Learning brain aneurysm microsurgical skills in a human placenta model: predictive validity

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OBJECTIVE Surgery for brain aneurysms is technically demanding. In recent years, the process to learn the technical skills necessary for these challenging procedures has been affected by a decrease in the number of surgical cases available and progressive restrictions on resident training hours. To overcome these limitations, surgical simulators such as cadaver heads and human placenta models have been developed. However, the effectiveness of these models in improving technical skills is unknown. This study assessed concurrent and predictive validity of brain aneurysm surgery simulation in a human placenta model compared with a “live” human brain cadaveric model.

METHODS Two human cadaver heads and 30 human placentas were used. Twelve neurosurgeons participated in the concurrent validity part of this study, each operating on 1 human cadaver head aneurysm model and 1 human placenta model. Simulators were evaluated regarding their ability to simulate different surgical steps encountered during real surgery. The time to complete the entire aneurysm task in each simulator was analyzed. The predictive validity component of the study involved 9 neurosurgical residents divided into 3 groups to perform simulation exercises, each lasting 6 weeks. The training for the 3 groups consisted of educational video only (3 residents), human cadaver only (3 residents), and human placenta only (3 residents). All residents had equivalent microsurgical experience with superficial brain tumor surgery. After completing their practice training, residents in each of the 3 simulation groups performed surgery for an unruptured middle cerebral artery (MCA) aneurysm, and their performance was assessed by an experienced vascular neurosurgeon who watched the operative videos.

RESULTS All human cadaver heads and human placentas were suitable to simulate brain aneurysm surgery. In the concurrent validity portion of the experiment, the placenta model required a longer time (p < 0.001) than cadavers to complete the task. The placenta model was considered more effective than the cadaver model in simulating sylvian fissure splitting, bipolar coagulation of oozing microvessels, and aneurysm neck and dome dissection. Both models were equally effective in simulating neck aneurysm clipping, while the cadaver model was considered superior for simulation of intraoperative rupture and for reproduction of real anatomy during simulation. In the predictive validity portion of the experiment, residents were evaluated for 4 tasks: sylvian fissure dissection, microvessel bipolar coagulation, aneurysm dissection, and aneurysm clipping. Residents trained in the human placenta simulator consistently had the highest overall performance scores when compared with those who had trained in the cadaver model and those who had simply watched operative videos (p < 0.001).

CONCLUSIONS The human placenta biological simulator provides excellent simulation for some critical tasks of aneurysm surgery such as splitting of the sylvian fissure, dissection of the aneurysm neck and dome, and bipolar coagulation of surrounding microvessels. When performing surgery for an unruptured MCA aneurysm, residents who had trained in the human placenta model performed better than residents trained with other simulation scenarios/models. In this age of
MANAGEMENT strategies for intracranial aneurysms have undergone dramatic changes in the past 2 decades. After refinements of neurointerventional techniques, endovascular treatment has become a valid alternative to surgery in an increasing number of patients with intracranial aneurysms. This paradigm shift has resulted in decreased exposure to open aneurysm cases for both practicing neurosurgeons and those in training. To fill this training gap, different vascular neurosurgery simulators have been proposed. However, to establish the real usefulness of a simulator, studies of its predictive validity are necessary. Studies comparing different types of brain aneurysm surgical simulation have reported both face and content validity. To our knowledge, concurrent and predictive validity have never been studied. These parameters refer to task-completing differences between experienced professionals and novices, the degree that 1 simulator correlates with previously described ones, and the end-point efficacy of simulators when one uses it to practice real situations. The objectives of this study are: 1) determine concurrent validity of human cadaver and human placenta brain aneurysm simulators; and 2) determine predictive validity by evaluating senior neurosurgical resident first-time performance in unruptured middle cerebral artery (MCA) aneurysm surgery after simulation training.

Methods

After approval by the local ethics committee, data were collected between April 2014 and May 2016. Human placentas were obtained and prepared as previously described, in the microsurgical laboratory of the Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil. Cadaver heads were obtained from the Anatomical Laboratory of the same institution. Participating neurosurgical residents were from the same university, and neurosurgeons belonged to the UFMG clinical hospital and Luxemburgo Hospital (UFMG-affiliated neurosurgery department in Belo Horizonte, Brazil).

The study consisted of 2 parts: 1) determining concurrent validity of biological simulators, and 2) determining predictive validity of brain aneurysm surgery simulation. The first part included 12 neurosurgeons who were asked to compare aneurysm microsurgery simulation between cadaveric head specimens and human placentas. For the second part, which used predictive validity methodology, 9 neurosurgical residents and 1 experienced vascular neurosurgeon participated (Fig. 1).

Human Placenta Aneurysm Surgery Simulation

Thirty human placentas were used. Twenty-four placentas were used in the first part of the study, and 6 in the second part. Fifteen human placentas had their vascular anatomy modified to create 1 large- and 1 narrow-neck aneurysm. The other 15 placentas were used to simulate sylvian fissure dissection. Each simulated aneurysm surgery used a total of 2 placentas. The placentas were perfused with colored saline and intravessel pressure was adjusted at the value desired by the surgeon.

Brain aneurysm surgery simulation utilizing the human placenta model was performed as previously reported. Large-neck aneurysms were created by balloon distention of the vessel, and small-neck aneurysms were created by suture closure of placenta vessels 2 cm distal to the exiting branch from a main vessel. The microsurgical exercises assessed in the human placenta aneurysm simulation model were sylvian fissure dissection, bipolar coagulation of microvessel bleeding, aneurysm dissection, and aneurysm clipping.

Human Cadaver Aneurysm Surgery Simulation

Two cadaver heads were used for the cadaver aneurysm surgery model. Donating families had signed consent forms authorizing use of the specimen for medical teaching experiments.

Four MCAs were the target of aneurysm simulation. Each artery was dissected using a surgical microscope (OPMI VARIO 700). An aneurysm was created on both the left and the right MCAs at the M1 bifurcation as described by Aboud et al. The distal MCA was perfused with red color dye (gouache color, Nanchang Lan Po Pen & Painting Material Co.) diluted in normal saline at a proportion of 1:5 ml to simulate arterial flow and aneurysm bleeding. Arterial pressure simulation was accomplished by placing a saline bag 120 cm above the cadaver head. The side of the cadaver head was used in 8 simulation exercises, 3 in the first part of the study and 2 in the second part. The side was used for 7 simulations, 3 in the first part and 1 in the second part. The exercises performed in the aneurysm surgery simulation with the human cadaver head were aneurysm clipping and blood suction.

Concurrent Validity Methodology

Twelve neurosurgeons, each with at least 1 year of independent practice, were enrolled in the concurrent validation study. Each neurosurgeon performed 1 simulated aneurysm surgery on the human placenta model, and 1 simulated aneurysm surgery on 1 side of a cadaver head. A questionnaire was answered by each neurosurgeon after completing both simulations (Table 1). All neurosurgeons allowed the use of their neurosurgical simulation performance videos for publication. Videos were randomly chosen to illustrate the training exercises.
The time necessary to complete aneurysm surgery on both models was compared and a multivariate ANOVA was used to correlate results. F-tests associated with the effect of the simulation on scores were obtained and their p values were reported. The significance level considered was 5% (p < 0.05).

### Predictive Validity Methodology

In the predictive validity portion of the study, 9 neurosurgical residents with similar levels of training and experience (at the transition from their junior to their senior year of residency, postgraduate year 4) were selected to undergo training consisting of 2 hours per week for a total of 6 weeks.

To compare their brain microsurgical ability, all 9 residents went through a brain tumor microsurgery evaluation at the end of their fourth year by their neurosurgical residency coordinator, so individual abilities could be assessed to rule out any major differences in their microsurgical ability. According to their residency coordinator, they all had similar microsurgical ability.

Each group attended only 1 of the following simulation sections: 1) videos showing how to perform the surgery without any hands-on activity; 2) aneurysm surgery practical simulation using a human cadaver; or 3) aneurysm surgery practical simulation using a human placenta. Three hospitals (indicated as Hospitals A, B, and C) joined the study. Hospital A had 2 residents in the video group and 1 in the placenta group. Hospital B had 2 residents in the cadaver group and 1 in the video group, and Hospital C had 2 residents in the placenta group and 1 in the cadaver group.

After the training period, under rigorous supervision the 9 residents each performed 1 open brain aneurysm surgery for an unruptured MCA aneurysm smaller than 12 mm. All surgeries were recorded on video with the surgeons’ authorization. One vascular neurosurgeon, blinded to the type of simulation section attended by each of the participating residents, watched the surgical video of the senior residents and evaluated their performance on 4 predetermined tasks: 1) sylvian fissure dissection, 2) use of vessel coagulation using bipolar cautery under microscopic view, 3) aneurysm dissection, 4) aneurysm clipping.

### TABLE 1. Concurrent validity of brain aneurysm surgery simulation

<table>
<thead>
<tr>
<th>Characteristic†</th>
<th>Aneurysm Simulation*</th>
<th>p Value‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Microscope &amp; microsurgical instruments handling</td>
<td>5 (0.0)</td>
<td>5 (0.0)</td>
</tr>
<tr>
<td>(2) Sylvian fissure dissection simulation</td>
<td>3.8 (0.39)</td>
<td>NA</td>
</tr>
<tr>
<td>(3) Bipolar coagulation of bleeding microvessels</td>
<td>5 (0.0)</td>
<td>NA</td>
</tr>
<tr>
<td>(4) Aneurysm neck &amp; dome dissection</td>
<td>3.8 (0.45)</td>
<td>NA</td>
</tr>
<tr>
<td>(5) Aneurysm clipping</td>
<td>4.0 (0.43)</td>
<td>3.8 (0.39)</td>
</tr>
<tr>
<td>(6) Aneurysm rupture management</td>
<td>3.3 (0.49)</td>
<td>3.8 (0.45)</td>
</tr>
<tr>
<td>(7) Real surgery anatomical reproduction during simulation</td>
<td>NA</td>
<td>5 (0.0)</td>
</tr>
<tr>
<td>Time in mins to complete the entire simulation</td>
<td>34.5 (12.3)</td>
<td>5.3 (2.3)</td>
</tr>
</tbody>
</table>

NA = not applicable.

* Likert scale (answers given by the 12 neurosurgeons when comparing the simulators with real surgery): 5 = exactly like, 4 = very similar, 3 = similar, 2 = little similarity, 1 = not similar. Data provided by the 12 participating neurosurgeons. Values given as mean (SD).

† Questionnaire (1–7) used all these statements asking the degree of similarity with real surgery.

‡ p value for multivariate ANOVA model associated with the effect of the different simulation models on scores, taking surgeon expertise into account (F-test).
Each task was evaluated using the 5-point Likert scale: 1 = not able to do the task; 2 = poor technique (imprecise hand maneuvers, not reaching end target); 3 = reasonable technique (imprecise hand maneuvers proximally, with end target reached after many tries); 4 = good technique (precise hand movements with end target reached at first try with partial execution of the task); and 5 = task completed with expert ability (good execution of the whole task). The 3 groups were compared in each task using ANOVA and pairwise comparisons conducted using the Bonferroni method.22 The significance level was taken as 5% (p < 0.05).

Results

All 30 placentas and the 2 cadaver heads were suitable for use with brain aneurysm surgery simulation. Perfusion of simulated blood was used in both models, enhancing the similarity of the simulators with real surgery. Thirty simulated surgeries were performed.

Placenta and Cadaver Aneurysm Surgery Simulation

Neurosurgical procedures specifically simulated in the human placenta model were: 1) use of bipolar cautery under microscopic vision to control microcirculation bleeding (Video 1); 2) sylvian fissure dissection (Video 1, Fig. 2A); 3) large-neck aneurysm and dome dissection (Video 2); 4) large-neck aneurysm clipping (Video 2, Fig. 2B); 5) small-neck aneurysm and dome dissection (Video 3); 6) small-neck aneurysm clipping (Video 3, Fig. 2C); and 7) large- and small-neck aneurysm bleeding rupture management (Videos 2 and 3).

VIDEO 1. Clip showing sylvian fissure dissection simulation. Copyright Marcelo Magaldi Ribeiro de Oliveira. Published with permission. Click here to view.

VIDEO 2. Clip showing large-neck aneurysm dissection and clipping simulation. Copyright Marcelo Magaldi Ribeiro de Oliveira. Published with permission. Click here to view.

VIDEO 3. Clip showing small-neck aneurysm dissection and clipping simulation. Copyright Marcelo Magaldi Ribeiro de Oliveira. Published with permission. Click here to view.

Patient setup in the operating room, neuroanesthesia, neurosurgical approach, and dural opening are not simulated using the human placenta aneurysm model.

Fig. 3 illustrates the aneurysm clip being positioned at a previously created dilation in an MCA in the cadaver head. Video 4 shows all the details of the cadaveric simulation.

VIDEO 4. Clip showing human cadaver head aneurysm surgery simulation. Copyright Marcelo Magaldi Ribeiro de Oliveira. Published with permission. Click here to view.

Concurrent Validity Methodology

Concurrent validity results showed important differences between human placenta and human cadaver simulation (Table 1). Microsurgical instrument utilization and surgical microscope manipulation were rated as exactly the same by all 12 neurosurgeons performing both simulated activities. Specific brain aneurysm surgical techniques (i.e., sylvian fissure and aneurysm dissection) were ranked as very similar to real surgery in the human placenta simulator by all participants.

Both biological simulators used perfusion that resembled blood circulation. The difference was in the microvessel circulation in the surrounding tissues present only in human placenta. Aneurysm clipping techniques were similar in both models, although the human placenta model offered 2 kinds of aneurysm shapes. Aneurysm...
rupture management simulation was also similar in both models, but in the human placenta it was not possible to clip the ruptured aneurysm if it was not dissected before from the allantois membrane and the placenta stroma.

The time to complete task execution varied from 18 to 57 minutes in the placenta model and from 2 to 9 minutes in the cadaver model (p < 0.001). This difference was due to the microdissection needed to open the simulated sylvian fissure and the aneurysm dissection from surrounding tissues before placing the clip. The aneurysm surgery technique in the human cadaver head was directly focused on the aneurysm clipping technique. Aneurysm rupture management in the cadaver head was rated as having a greater similarity to real surgery than in the human placenta due to neuroanatomical structures present on that model.

Predictive Validity Results

Figure 4 shows the results of the blinded evaluation of the MCA surgical videos of each resident by a neurovascular surgeon (Fig. 4A, sylvian fissure dissection performance; Fig. 4B, MCA aneurysm dissection performance; Fig. 4C, microvascular bipolar coagulation performance; and Fig. 4D, aneurysm clipping performance).

Sylvian fissure and aneurysm dissection phases were performed significantly better by the residents who had trained with the placenta model (rated as good technique), while these tasks could not be satisfactorily executed by residents in the other groups. Complete aneurysm dissection was not performed by any of the residents because of the increased risk of aneurysmal rupture; however, partial dissection of the aneurysm was performed better by those residents trained in the placenta group. Aneurysm clipping was performed better by residents trained using the biological simulator (placenta and human cadaver) groups than the video group. However, there were no significant differences between the human cadaver and the human placenta groups. Bipolar coagulation was performed equally well by the residents independent of the training group.

Mean performance values in the 3 groups (overall differences) were statistically significant for aneurysm clipping (p < 0.001), aneurysm dissection (p < 0.001), and sylvian fissure dissection (p < 0.001). Pairwise differences were detected for aneurysm clipping (placenta vs video, and cadaver vs video, p < 0.001), aneurysm dissection (placenta vs video, and cadaver vs video, p = 0.03 and p = 0.01, respectively), and sylvian fissure dissection (placenta vs video, and cadaver vs video, p = 0.003 and p = 0.001, respectively). Mean differences were not statistically significant for bipolar coagulation using microscopic vision (p = 0.422 for overall difference among groups).

Discussion

In this study, we found that the human placenta is an excellent simulator for teaching aneurysm surgery when compared with other existing models. In the concurrent validity experiment, when compared with the aneurysm model in cadaveric heads, the human placenta model was superior in teaching 2 critical and important phases of aneurysm surgery, i.e., sylvian fissure splitting and aneurysm dissection. These phases cannot be adequately simulated in the cadaveric aneurysm model because the sylvian fissure must be dissected for the preparation of the artificial aneurysm and the aneurysm (being artificially constructed) is separated from the surrounding structures. Aneurysm dissection and control of oozing from around the target area are other phases of the surgery that are well simulated with the human placenta model. The human cadaver model performed better in simulating aneurysm rupture management and, obviously, in reproducing nor-
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Evaluations of human brain aneurysms microsurgical training were conducted. 
17 Chicken-wing vessels provide a substrate more difficult to use routinely and require a specific infrastructure setup. The human placenta does not possess neuroanatomical structures, but its simulation model can provide microsurgical technical training. All neurosurgeons who participated in the concurrent validity study commented that although human brain anatomy is best learned on the cadaver model, it may not be the best method to practice brain aneurysm surgery techniques, as microsurgical techniques cannot be simulated in the human cadaver head whereas many microsurgical features can be simulated in a human placenta model. The brain aneurysm simulation in the human placenta is cheaper and simpler to develop than in a cadaveric head. The human placenta simulator was also preferred by the evaluators because of the better ability to simulate microcirculation and blood flow. The use of bipolar coagulation under microscopic vision in the human placenta was believed to be exact.

In the second part of the experiment, we studied the degree of surgical efficiency performance on brain aneurysm surgery after exposure to various simulation training (predictive validity). A single performance of senior residents was evaluated. The objective was to determine if simulation before the surgery resulted in improved bimanual performance during aneurysm surgery, which has been shown to occur in neurosurgical virtual simulation using NeuroTouch. The human placenta offers simulation of many microsurgical tasks necessary to perform aneurysm surgery. The residents who trained in the human placenta model performed better during their first aneurysm surgery than residents trained in a cadaveric model or those who had just watched surgical videos without hands-on experience. This was confirmed by the blind evaluator, especially during sylvian fissure splitting and aneurysm dissection. Watching videos without hands-on practice was the least helpful training method. Human cadavers were useful for practicing aneurysm clipping, while simulation of utilization and handling of the bipolar coagulator was equivalent among the 3 training groups considered because of the participants’ previous experience in microsurgery for brain tumors.

Aneurysm surgery simulators described in the literature include virtual reality models, live animals, synthetic models, human cadavers, and human placenta. Each has its advantages and disadvantages. Virtual simulators are expensive and at the present time lack adequate haptic feedback, while live animals are becoming more difficult to use routinely and require a specific infrastructure setup. Chicken-wing vessels provide a substrate to practice microsurgical suturing and tissue handling techniques but lack adequate simulation of many of the conditions encountered during aneurysm surgery. Synthetic brain aneurysm models lack fidelity. Human cadaver aneurysm simulation has been described recently and the human placenta has been described by our group as a high-fidelity, low-cost alternative model for cerebrovascular microsurgical training. Biological brain aneurysm surgery simulators possessing the capacity for partial task similarities with real surgery were chosen for this study.

Our study has several limitations. This study was performed to provide predictive validity of simulated brain aneurysm microsurgical techniques. The sample size was small and only involved neurosurgeons and residents from one institution. A multicenter study is needed to validate these results. The concurrent validity methodology used in this study was based on content validity questions regarding both simulators. Although the number of participating neurosurgeons was small, the authors believe it was sufficient to compare both models. The evaluation of neurosurgical resident performance was the subjective impression of only 1 cerebrovascular surgeon, and future studies will need to use a larger number of evaluators and assessment of intraobserver variation. Microsurgical performance was compared before and after training in different surgical procedures, as brain tumor previously and aneurysm clipping after, which is not the ideal comparative methodology, but we wanted to evaluate skills performance on the first brain aneurysm surgery.

Conclusions

Testing the concurrent validity of biological simulators to practice brain aneurysm surgery has shown that the human placenta model offers a useful set of high-fidelity partial tasks training. Human cadavers offer 1 task (aneurysm clipping). Predictive validity concluded that previous microsurgical training in a human placenta simulator had a positive impact on neurosurgical residents’ performance when they performed some critical phases of MCA aneurysm clipping operations under close supervision.

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References


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**Disclosures**

Dr. Lanzino has served as a consultant to Covidien/Medtronic.

**Author Contributions**

Conception and design: M de Oliveira. Acquisition of data: M de Oliveira, Ferrarez, Ramos, Malheiros, Nicolato, Ferreira, F de Oliveira, de Sousa, Costa. Analysis and interpretation of data: M de Oliveira, Ferrarez, Ramos, Malheiros, Nicolato, Ferreira, F de Oliveira, de Sousa, Costa, Gusmao, Lanzino, Del Maestro. Drafting the article: M de Oliveira, Ferrarez, Ramos, Del Maestro. Critically revising the article: M de Oliveira, Ferrarez, Ramos, Del Maestro, Gusmao, Lanzino, Del Maestro. Approved the final version of the manuscript on behalf of all authors: M de Oliveira. Statistical analysis: Machado. Study supervision: M de Oliveira.

**Supplemental Information**

**Videos**


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