Three-dimensional Cerebrovascular Bypass Training. A New Low-Cost Home-Made Model

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ABSTRACT

Background: Vascular anastomosis in neurosurgery is a crucial lifesaving skill requiring intensive continuous training. This makes laboratory training an invaluable aspect of the training. However, many residents have little exposure to this training due to lack of good training models. **Objective:** To introduce an easily replicable anatomically accurate brain model with major blood vessels and pulsatile blood flow. **Materials and Methods:** The brain model is made using a 3D printed resin mold. The mold is filled with silicone and mixed with pigment additives to replicate the color and consistency of brain tissue. Dura is made from quick drying silicone paste with grey dye. The blood vessels are made from a silicone 3D printed mold of an MRA. Liquid with Paprika oleoresin (e160c) dye is used to simulate blood and is pumped through the vessels to simulate pulsatile motion. **Results:** The model was used by 8 residents and 2 neurosurgeons. They unanimously noted that the model offered a more realistic 3D environment compared to the regular silicone and chicken wing models. **Conclusion:** This model offers a near realistic simulation to real surgery in anatomy, texture and pulsatile blood flow. The model is easily replicable as it utilizes readily available silicone materials. Application will range from preoperative case simulation and training in vascular anastomosis and bypass surgery to aneurysm management.

Keywords: 3D Model in Neurosurgery, Bypass, Neurosurgery Training

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1

Introduction

Vascular anastomosis is an invaluable skill crucial to all neurosurgeons in this era of microsurgery. Although endovascular procedures have become the more commonly used, surgical management still remains strongly indicated in Moya Moya disease, management of complex aneurysms among other conditions (Belykh *et al.*, 2016; Cikla *et al.*, 2018; Colpan *et al.*, 2008; Shi *et al.*, 2015). Aneurysms are a relatively common neurosurgical pathology whose management in many centers is largely endovascular with coiling or stenting. This shift of management technique has decreased the resident's vascular anastomosis skill and experience (Shah *et al.*, 2018). Three dimensional models have been used in an attempt to reduce this deficit. The use of 3D technology has been explosive in various fields including orthopaedics, plastic surgery and vascular surgery. However, it has been largely underexplored in neurosurgery until recently (Ploch *et al.*, 2016) Most anatomy textbooks and atlases and most radiological investigations like CT and MRI offer a 2D representation of anatomy which is difficult to visualize and correlate with intraoperative anatomy (Shah *et al.*, 2018; Panesar *et al.*, 2019). Recent studies have even argued that anastomosis training models are superior to the traditional apprenticeship training (Cikla *et al.*, 2018). As the 3D printing software and machines become more available and affordable, many centers have a well-established 3D printing system used for various activities including teaching, prosthesis creation etc. As demonstrated by Sandip S. Panesar *et al.*, patient and pathology specific anatomy models can be 3D printed for preoperative preparation to understand the regional anatomy and pathology to aid in planning the best approach (Panesar *et al.*, 2019).

Many centers especially in the developing countries may not be privileged enough to have sophisticated 3D printers. The method presented in this paper is a new home-made low-cost silicone based anatomical brain model with pulsatile blood flow for preoperative case simulation and resident training in vascular anastomosis and bypass surgery. This model uses ordinary silicone material available in most stores making it easily replicable.

Materials and Methods

The method described in this paper is a new method to make homemade low cost and easily replicable models. To make a brain model, we need an already made rigid model. It is important to keep in mind that the scale must be 1:1. The model can be plastic or made using a 3D printer. However, the problem with making the model with the 3D printer is that the printing is done in layers of 0.2 mm, and we need a smooth model. To create a smooth model, we use a resin printer. If, however we use a rigid human brain model, we need to properly examine it for defects so that we can produce anatomically accurate mold for our model. The rigid brain needs to be dry on the entire surface that will be in contact

with the silicone. We must keep in mind that brain will be dried, without becoming dehydrated because it would alter its normal anatomy (Fig. 1).

Figure: 1 Brain model in the mold awaiting cure time

A plastic container or cardboard is used, leaving a gap of 2-3 cm between the brain and the edges of the container. The container will be filled with silicone. We use silicone, tooldecor 25 a heat-resistant silicone for casting. We put the brain in the silicone and wait for cure time. The brain model is removed after it cures leaving an empty mold of the brain in the silicon. The empty mold is filled with silicone mixed with pigment additives Flesh Tone and White (PMS White) to replicate the color and consistency of brain tissue. Then we wait the cure time and remove it (Fig. 2).

Figure 2: Brain model after being removed from the mold with pia matter

The model needs to create a with no cortical vessels or pia matter so that we can have good model with all gyri and sulci. Then the brain is cut in the midline, that way we will have access to the ventricular system, and a mold is created. The hemispheres are joined by Corpus Callosum created from silicon together with the ventricular system.

The dura mater is made using quick-drying silicone paste combined with grey polymer "O" PO-MIX 622.2-1 RAL 7040 dye to simulate the dura mater in its color. This is applied with a brush on the entire inner surface of the skull and allowed to dry. This layer can now easily be separated from the skull model (Fig. 3).
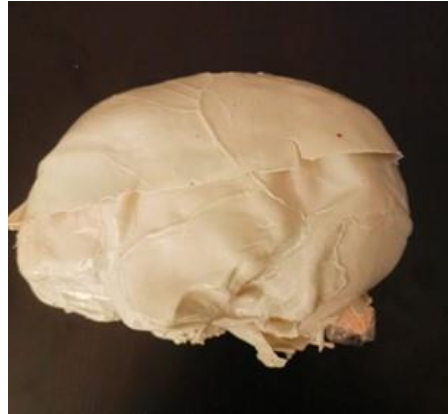

Figure 3: Brain covered by dura matter. Also seen is the marking of the MMA shown by the arrow

Arachnoid was created using self-adhesive, transparent PVC FLEX paper. This allows a difference in consistency between materials used. This material does not adhere to silicone, it is low cost, readily available and very similar to arachnoid (Fig. 4).

Figure 4: Showing dura and arachnoid matter and sylvian fissure

Pia Mater

The pia mater is made with a layer of silicone tool decorator 15.

Vessels

For this practice we have used artificial silicone vessels made with tool decorator 25. The vessels were made of two layers and sizes 1.0 x 70mm 1.5 x 70mm, these vessels tolerate suturing well without tearing (Fig. 5 and Fig. 6).
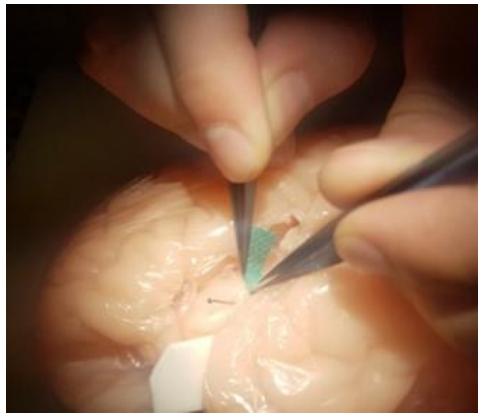
Figure 5: Performing dissection of the sylvian fissure, the synthetic vessel is fixed at one end to make it easier to suture it. When simulating pulsatile flow, the vessel has to be left free so as not to interrupt flow

Figure 6: View through a microscope: End to side bypass anastomosis using black monofilament non-absorbable polypropylene suture 10-0

Results

The models were used by eight neurosurgery residents with prior experience in anastomosis with silicone and chicken wing models and two vascular neurosurgeons. The feedback was unanimous: the models offered a more realistic 3D experience as it was anatomical with a skull, brain, and meninges. All the participants recommended the use of this model in future trainings (Fig. 7).
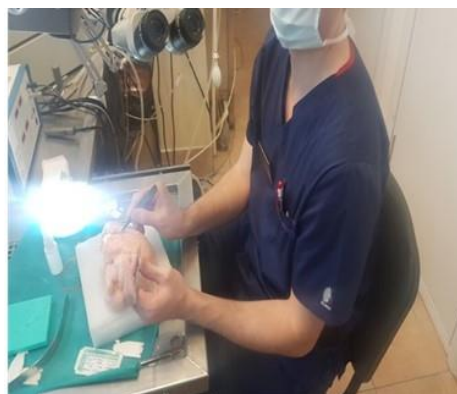

Figure 7: A neurosurgeon demonstrating anastomosis on the brain model

The realization of a 3D skull allows the most realistic interaction since it adds to the surgical skills the realization of the approach and the interaction between the model of the brain, the meninges, the skull and the vessels (Fig. 8 and Fig. 9).

Figure 8: view on the monitor during anastomosis demonstration

Figure 9: Pterional craniotomy showing the model intracranial

Discussion

Microsurgery training should be continuous and repetitive (Belykh and Byvaltsev, 2014). This requires continuous access to readily available training models. This training has been seen to enhance resident knowledge and technical proficiencies (Zammar *et al.*, 2015). When tested on live models, residents with prior training on dry models like silicone tubes performed the anastomosis faster and more confidently than ones without prior experience with the models (Zammar *et al.*, 2015; Olabe *et al.*, 2011). Byvaltsev V.A *et al*, describes the standard anastomosis training into three stages: dry training, using non biological materials like silicone, wet training which involves using nonliving biological tissue like chicken wings, and finally wet training using live models like rats (Byvaltsev *et al.*, 2018).

The closer to live surgery a training model is the better (Colpan *et al.*, 2008). The simulation models designed for training should comply with ethical limitations and simulate reality as much as possible (Güvençer *et al.*, 2007). In addition, a good model should be affordable, safe, make use of readily available materials and easily replicable (Aimar *et al.*, 2019). Creation of a model that meets the above characteristics is challenging task. Many models have been developed to aid anastomosis training with varying results. These include silicone tubes, synthetic vessels, chicken wings, chicken tracheas and esophagus (Güvençer *et al.*, 2007), turkey carotids, rats, cadaveric heads and cylindrical vegetables like green beans and yard long beans (Belykh *et al.*, 2016; Colpan *et al.*, 2008; Belykh and Byvaltsev, 2014; Aboud *et al.*, 2002; Grahem *et al.*, 2017).

By far the best model closest to the real surgical environment in dimension and texture is the use of a fresh cadaver (Byvaltsev *et al.*, 2018; Grahem *et al.*, 2017). However, it carries with it the risk of infection spread if not properly prepared. Hence the use of fresh a cadaver requires a highly specialized center with a good screening and storage facility (Byvaltsev *et al.*, 2018). Addition of pulsatile arterial filling improves the surgical experience mimicking active blood flow. This may be done by cannulation of major arteries perfusing the brain (Tanweer *et al.*, 2019). This was first described by Aboud, *et al.* (2002). This has been attempted on formaldehyde fixed cadavers with a mechanical pressure pump to simulate pulsatile blood flow, however the main disadvantage is the stiffness of the tissues (Güvençer *et al.*, 2007).

The use of chicken wings and turkey neck vessels is very popular in training with mechanical pumps to simulate blood flow (Aboud *et al.*, 2002; Tamrakar, 2017). This method is very affordable and readily available and may not carry infectious, storage and ethical concerns. However, the vessels do not mimic normal human vasculature and may have artifacts from freezing (Achar *et al.*, 2011).

Live animal models like rats offer a much more realistic feel. Rats have been used for training vascular surgeons since the inception of micro neurosurgery vascular anastomosis (Aboud *et al.*, 2002; Achar *et al.*, 2011). Their pulsatile flow and a functional clotting system mimic the actual surgical environment. However, storage feeding, use of anesthetic agents and some ethical factors offers some challenges to the use of this model (Byvaltsev *et al.*, 2018; Achar *et al.*, 2011). Human and bovine placental vessels have also been used in anastomosis training (Belykh *et al.*, 2016). Like the fresh human cadavers, they need a specialized storage and screening to avoid infection spread. A validation study by Belykh E *et al* found that human and bovine placenta vessels approximated M2-M4 and ICA respectively and were convenient for training (Belykh *et al.*, 2016). Simulation of blood flow in a model is a very important component as it gives the feel of bleeding with the pulsatile flow seen in major arterial systems. The common methods used are continuous saline flow, mechanical water pumps and infusion pump (Olabe *et al.*, 2011; Mokhtari *et al.*, 2017).

Our model offers a very affordable method to make anatomically accurate brain models with a 1:1 size ratio. The model is a silicone-based design with elastic cerebral vessels that can be perfused using an infusion pump or any other available method to simulate blood flow and pulsations seen in arterial flow. Among other pathologies, aneurysms can be created and clipped or bypassed depending on the training procedure. The use of a 3D printed models allows this model to be used both preoperatively to plan and simulate elective cases. This makes it easier for the surgeon to plan the approach and prepare for any possible maneuvers beforehand. Another use for this model is during training of neurosurgical residents in vascular anastomosis. This method is affordable reusable and easy to replicate. It offers an anatomically accurate model with all contours and texture similar to brain tissue without the huge cost of procurement, storage and associated infection risk encountered with fresh cadavers.

Despite offering all the above stated advantages, it has some limitations. Replicating the model requires a good 3D printer and different types of silicon material hence some centers might have some challenges. Another limitation is the difference in texture compared to live or fresh cadaver models. The model is slightly more rigid. With continued perfection of the technique and materials, this limitation can be overcome. However once produced it can be reused multiple times. The absence of coagulation is another short coming with using our model. This can only be experienced in a live model like rats.

Conclusion

Training of neurosurgeons in vascular anastomosis and bypass surgery remains a huge challenge. Our model offers the balance of an anatomically accurate model, affordability, replicability without the associated risks and costs associated with fresh cadavers. This model will help standardize training in this field in centers not equipped to manage fresh cadavers.

Conflict of Interest: All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript

Ethical Approval: For this type of study formal consent is not required.

Informed consent: This article does not contain any studies with human participants performed by any of the authors.

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