ON-LINE APPENDIX

SUPPLEMENTAL MATERIALS AND METHODS

4D PC MRI Scan

The 4D PC MR imaging sequence used a peripheral pulse unit, and the velocity sensitivity encoding parameter was set to 80 cm/s. Typically, for 65 heart beats per min, we obtained 16 time-steps for 1 cardiac cycle. The 4D PC MRI data were exported as DICOM files for further postprocessing.[1]

Velocity Field Postprocessing

The vessel lumen was segmented by using an interactive watershed analysis performed on the gradient of the reconstructed 3D rotational angiography (RA) volume. The 3D velocity fields were obtained by a combination of 4D PC MRI and 3D RA data. The aim of this method is to restrict the velocity domain calculation to the 3D RA vessel lumen because the spatial and contrast resolution of 4D PC MRI magnitude images do not provide accurate boundaries of the vessel. The postprocessing, performed with MATLAB (R2016b; MathWorks, Natick, Massachusetts), is briefly described below, and more information can be found in reference 2:

- Segmentation of the 3D RA DICOM stack with a watershed based algorithm.[3,4]
- The centerline of the segmented vessel was computed similarly to a published description by using the Vascular Modeling Toolkit (VMTK) library (www.vmtk.org).[5]
- Aliasing correction to remove phase jumps during the systolic phase.
- Rigid co-registration of the segmented vessel (3D RA) with the PC MRI data and linear voxel interpolation by assuming zero velocity at the vessel wall.
- Creation of a volumetric mesh of the circulating volume, which is made of approximately 0.1-mm size tetrahedrons, each containing 3 components of the velocity fields.

The method of vessel lumen segmentation provided robust and user-independent vessel lumen and was saved as STL files for 4D flow MR imaging postprocessing and geometric measurements of aneurysm features, respectively. These velocity data were exported in visualization toolkit (VTK) format for further analysis.

Calculation of Parent Vessel Flow Rate

The ICA flow measurements were performed by placing measurement planes separated by 2 mm on the vessel centerline within a distance selected by the user at the C3-4 segment (Bouthillier nomenclature). The 4D PC MRI data were then interpolated in 0.1 mm within the boundaries of the vessel provided by the 3D RA for each plane. By using a previously published partial volume correction method,[2] the instantaneous flow rate at each measurement plane was subsequently computed for each time-step during the cardiac cycle. The temporal averaged flow rate of each measurement plane was then averaged to obtain the mean ICA flow rate (parent vessel flow rate).

FD Selection during Interventional Procedures

There were 3 different FDs used in this study. They were Pipeline Embolization Device (Covidien, Irvine, California) for 23 aneurysms, Silk (Balt Extrusion, Montmercy, France) for 10 aneurysms, and Flow Re-direction Endoluminal Device (Microvention, Tustin, California) for 8 aneurysms. Considering the overall effectiveness and complication level,[6] our deployment strategy was to primarily implant a single FD layer, except in 6 cases in which the telescoping technique was desired to effectively lengthen the FD coverage. Although 3 types of FDs were used in our study and 6 cases were implanted with 2 FDs, there was no obvious discrepancy in treatment responses among them (On-line Table).

REFERENCES

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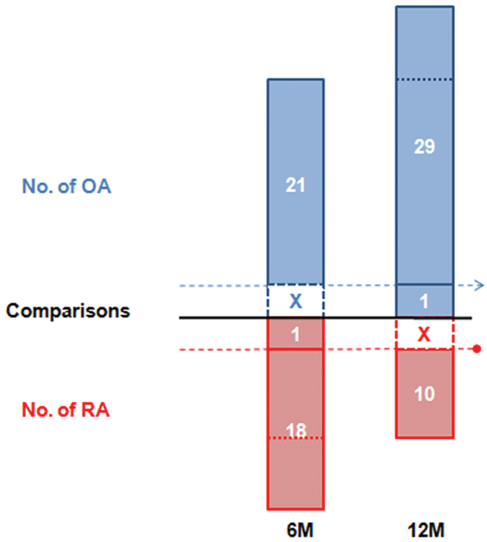

ON-LINE FIGURE: Illustration of grouping aneurysms at 6 (6M) and 12 months (12M). White digits in the column show the numbers for different treatment responses at follow-up. "X" in the blank column represents missing follow-up for 2 cases at the respective time points. Peripheral portions outside the *short dotted line* in the columns represent 8 remnant aneurysms at 6 months (red), but occluded at 12 months (blue). *Blue dotted arrow* indicates continuing follow-up. *Red long dotted line with round terminal* indicates that other treatment(s) replaced the follow-up after 12 months. Note:—OA (blue region) indicates occluded aneurysms; RA (red region), remnant aneurysms.

On-line Table: Application distribution of FDs from different manufacturers[a]

	PED	Silk	FRED	Total
No. occluded aneurysm at first 6 months	13 (2)	5 (1)	3	21 (3)
No. occluded aneurysm during second 6 months	4 (1)	2	2	8 (1)
No. remnant aneurysm at 12 months	6 (2)	2	2	10 (2)
No. missing follow-up at 6 or 12 months	0	1	1	2
Total	23 (5)	10 (1)	8	41 (6)

Note:—PED indicates Pipeline Embolization Device; FRED, Flow Re-direction Endoluminal Device.
[a] Data in parentheses represent the case number of subjects who had 2 FDs implanted for 1 case.