Assessment of the MAFA ratio as a quantitative prognostic marker of aneurysm occlusion after flow diverter treatment.

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Background and purpose

Flow-diverter stents (FDSs) have been used effectively to treat wide neck and complex intracranial aneurysms (IAs) [1]. However, treatment strategies - such as single or layered FD stenting and/or adjunctive coiling - vary significantly and are inconsistent between different centers, largely due to the absence of reliable angiographic endpoints [2].

Previously, the normalized mean aneurysm flow amplitude ratio (MAFA-R) has been described as a novel metric to quantify aneurysm flow reduction that occurs as a result of FD stenting [2-4]. The aim of this study was to analyze the potential value of measuring per-operative hemodynamic changes to evaluate FDS treatment outcome in a large prospective and consecutive series.

Materials and methods

We included consecutive patients harbouring unruptured saccular sidewall IAs of the internal carotid artery (ICA) eligible for FDS placement. Data was acquired with a flat-panel angiographic C-arm system (Allura FD20/20, Philips Healthcare). First a 3D rotational angiogram of the vessel carrying the aneurysm was acquired. Then, two high frame rate DSA sequences (60 fr/sec) were acquired before and right after the implantation of the FDS with a contrast injection of 1.5 ml/sec for a duration of 4 sec.

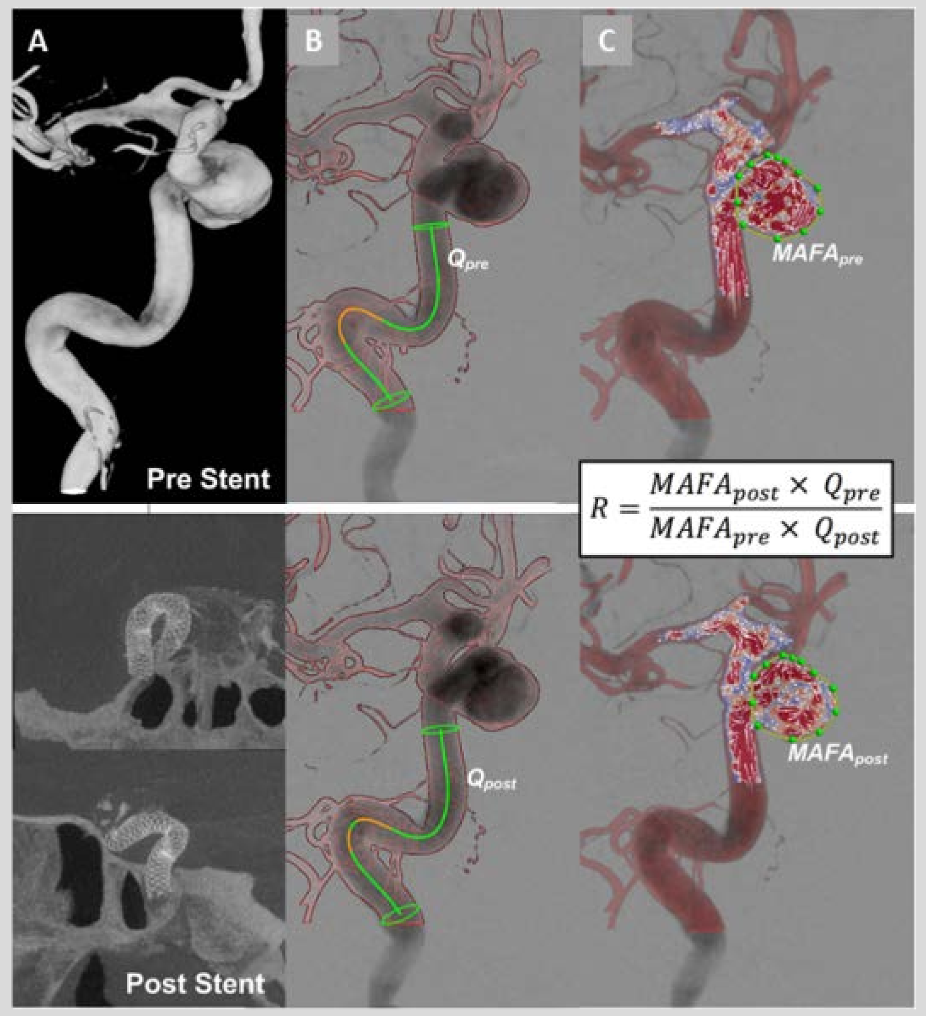

Figure 1: Arterial and aneurysmal flow calculation. A-First row: 3D image of a carotid ophthalmic aneurysm. A-Second row: Post implantation cone-beam CT (AP and lateral) showing a deployed FDS. B, C: Representation of successive steps leading to MAFA ratio calculation for both pre- (first row) and post- (second row) stent acquisitions. B: Vessel segment used for the volume flow rate calculation on co-registered 3D and DSA image C: Representation of the projected velocity fields with their respective MAFA values computed within a region of interest.

Flow reduction was assessed using dedicated software based on optical flow principles (AneurysmFlow, Philips Healthcare). First, the volumetric flow rate was measurement in the upstream artery through the joint registration of the 2D DSA images with the 3D geometry of the vessel. Secondly, the aneurysm velocity fields projected in the line of sight of the detector were measured from which the time- and space-averaged velocities (MAFA) values are derived (Figure 1). The flow modification induced by the stent was assessed by the post-stent-over-pre-stent ratio of MAFAs (MAFA-R), normalized to the parent vessel volumetric flow rates (Q), respectively, taking into account any occurrence of new physiological conditions during the procedure:

$$MAFA\text{-}R = \frac{MAFA_{post} \times Q_{pre}}{MAFA_{pre} \times Q_{post}}$$

The MAFA-R performance for prediction of complete aneurysm occlusion was tested against the thrombosis incidence at 3, 6, and 12 months by using the receiver operating characteristic (ROC) analysis performance test (Figure 2). The Area Under the Curve (AUC) was determined, as well as the threshold maximizing the sum of sensitivity and specificity. The analysis was carried out on the total aneurysm cohort as well as for a subgroup of aneurysms > 10mm.

Results

We included 71 patients harboring 72 unruptured saccular aneurysms. All patients included in the study were successfully treated with FDS without coiling. For 2 patients, the 12 months imaging follow-up was not available. From the 72 aneurysms, 18 were excluded from the ROC analysis because the MAFA-R could not be calculated reliably. Main issues with optical flow imaging were related to a low confidence measurement of the volumetric arterial flow rate due either to 2D-3D registration failure or an insufficient pulsatile behavior of the CA-blood mixing flowing in the vessel.

Follow-up	Cases	Occlusions	AUC	p-value	MAFA-R	Sensitivity	Specificity
3 months	54	11 (20%)	0.594	0.400	0.62	46%	79%
6 months	54	31 (57%)	0.565	0.431	0.93	84%	35%
12 months	52	39 (75%)	0.664	0.0920	0.89	80%	62%

Table 1: Results of the ROC analysis for determination of the optimal MAFA-R threshold for the complete aneurysm cohort. The number of cases considered, the rate of full aneurysm occlusions, the area under curve (AUC), p-value and thresholds at 3, 6 and 12 months.

Results of the ROC analysis for the complete aneurysm cohort are presented in Table 1. At 12 months follow-up, 39 out of 52 aneurysms occluded (75%). The MAFA-R threshold for prediction of aneurysm occlusion was 0.89 (AUC=0.66, p=0.092081).

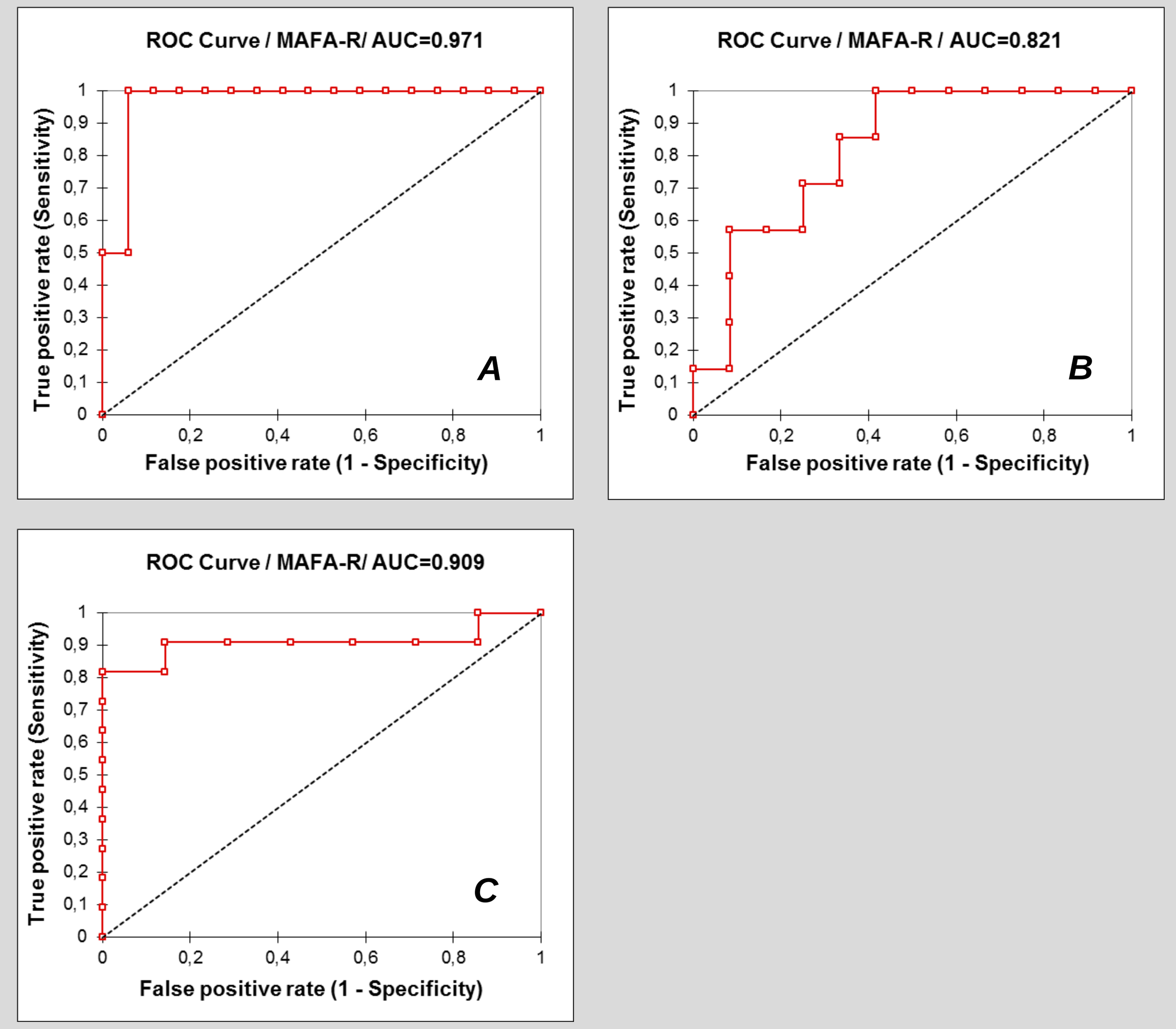

Figure 2:ROC performance curves for MAFA-R for the large aneurysm cohort corresponding to follow-up at 3 months (A), 6 months (B) and Row 12 months (C).

For the large (>10mm) aneurysm subgroup, the results of the ROC analysis are presented in Figure 2 and Table 2. At 3 months follow-up, 2 out of 19 aneurysms occluded (11%). The MAFA-R threshold was found to be 0.64 (AUC=0.97, p<0.0001). At 6 months, 7 out of 19 aneurysms occluded (37%) with a MAFA-R threshold of 0.93 (AUC=0.82, p<0.001080). At 12 months follow-up, 11 out of 18 aneurysms occluded (61%) with a MAFA-R threshold of 0.89 (AUC=0.91, p<0.0001).

Follow-up	Cases	Occlusions	AUC	p-value	MAFA-R	Sensitivity	Specificity
3 months	19	2 (11%)	0.971	<0.0001	0.64	100%	94%
6 months	19	7 (37%)	0.821	0.00108	0.93	100%	58%
12 months	18	11 (61%)	0.909	<0.0001	0.89	82%	100%

Table 2: Results of the ROC analysis for determination of the optimal MAFA-R threshold for the large (>10mm) aneurysm cohort. The number of cases considered, the rate of full aneurysm occlusions, the area under curve (AUC), p-value and thresholds at 3, 6 and 12 months.

Discussion

Our study describes a DSA-based method using optical flow imaging that was successfully used to predict complete aneurysm occlusion after treatment with FDS. The method was particularly accurate for a subgroup population of large IAs (≥10mm). The accuracy of the ROC performance test was increasing from 67% for all aneurysms, to 91% for large-sized aneurysms.

The rather larger region of interest and low velocities encountered in large aneurysms compared to small ones could explain these results. Slower velocities may be caught more accurately with the temporal resolution of the detector (60 images/sec) and therefore provide more reliable MAFA-R for large aneurysms than small ones.

Aneurysm occlusion after flow diverter stenting will depend on multiple factors including location, hemodynamics, patient healing peculiarities, aneurysm neck size, anti-aggregation response, etc. Nevertheless, we demonstrated that measuring the intra-aneurysm flow during the procedure with a method that takes in consideration the upstream vessel volumetric flow rate is able to predict independently the outcome by establishing a threshold for further clinical investigation.

This prospective series of systematically treated, evaluated and followed aneurysms, confirms that MAFA-R may be a potential useful indicator of successful treatment in the current clinical framework of FDS endovascular procedures.

Conclusion

MAFA-R is a potential marker of complete aneurysm occlusion in current clinical framework of FDS treatment. The accuracy of the test increases with the size of the aneurysms, up to 91%. This functional assessment may potentially help the clinician to adapt the treatment in real-time during the procedure.

References

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