# Vasculature and Aneurysm Design

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Team 23: In-vitro Tube Model System

ME450—Section 3

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## Introduction

The primary goal of this capstone project is to create an anatomically and physiologically accurate cerebral aneurysm model that will be used to test Dr. Timothy Becker's aneurysm repair device. A secondary goal is to 3D print the vasculature structures in the model, ensuring its anatomical accuracy and reproducibility; therefore, it is necessary to have the dimensions and 3D designs for relevant vessels and aneurysm types and locations.

The task of this analytical analysis is to perform the following:

- Identify relevant vessels in cerebral vasculature system.
- Identify the common locations of aneurysms that Dr. Becker aims to treat.
- Identify the sizes and shapes of aneurysms that Dr. Becker aims to treat.
- Create a 3D SolidWorks model of identified relevant vasculature with accurate dimensions.
- Parametrically design aneurysms on the 3D model.

By completing the above tasks, the team will be able to move forward in the design of the vasculature and aneurysm subsystem of the model. When the casting method and materials are decided, the team will be able to start testing the entire subsystem as a whole.

## Design Variables:

Design variables in this analysis will include the following:

- Vasculature size (male/female, age, etc)
- Relevant vessels and their geometries
- Locations and orientations of aneurysms
- Type of aneurysms
- Dimensions of aneurysms

### *Assumptions*

Relevant vasculature and aneurysm geometries were obtained from Dr. Becker. The following assumptions will be made:

- Average adult cerebral vasculature system.
- The vascular scope will include the Internal Carotid Artery (ICA) and Middle Cerebral Artery (MCA) within the vicinity of the Circle of Willis.
  - Smaller branches can be neglected.
- Saccular side-wall and bifurcation aneurysms.
  - All wide-neck aneurysms (dome to neck ratio less than 2:1).
  - Small, medium, and large aneurysms.
  - 2-3 aneurysms per model.

## Dimensions and Schematics

### *Vasculature*

To describe the geometry of the vasculature, including diameters and bifurcation angles, references shown in Figure 1 will be used. All diameters will refer to the lumen, or inside diameter, of the vessel at an intermediate point between vessel branches for an average adult.

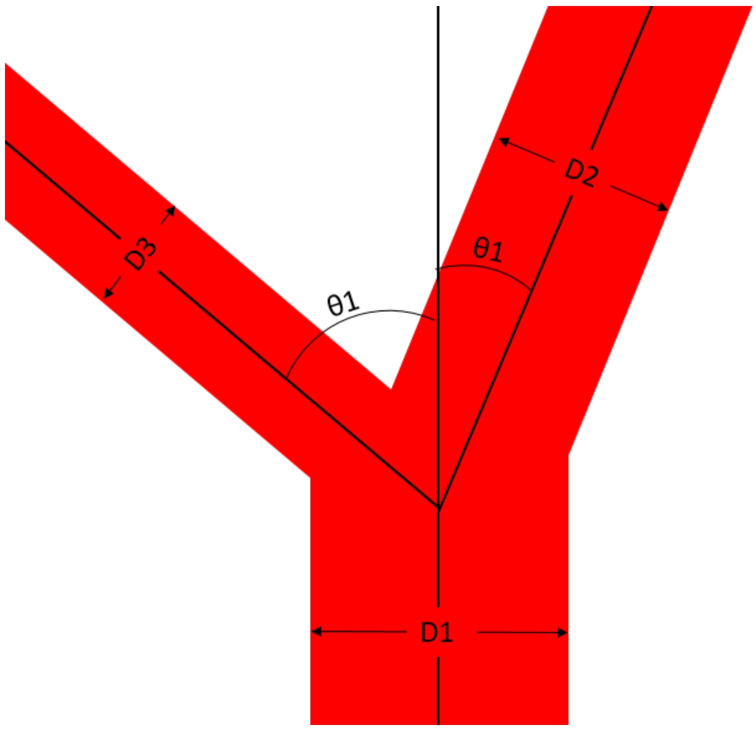



Figure 1. Vessel Diagram

The geometry of the ICA and MCA and the major branches have significant variation in all three dimensions; however, for the sake casting, the model will need to accurate in two dimensions, therefore, multiple views will be utilized and projected onto a single plane.

The lateral view of the ICA at the point of bifurcation from the common carotid artery (CCA) up to the carotid siphon, shows the most variation, with negligible angling in other planes. Several points were chosen along the ICA from an angiogram in this plane, and were used to create the first spline of the ICA, and entry point of the model [1]. A list of these points is provided in Table 1 on the next page. The diameter of the ICA is about 5mm throughout this section [2].

Table 1: ICA Spline Points

| X (mm) | Y (mm) |
|---|---|
| 0 | 0 |
| 2.469136 | 13.75661 |
| -0.35273 | 26.10229 |
| -4.58554 | 38.44797 |
| -5.64374 | 47.26631 |
| -3.88007 | 61.37566 |
| -4.58554 | 73.72134 |
| -9.87654 | 79.01235 |
| -16.9312 | 82.53968 |
| -21.5168 | 85.71429 |
| -23.6332 | 92.06349 |
| -25.3968 | 97.70723 |
| -31.0406 | 99.11817 |
| -38.448 | 99.11817 |
| -41.2698 | 101.2346 |
| -40.9171 | 103.351 |
| -38.8007 | 106.1728 |
| -35.2734 | 110.4056 |

The carotid siphon is an important part of the ICA because it marks the entry point of the vessel into the skull, through the foramen lacerum and cavernous sinus of the sphenoid bone and then through the dura, the brain's protective epithelium [1]. From this point, the ICA only extends about 13mm until it branches into the ACA and MCA [3]. The angle of the carotid siphon also makes it an important landmark because it is so sharp, 35°, on average [4].

After the carotid siphon, the ICA branches into the ophthalmic artery, which will not be included in this model because of its small size and negligible influence on the flow [2]. The ICA also changes direction around this point, going "into the page" from the lateral view perspective, and therefore, the frontal view of the ICA will be used for a small segment, with this second spline generated similarly as the first, but projected onto the x-y, or lateral, plane [1].

As the ICA approaches the MCA-ACA bifurcation, it branches into the posterior and anterior communicating arteries (PCoA and ACoA). The ACoA is relatively small and will be neglected, but the PCoA will be included in the model, as it is a common bifurcation aneurysm location, and will need to be present to divert flow because the ICA diameter reduces at this point to about 3.6mm on average [5]. The diameter and bifurcation angle of the PCoA are 1.4mm and about 45°, respectively [2]. Since only the length of the PCoA proximal to the ICA bifurcation is relevant for this model (no aneurysms will be modeled along the PCoA), the modeled PCoA will divert upwards towards the top of the model where the flow will exit.

Closely after the PCoA bifurcation, the ICA ends, sharply branching into the ACA and MCA. The MCA is the major branch, with a diameter of 2.6mm and bifurcation angle of 59°. The ACA has a diameter and bifurcation angle of 2mm and 90°, respectively [5]. Because of these sharply diverting flows, relatively large aneurysms can be seen at this bifurcation. Both the ACA and MCA will eventually divert upwards for the flow to exit the model.

*Aneurysms*

Aneurysms will be modeled as revolved ellipses with dimensions referenced as shown in Figure 2 below.

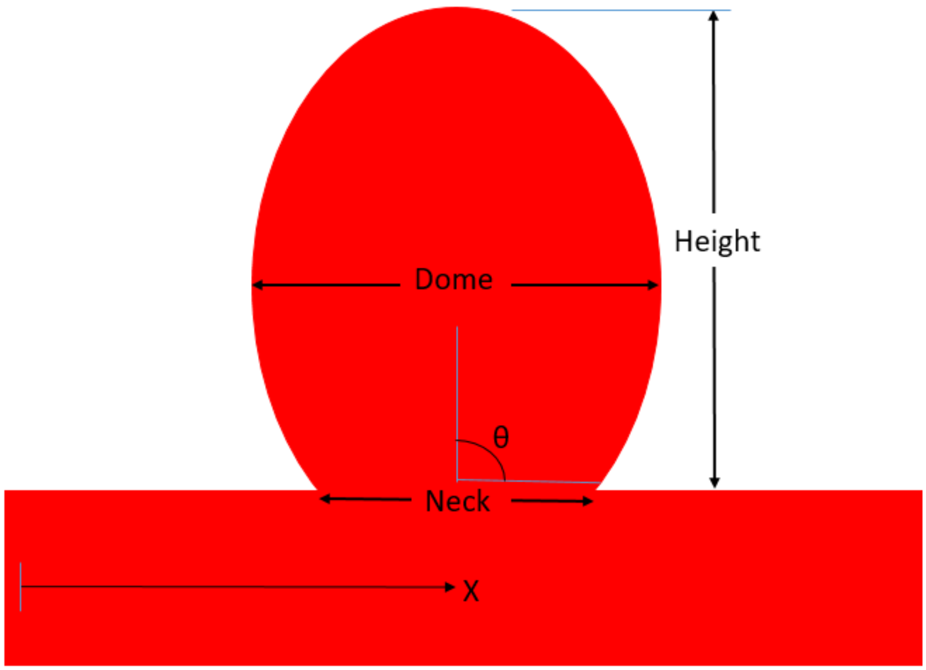



Figure 2. Aneurysm Diagram

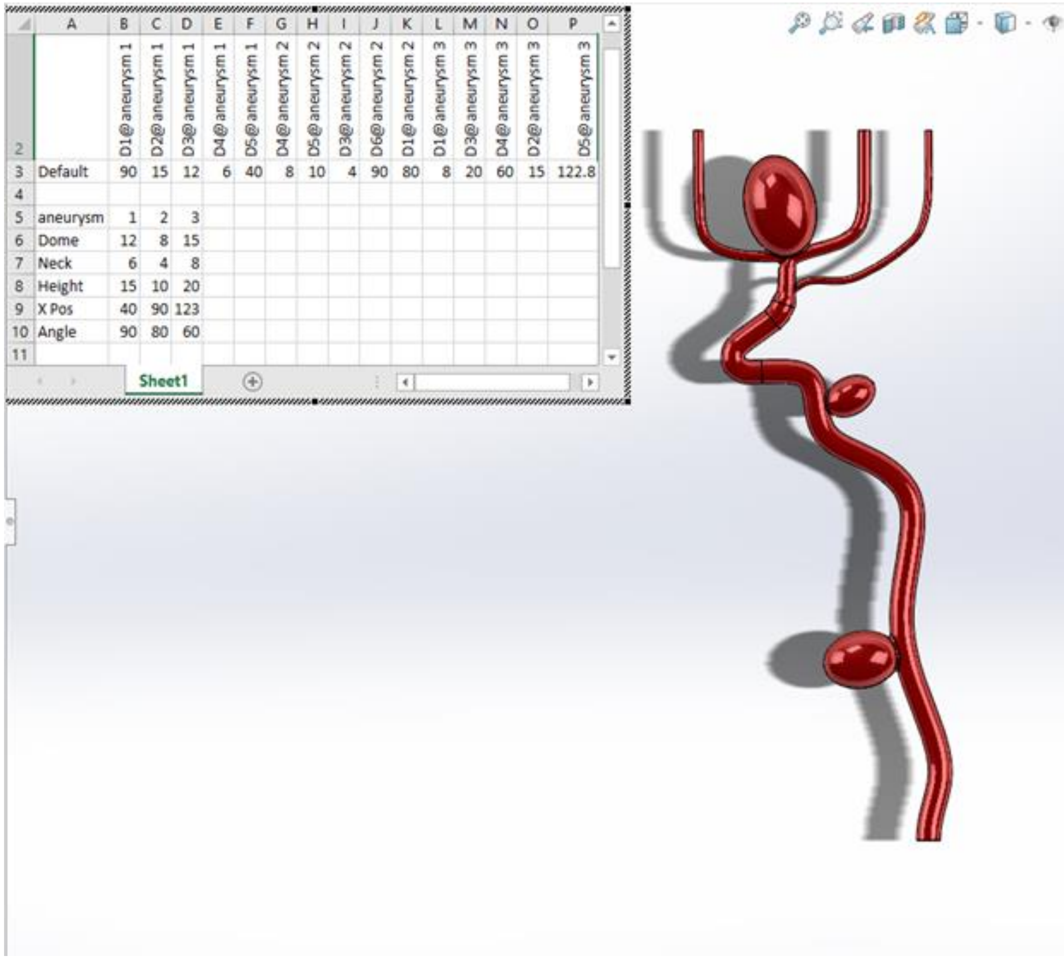
The x-position refers to the lateral distance from the entry point of the model (ICA bifurcation from the CCA) and the angle theta refers to the orientation of the aneurysm measured from the main artery, which is especially important for bifurcations. The scope of size-related dimensions, as given by Dr. Becker will be:

- Dome width: 8-15mm
- Neck width: 4-8mm
- Height: 10-20mm

Aneurysms will be parametrically designed per these dimensions along the main ICA-MCA spline using a design table in SolidWorks, so that inputs can be easily changed and a new model quickly created.

*CAD Model*

Figure 3 below depicts the anatomically accurate vasculature with three parametrically designed aneurysms along the main ICA-MCA spline; one small, one medium, and one large. The design tree is included for dimension references.



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | D1@aneurysm 1 | D2@aneurysm 1 | D3@aneurysm 1 | D4@aneurysm 1 | D5@aneurysm 1 | D4@aneurysm 2 | D5@aneurysm 2 | D3@aneurysm 2 | D6@aneurysm 2 | D1@aneurysm 2 | D1@aneurysm 3 | D3@aneurysm 3 | D4@aneurysm 3 | D2@aneurysm 3 | D5@aneurysm 3 |
| 3 | Default | 90 | 15 | 12 | 6 | 40 | 8 | 10 | 4 | 90 | 80 | 8 | 20 | 60 | 15 | 122.8 |
| 4 | | | | | | | | | | | | | | | | |
| 5 | aneurysm | 1 | 2 | 3 | | | | | | | | | | | | |
| 6 | Dome | 12 | 8 | 15 | | | | | | | | | | | | |
| 7 | Neck | 6 | 4 | 8 | | | | | | | | | | | | |
| 8 | Height | 15 | 10 | 20 | | | | | | | | | | | | |
| 9 | X Pos | 40 | 90 | 123 | | | | | | | | | | | | |
| 10 | Angle | 90 | 80 | 60 | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | |



Figure 3. Cerebral Vasculature and Parametric Design of Aneurysms

<u>Conclusion</u>

The above CAD model will be 3D printed and used to cast the lumen of the tube model for this project with anatomically correct geometries. The volume of this part is 7,450mm$^3$, as given by SolidWorks, which will help determine the cost of the 3D printing job once a material is known.

Casting methods and materials are still being tested; however, it is likely that this vessel core will be printed in a flexible material, suspended inside a two-part mold with the outer tube dimensions in an even more flexible material, from which the core can be pulled out of. This design will be the basis of the tube model, and used to design the top and bottom pieces of the mold, with swept cuts following the exact same splines, and aneurysms in the same positions (also parametrically designed), only larger. An example of how this mold could look is shown in Figures 4 and 5.

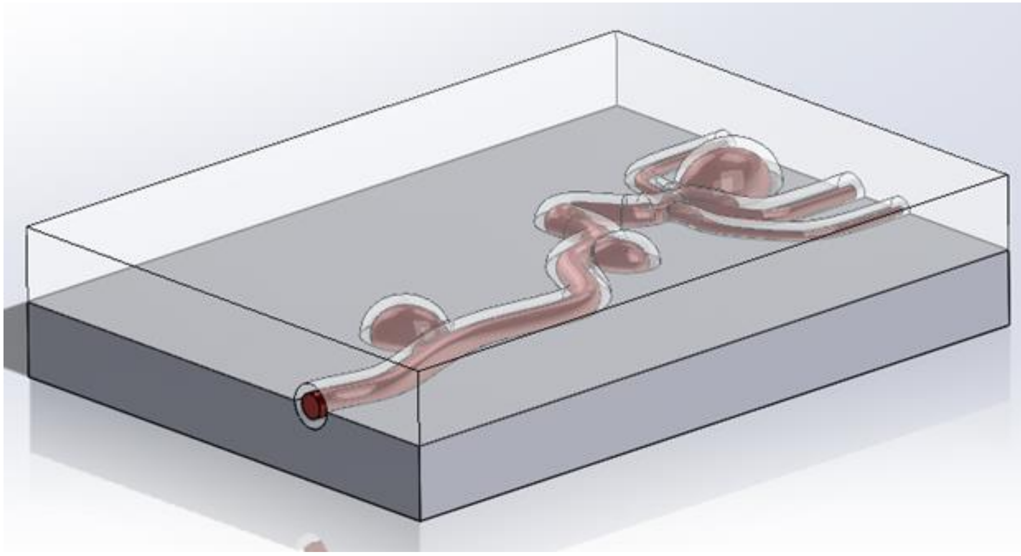


Figure 4. Assembly View of Cast Mold

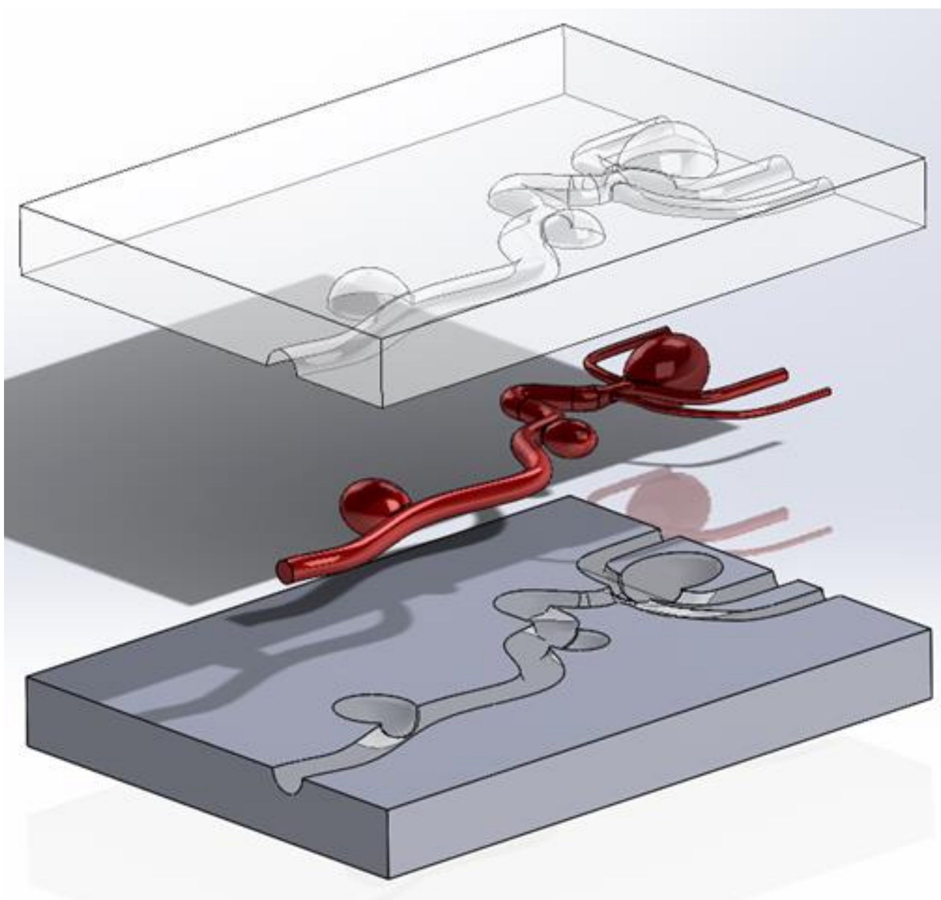


Figure 5. Exploded View of Cast Mold

From this mold, the vasculature that would be cast would look as shown in Figures 6 a and b.

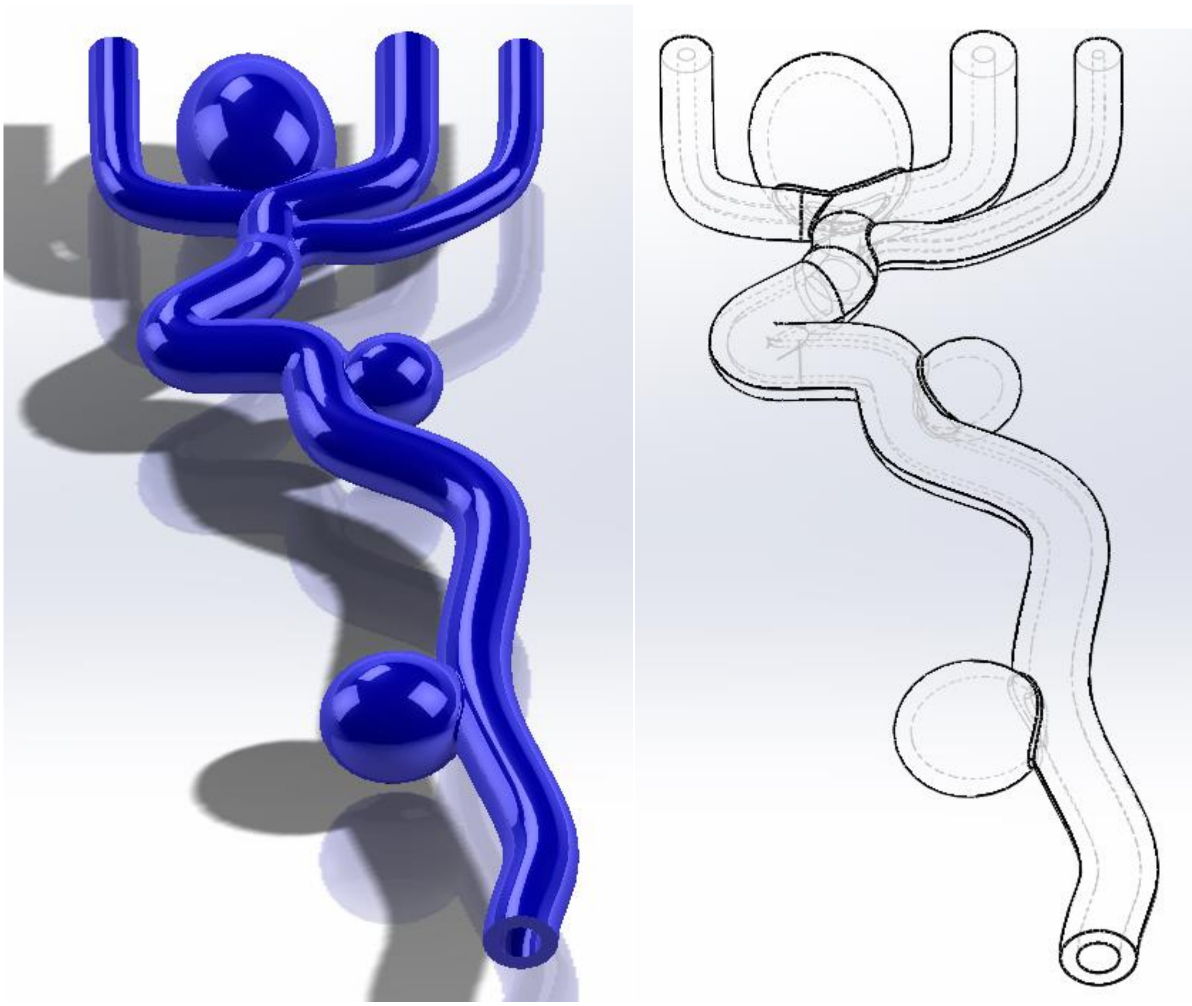


Figure 6 a & b. Casted Vascular Tube

References

[1] Themes, UFO. "Craniocerebral Diseases | Radiology Key". *Radiologykey.com*. N.p., 2015. Web. 18 Nov. 2016.

[2] S. Kamath, "Observations on the length and diameter of vessels forming the circle of Willis.", *J Anat.*, vol. 133, no. 3, pp. 419-423, 1981.

[3] J. Lang, *Clinical Anatomy of the Head: Neurocranium · Orbit · Craniocervical Regions*, 1st ed. Springer Science & Business Media, 2012, pp. 166-167.

[4] Â. Silva Neto, R. Câmara and M. Valença, "Carotid siphon geometry and variants of the circle of Willis in the origin of carotid aneurysms", *Arq. Neuro-Psiquiatr.*, vol. 70, no. 12, pp. 917-921, 2012.

[5] T. Ingebrigtsen, M. Morgan, K. Faulder, L. Ingebrigtsen, T. Sparr and H. Schirmer, "Bifurcation geometry and the presence of cerebral artery aneurysms", *Journal of Neurosurgery*, vol. 101, no. 1, pp. 108-113, 2004.