providing several advantages, by using an MR cisternography (MRC) sequence [16, 17].

In our center, the patient selection is performed with MRI by a protocol composed of diffusion-weighted imaging (DWI), magnetic resonance angiography (MRA), fluid-attenuated inversion recovery (FLAIR) sequences, and an MRC sequence. MRA and MRC are timely fused in order to have a clear detection of vessel anatomy, before and during EVT [16].

Our retrospective study aims to assess if the fusion process may affect patient clinical outcome, EVT outcome, EVT duration.

## 2. Materials and methods

### 2.1. Study design

This single-center study received ethical approval from our Institutional Review Board (ref. num. MECE77-21) and was performed following the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written informed consent was waived due to the study's retrospective design.

From our hospital record database, patients with AIS were retrospectively evaluated for our study from January 2020 to January 2021. From both radiological and hospital database, all medical records of each patient with AIS during this period were evaluated. 22 patients were selected as Group 1 for the study according to different inclusion and exclusion criteria.

Patients selection inclusion criteria were the following: symptoms suggestive for anterior AIS [National Institutes of Health Stroke Scale (NIHSS) $\geq$ 1], lower age limit of 18, absence or limited motion MRI artifacts for all sequences (FLAIR, DWI, MRA, and MRC), DWI suggestive for AIS in the middle cerebral artery (MCA) territory, MRA suggestive for M1 or M2 MCA occlusion, EVT for the occlusion, presence of clinical data at admission, discharge, and follow-up.

Exclusion criteria were hemorrhagic stroke (showed using CT), an AIS in a different territory from MCA (demonstrated by DWI), wake-up stroke, presence of lacunar infarcts only, absolute MRI contraindications, administration of intravenous thrombolysis.

Sex, age upper limit, NIHSS upper limit, pre-stroke modified Rankin Scale (mRS), side of MCA occlusion, and comorbidity were not taken into account as inclusion or exclusion criteria.

To test our cohort of 22 patients (Group 1) with a control group, we selected 23 patients (Group 2) from our hospital record database with the same exclusion and inclusion criteria, except for the MRC sequence in their study protocol. To select this second group, we evaluated our record from 2018 to 2020; during this period MRC was not part of our AIS-MRI acquisition protocol yet. Each patient of both groups underwent EVT. Some of the selected data were included in previous studies [16].

### 2.2. Data analysis

The following demographic and clinical data were collected: age, sex, pre-stroke mRS, mRS at discharge and mRS at 90 days (mRS90), NIHSS at admission, at 24h (NIHSS24h) and at discharge, Alberta Stroke Program Early CT (ASPECT) and ASPECT-DWI scores respectively evaluated in CT and DWI MRI sequence, site and side of MCA occlusion, time from AIS symptom onset to groin puncture for EVT ("onset to groin"), EVT duration, EVT approach (thromboaspiration or combined techniques), modified treatment in cerebral infarction (mTICI). mTICI 2b, 2c, and 3 were considered as successful EVT. When recanalization was not achievable, the time for EVT duration was calculated by using the last DSA acquisition time.

### 2.3. Data acquisition

Philips Ingenia 1.5 T (Philips Healthcare, Best, The Netherland) was used as the MRI scanner. The following parameters were used for the MRI protocol: EPI-DWI, 4 b-value 0, 50, 500, 1000 s/mm $^2$, 1.5 $\times$ 2.2 $\times$ 5mm voxel, 22 slices, TR 2700ms, TE 85ms, 1min 2s duration; MRA (TOF-3D without contrast medium), 0.8 $\times$ 0.9 $\times$ 1,6mm voxel, 126 slices, TR 23, TE 6.9, 3min 40s duration; FLAIR 0.9 $\times$ 1.2 $\times$ 5mm voxel, 22 slices, TR 11000ms, TE 130ms, TI 2800ms, 2min 34s duration; MRC sequence was performed with a Balanced Fast Field Echo set with 0.7 $\times$ 0.7 $\times$ 0.8mm voxel, TR 6.2 TE 3.1, -0.35mm gap, 125 slices, 75 s duration.

### 2.4. Fusion of MRA and MRC – MR (A + C)

MRA and MRC were fused together in one image set, by an automatic process provided by a built-in software of the MR Scanner (Philips Intellispace Portal IX) (Figure 1), which automatically overlays MRA and MRC, coregistering them. This procedure allows the new fused image set to be viewed in multi-planar reconstruction (MPR) and Maximum Intensity Projection (MIP) mode in standard coronal, axial, and sagittal planes (plus different user-defined oblique planes) (Figures 2, 3, and 4).

From now on the MRA and MRC 3D-fused images are referred to as MR (A + C).

MR (A + C) could be also reconstructed in one single fused Volume Rendering (VR) image set in order to easily outline vessel anatomy before and beyond the occlusion in a single 3D-VR image (Figures 1 and 4).

Image sets (2D-fused and 3D-fused volumes) were digitally sent to the Angiography Suite (Siemens Artis Q Biplane, Siemens Healthineers, Erlangen, Germany) and were reviewed by the interventional neuroradiologist before and during the EVT as reference for vessel anatomy beyond the clot obstruction.

### 2.5. Statistical analysis

All statistical computations were performed using SPSS version 16.0 (SPSS Inc., Chicago, IL). Descriptive statistics were used to evaluate and summarize data (arithmetic mean, median, range, absolute numbers, and percentages). Shapiro-Wilk test was used to test data for normal distribution. For the non-normally distributed data, non-parametric approaches were used, regardless of the type of variable. Mann-Whitney U test was used to test two different independent groups for differences in selected variables. A Chi-square test was performed to test for association between categorical variables. Yates corrected values were reported for Chi-square to reduce approximation error. A value of $p < 0.05$ was considered statistically significant. Moreover, Grubbs' test and generalized ESD (extreme studentized deviate) method were used to determine whether the most extreme values were significant outliers from the rest (Figure 5). A post hoc power analysis of the retrospective study was also performed.

## 3. Results

45 patients were selected for the study and divided into two groups respectively Group 1 with the MRC sequence and fusion MR (A + C) and Group 2 without it.

22 patients were selected for Group 1 (10 males and 12 females; 75.59 years $\pm$ 10.87, median 78, range 53–92) and 23 for Group 2 (10 males and 13 females; 75.04 years $\pm$ 12.12, median 80, range 37–89). No differences between sex ($p = 0.86$) and age ($p = 0.96$) were found between the groups. Post hoc statistical power analysis for retrospective studies obtained a value of 0.6.

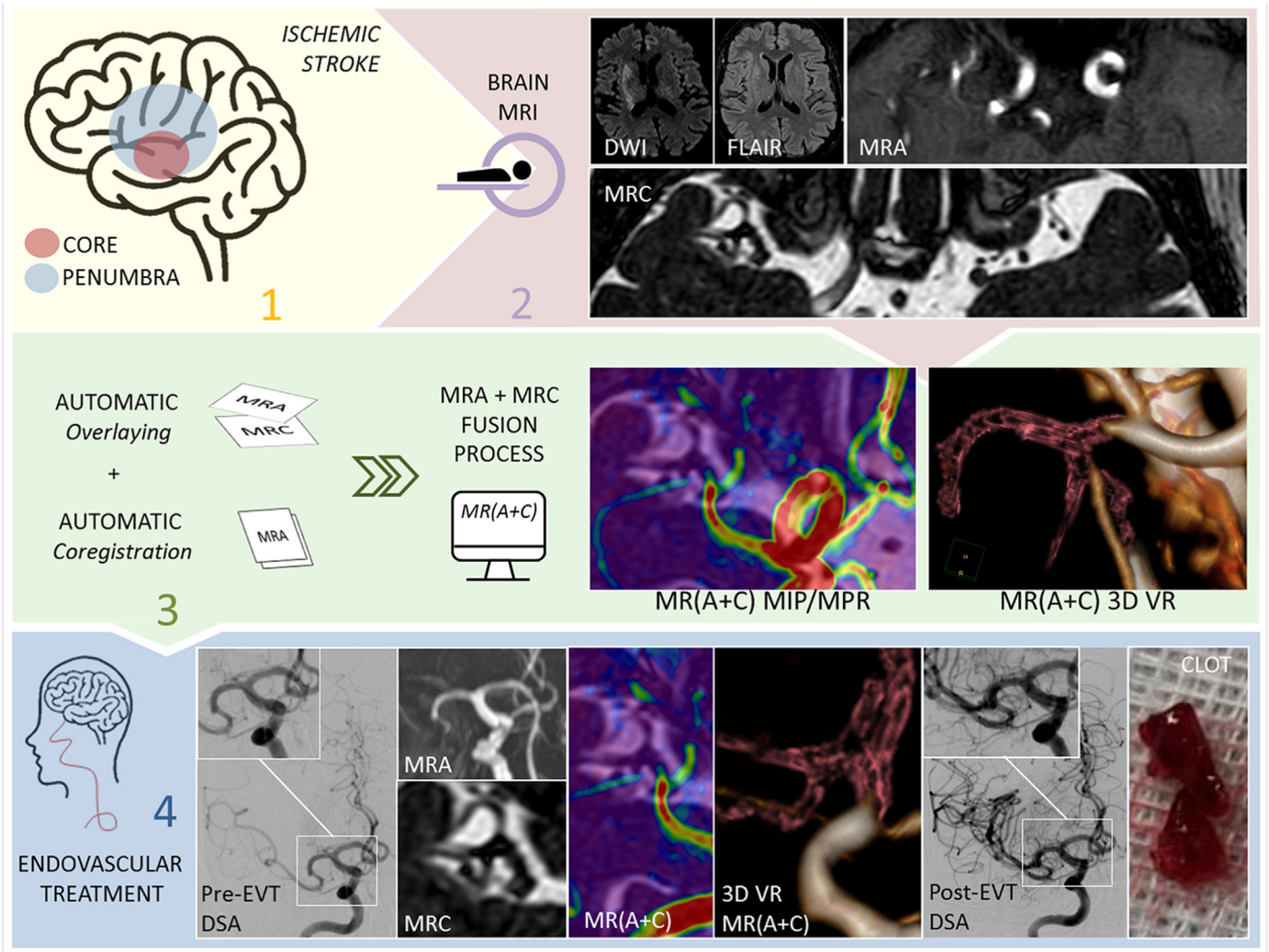


**Figure 1.** *Workflow.* The figure shows the integration of the fusion process of Magnetic Resonance Angiography and Cisternography in the diagnosis and endovascular treatment of anterior circulation acute ischemic stroke. **1** Clinical recognition of an acute ischemic stroke. **2** Brain MRI with the sequences DWI, FLAIR, MRA, and MRC. **3** Fusion process with the automatic overlaying and coregistration generates in a few seconds MR (A + C) MIP/MPR and VR image data sets. **4** Endovascular treatment is performed on the patient affected by the acute ischemic stroke, with MR (A + C) serving as guidance. *MRA = Magnetic Resonance Angiography; MIP = Maximum Intensity Projection; MRC = Magnetic Resonance Cisternography; MPR = Multi Planar Reconstruction; MR (A + C) = Magnetic Resonance Angiography and Magnetic Resonance Cisternography fused images; VR = Volume Rendering.*

### 3.1. Ability to depict vessel anatomy beyond the obstruction

The automatic fusion process of MR (A + C) outlined MCAs ahead of the clot and before it, depicting their courses, angles, calibers, and branches in every single patient of Group 1. On the other hand, in Group 2 MRA was able to provide MCAs anatomies details only before the occlusion, since MRC was not performed in these patients.

### 3.2. NIHSS

Group 1 vs Group 2 presented no significant differences for NIHSS; respectively NIHSS at admission was 10.45 ± 5.40 [median 10.5, range 3–19] vs 11.52 ± 6.47 [median 12, range 1–22] ($p = 0.49$), NIHSS at 24 h 9.86 ± 6.76 [median 8, range 0–24] vs 9.39 ± 5.98 [median 10, range 0–20] ($p = 0.97$), NIHSS at discharge 7.68 ± 5.90 [median 7, range 0–21] vs 6.61 ± 4.64 [median 6, range 0–16] ($p = 0.67$).

### 3.3. mRS

Group 1 vs Group 2 presented no significant differences for mRS; respectively mRS pre-stroke was 0.36 ± 0.7 [median 0, range 0–3] vs 0.78 ± 1.04 [median 0, range 0–3] ($p = 0.89$), mRS at discharge 3.18 ± 1.56 [median 3, range 0–6] vs 2.78 ± 1.47 [median 3, range 0–6] ($p = 0.40$), mRS at 90 days 2.63 ± 1.89 [median 3, range 0–6] vs 2.96 ± 2.20 [median 3, range 0–6] ($p = 0.62$), and numbers of death at 3 months (mRS 90 days = 6) 2 patients (9.09%) vs 5 patients (21.74%) ($p = 0.45$).

### 3.4. ASPECT

No differences between the two groups were found for both ASPECT and ASPECT-DWI scores; respectively it was for Group 1 and Group 2 of 8.32 ± 1.49 [median 8, range 6–10] vs 8.30 ± 1.14 [median 8, range 7–10] ($p = 0.98$) and 7.54 [median 7.5, range 5–10] ± 1.37 vs 7.56 ± 1.27 [median 7, range 5–10] (p = 0.93).

### 3.5. Site and side of MCA occlusion

Group 1 vs Group 2 presented no significant differences for the site of MCA occlusion; respectively it was 11 occlusions of the M1 branch of MCA (50%) and 11 occlusions of an M2 branch of MCA (50%) for Group 1 vs 14 occlusions of the M1 branch of MCA (60.87%) and 9 occlusions of an M2 branch of MCA (39.13%) ($p = 0.66$) for Group 2.

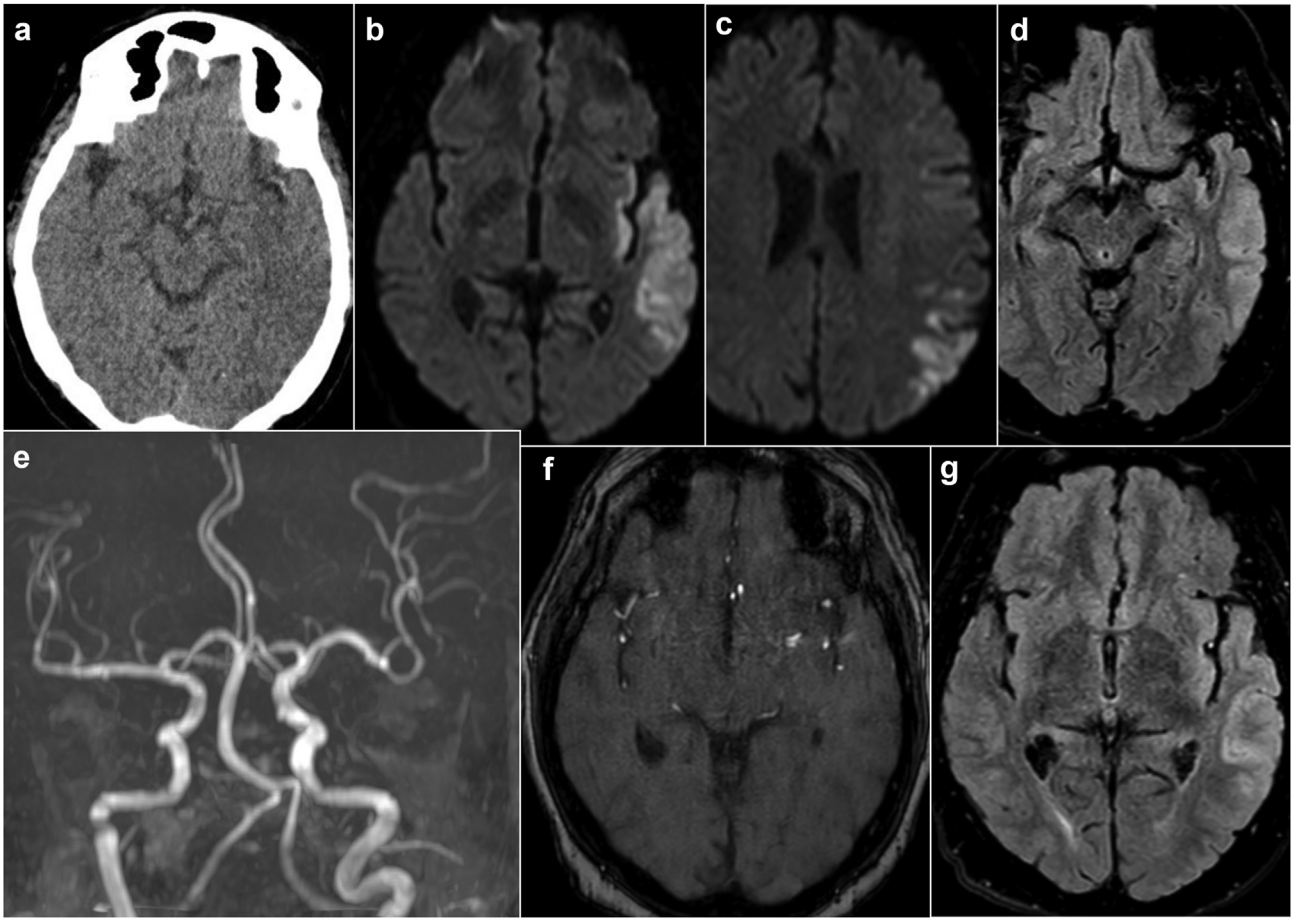


**Figure 2.** M2 left middle cerebral artery occlusion (Computed Tomography and Magnetic Resonance Imaging). **a** Computed Tomography axial image shows M2 left middle cerebral artery hyperdense thrombus and early ischemic signs in the left insula and temporoparietal lobe. **b** and **c** Axial DWI images show restricted diffusivity in the left insula and temporoparietal lobe. **d** and **g** Axial FLAIR images show hyperintensity in the left insula and temporoparietal lobe. **e** and **f** MRA-MIP and axial MRA do not show "at a glance" the exact site of M2 left middle cerebral artery occlusion. *MRA = Magnetic Resonance Angiography; MIP = Maximum Intensity Projection.*

Group 1 vs Group 2 presented no significant differences for the side of MCA occlusion; respectively it was 12 on the left side (54.55%) and 10 on the right side (45.45%) vs 12 on the left side (52.14%) and 11 on the right side (47.83%) ($p = 0.89$).

### 3.6. AIS onset to groin

No differences between the two groups were found for the onset of AIS symptoms to EVT groin puncture (onset to groin). It was for Group 1 of 344.28 min ± 131.72 [median 287, range 175–630] and for Group 2 of 324.70 min ± 178.86 [median 328, range 50–860] ($p = 0.80$).

### 3.7. EVT duration, technique, and success

There was a significant difference between Group 1 and Group 2 in the duration of the EVT (Figure 5).

Group 1 had an EVT of 51.59 min ± 30.94 [median 42.5, range 15–128] and Group 2 of 71.96 min ± 34.55 [median 64, range 22–150] ($p < 0.05$, $p = 0.040$). Group 1 presented an EVT duration average of 20.37 min shorter compared to Group 2.

For both groups, there was a high rate of EVT success, in more than 90% of the patients of each group (successful EVT was considered by our study as mTICI 2b, 2c, or 3). Group 1 had successful EVT reperfusion in 20 cases (90.91%) while Group 2 in 21 cases (91.30%), with no differences between groups ($p = 0.63$).

The EVT approach (thromboaspiration alone vs combined technique) did not differ between groups ($p = 0.67$); respectively thromboaspiration alone was used in 10 patients (45.45%) for Group 1 and 8 patients (34.78%) for Group 2. The combined technique was used for the remaining patients of both groups. No significant differences were noted evaluating the number of passes in Group 1, 2.14 ± 1.12 [median 2, range 1–4] and Group 2, 2 ± 0.95 [median 2, range 1–4], ($p = 0.76$). Only 1 case (4.35%) of clot fragmentation and distal embolization during EVT occurred in Group 2.

Demographic data, clinical data, and results are summarized in Table 1.

## 4. Discussion

Recent studies highlighted that EVT reperfusion in AIS, even up to 24 h from symptom onset, has a high level of evidence in reducing both mortality and morbidity [3, 5, 6].

In AIS of MCA territory, clot removal was reported to be challenging in some peculiar anatomical settings. According to Alverne et al., although EVT failure is a multifaceted problem and should account for different issues, one of the major drawbacks to consider is the unfavorable anatomical arteries configuration [11]. Intracranial tortuosity, curved or branching vessels of MCA have been shown to represent an independent predictor of EVT failure by Zhu et al. [18].

For both thromboaspiration and mechanical thrombectomy, different thresholds of vessel angulation have been reported to have a negative impact on EVT success, such as recurrent branches and curved MCA, acute angulation of internal carotid artery (ICA) and of M1 and M2 branches of MCA, acute M1/M1 angle (proximal M1 angle and the

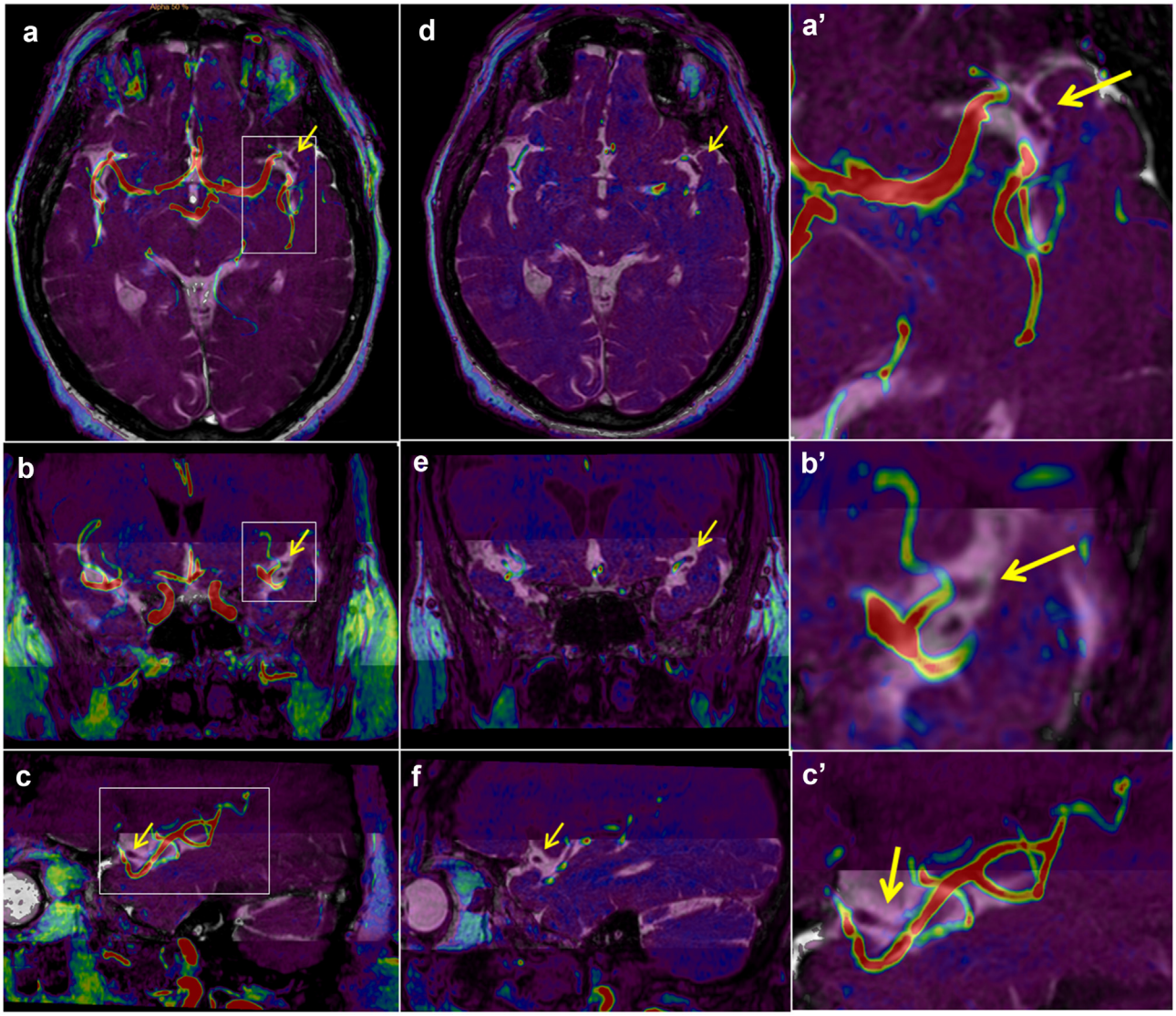


**Figure 3.** M2 left middle cerebral artery occlusion: fused Magnetic Resonance Angiography and Cisternography images (MR(A + C)) with and without MIP reconstructions. **a,b,c** Axial, coronal and sagittal planes of MR (A + C) made with an MRA-MIP reconstruction show the site of M2 left middle cerebral artery branch occlusion (yellow arrows). **d,e,f** Axial, coronal and sagittal planes of MR (A + C) made without MIP reconstruction show the site of M2 left middle cerebral artery branch occlusion (yellow arrows). **a',b',c'** Zoomed images of **a,b,c,** (2x) better show the exact site of occlusion (yellow arrows), allowing to depict the trajectories of the occluded M2 branch of the middle cerebral artery, beyond the vessel occlusion placed at vessel origin. Please note the panoramic view of the site of occlusion and its relationship with the anatomical configuration beyond it, by using MR (A + C) with MIP reconstruction. These images (**b'** and **c'**) resemble the angiographic images that the interventional neuroradiologist observed during the endovascular procedure. *MRA = Magnetic Resonance Angiography; MIP = Maximum Intensity Projection; MRC = Magnetic Resonance Cisternography; MR(A + C) = Magnetic Resonance Angiography and Magnetic Resonance Cisternography fused images.*

segment immediately conterminous to the thrombus) [10, 11, 15, 19]. Bernava et al. recently showed in their cohort of 85 patients with AIS that the first-line treatment with thromboaspiration has a greater rate of success for angles of interaction $\geq$125.5° between the aspiration catheter and the clot [15]. Thus, achieving a position of the aspiration catheter with a similar axis to the occluded branch at the clot position may optimize the aspiration force, increasing EVT efficacy [15]. On the other hand, acute angles of interaction decreased the efficacy of thromboaspiration, resulting in a change of technique, such as rescue stent thrombectomy which was effective in 92.6% of clot aspiration failure [19].

Further, Snelling et al. described how unfavorable vascular anatomy increased EVT duration and could worsen the outcome in their cohort of 61 patients with AIS undergoing thrombectomy [13].

The abovementioned studies show that the understanding of the underlying vascular anatomy could be crucial in EVT success and might play a pivotal role in guiding EVT, potentially modifying its duration or management.

Arterial vessel course and anatomy can be shown by MRA only if there is a detectable signal of blood flow. For this reason, MRA is not able to show MCA anatomy beyond the vessel obstruction in AIS [17, 20]. Some authors tried to propose a solution to these different issues with the use of MRI in a combined approach by fusing MRA and MRC sequences [17, 20]. MRC, with its high spatial resolution and intrinsic high contrast resolution, can straightforwardly discern vessels and cranial nerves from cerebrospinal fluid, thus recognizing and outlining MCAs in Sylvian cisterns (Figure 4c). The use of these two sequences fused can show the anatomy both before and beyond the vessel obstruction, due to their peculiar characteristics [15, 16, 18].

Recently, Ozaki et al. proposed a method of MRA fusion with a 3D-SPACE MRC sequence, as a helpful tool for AIS in describing the course

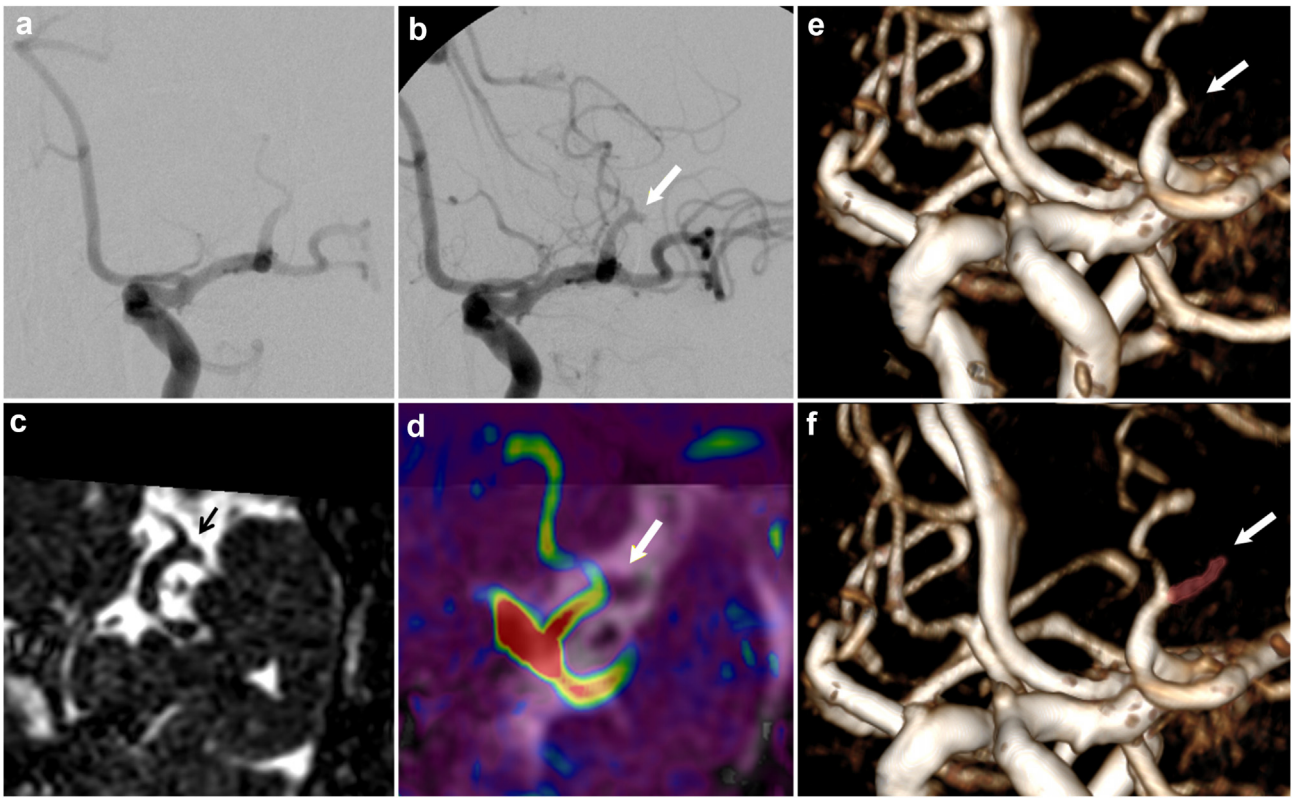


**Figure 4.** M2 left middle cerebral artery occlusion DSA pre and post-EVT, MRC, MRA, MR (A + C)) **a.** Oblique DSA anteroposterior view of the left internal carotid artery and middle cerebral artery shows a vertical vessel with a regular profile. There is a thrombus that hides the origin of a branch arising from the vertical vessel. **b.** The same DSA view after EVT shows partial recanalization of the origin of the abovementioned M2 branch (white arrow). The EVT was performed with a thromboaspiration right near the branch origin since fused images exactly showed where the occluded branch was. **c.** and **d.** Coronal views of respectively zoomed (2,5x) MRC and MR (A + C) show the vessel anatomy beyond the occlusion (black arrow in **c.** and white arrow in **d.**) and allow for detection where it was the exact origin of the occluded vessel. Unfortunately, after several attempts, it was not possible to obtain a complete vessel recanalization. Nonetheless, this technique showed its potential in promptly detecting vessel obstruction even when the vessel origin is "missing" since hidden by a thrombus. Please note how **c.** and **d.** resemble the same DSA projection of **b. e.** Volume Rendering MRA in oblique anteroposterior view of the left internal carotid artery and middle cerebral artery shows a vertical M2 branch. There is a thrombus that hides the origin of a branch arising from a vertical vessel (arrow). **f.** Oblique 3D Volume Rendering MR (A + C) shows "at a glance" the "missing origin" of the MCA branch which is hidden by a thrombus (arrow). *MRA = Magnetic Resonance Angiography; MRC = Magnetic Resonance Cisternography; DSA = Digital Subtraction Angiography; EVT = Endovascular treatment; MR(A + C) = Magnetic Resonance Angiography and Magnetic Resonance Cisternography fused images.*

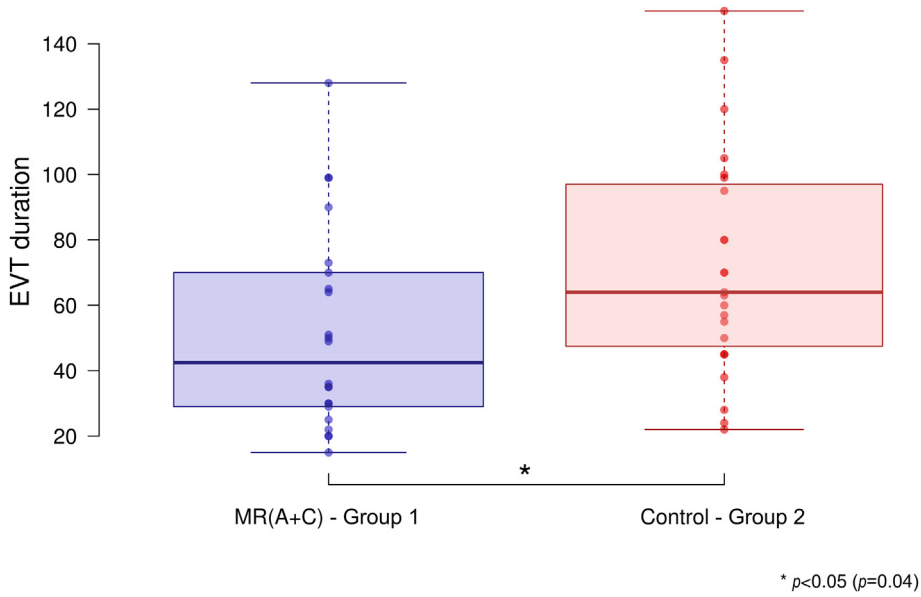


**Figure 5.** Boxplot showing endovascular treatment (EVT) duration in both groups. Lower and upper box boundaries represent respectively the 25$^{th}$ and 75$^{th}$ percentiles, the line inside represents the median value, while dots show EVT duration values. No significant outliers were detected. Alpha value was set at 0.05. *MR(A + C) = Magnetic Resonance Angiography and Magnetic Resonance Cisternography fused; EVT = Endovascular Treatment; * = significance.*

**Table 1. Comparison of demographic and clinical data between Group 1 (MR(A + C) - fused images) and Group 2 (control).** ASPECT = Alberta Stroke Program Early Computed Tomography scores; ASPECT-DWI = ASPECT score evaluated in Diffusion Weighted Imaging; EVT = Endovascular Treatment; NIHSS = National Institutes of Health Stroke Scale; MCA = Middle Cerebral Artery; mRS = modified Ranking Scale; mTICI = modified Treatment In Cerebral Infarction; MR (A + C) = Magnetic Resonance Angiography and MR-Cisternography fused images; * = significance. Data are reported as mean ± SD [median, range] and absolute number with percentage (%).

| | *Group 1 – MR(A + C) n = 22 patients* | *Group 2 – control n = 23 patients* | p-value |
|---|---|---|---|
| Age (years) | 75.59 ± 10.87 [78, 53-92] | 75.04 ± 12.12 [80, 37-89] | $p = 0.96$ |
| Sex | 10 males (45.45%)<br>12 females (54.55%) | 10 males (43.48%)<br>13 females (56.52%) | $p = 0.86$ |
| NIHSS at admission | 10.45 ± 5.40 [10.5, 3-19] | 11.52 ± 6.47 [12, 1-22] | $p = 0.49$ |
| NIHSS at 24 h | 9.86 ± 6.76 [8, 0-24] | 9.39 ± 5.98 [10, 0-20] | $p = 0.97$ |
| NIHSS at discharge | 7.68 ± 5.90 [7, 0-19] | 6.61 ± 4.64 [6, 0-16] | $p = 0.67$ |
| mRS pre-stroke | 0.36 ± 0.79 [0,0-3] | 0.78 ± 1.04 [0,0-3] | $p = 0.89$ |
| mRS at discharge | 3.18 ± 1.56 [3,0-6] | 2.78 ± 1.47 [3,0-6] | $p = 0.40$ |
| mRS at 90 days | 2.63 ± 1.89 [3,0-6] | 2.96 ± 2.20 [3,0-6] | $p = 0.62$ |
| mRS = 6 at 90 days | 2 (9.09%) | 5 (21.74%) | $p = 0.45$ |
| ASPECT | 8.32 ± 1.49 [8, 6-10] | 8.30 ± 1.14 [8, 7-10] | $p = 0.98$ |
| ASPECT-DWI | 7.54 ± 1.37 [7.5, 5-10] | 7.56 ± 1.27 [7, 5-10] | $p = 0.93$ |
| Site of MCA occlusion | 11 M1 (50%)<br>11 M2 (50%) | 14 M1 (60.87%)<br>9 M2 (39.13%) | $p = 0.66$ |
| Side of MCA occlusion | 12 left (54.55%)<br>10 right (45.45%) | 12 left (52.17%)<br>11 right (47.83%) | $p = 0.89$ |
| Onset to groin (min) | 344.28 ± 131.72 [287,175-630] | 324.70 ± 178.86 [328, 50-860] | $p = 0.80$ |
| EVT duration (min) | 51.59 ± 30.94 [42.5, 15-128] | 71.96 ± 34.55 [64, 22-150] | $\mathbf{p = 0.040}$* |
| EVT technique | 10 aspiration (45.45%)<br>12 combined (54.55%) | 8 aspiration (34.78%)<br>15 combined (65.22%) | $p = 0.67$ |
| Successful EVT (mTICI 2b,2c,3) | 20 success (90.91%)<br>2 not success (9.09%) | 21 success (91.30%)<br>2 not success (8.70%) | $p = 0.63$ |
| Number of passes | 2.14 ± 1.12 [2,1-4] | 2 ± 0.95 [2,1-4] | $p = 0.76$ |
| Distal clot embolization due EVT | 0 (0%) | 1 (4.35%) | $p = 0.33$ |
| Ability to detect vessel anatomy beyond the occlusion | 22 (100%) | - | - |

of an occluded vessel [17]. Nonetheless, this study was performed on a single patient in his eighties with an AIS who did not undergo EVT. Kuribara et al. used a similar fusion technique between MRA and MRC 3D-FIESTA on 5 patients affected by AIS [20]: the reported acquisition time of MRC (3 T) was 137 s, and the automatic fusion was performed in less than 10 minutes [20].

A similar approach was described lately by Mormina et al. in a technical note, which have used a ~75-second MRA sequence fused with MRC (Balanced Fast Field Echo at 1.5 T), that provided 2D and 3D MPR and MIP fused images set, and Volume Rendering fused images set [16]. The present study analyzed a cohort of patients (Group 1) in which the same technique has been used in the AIS setting.

Further, vessel anatomy ahead of the clot has been shown also in a group of 14 patients by using the retrograde flow shown by cone-beam CT, with a reported prediction of the MCA course in 79% of the cases [21].

In our work, we evaluated MR (A + C) in an AIS setting as a tool to shed a light on the anatomy before the vessel obstruction and in particular on the unknown anatomy beyond it, in order to assess if EVT could have been influenced by it. For this purpose, it was used a 75-second (1.5 T) MRC sequence fused automatically with MRA. The process generated in a few seconds an MR (A + C) image set, which was able in all patients of Group 1 to show promptly the anatomy beyond the vessel obstruction. The second endpoint of the study was to assess if the use of MR (A + C) before and during EVT could affect patient clinical outcome, EVT outcome, or EVT duration.

Our results showed that there was an EVT duration reduction in the group of patients who were selected for EVT with MR (A + C) (Group 1) if compared to the control group (Group 2) of an average of 20.37 min ($p < 0.05$; $p = 0.040$) (Table 1). We may explain this result by speculating that a better understanding of the underlying vessel anatomy of MCA in an AIS setting may have allowed the neuro-interventional team to "see beyond the obstacle" of the obstructed vessel, performing the procedure accordingly, thus reducing EVT duration. This technique was able to promptly depict vessel anatomy and to show at a glance the course, caliber, angle, and possible branching of MCA beyond the obstruction in each patient. On the other hand, considering the retrospective nature of the study, it was not possible to understand how the neuro-interventional team changed their approach before or during EVT due to MR (A + C).

The use of MR (A + C) did not modify patients outcome, such as NIHSS at 24 h ($p = 0.97$), NIHSS at discharge ($p = 0.67$), and mortality (mRS = 6) ($p = 0.45$), comparing both groups.

This could probably be explained by two main factors. Firstly, the average time of the "onset to groin" of both groups was higher than 5 h and 20 min, thus probably reflecting in already a well-defined ischemic core with no significant differences in ASPECT scores between groups. Secondly, the small sample size of our study may be identified as a reason for this lack of significance.

Conversely, the absence of this significance should account for the use of MR (A + C) in MRI patients' selection for AIS as a safe technique (Table 1). In particular, even if the duration of MRI in Group 1 was 75 s longer than in Group 2, there were no significant differences in the "onset to groin" ($p = 0.80$) time and all of the above-mentioned clinical outcome data, comparing both groups.

MR (A + C) has helped detect timely and safely the location of blood flow obstruction and the MCA course after it. Moreover, being able to outline the MCA course could have aided the vascular navigation and EVT by showing in advance challenging vessel configurations, such as a "missing" origin of an MCA branch (hidden by a clot) (Figures 2, 3, and 4) or a clot in a bifurcation.

## 5. Limitations

In our retrospective study, we decided to use as exclusion criteria, among others, patients who underwent intravenous thrombolysis administration. We made this selection since we wanted to evaluate if

MR (A + C) fused images alone could have any impact on EVT duration, avoiding as much as possible potential EVT "speed modifier", such as thrombolysis. Nonetheless, we did not have enough patients with both thrombolysis and MRI fused images available for subgroup analysis. A future similar study assessing (sub)groups with thrombolysis administration in an AIS setting and MRI fused images could help evaluate better this potential above-mentioned bias. Further, this study is focused only on MCA AIS (M1 and M2 branches only); neither posterior circulation strokes (vertebral arteries and basilar artery) nor "tandem" or "I/T/L" occlusions were considered. Finally, the small sample size of both groups could be recognized as a drawback of the study, limiting the post hoc statistical power of our analysis.

## 6. Conclusions

EVT of AIS is a life-saving time-dependent procedure and could be challenging if particular anatomical vessel configurations are encountered. Our study showed that MR (A + C) is a fast, safe and helpful tool in depicting vessel anatomy before and beyond the vessel obstruction, thus potentially guiding the EVT approach. Moreover, the use of MR (A + C) images can play a role in EVT duration reduction in AIS patient treatment.

## Figures source

Some figures parts (Figures 1, 2, 3, and 4) are released in CC BY 3.0 license from a previous study [22].

## Declarations

### *Author contribution statement*

Enricomaria Mormina, Agostino Tessitore, Antonio Armando Caragliano: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Marco Cavallaro, Orazio Buonomo: Performed the experiments; Wrote the paper.

Mirta Longo: Performed the experiments; Analyzed and interpreted the data.

Francesca Granata; Sergio Lucio Vinci: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Michele Caponnetto: Analyzed and interpreted the data.

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### *Data availability statement*

Data will be made available on request.

### *Declaration of interests statement*

The authors declare the following conflict of interests: Enricomaria Mormina is an editorial team member of Heliyon.

### *Additional information*

No additional information is available for this paper.

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