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# Development of Patient-Specific Cerebral Vascular Phantoms by Additive Manufacturing Technology and Advanced Molding

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## Introduction

The manufacturing of patient-specific cerebral vascular phantoms offers a unique opportunity to study hemodynamics of human cerebrovascular disease, test the performance of novel microsurgical or endovascular devices and simulate procedures for training purposes. Although few additive manufacturing techniques are in the public domain, the generation process of these vascular models is not yet well established and there are several limitations related to printing materials and techniques, such us labor-intensive removal of 3D scaffolding and residual support material left in the lumen of the phantom (1-5). Here, we present a novel technique to manufacture hollow, elastic and high fidelity cerebral vasculature that overcomes these limitations.

## Methods

A sequential five-step fabrication technique was developed (Figure 1): (1) patient-specific cerebral vascular 3D geometry was extracted from CTA and 3D-printed in ABS plastic, (2) the printed structure corresponding to the vascular lumen was submerged in silicone to create a negative mold, (3) the silicone mold was used to cast low melting temperature metal to the shape of the vascular lumen, (4) the metallic cast was coated with silicone to create the vessel wall, and (5) the cast metal filling the silicone vessel phantom was removed by hot water flush, leaving a hollow cerebral vasculature. Resulting phantoms were tested by x-ray angiography, intravascular pressure curves of pulsatile flow, burst pressure, presence of residual intraluminal debris and haptic feedback from 4 cerebrovascular neurosurgeons (scale 1 to 5, 1 highly unrealistic, 5 highly realistic).

## Results

Elastic and hollow patient-specific vascular phantoms were manufactured (Figure 2). The luminal angioarchitecture of the phantoms per angiography closely matched the native 3D geometry of CTA. Intravascular pressure curves were consistent with shape and values of human arteries under physiological conditions. Minimal amounts of metal residual were found after serial cross-section of the phantoms, mainly in small distal branches. Average score from neurosurgeon on haptic properties of the phantom vessels was 4.5.

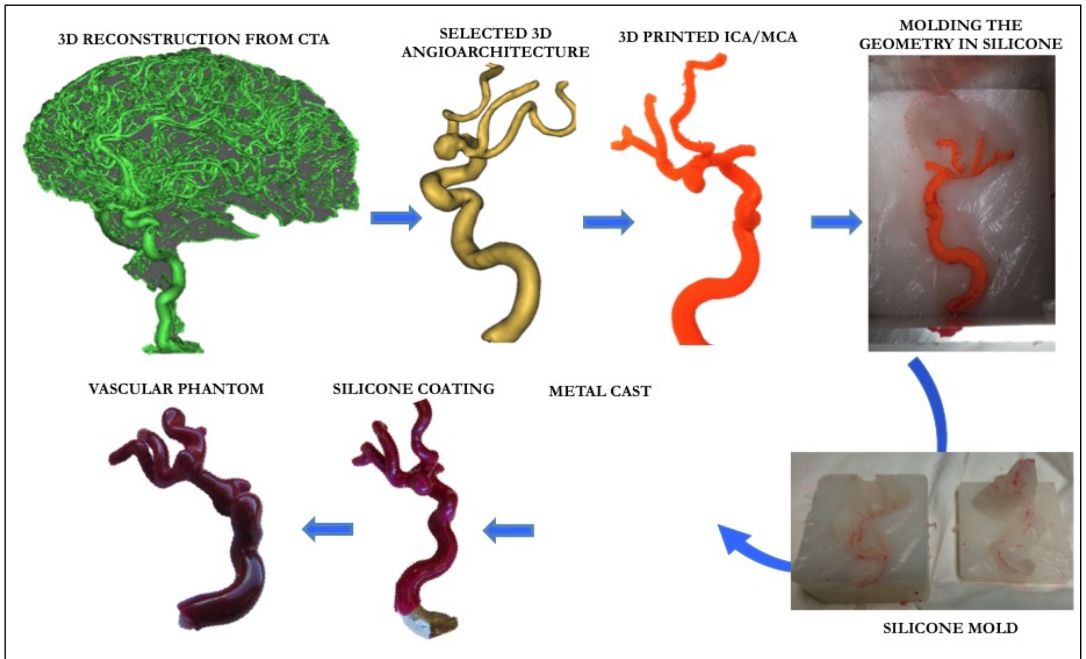


Figure 1: Manufacturing process of phantom artery with MCA bifurcation aneurysm

## Conclusions

Cerebral vascular phantoms manufactured by 3D printing and advance molding techniques have high anatomical and mechanical accuracy and are suitable for cerebrovascular flow research, testing of new endovascular devices and surgical training.

## References

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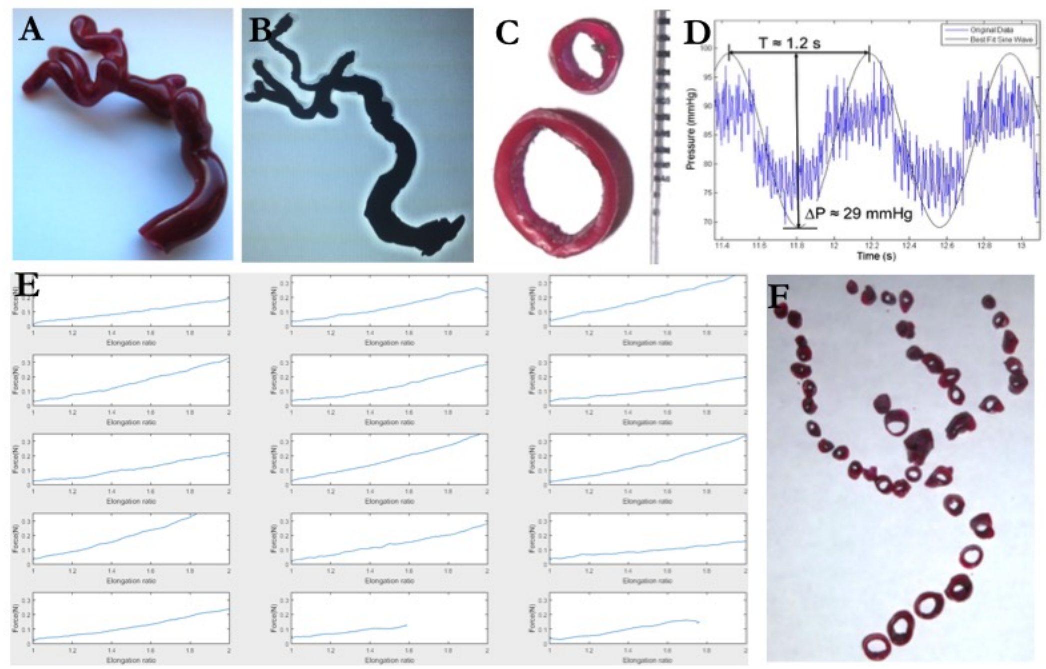


Figure 2: Morphological and mechanical testing of phantom arteries (A) by angiography (B), wall thickness by serial cross section (C), pressures curvatures generated by pulsatile system (D), tensile testing (E) and evaluation of retained intraluminal debris (F).