



Quality Assurance During Brain Aneurysm Microsurgery—Operative Error Teaching

Marcelo Magaldi Oliveira^{1,3}, Carlos Eduardo Ferrarez¹, Renan Lovato², Pollyana Vieira Costa¹, Jose Augusto Malheiros¹, Leonardo Avellar¹, Manuel Granja⁴, Eric Sauvageau³, Carla Machado⁴, Ricardo Hanel³

■ **INTRODUCTION:** Quality assurance (QA) is a way to prevent mistakes in advance. Although it has been previously reported for surgical setup, there is no effective approach for minimizing microsurgical technical errors before an operation is done. Neurosurgery resident operative errors during brain aneurysm surgery could be foreseen by practicing in an ex vivo hybrid simulator with microscopic fluorescein vessel flow image.

■ **METHODS:** Five vascular neurosurgeons and 8 junior/senior neurosurgical residents voluntarily joined this research initiative. The following methodology was adopted: 1) Identification of the 7 most-common resident operative performance errors during brain aneurysm surgery; 2) Design of exercises to prevent common mistakes in brain aneurysm microsurgery using a placenta simulator; and 3) Blinded staff neurosurgeon evaluation of resident performance during real brain aneurysm microsurgery.

■ **RESULTS:** All key steps to perform such intervention were accomplished with a simulator that uses 2 placentas, a synthetic cranium, and microscopic fluorescein vessel flow image. Neurosurgery residents trained in this model had better surgical performance with fewer perioperative mistakes ($P < 0.05$). Fine microsurgical dissection of the arachnoid membrane and aneurysm sac were the most commonly improved tasks among the 7 common operative mistakes. Brain parenchyma traction with secondary bleeding was the only error not prevented after previous simulator training.

■ **CONCLUSIONS:** There was a left-shift on the quality assurance line with residents who practiced brain aneurysm microsurgical errors in an ex vivo model. A

multicentric prospective study is necessary to confirm the hypothesis that real operative error could be reduced after training in a realistic simulator.

INTRODUCTION

Quality assurance (QA) is a way of preventing mistakes.¹ Considering the high-technical demands of neurosurgical practice, the neurosurgeon's opportunity to work in the central nervous system should always be supported by high-end quality of care and minimal surgical error.²⁻⁴

Brain aneurysm microsurgery is a delicate intervention that requires extenuating training.⁵⁻¹⁰ Year to year, neurosurgery residents are less exposed to this treatment modality, so perioperative surgical errors could be more frequently seen as training in microsurgery technical skills is slowly fading away.^{8,11,12} Our group has published the predictive validity of a placenta-based brain aneurysm microsurgical training model and the assessment and scoring of microsurgical skills for brain aneurysms (named SAMBA), putting such a simulator in a comfortable position to explore QA of brain aneurysm microsurgical skills.^{1,8,12,13}

Gupta et al.¹⁴ published a survey on neurosurgical complications in teaching hospitals and concluded that resident procedural mistakes are the main cause of misleading patient safety. Our hypothesis is that QA could be safely achieved during neurosurgery residency by rehearsing on common predetermined mistakes in an ex vivo model, foreseeing and correcting errors before they happen.

This study aimed to set a pilot research to determine whether QA in brain aneurysm microsurgery can be achieved by learning and correcting mistakes in a controlled environment (simulator), with sequential real operation improved safety.

Key words

- Brain aneurysm
- Fluorescein
- Human placenta
- Microsurgery
- Neurosurgical education
- Neurosurgical simulation

Abbreviations and Acronyms

QA: Quality assurance

³Neurosurgery Department, Neurosurgical Simulation Laboratory, Baptist Medical Center, Jacksonville, Florida, USA; and ⁴Preventive and Social Medicine Department, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

To whom correspondence should be addressed: Marcelo Magaldi Oliveira, M.D., Ph.D. [E-mail: mmagaldi@hotmail.com]

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From the ¹Neurosurgery Department, Placentarium, Belo Horizonte, Brazil; ²Neurosurgery Department, Santa Casa de São Paulo School of Medical Sciences, São Paulo, Brazil;

METHODS

After approval by the ethics committee, the project was conducted at the Placentarium and University Hospital from January 2017 to December 2018. The study methodology consisted of 3 parts: 1) identification of resident performance errors, 2) description of brain aneurysm common microsurgical mistakes in a placenta simulator, and 3) evaluation of resident performance by blinded staff neurosurgeons during real brain aneurysm microsurgery. Five vascular neurosurgeons and 8 junior/senior neurosurgical residents voluntarily joined the research.

Identification of Resident Performance Errors

Five cerebrovascular neurosurgeons reported the most common microsurgical technical mistakes during brain aneurysm microsurgery based on their previous experience with neurosurgery resident teaching (**Table 1**). Identified errors are as follows: 1) opening sylvian fissure without fine dissection, 2) traction in brain parenchyma with bleed, 3) use of bipolar for coagulation without precision, 4) sub-total dissection of aneurysm neck, 5) force applied to tissue while placing the clip, 6) no confirmation of an adequate clip positioning with vessel distortion or occlusion, and 7) no confirmation of flow absence inside aneurysm sac and good flow on vessels. Each identified error had to be cited at least once by all participating neurosurgeons before being added to our list.

Description of Brain Aneurysm Microsurgical Mistakes Exercises in a Placenta Simulator

The 5 cerebrovascular surgeons described 7 exercises in a placenta model for common mistakes rehearsal (**Table 1**). In order to do this, some modifications were implemented in the biological ex vivo brain aneurysm simulator. Placentas were put into a synthetic cranium and a microscopic fluorescein equipped with a fluorescein filter device was used. Human placenta acquisition, cleaning, and aneurysm construction modifications have been described in a previous report.⁹

We developed a synthetic cranium, registered internationally at the National Institute of Intellectual Property (BR 30 2 015 005 201

5) for placenta hybrid usage and manufactured by Modefer LTDA (São Paulo, Brazil). It has the size and skull shape of a white adult male, fabricated on a 3-dimensional printer, with a solid base of 30° lateralization and 15° head extension, simulating a basic surgical position for frontotemporal approach. Pterional standard craniotomy was performed on both sides of the skull to allow access to the intracranial placenta on both sides of the model.

The simulator was assembled by placing two placentas inside the skull, with the top one simulating the sylvian fissure opening, and the inferior placenta contained the aneurysms. All placentas had their umbilical cord vessels cannulated with a 6-French urinary catheter for colored saline perfusion.⁶ Aneurysm clipping exercises were reproduced in placenta vessels with similar diameters to the middle cerebral artery (3–4 mm). Each simulation used an operating table, OPMI VARIO 700 (Carl Zeiss Meditec, Jena Germany) surgical microscope, micro-scissors, micro-dissectors, micro-forceps, aneurysm clips, clip applicator, bipolar, urethral catheters, intravenous line, two 500 mL saline bags with different-colored saline (red and blue gouache infused into the saline bag), gloves, and surgical clothing. A special lens connected to the microscope was used for fluorescein image visualization of vessels in the simulator¹⁵ (**Video 1**).



Video available at
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Staff Neurosurgeons Blinded to Evaluation of Resident Performance During Real Brain Aneurysm Microsurgery

Eight participating residents were divided into 2 groups. They all had 6 months of microsurgical experience from brain tumor operation, without any vascular microsurgery practice. The first group had no further training than regular residency activities. The other group practiced the previously described 7 common operative errors with the placenta model for 20 hours. All 8 residents performed 2 brain aneurysm microsurgeries under supervision, as commonly done during neurosurgery residency training. Residents were evaluated (video analysis) by blinded staff members, and each best performance was chosen for analysis. Every operative error was scored with 1 point, so that 7 points meant all mistakes were done and 0 points meant no mistakes were done (**Table 2**). Statistical

Table 1. Brain Aneurysm Microsurgical Errors and How to Reproduce Them in the Placenta

Brain Aneurysm Microsurgical Error	Patient Safety Implications	How to Reproduce in the Placenta Simulator
Indelicate sylvian fissure opening	Neurological deficit, blood loss	Indelicate allantois membrane opening with bleeding and tissue disruption
Brain parenchyma traction	Neurological deficit, blood loss	Traction to placenta surface and stroma with vessel and tissue disruption
Bleeding with successive bipolar coagulation	Neurological deficit, blood loss	Bleeding from vessel attached to the allantois with difficult bipolar usage
Subtotal aneurysm dissection	Incomplete aneurysm identification with aneurysm or vessel rupture while clipping	Incomplete allantois dissection around vessel/aneurysm with subtotal view of aneurysm
Excessive force during clip placement	Acute aneurysm rupture, arterial branch rupture	Force clip through allantois with vessel, aneurysm, and tissue disruption
Subtotal aneurysm neck occlusion	Future aneurysm rupture, potential life threaten	Residual unclipped aneurysm neck, especially deep into the placenta stroma
Arterial branch clipped within aneurysm	Neurological deficit	Fluorescein vessel flow microscopic vision with verification of all vessels

Table 2. Neurosurgical Resident Errors During Brain Aneurysm Microsurgery

Resident Previous Training	Arachnoid Opening Without Fine Dissection	Traction in CNS with Bleed	Use of Bipolar for Bleeding Without Precision	Sub-total Dissection of Aneurysm Neck	Force to Tissue while Placing the Clip	No Confirmation if Clip is Well-Positioned or Compressing a Vessel	No Confirmation of Flow Absence Inside Aneurysm Sac and Good Flow on Vessels	Resident Mistake Final Score
R regul	1	1	1	1	1	0	0	5
R regul	1	1	1	1	0	1	0	5
R regul	1	1	0	1	1	1	1	6
R regul	1	1	0	1	1	0	1	5
R Simul	0	1	0	0	0	0	0	1
R Simul	0	1	0	0	0	0	0	0
R Simul	0	1	0	0	0	0	0	1
R Simul	0	1	0	0	1	0	0	2
Median R regul (IQR)	1 (0)	1 (0)	0.5 (1)	1 (0)	1 (0.5)	0.5 (1)	0.5 (1)	5 (0.5)
Median R Simul (IQR)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0.5)	0 (0)	0 (0)	1 (1)
<i>P</i> value	0.008	>0.999	0.127	0.008	0.186	0.127	0.127	0.017

Scores: 0 means no mistake, 1 means mistake.

IQR, interquartile range; R, neurosurgical resident; Regul, regular residency training; Simul, surgical error taught by placenta simulator training (2 placentas in a synthetic cranium with fluorescein image).

analysis of performance was based on nonparametric statistics, median and interquartile range reported. The Mann-Whitney test was used for comparison of medians and a statistically significant result was considered as $P < 0.05$.

RESULTS

All 5 neurosurgeons agreed that avoiding the 7 errors reported in **Table 1** is important for a successful operation and they can be simulated in the placenta model with a high degree of fidelity. The described simulator that uses 2 placentas, a synthetic cranium, and a microscopic fluorescein image can reproduce all key steps of a real operation.

Table 2 shows that the group previously trained with the placenta model had better performance during real operation—consequently, fewer microsurgical errors were committed by this group when compared with the results of the group with regular residency training.

Among the 7 common errors reported in **Table 1**, bleeding of the brain parenchyma was always present in a real operation independent of previous training. Fine-motor hand ability required during arachnoid membrane and aneurysm dissection was a positive skill acquired after placenta training ($P < 0.05$). Practical knowledge of sequential part tasks needed in brain aneurysm microsurgery was another positive factor seen after ex vivo simulator training. A better control of the fine-motor force transferred to tissues by the surgeon's hand (noted in the aneurysm clipping maneuver) and complete verification of adequate aneurysm neck clipping were also documented.

DISCUSSION

To the best of our knowledge, this is the first time microsurgical errors possible during a brain aneurysm operation were evaluated in a realistic and controlled environment. We believe this was only possible thanks to the availability of a high-fidelity simulator to investigate neurosurgical resident ability towards error avoidance.

Quality of delivered care, health system cost, health technology, patient safety, and surgical education training are topics related to surgical result improvements.³ QA is well reported in the medical field, although the quantification of specific patterns in certain surgical procedures towards reducing surgical errors has not previously been described. Using a high-fidelity simulator to practice avoidance of common surgical errors is one way to achieve better results, as many tasks in microsurgery require good fine-motor hand ability that can only be obtained with hands-on training. This matches the goal of QA: Shifting the curve to the left with mistakes or errors reproduced in a controlled environment, potentially preventing these errors.

Our placenta simulator for brain aneurysm microsurgical training has undergone important modifications since its first description in 2014.⁶ Using placentas inside a synthetic cranium not only has a better esthetical appearance, but provides more realistic 3-dimensional exposure of the surgical field, providing more challenging exercises than the ones seen with a flat placenta model—with more dexterity required by the student to reach proficiency. Addition of fluorescein imaging to this model makes it very realistic according to neurosurgeons, as the parent vessel patency can be verified at the end of the procedure. The microscopic universally adapted lens described by Lovato et al.¹⁵ was an important contribution to brain aneurysm microsurgery practice in the placenta model, as it completes the simulator and includes all tasks executed during an actual operation.¹⁵⁻¹⁷

Microsurgical precision necessary in arachnoid and aneurysm dissection was a positive acquisition with placenta training ($P < 0.05$). This highlights the importance of skill in tissue dissection in cerebrovascular surgery and the presence of such characteristics can be found in the placenta simulator. Human cadavers and live animals such as rats have aneurysms built on their vessel wall, eliminating the fine dissection task during simulation.⁷ Neurosurgeons who joined this study agreed that such abilities are very important for a safe surgical intervention.

Our results highlight that theoretical learning in microsurgery is not enough to ensure a good clinical outcome. Practical training is crucial in the learning curve—and this is now possible in a controlled environment. Only the placenta simulator can fulfill all technical microsurgical requirements to provide a safe environment for neurosurgeons, meaning that mistakes can be reduced in real interventions.

The main drawback of our study is the limited numbers of participants, which makes our statistical results weaker. Despite that, we consider this research to be an important contribution to the scientific community—original study with a larger number of participants would not be possible in a single institution due to the reduced numbers of brain aneurysm microsurgeries performed in a single hospital. A large multicenter randomized trial is necessary for final validation of our hypothesis.

CONCLUSIONS

There was a leftward shift on the quality assurance line for residents who practiced brain aneurysm microsurgery in an ex vivo model. A multicenter prospective study is necessary to confirm the hypothesis that real operative error could be reduced after training in a realistic simulator.

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