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Original Article

A computational fluid dynamics (CFD) study of WEB-treated aneurysms: Can CFD predict WEB "compression" during follow-up?

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ABSTRACT

Background. – Recent reports have revealed a worsening of aneurysm occlusion between WEB treatment baseline and angiographic follow-up due to "compression" of the device.
Objective. – We utilized computational fluid dynamics (CFD) in order to determine whether the underlying mechanism of this worsening is flow related.
Methods. – We included data from all consecutive patients treated in our institution with a WEB for unruptured aneurysms located either at the middle cerebral artery or basilar tip. The CFD study was performed using pre-operative 3D rotational angiography. From digital subtraction follow-up angiographies patients were dichotomized into two groups: one with WEB "compression" and one without. We performed statistical analyses to determine a potential correlation between WEB compression and CFD inflow ratio.
Results. – Between July 2012 and June 2015, a total of 22 unruptured middle cerebral artery or basilar tip aneurysms were treated with a WEB device in our department. Three patients were excluded from the analysis and the mean follow-up period was 17 months. Eleven WEBs presented "compression" during follow-up. Interestingly, device "compression" was statistically correlated to the CFD inflow ratio ($P = 0.018$), although not to aneurysm volume, aspect ratio or neck size.
Conclusion. – The mechanisms underlying the worsening of aneurysm occlusion in WEB-treated patients due to device compression are most likely complex as well as multifactorial. However, it is apparent from our pilot study that a high arterial inflow is, at least, partially involved. Further theoretical and animal research studies are needed to increase our understanding of this phenomenon.

Introduction

The WEB intra-saccular flow disrupter (Sequent Medical, Alisa Viejo, California) is a novel endovascular approach to treat broad base intracranial aneurysms. A recent report has demonstrated a worsening of aneurysm occlusion between postoperative baseline and follow-up due to "compression" of the device [1]. Cognard et al. described a worsening between the post-procedural and follow-up angiographies in 10 of 14 cases (71.5%) and a "compression" of the WEB in 9 of 14 cases (64.3%) (Fig. 1). In a larger series, other authors [2] demonstrated that this phenomenon was not infrequent with a WEB shape modification in 32% of cases.

Yet the underlying mechanisms are still unknown. The WEB device is expected to better resist arterial flow due to its volumetric shape and radial force, therefore some suspect that WEB shape is modified by clot retraction [3].

However, neither mechanism has yet been demonstrated. Here, we sought to determine whether the reported worsening of aneurysm occlusion is flow related using computational fluid dynamics (CFD) technology.

Material and methods

Data collection

From our prospectively maintained database, we retrospectively extracted all consecutive patients treated with a WEB device in our institution between July 2012 and June 2015 for either a

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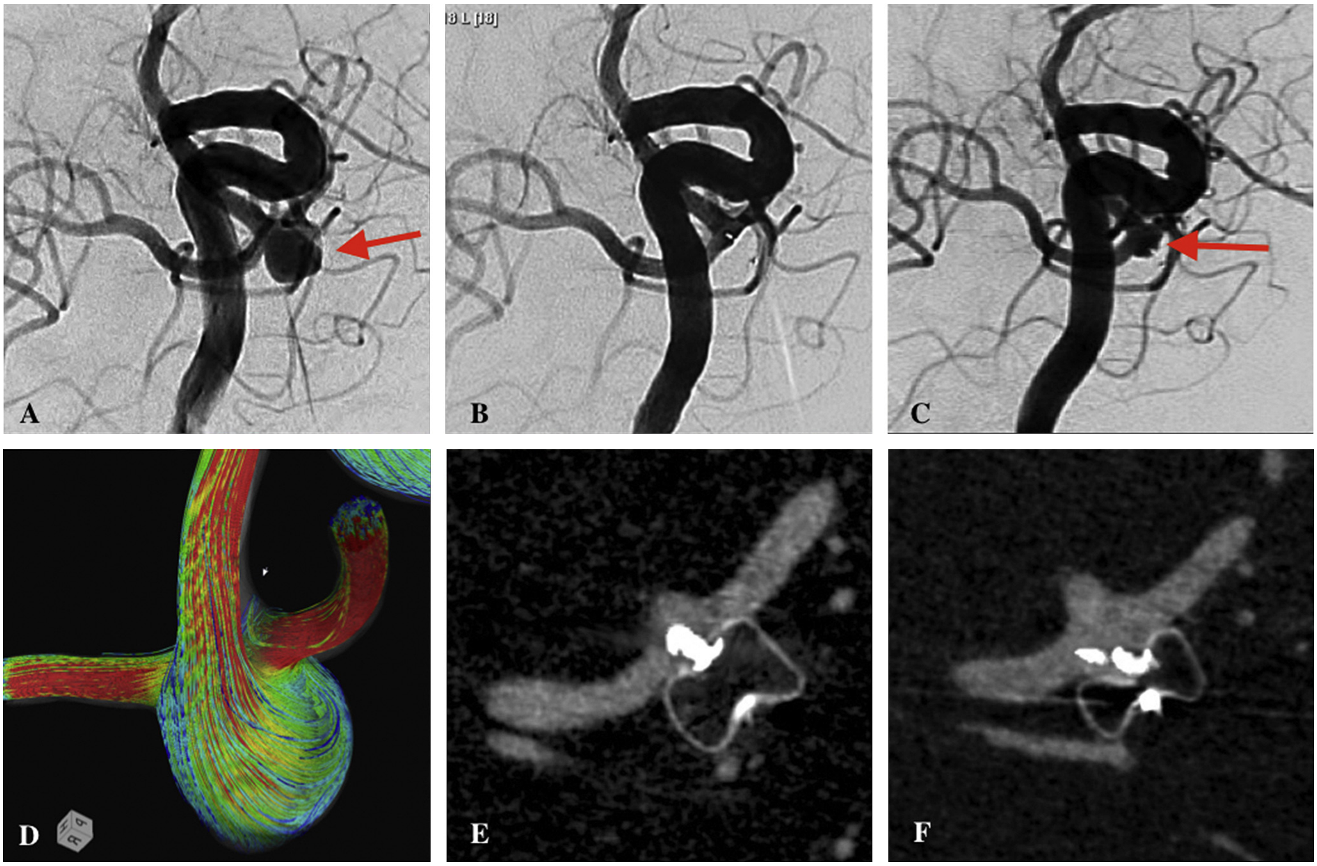

Fig. 1. A. Right 6.5 mm MCA aneurysm (A). DSA (B) and VasoCT (E) showing immediate and complete occlusion obtained after WEB-SL delivery. At the 6-month follow-up, DSA (C) and VasoCT (F) depict a small recanalization with an opacification of the proximal recess (arrow in C) due to WEB shape modification with a "butterfly" aspect. The pre-operative CFD analysis (D, inflow view) calculated a high inflow ratio: 1.02, thus a high "compression" risk.

middle cerebral artery (MCA) or basilar tip aneurysm, that were unruptured, untreated and without partial thrombosis. Informed consent was obtained in each case. The study was conducted under the rules of local ethics committee. Patients with obvious bad technical results were excluded, i.e. absence of neck sealing and blood flow penetrating inside the aneurysm around the WEB due to an undersized device. Patients without follow-up imaging were also excluded.

Pre-operative 3D rotational angiography (3DRA) acquisitions and follow-up digital subtraction angiography (DSA) were recorded. Morphological parameters (aneurysm volume, neck size, aspect ratio defined as depth/neck ratio) were measured from 3DRA. Contrast enhanced high resolution cone-beam CT (VasoCT [4]) was systematically used at the end of the procedure and during follow-up angiographies. Angiographic follow-up was performed at 6, 18 and 32 months after treatment.

Two authors (J.C and C.M.) blind reviewed all follow-up imaging from CFD data to determine the presence or absence of WEB device shape modification (defined as a shortening of the distance between the proximal and distal WEB markers between post-operative images and follow-up). The analysis was based on 2D images and VasoCT systematically performed during follow-up. Reviewers also analyzed and the presence or absence of complete aneurysmal occlusion. Differences between the results of the 2 observers were discussed in an additional meeting to reach consensus.

The anatomical results were evaluated using the Bîcetre occlusion scale score (BOSS) [5].

Treatment technique

Endovascular treatment was performed using a biplane flat panel angiographic system (Allura Xper 20/10; Philips, Best, Netherlands). Endovascular procedures were performed under general anesthesia and systemic heparinization. WEB-DL, WEB-SL and WEB-SLS were used at the operator's discretion.

CFD analysis

CFD analysis was carried out using a novel CFD package (*hemoscope* v1.4, EBM Corp., Japan) that was developed specifically for aneurysmal flow research by medical professionals as previously reported [6].

Vascular geometry

Initially, a three-dimensional geometry of the vascular lumen was constructed by a medical-image processing package (Ziostation2, Ziosoft, Inc., Japan). Input images came from 3DRA. The reconstructed slice images gave a spatial resolution of approximately 0.2 mm. The region of interest in anterior circulation included the internal carotid artery, anterior cerebral artery A1 segment, MCA M1 and M2 segments. The posterior circulation included the basilar artery, superior cerebellar artery, and posterior cerebral artery P1 segment. These major arteries and other branches were included in CFD if the diameter of each artery was greater than 1.0 mm. Hence, the diameter denotes the median of equivalent circle diameters scan-measured along a center line at