

CASE REPORT

The Use of Simulation and Deep Learning Models in the Endovascular Treatment of Ruptured Intracranial Aneurysms: A Case Report

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ABSTRACT

Introduction: The current paper presents an examination of the emerging role of deep learning-based simulation software in enhancing preprocedural planning for intracranial aneurysm treatment using flow diverters. Intracranial aneurysms pose significant risk due to their potential rupture leading to life-threatening subarachnoid hemorrhage. Innovative endovascular treatment options like flow diverters, which redirect blood flow and promote healing, are gaining attention. The role of simulation software in optimizing these procedures is becoming increasingly crucial. **Case presentation:** This study involves a 47-year-old female patient diagnosed with an intracranial aneurysm. Through diagnostic angiography and 3D rotational angiography imaging, the complex aneurysm anatomy was determined and the need for flow diverter placement ascertained. The Sim&Size™ software was used to simulate the size and placement of the flow diverter, based on the patient’s specific vascular anatomy. The procedure, including the placement of the flow diverter as per the simulation, was successful. **Conclusion:** The Sim&Size™ simulation software significantly contributes to the enhancement of intracranial aneurysm treatment planning. By providing patient-specific simulations, it improves procedural precision and reduces the risk of complications, thus potentially optimizing patient outcomes. However, the quality of the simulation is contingent on the accuracy of the input data, and it does not account for physiological dynamics. Despite these limitations, this tool represents a promising development in neurointerventional practice.

Keywords: intracranial aneurysms, flow diverter, simulation software, endovascular treatment

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INTRODUCTION

Intracranial aneurysms occur when a weakened area of a blood vessel wall becomes vulnerable to the pressure of blood flow, causing it to expand outwards. They are a significant concern because of the potential risk for rupture, leading to life-threatening intracranial hemorrhage. Most commonly, a subarachnoid hemorrhage occurs in case of intracranial aneurysms and life-threatening hemorrhagic shock in the case of abdominal aortic or other visceral aneurysms.^{1–4}

Epidemiologically, intracranial aneurysms are relatively common, with a reported prevalence of 2–3% in the general population. They can occur at any age, but the incidence increases with advancing age, peaking between 50 and 60 years. Women have a higher incidence of aneurysm formation than men, with a male-to-female ratio of approximately 1:2.⁵

Diagnosing aneurysms typically involves a combination of imaging techniques. Magnetic resonance imaging (MRI) and computed tomography (CT) scans, including CT angiography or magnetic resonance angiography (MRA), are commonly used to visualize the blood vessels and identify the presence and characteristics of an aneurysm. Additionally, diagnostic cerebral angiography may be performed for detailed evaluation and treatment planning.^{4,6}

Treatment options for intracranial aneurysms aim to prevent rupture and subsequent bleeding. The choice of treatment depends on several factors such as aneurysm size, location, patient age, and overall health. Two main treatment modalities are widely employed: neurosurgical approach and endovascular approach.

The neurosurgical approach involves placing a small metal clip around the base of the aneurysm to isolate it from the circulation – surgical clipping. The endovascular approach involves, in most situations, a coiling procedure, where platinum coils are inserted into the aneurysm to promote blood clot formation, increase the stability of the aneurysm and subsequent vessel healing.^{7,8}

Flow diverters are an innovative endovascular treatment option for intracranial aneurysms that have gained significant attention in recent years. They are a type of stent-like device designed to divert blood flow away from the aneurysm, promoting gradual thrombosis within the aneurysm sac and subsequent vessel healing.⁹

Flow diverters are deployed within the parent artery, spanning across the neck or opening of the aneurysm. These devices have a high metal surface coverage, which promotes flow diversion and prevents blood from entering the aneurysm sac. Over time, the aneurysm becomes

isolated from the circulation, leading to thrombosis and eventual shrinkage.^{10,11}

The purpose of this case report is to illuminate the pivotal role of artificial intelligence-based simulation software, specifically Sim&Size™ (Sim&Cure, Montpellier, France), in the planning and execution of endovascular procedures, with a focus on flow diverter placement for intracranial aneurysm treatment. The ultimate goal is to enhance the understanding of its utility in improving procedural precision, patient-specific customization, and potentially mitigating perioperative complications. We aim to validate the software's ability to model and predict the behavior of flow diverters within the parent artery, thereby providing valuable insights that could influence procedural strategy and device selection. Through this research, we seek to provide evidence to substantiate the integration of such advanced computational tools in neurointerventional practice, reinforcing their potential to optimize patient outcomes.

CASE PRESENTATION

We report the case of a 47-year-old female patient admitted to the Emergency Room of the Mureş County Emergency Hospital with recent onset of intense headaches, loss of balance and difficulty speaking. The cranial CT scan revealed subarachnoid hemorrhage in the basal cisterns and perimesencephalic spaces. A subsequent contrast-enhanced cranial CT revealed a large aneurysm (7.7 × 6.3 mm) located at the ophthalmic segment of the right internal carotid artery. Due to the location of the aneurysm and the anatomical features, the patient was referred to our laboratory for endovascular treatment.

We initialized a diagnostic angiography in order to plan the treatment. We performed selective catheterization of the right internal carotid artery, using a Vertebral 5F catheter, and highlight the aneurysm on the digitally subtracted angiography (DSA) in Figure 1.

In order to further understand the complex anatomy, we performed a 3D rotational angiography (3D-RA). Due to the relatively large neck of the aneurysm (4 mm), we considered that a simple coiling procedure would not have the desired long-term outcome and opted for the implantation of a flow diverter, covering the neck of the aneurysm.

Considering the complex anatomy, the position of the aneurysm in close proximity to the curvatures of the internal carotid artery, and the changes in diameter of the parent artery, proximal and distal to the neck of the aneurysm, we opted for simulation of the flow diverter size and placement. For this purpose, we imported the 3D-RA in the



FIGURE 1. DSA of the right internal carotid artery (A) and virtual reconstruction after 3D-RA (B)

Sim&Size™ software and decided for a PED-325-20: ev3 Pipeline™ Flex 3.25 mm × 16 mm flow diverter (Medtronic, Minnesota, USA). After multiple simulations, we ended up with a satisfactory placement of the flow diverter, starting proximal with the bifurcation of the internal carotid artery, ensuring both safe appositions, as well as optimal metal coverage surface, as represented in Figure 2.

The procedure was carried out the following day. With the patient under general anesthesia, we performed another 3D-RA, catheterized the aneurysmal sack with a Synchro 0.014' micro guidewire supported by a Headway 17 microcatheter, and implanted two platinum coils, Axium Prime 3D 4 mm × 10 cm, in the aneurysmal sack, as visible in Figure 3.

Furthermore, we catheterized the distal segment of the internal carotid artery and started deploying the Pipeline™ Flex 3.25 mm × 16 mm flow diverter, as recommended by the simulation – with the distal end of the flow diverter placed proximal to the bifurcation of the internal carotid artery (Figure 4). After complete deployment of the flow diverter, we performed a single-shot acquisition, which confirmed the proper placement of the flow diverter.

Finally, a DSA with contrast media injection from the proximal right internal carotid artery was performed, confirming the success of the procedure, with delay of contrast diffusion within the aneurysmal sack, as visible in Figure 5.

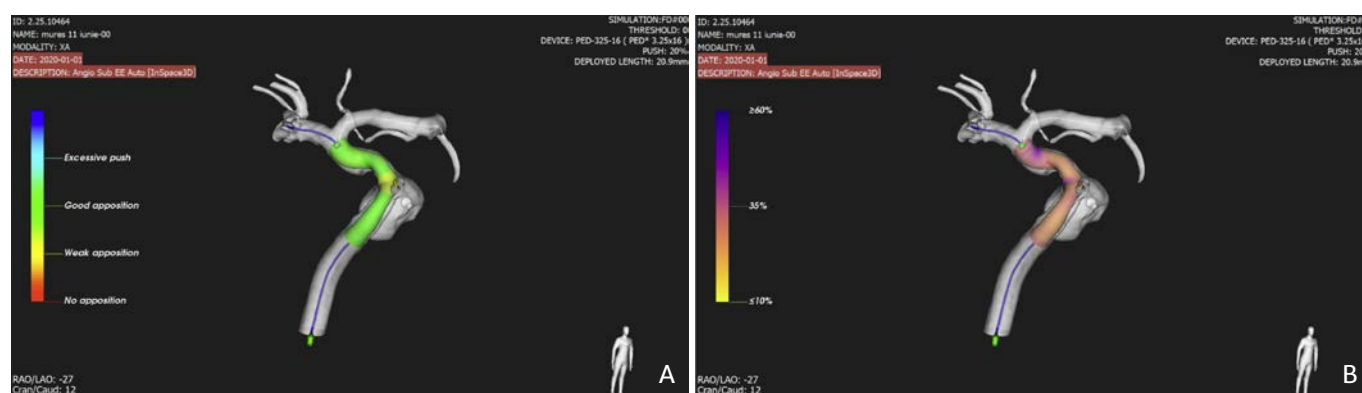


FIGURE 2. Sim&Size™ simulation showing the apposition of the flow diverter (A) and its metal coverage surface (B)



FIGURE 3. Selective catheterization of the aneurysmal sack and coiling

DISCUSSION

In the realm of intracranial aneurysm treatment, the integration of advanced computational tools, such as simulation software, can revolutionize procedural planning and predict outcomes. Specifically, Sim&Size™, developed by

Sim&Cure, has shown substantial promise in the context of flow diverter implantation for aneurysm management.^{12,13}

Flow diverters represent an evolutionary leap in the field of endovascular treatment of intracranial aneurysms. They work by disrupting the flow of blood within the aneurysm, promoting thrombosis, and leading to the gradual shrinkage and ultimate obliteration of the aneurysm sac.¹² However, their implantation demands precision, and for this reason, software like Sim&Size™ becomes invaluable.

Sim&Size™ enables the simulation of the positioning of the flow diverter within the internal carotid artery, providing insights into the procedural strategy. This software provides a patient-specific simulation model that helps physicians predict the behavior of the flow diverter within the vascular system, using data derived from the patient's vascular anatomy.¹³ This capability to create a patient-specific model differentiates this technology and underpins its benefits.

A recent study conducted by Mantilla *et al.* included 68 patients treated for cerebral aneurysm with flow diverter implantation.¹⁴ Their results revealed that for the cases in which a simulation was used for treatment planning, the stent shortening was significantly lower. We can rely on the findings of such studies since the use of flow diverters has gained popularity only in the last 5 years. Another factor to consider is the cost of such devices. With an average price of around 10,000 USD for a single flow diverter,¹⁵ the proper positioning of the stents is absolutely crucial.

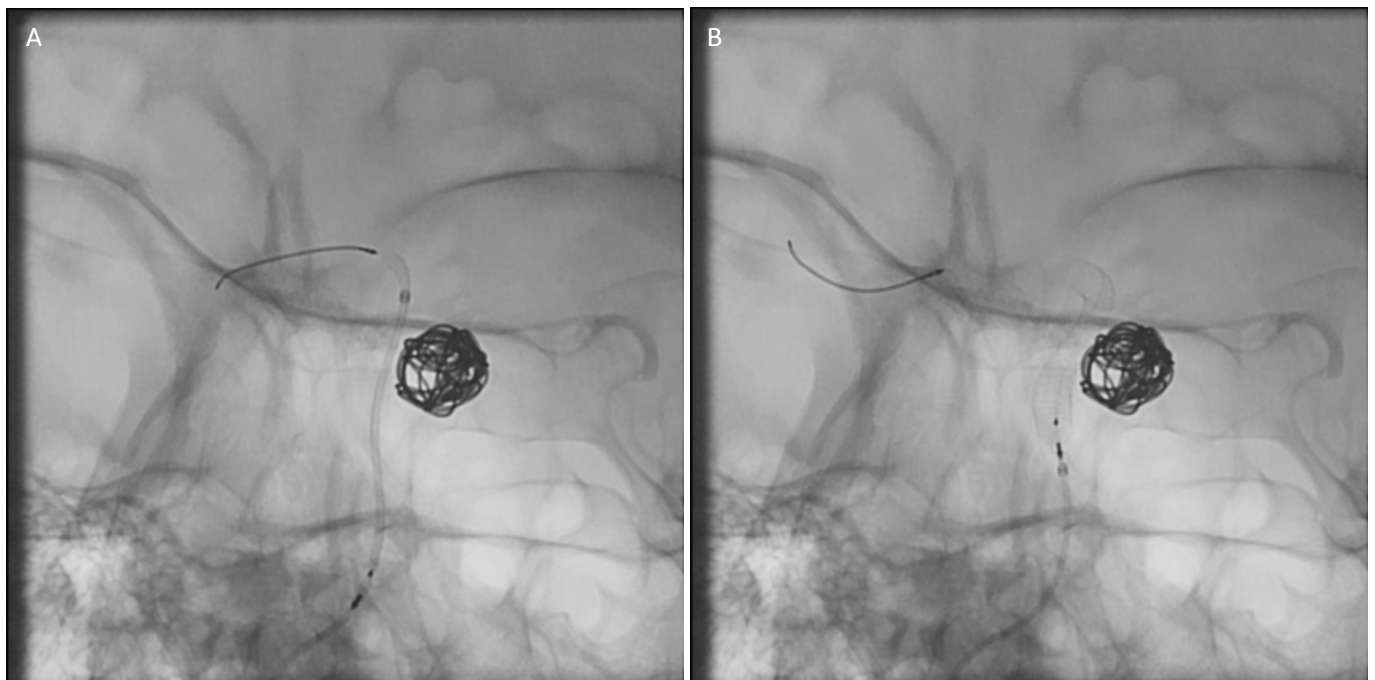


FIGURE 4. Fluoroscopy of the right internal carotid artery before (A) and after the complete deployment of the flow diverter (B)

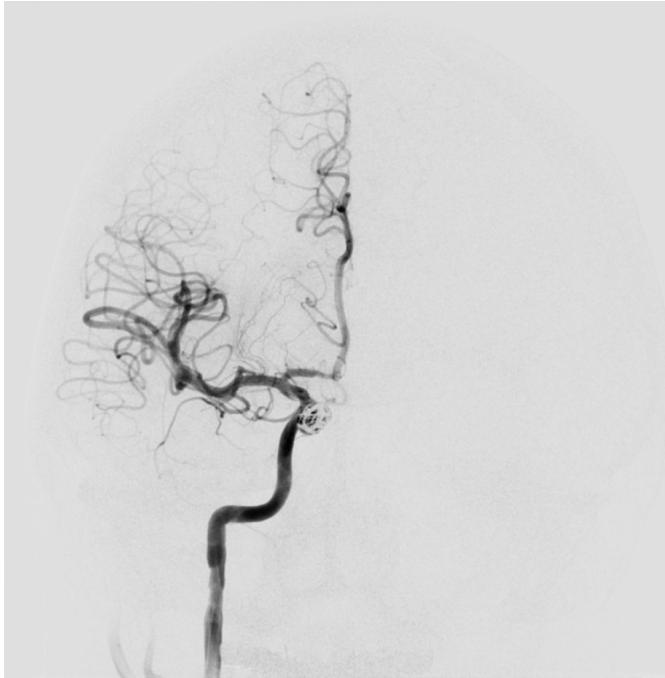


FIGURE 5. Final DSA of the right internal carotid artery

Improper anchoring and incorrect apposition on the wall of the parent artery can lead to stent migration in time, followed by changes in porosity and loss of diversion effect. Incorrect sizing of the stent can lead to inefficient degree of metal coverage surface and unwanted lengthening or shortening. The latter can be an issue if the extremities of the stent are too close to the aneurysmal sack, which may lead to the prolapse of the entire device inside the aneurysm. Excessive lengthening of the flow diverter can also be an issue, if its position is not planned ahead, since the proximal end may end up in a curved portion of a vessel, causing improper anchoring or “fish-mouth” effect, with abrupt decrease of the stent diameter.^{16,17}

There are multiple advantages of using such simulation software. Firstly, by offering a patient-specific model, it enhances the accuracy of preprocedural planning. This degree of customization leads to more precise and safer implantation, thus potentially reducing the risk of perioperative complications.¹⁷ It also allows for the prediction of the device's behavior within the vessel, thereby informing the choice of device, its positioning, and deployment strategy.

Secondly, it can improve the efficiency of the procedure, as the visualization provided by the software reduces the need for multiple angiograms, leading to a reduction in radiation exposure and contrast medium usage. This holds implications for both patient safety and procedural cost-efficiency.

Thirdly, it provides an excellent tool for education and training of neuro-interventionalists, aiding in the visualization of complex intracranial aneurysm anatomy and procedural steps.¹⁸

Despite these significant advantages, some limitations persist. The quality of the simulation is directly dependent on the quality of the input data, in this case, the imaging of the patient's vascular anatomy. Any imperfections in the imaging could lead to inaccuracies in the simulation.¹⁹ Furthermore, the software does not account for the dynamic nature of the human body, including potential changes in blood flow and vascular reactivity during the procedure. Additionally, while the software can reduce the likelihood of complications, it does not entirely negate them. Further research and development of these tools may refine their accuracy and expand their application.

CONCLUSION

The use of simulation software, such as Sim&Size™, is a promising approach that augments procedural planning in the treatment of intracranial aneurysms with flow diverters. This offers potential improvements in patient outcomes and procedural efficiency, though certain limitations need to be acknowledged and addressed.

CONFLICT OF INTEREST

Nothing to declare.

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