Assessment of morphology and hemodynamics in a surgically clipped neck of a cerebral aneurysm: illustrative case

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BACKGROUND Silent magnetic resonance angiography reduces metal artifacts, enabling clear visualization of the clipped neck following surgical clipping of cerebral aneurysms. This study aimed to delineate the morphology of the clipped neck complex in cerebral aneurysms using three-dimensional (3D) multifusion imaging of silent magnetic resonance angiography and fast spin echo magnetic resonance cisternography. Additionally, computational fluid dynamics analysis was utilized to evaluate the hemodynamics of the parent vessel at the clipped neck, allowing for a detailed assessment of hemodynamics at the clipped neck.

OBSERVATIONS The 3D multifusion image enabled visualization of the orientation and shape of the clip within the clipped neck complex, alongside the morphology of the parent vessel. In the hemodynamic analysis of the parent vessel at the clipped neck, areas of high-intensity magnitude of wall shear stress (WSSm) variation corresponding to the clip’s contour, along with significant vector of wall shear stress (WSSv) variation related to vector directionality, were visualized in 3D. The intentional residual neck, coated with muscle grafts, was depicted as an area with low WSSm variation values and high WSSv variation values.

LESSONS Three-dimensional multifusion imaging, along with computational fluid dynamics analysis of the parent vessels, facilitated both the morphological and hemodynamic visualization and assessment of the clipped neck complex following neck clipping surgery for cerebral aneurysms.

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KEYWORDS computational fluid dynamics; magnetic resonance image; multifusion imaging; neck clipping; silent magnetic resonance angiography; wall shear stress

Surgical clipping of cerebral aneurysms is commonly performed alongside endovascular coil embolization for both unruptured and ruptured aneurysms.1 In the postclipping follow-up of cerebral aneurysms, precise visualization of the clipped neck complex is crucial, involving assessment for residual neck, recurrence, de novo aneurysms, and the morphology of the parent vessel.2 Computed tomography angiography is an invasive procedure associated with specific risks related to contrast agent side effects and radiation exposure. Additionally, non-invasive time-of-flight (TOF) magnetic resonance angiography (MRA) can provide an inadequate depiction of the clipped neck due to susceptibility artifacts from the clips. With recent advancements in MR technology, silent MRA is a non–contrast-enhanced form of MRA that utilizes zero echo time and arterial spin labeling to visualize blood flow within cerebral vessels with minimal metal artifacts. Silent MRA has been reported to provide detailed visualization of remnants after clipping.3 Furthermore, magnetic resonance cisternography (MRC) using T2-weighted fast spin echo (FSE) sequences can delineate the outer contour of the entire clipped neck complex, including brain parenchyma, cranial nerves, parent vessels, and clips. In this study, we employed silent MRA, instead of TOF-MRA, and FSE-MRC to generate three-dimensional (3D) multifusion imaging of these structures and visualize the morphology of the clipped neck complex. Additionally, volume data from silent MRA were submitted to computational fluid dynamics (CFD) analysis to assess the hemodynamics of the parent artery at the clipped neck. To the best of our knowledge, this report represents the first assessment of the clipped neck complex after surgical neck clipping for cerebral aneurysms, both morphologically and hemodynamically.

ABBREVIATIONS 3D = three-dimensional; CFD = computational fluid dynamics; FSE = fast spin echo; MCA = middle cerebral artery; MRA = magnetic resonance angiography; MRC = magnetic resonance cisternography; MRI = magnetic resonance imaging; TOF = time-of-flight; WSS = wall shear stress; WSSm = magnitude of wall shear stress; WSSv = vector of wall shear stress.

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Illustrative Case

A 67-year-old woman was referred to our hospital by an ophthalmologist due to discomfort in her right eye. Head magnetic resonance imaging (MRI) revealed a tumor (14 mm in diameter) in the upper part of the right orbit, and simultaneous MRA identified an unruptured intracranial aneurysm (2.8 mm in diameter) in the right middle cerebral artery (MCA). Since both were asymptomatic, they were managed with observation.

Four years later, she developed diplopia on lateral gaze, and an increase in the size of the orbital tumor (20 mm in diameter) was noted. Subsequently, total excision was performed, and the pathological diagnosis was lacrimal pleomorphic adenoma. The right MCA aneurysm, located at the neck of the right M1–2 bifurcation, exhibited a bumpy dome shape with a red bleb, extending superolaterally and immediately distal to multiple perforators. Careful clipping was performed from a direction that avoided involving the perforators, perpendicular to the M2 course, using a titanium clip with a 90° bend and 7.5-mm size (Sugita titanium clip No. 21, Mizuho Medical Co., LTD.). Due to the shape of the aneurysm, complete clipping was deemed impossible. Therefore, an intentional residual neck was left, covered with a muscle graft, and reinforced with coating using Surgicel (Johnson & Johnson MedTech) and Bolheal (Astellas Pharma Inc.; Fig. 1).

Approximately 5 years after the neck clipping surgery, follow-up head MRI was performed for the right MCA aneurysm (Fig. 2). TOF-MRA, silent MRA, and FSE-MRC were conducted in the same session (Fig. 2). The maximal intensity projection image of TOF-MRA poorly depicted the clipped neck due to magnetic susceptibility artifacts caused by the clip, with discontinuity in the parent vessels (Fig. 2A). In contrast, simultaneous silent MRA demonstrated a well-defined clipped neck complex, including the intentional residual neck and parent vessels (Fig. 2B). The minimum intensity projection image of MRC clearly depicted the clipped neck complex as a region of low signal intensity, with the surrounding brain parenchyma showing moderate signal intensity and the cerebrospinal fluid in the cistern appearing as high signal intensity, allowing clear delineation of the boundary between the aneurysm and surrounding structures (Fig. 2C). A 3D multifusion image was created by reconstructing 3D images from TOF-MRA, silent MRA, and FSE-MRC and aligning them in X-Y-Z coordinates (Fig. 2D–I).

Following the orbital tumor surgery, neck clipping was performed. The aneurysm, located at the neck of the right M1–2 bifurcation, exhibited an unruptured intraorbital aneurysm (2.8 mm in diameter) in the right middle cerebral artery (MCA). Since both were asymptomatic, they were managed with observation.

The clipped neck complex was analyzed using a commercial CFD package (Hemoscope v1.4, AMIN Corp.), as described elsewhere. The morphology of the preoperative aneurysm and the postoperative clipped neck with an intentional residual neck complex, including surface area, volume, neck size, dome length, and aspect ratio, was quantified. Hemodynamic parameters, such as streamlines, pressure drop (in mm Hg), flow rate (in mL/min), magnitude of wall shear stress (WSSm; in Pa), and vector of wall shear stress (WSSv; in degrees), were evaluated (Fig. 3).

In the WSSm variation image, the clipped neck complex was depicted as a region of high intensity (in Pa) outlining the clip contour, with the clipped neck dome shown as a region of moderate intensity (Fig. 3E). Conversely, in the WSSv variation image, the clipped neck dome appeared as a region of high intensity, with the surrounding clipped neck depicted as a region of moderate intensity (Fig. 3F). The intentional residual neck appeared as a localized region of low intensity in WSSm variation and high intensity in WSSv variation. The streamlines, pressure drop (in mm Hg), static images of WSSm variation (in Pa) and WSSv variation (in degrees; Fig. 3B, C, E, F), and dynamically changing movies of WSSm (in Pa) and WSSv (vector arrows) synchronized with pulsation (Videos 1 and 2) are presented.

Ten years after neck clipping surgery, a follow-up MRI examination (silent MRA, FSE-MRC) for the clipped neck complex was conducted, revealing no changes in the shape of the clipped neck or the morphology of the parent vessels. Additionally, the intentional residual neck showed no enlargement or reduction in size, and CFD findings indicated low intensity in WSSm variation and high intensity in WSSv variation. Morphologically and hemodynamically, it was confirmed that the right MCA aneurysm after neck clipping remained stable over the long term.

Patient Informed Consent

The necessary patient informed consent was obtained in this study.
Discussion

In this case, 3D multifusion imaging was utilized by overlapping and reconstructing silent MRA and FSE-MRC images for morphological assessment of the post–neck clipping surgery. Due to the complex anatomical structure of the clipped neck complex, it is challenging to accurately understand the spatial relationship between the clipped neck and parent vessels by simply reviewing individual 2D source images. Silent MRA provided good-quality visualization of the clipped neck complex, while FSE-MRC depicted the overall anatomy of the clipped neck complex, including the parent arteries, adjacent brain parenchyma, and cranial base bone structures, along with the clip itself. As a result, 3D multifusion imaging combining silent MRA and FSE-MRC enabled detailed visualization of the angioarchitecture of the clipped neck complex in a single 3D image.

CFD assessment of the clipped neck complex was performed using volume data from silent MRA to evaluate the hemodynamics of the parent artery at the clipped neck following neck clipping surgery. The results indicated that at the clip site, the flow entering the aneurysm dome is strongly impeded by the clip at the neck, resulting in significant flow collision. Consequently, the tangential WSS on the vascular wall at the clipped neck area exhibited high-intensity (in Pa) WSSm regions. WSSm variation (in degrees), related to local fluctuations of WSSm, delineated a morphology closely following the contour of the clip. Conversely, WSSv exhibited a multitude of directions due to flow collision, resulting in significant low-value regions of WSSv.
variation along the vascular wall at the clipped neck area. These findings suggest that through CFD analysis of the parent artery at the clipped neck area, the complete occlusion of the aneurysm dome by the clip was inferred to be visually represented and assessed in terms of hemodynamics.

Additionally, in this case, the right MCA aneurysm, which was small (3.2 mm in diameter) and exhibited multiple perforators at the neck, led to the decision to forego complete clipping and instead opt for an intentional residual neck. The residual neck was coated with muscle graft, Surgicel, and Bolheal. In this residual neck area, low values of WSSm variation and high values of WSSv variation were observed. It has been reported that in areas where the dome or bleb of an aneurysm contacts surrounding structures such as brain parenchyma, low values of WSSm variation and high values of WSSv variation are observed. Moreover, regions of neck remnants post–coil embolization exhibit low values of WSSm variation and high values of WSSv variation, indicating the progression of thrombosis and a subsequent reduction in the size of the remnant. In this case, it was inferred that the coated residual neck, in contact with the outer wall, mitigated tangential forces on the wall, resulting in low values of WSSm and WSSm variation and, consequently, a multitude of movements of WSSv and high values of WSSv variation associated with directional variations of the vector. CFD analyses conducted at 5 and 10 years postsurgery revealed minimal arterial sclerotic changes of parent arteries at the clipped neck, with parameters such as WSSm, WSSm variation, WSSv, and WSSv variation remaining stable. This suggests that the clipped neck complex, including the intentional residual neck, remained hemodynamically stable over the long term.

Observations

The 3D multifusion image of silent MRA and FSE-MRC enabled visualization of the shape and orientation of the clip within the clipped neck complex, concurrently with the trajectory and morphology of the parent vessel. In the CFD analysis of the parent vessel at the clipped neck complex, areas of high-intensity (in Pa) WSSm variation corresponding to the contour of the clip, along with regions of complex changes in WSSv variation related to vector directionality, were visualized in 3D. The intentional residual neck, coated with muscle grafts, was depicted as an area with low WSSm variation values and high WSSv variation values.

Lessons

In this instance, we reconstructed and generated 3D multifusion imaging by overlapping silent MRA, instead of TOF-MRA, and FSE-MRC for the post–neck clipping evaluation of cerebral aneurysms, enabling visualization of the morphology of the clipped neck complex in three dimensions. Furthermore, we conducted CFD analysis of the parent vessel at the clipped neck using volume data from silent MRA and evaluated it hemodynamically. The fusion of silent MRA and FSE-MRC in 3D multifusion imaging, along with CFD analysis of the clipped neck, facilitated both the morphological and hemodynamic visualization and assessment of the clipped neck complex after neck clipping surgery for cerebral aneurysms.

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References

Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: Satoh. Acquisition of data: Satoh, Ichikawa. Analysis and interpretation of data: Satoh, Ichikawa. Drafting the article: Satoh. Critically revising the article: Satoh, Fuji, Date. Reviewed submitted version of manuscript: Satoh, Ichikawa. Approved the final version of the manuscript on behalf of all authors: Satoh. Administrative/technical/material support: Satoh. Study supervision: Date.

Supplemental Information
Videos

Previous Presentations
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