

## Ex Vivo Aneurysm models mimicking real cases for the preoperative training of the clipping technique

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**Abstract:** Training in a specialty like cerebrovascular neurosurgery becomes more and more difficult as the access to training is limited by the increasing number of neurosurgical departments and the lack of expert centers for specific pathology. This is why an increased investment in experimental training is encountered in many centers worldwide. The best models for training the clipping technique are ex Vivo on cadaveric heads aneurysm models, animal models or augmented reality models. We present a few ex Vivo models of aneurysms mimicking ACOA, ACM bifurcation and basil artery tip aneurysms using a pulsed continuous perfusion system. Clipping training on aneurysm models is an invaluable tool both for the residents and for the specialists with a special interest in cerebrovascular surgery.

**Key words:** aneurysm model, clipping, microanastomosis

### Introduction

Cerebrovascular surgery, as a very challenging subspecialty of neurosurgery requires both a thorough knowledge of anatomy and skull base approaches, and refined technical skills. If the anatomy and the usual neurosurgical approaches can be learned from books and online video materials, and the skull base approaches can be learned by assisting in the surgery or hands on courses, there is no way of acquiring the required technical skill needed in complex vascular cases through learning on human patients at least, without having a long list of failure. In order to address this training issue, the

resident with a special interest in cerebrovascular surgery should attend many hands on courses of skull base surgery and microneurosurgery, but more importantly should have access to training in a neurosurgical laboratory with ex vivo and in vivo animal models, cadaveric heads and if available virtual reality and 3D printed models on a weekly basis.

A good model is one that comes closer to the real operative experience, and this is only possible in cadaveric surgical simulation where real vessels are used to build the models and a pulsed flow system is used after the vascular malformation model has been implanted in a cadaveric head, or in

augmented reality computer models. Although the haptic performances of the virtual reality and the 3d reconstruction of the cerebral arteries, veins and malformation models bring this closer to the real experience it is nonetheless lacking brain manipulation and the realistic surgical feedback. [1,5]

### **Method**

We used chicken wings to create different aneurysm models. In all cases we dissected both the main artery and the main vein past the bifurcation. Then we implanted a vein or an artery segment at different sites, either at the main artery bifurcation or past this spot. Because we used an ex vivo model there was no need for ethical approval. All the aneurysm models were checked by inserting first water and then air to identify the eventual leaking points. In some cases we used a colored dye to perfuse the vessels to make sure. In some of the cases we connected the main arterial branch to a pulsed continuous infusion system using a processor to open and close a valve interposed in the tubing system coming from a pressured perfusion sac with variable pressure, between 80 mmHg and 180 mmHg.

### **Building the aneurysm**

We used the microsurgical technique of vessel dissection and we first exposed the artery which lies deep in the bone, past its bifurcation and the superficial lying vein and its quadrifurcation in every case.

We performed different types of aneurysm models, starting with a fusiform one which is made by interposing a vein segment in an

artery using two termino-terminal anastomosis.

The simplest type of saccular aneurysm is made with only a terminolateral anastomosis using a fishmouthed vein segment, but this does not meet the criteria of resembling the real cases where the aneurysm forms at a bifurcation.

As the main artery bifurcation is in sharp angle, this allowed us to implant an aneurysm in this bifurcation. For this a linear incision was made from one branch to the other on the internal edge, than a vein segment with one end ligated was anastomosed in a continuous fashion starting with the back wall. The vein segment has to be prepared either by one incision or by two 180° incisions so that the cut edge perimeter equals that of the incision in the artery. In order to make this anastomosis easier, the two branches can be split apart using two adventiceal stitches so that it is reduced to a simple yet longer terminoterminal anastomosis.

In order to create a basilar bifurcation aneurysm model we terminolaterally implanted two ends of the same long arterial segment at 0° and 180° immediately proximal to the main artery bifurcation and then we performed a 5 branched incision in all 5 vessels. We then performed a running suture to anastomose the free end of an augmented edge vein to this branched incision. This anastomosis is technically quite difficult and it cannot be performed using only one continuous suture.

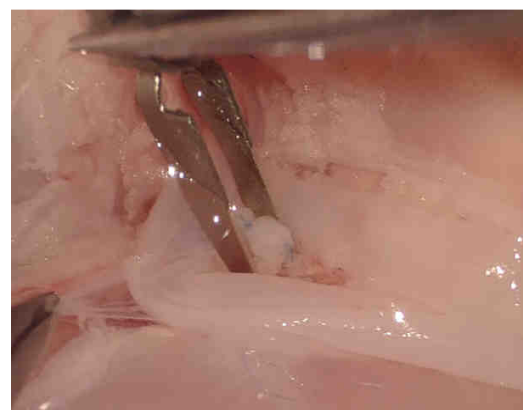
Using a terminolaterally anastomosis a long arterial branch is implanted in the bifurcation of the main branch to resemble a

MCA trifurcation. Then we performed a y incision in all three branches. A “V” incision in the cut edge of the vein segment approximates its shape. Then a continuous or interrupted sutures were performed. In all of these cases the aneurysm can be fixed to the arterial branches using many adventitial stitches in order to give it the required shape and orientation. An MCA Quadrifurcation aneurysm can be built making an incision in both walls of the main artery starting from the bifurcation than extending this incisions on the internal margin of both branches. Following, a vein segment is split open on its longitudinal axis and an anastomosis is started on the back wall of the cut artery, than the vein is reflected onto itself and the front wall of the aneurysm is anastomosed to the anterior cut edge of the artery. Before completing the anastomosis both free edges of a long arterial segment are TL anastomosed between the artery and the vein at 180 degrees. This construct can be used as both a MCA quadrifurcation or as a basilar bifurcation giant aneurysm with the neck implanted on both PCA's and both SCA's.

One of the most technically difficult model is a giant ACoM aneurysm, irrespective of the dome orientation when the neck comprises both a2 segments and the acom on the entire length. In order to build this kind of model a short arterial segment is recolcted and cut open on its length. Two liniar mirroring incisions are cut in the branches at a distance of half a centimeter distal from the bifurcation. The "ACoM" segment is sutured continuously to the inferior edge of the branches' incisions. This H shaped anastomosis is impossible to

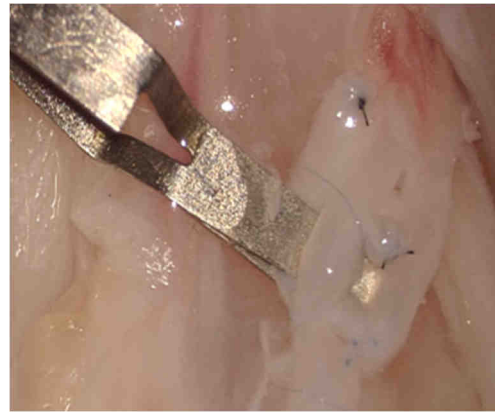
perform with continuous sutures on all walls so we continued ligating the back wall of the aneurysm to the back wall of the "acom". Then, the lateral side of the aneurysm is anastomosed to the both A2' s starting with the back wall.

Once constructing the aneurysm was finished, the flow through it was verified with serum and to check for eventual leaks. At this step we usually encounter some leaks from small branches that were missed during vessel harvest or vessel skeletonising.

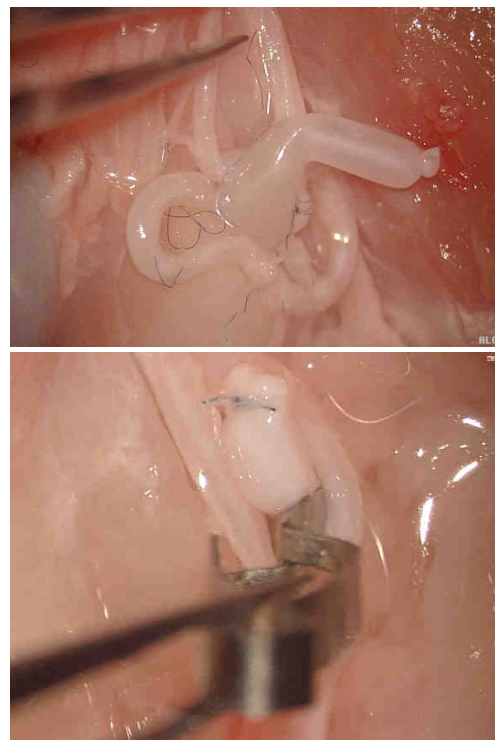


**Figure 1** - a model of blister aneurysm implanted at an artificially created bifurcation. A straight clip parallel to parent vessel was applied

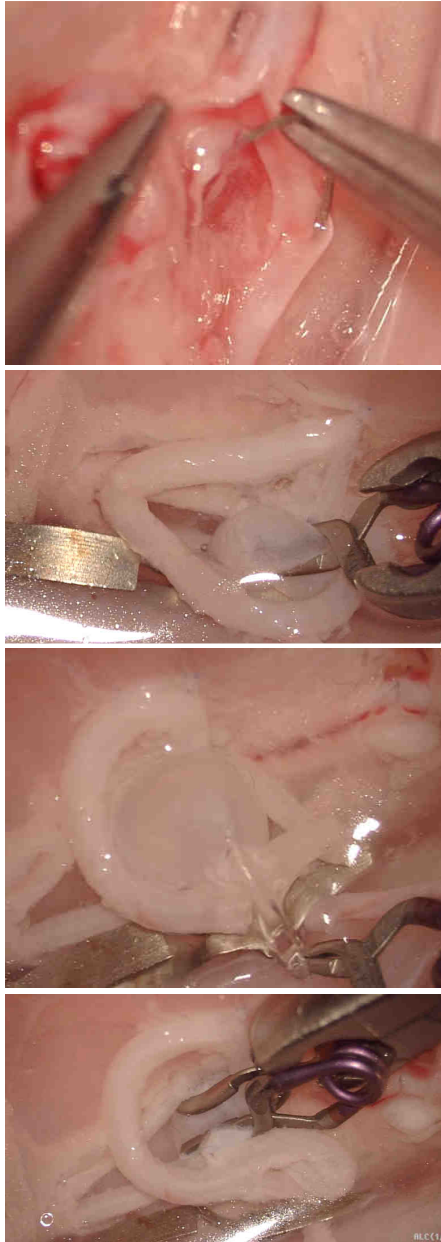
Another cause for leakage is either the distance between stitches is different between the vessels, especially when an artery to vein anastomosis is executed, or if continuous suture was used it was not properly tightened. The problem when using continuous suture is that it can narrow the lumen but this problem can be easily prevented by fishmouthing the donor vessel depending on how large we want the aneurysm neck.



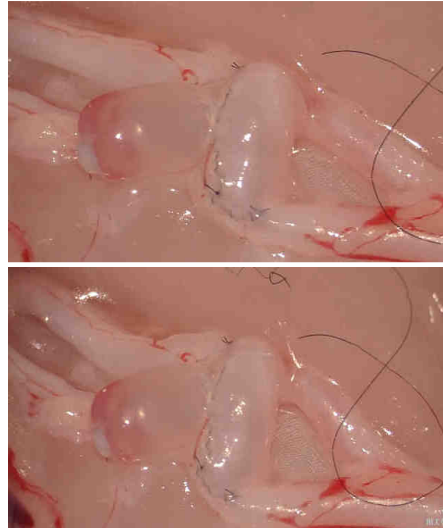
**Figure 2** - a bilobed aneurysm was implanted in a natural bifurcation of the arteries. The clip is closed on the neck of the aneurysm with the blades inserted between the two arterial branches



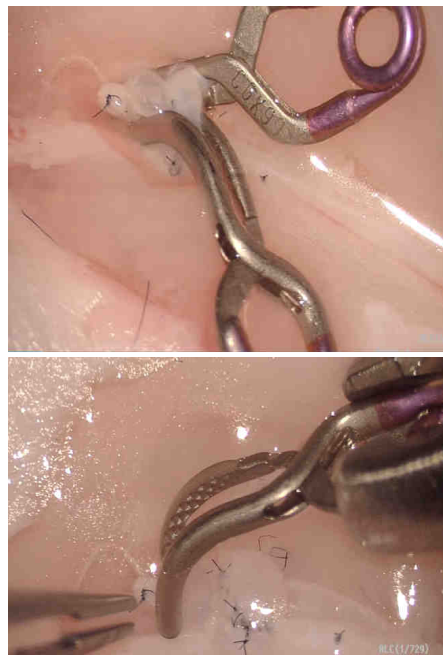
**Figure 3** - model of basilar tip bifurcation aneurysm performed by anastomosing the vein segment on a 5 branched incision in the reconstructed PCA's-SCA's complex. This is difficult to occlude with a single clip



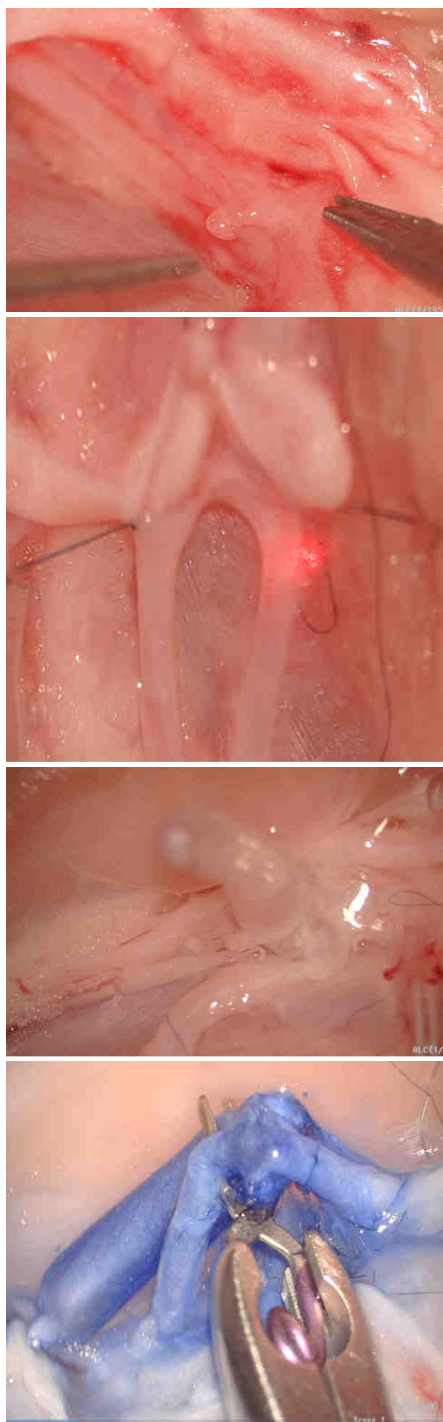
**Figure 4** - A MCA quadrifurcation/ basilar tip bifurcation giant aneurysm. Incompletely occlusion with one clip. A rupture in the aneurysm dome is simulated and a stacked clip technique is used, inserting multiple clips between the 4 branches, such as the flow is patent in all of them



**Figure 5** - the flow through a ACoA aneurysm model at 80mmHg and 140mm Hg using a continous pulsed flow system



**Figure 6** - Clipping an ACoA aneurysm using either two clips which occlude the ACoA and using a single curved clip between the "A2" branches to completely occlude the neck



**Figure 7** - Building an MCA quadrifurcation aneurysm model inserted on all 4 branches: we used a two bifurcated arteries, both cut in a y shape. Than we kept them open using by fixating in the muscle walls with two stiches and after anastomosing these two vessels we implanted the aneurism between them. The aneurism was checked with a colored solution and clipped using a between branches technique

### Discussion

Based on the thorough full study of the angiography and angioCT studies the surgeon should make an image of the steps implied in successful clipping of an aneurysm. The surgical approach should be chosen as to allow a good visibility to the vessels proximal and distal to the aneurysm and a good access to the aneurysm neck. Also the approach should take into consideration the orientation of the aneurysm and the relation of the dome with the surrounding vessels, and with parenchima, cranial nerves and tentorium. Once the operative corridor has been Established the surgeon should correlate all the information given by the angio, mri and angioCT images and during the arachnoid dissection around the aneurysm he should compare the setting in his mind with the real setting. The more experienced the surgeon, the less the difference between the real and the imagined. Yet there are a few methods to surpass this difference which is to have a perfect operative understanding of the aneurysm, including training on a virtual reality model or training in an animal model or training of a sintetic 3d printed model. [9,10]

The best aneurysm models reported so far in the literature are those testing both the

anatomical knowledge and the technical skills. Lawton et al used a model of 3D printed aneurysm implanted into cadaver and prepared for surgical simulation, while a group from Little Rock designed a “live cadaver” model using a pulse generator, and vein segments to create aneurysms in cadaver heads connected to a closed flow system. [1,4,8]

The accuracy of reproducing the real aneurysm surgery in an experimental setting should be balanced with the cost, thus training on chicken wing on rat, bigger animals like rabbit or swine or human placenta models is the cheapest, while training on cadaveric heads with vein models, 3D printed models can increase the cost to more than 2000 \$ per model. The virtual reality model for training, even if the most expensive, around 300000\$ for a surgery rehearsal platform is the farthest away from the real surgery. [2,7,12,13]

All of these experimental methods of training have their shortcomings. The synthetic and the virtual models are far from reaching the real feel sense one can develop only training with real vessels and also one cannot train dissecting around the aneurysm using these models. The in Vivo animal model can approximate relatively simple aneurysm conformations and in larger vessels than we usually encounter in brain as it is difficult to build an aneurysm model in a living animal and it takes too much time to reperfusion to be feasible in smaller animals like rats where the vessels resemble those in the brain.

The ex Vivo model lacks the flow and the real vessels reactivity to manipulation but this shortcoming can be exceeded by connecting the vessels to a pulsating flow system. Also it

allows building of complex giant aneurysms to resemble giant ACoM, ICA, MCA trifurcation or quadrifurcation aneurysms.

There is no aneurism model so far to take into consideration the perforating vessels

We routinely use chicken wings for aneurysm and avm models as their vessels have a similar calibre with the A1 and A2 segments. The wall of the chicken wing arteries have a slightly better developed muscular tunica than those in the brain. [2]

Excepting the fact that aneurism models are a useful tool to practice clipping the aneurysm implantation technique is a good practice for vessel dissection and practicing microanastomosis.

This study has an important limitation in that it does not take into account the skull base and the cisternal anatomy.

The 3D printers are limited by the impossibility to reproduce aneurism models smaller than 1mm and given the fact that it is based on information from the angio MRI, the printed model cannot include the perforators, which should be the main concern for a successful surgery. As more performant MRI machines will be available for clinical use the perforators may become visible in the 3D reconstruction and can be used for the printed models. Using cadaveric models is the most appropriate experimental model as it tests the anatomical knowledge and the arachnoid dissection technique, but it cannot mimic an in vivo environment, even if the arteries are connected to a continuous perfusion system. [3,8]

The virtual reality aneurysm clipping simulation provides a realistic haptic virtual

reality clipping of patient based cerebral aneurysm. The system is designed to give the user the sense of the force of the clip and the tissue deformation as the clip is positioned on the aneurysm neck.

## Conclusion

Clipping Training on aneurysm models is an invaluable tool both for the residents and for the specialists with a special interest in cerebrovascular surgery. Using ex vivo models allows constructing a complex shape aneurysms to resemble real cases, which are time consuming, and thus difficult to build in vivo models and also is the less resource consuming method with advantages comparable to the other experimental models described in literature.

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