Continuous Instrument Tracking in a Cerebral Corticectomy Ex Vivo Calf Brain Simulation Model: Face and Content Validation

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BACKGROUND AND OBJECTIVES: Subpial corticectomy involving complete lesion resection while preserving pial membranes and avoiding injury to adjacent normal tissues is an essential bimanual task necessary for neurosurgical trainees to master. We sought to develop an ex vivo calf brain corticectomy simulation model with continuous assessment of surgical instrument movement during the simulation. A case series study of skilled participants was performed to assess face and content validity to gain insights into the utility of this training platform, along with determining if skilled and less skilled participants had statistical differences in validity assessment.

METHODS: An ex vivo calf brain simulation model was developed in which trainees performed a subpial corticectomy of three defined areas. A case series study assessed face and content validity of the model using 7-point Likert scale questionnaires.

RESULTS: Twelve skilled and 11 less skilled participants were included in this investigation. Overall median scores of 6.0 (range 4.0-6.0) for face validity and 6.0 (range 3.5-7.0) for content validity were determined on the 7-point Likert scale, with no statistical differences between skilled and less skilled groups identified.

CONCLUSION: A novel ex vivo calf brain simulator was developed to replicate the subpial resection procedure and demonstrated face and content validity.

KEY WORDS: Corticectomy, Ex vivo models, Neurosurgical simulation training, Subpial resection, Surgical education, Validation studies

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In neurosurgery, a corticectomy technique called subpial resection is a critical bimanual skill for trainees to learn. This procedure involves the resection of a pathological lesion while preserving the pia and minimizing damage to surrounding tissue.[1-3] Neurosurgical simulation training is not presently an educational component of core curricula, which limits the training opportunities for residents to acquire subpial resection technical skills. Surgical training is evolving from an apprenticeship model to more competency-based educational frameworks.[4,5] These frameworks must have assessment capacity based on quantifiable objective metrics and be transparent to both the educator and the trainee.[6,7] To create safe learning and training environments, surgical simulators are being used to simulate complex patient operative pathologies in risk-free environments.[8] Data from virtual reality (VR) simulator platforms have demonstrated improved trainee surgical performance, and intelligent tutors powered by artificial intelligence (AI) have been validated. These systems can continuously assess surgical skills by tracking instrument movement, deliver tailored feedback to improve skills, and mitigate errors in simulated complex procedures.[6,7,9,10] One limitation in using VR simulators is the lack of realistic haptic feedback since these platforms do not utilize the actual surgical

ABBREVIATIONS: AI, artificial intelligence; **PGY,** postgraduate year; **VR,** virtual reality.

instruments used during human operative procedures. Previous research at our center has outlined the creation of ex vivo calf brain simulation models and demonstrated the ability to continuously track surgical instruments.[11] Our group has also developed best practices for the utilization of ex vivo simulation models for neurosurgical training called the "ex vivo brain model to assess surgical expertise" checklist.[12] To address the challenges in training neurosurgical residents for corticectomy procedures, we sought to develop a simulation model that combines the advantages of the realism of ex vivo models while integrating innovative continuous movement tracking technologies. The first objective is to assess face and content validity for the ex vivo calf brain subpial resection model. Face validation and content validation are qualitative assessments. In face validation, assessors determine visual and tactile realism, overall simulated environment, tools used in the simulation and user interface compared with real-world conditions. Content validation involves the assessment of task reproducibility and simulation ability in meeting certain educational objectives.[12] These initial validation steps are imperative in moving a novel simulation forward and justifying further resource utilization. Traditionally, these validation assessments are performed by experts in the field rather than trainees.[13] It is unknown if experts' validation is significantly different from senior trainees' validation who have some experience in the field. Therefore, the second objective is to investigate if significant differences in face and content validity between skilled and less skilled participants are present.

METHODS

Study Design

A case series study was performed to assess the ex vivo calf brain model's face and content validity. Participants were divided into two groups: Group A "skilled" and Group B "less skilled." Skilled participants were board-certified neurosurgeons and epilepsy, neurosurgical oncology, and pediatric neurosurgery fellows. Less skilled participants were senior neurosurgery residents and fellows in other neurosurgical subspecialties. This study was approved by the McGill University Health Centre Research Ethics Board, Neurosciences-Psychiatry. All participants signed an informed consent form before trial participation. The participants and any identifiable individuals present consented to publication of their image and/or surgical video. Participants outlined their subpial technique experience before the trial and assessed the utility of the ex vivo calf brain simulated surgery model through a questionnaire administered on trial completion. They were asked to rate their satisfaction with the model using a 7-point Likert scale, with 1 being completely unrealistic and 7 being completely realistic. As no previous consensus on a median score for face and content validity has been reached,[13] a median score ≥4.0 on a 7-point Likert scale was deemed sufficient validity.[12,14]

Ex Vivo Animal Brain

Calf brains were used in this study because of their morphological similarity to the human pediatric brain, availability, low cost,[11,12,15] and utility for training microsurgical techniques.[16-18] Fresh calf brains of similar weight, structure, and well-defined gyri were obtained from a local butcher (Figure 1A). A human skull model (Walter Products) with a craniotomy window created off midline (Figure 1B) was used. The study used the "ex vivo brain model to assess surgical expertise" checklist[12] for ex vivo brain simulation development and assessment.

Subpial Resections

Participants received standardized verbal and written instructions on instrument use and function and presented with a 2-dimensional microscopic image outlining the location of the three subpial resections to be performed (Figure 2A and 2C). In a realistic operative room environment, the subpial cortical resections were performed using a pair of microscissors to make an initial incision in the pia mater, a bipolar forceps to lift the pia, and a SONOPET ultrasonic aspirator (Stryker) (Figure 1C and 1D) to remove the assigned cortical area (Figure 2A). Neurosurgical operations were performed using an OPMI Pico surgical microscope (Carl Zeiss Co.). Procedures were recorded using the operating microscope and a facing camera, allowing a broader instrument view for evaluation of tracking data and postoperative performance. Instrument tracking results are beyond the scope of this article, and analysis is underway to assess the tracking data utility. Microscopic video is provided to help appreciate the subpial resection in the calf brain model (Video).

Statistical Analysis

IBM SPSS statistical software was used for data analysis (IBM Corp. Released 2021. IBM SPSS Statistics for Macintosh, Version 28.0: IBM Corp). Nonparametric Mann–Whitney U tests ware used for comparisons between groups. The data set collected during the study is available on a reasonable request from the corresponding author.

RESULTS

Twenty-three participants were enrolled, 12 Group A "skilled" along with 11 Group B "less skilled." Participant demographic and subpial resection data are provided in Table 1. Sixty-nine simulated subpial resection scenarios were created, where each participant performed three different resections.

Model Validation

Face Validity

Face validation was based on 11 items as outlined in Table 2. These included:

Overall Simulated Task

Participants in both groups found the overall operative setup realistic (skilled: median 6.0 [range 3.0-7.0]; less skilled: median 5.0 [range 1.0-7.0]) (P = .83). Appearance and tactile feedback of the simulated tissue was realistic (skilled: median 6.0 [range 3.0-7.0]; less skilled: median 6.0 [range 2.0-7.0]) (P = .52).

Visual and Sensory Realism

Sensory realism of simulated pia rated median 6.0 (range 3.0-7.0) and median 6.0 (range 1.0-7.0) among skilled and less skilled, respectively (P = .78). The visual realism of simulated pia also was found to be realistic (skilled: median 6.0 [range 4.0-7.0]; less skilled: median 6.0 [range 3.0-7.0]) (P = 1.0).

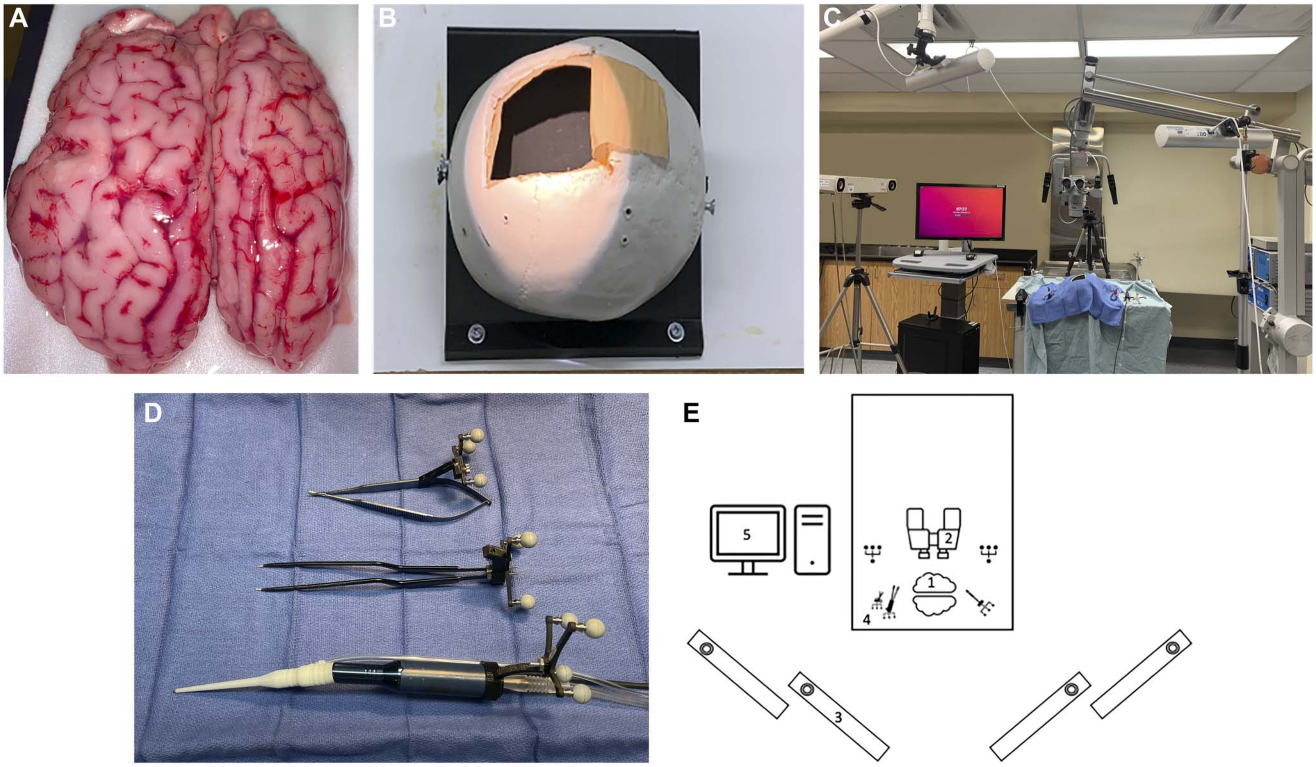

FIGURE 1. *Ex vivo calf brain corticectomy model.* **A**, *Fresh calf brain.* **B**, *Human skull model with an off-midline craniotomy window.* **C**, *View of the realistic operative environment.* **D**, *Surgical instruments used: microscissors, bipolar, and ultrasonic aspirator with fiducial markers attached through three-dimensional-printed polylactic acid mounts to capture instrument movement.* **E**, *Drawing representing the setting of the ex vivo model: (1) the brain model with the references on each side, (2) the operating microscope positioned over the ex vivo brain, (3) four optical cameras positioned around the trainee for instrument movement capture, (4) the three surgical instruments with mounted fiducials, and (5) the computer recording instrument tracking data and microscope live video setup.*

Surgical Instruments

In relation to the use of surgical instruments, the ultrasonic aspirator achieved the highest median score of 6.0 in both groups (range 4.0-7.0) (*P* = .74).

Content Validity

Content validation was based on 10 items as outlined in Table 3. These included the following:

Coordination and Bimanual Training

Skilled participants assigned a median score of 6.0 (range 3.0-7.0) in task's ability to train hand-eye coordination and bimanual training vs median 6.0 (range 1.0-7.0) in the less skilled group (*P* = .88).

Surgical Instruments

With respect to surgical instruments, in both groups, content validity was achieved for microscissors (skilled; median 4.0 [range 2.0-6.0], less skilled; median 6.0 [range 1.0-7.0]) (*P* = .09) and the ultrasonic aspirator (skilled; median 6.0 [range 4.0-7.0], less skilled; median 7.0 [range 2.0-7.0]) (*P* = .69). Bipolar forceps did not reach content validity in the skilled group (median 3.5 [range 2.0-6.0] vs less skilled; median 5.0 [range 1.0-7.0]) (*P* = .19). This might have been due to inability to use the bipolar for coagulating tissues because the simulator lacked perfusion and the bipolar was not connected to the electrosurgical unit.

Subpial Resection Training and Utility for Trainees

This simulated task was seen as highly appropriate in replicating and practicing subpial resections (skilled; median 6.0 [range 1.0-7.0], less skilled; median 7.0 [range 2.0-7.0]) (*P* = .69). Both groups approved the overall task usefulness in training residents (skilled; median 7.0 [range 2.0-7.0], less skilled; median 7.0 [range 2.0-7.0]) (*P* = .83). This was considered most useful during junior years of residency training (post graduate year 1-3) (skilled; median 7.0 [range 4.0-7.0], less skilled; median 7.0 [range 1.0-7.0]) (*P* = .69).

Overall Task Difficulty and Satisfaction

The task had a low difficulty level (median 3.0, range 1.0-6.0) among both groups. Eighteen participants (78.3%, median ≥4)

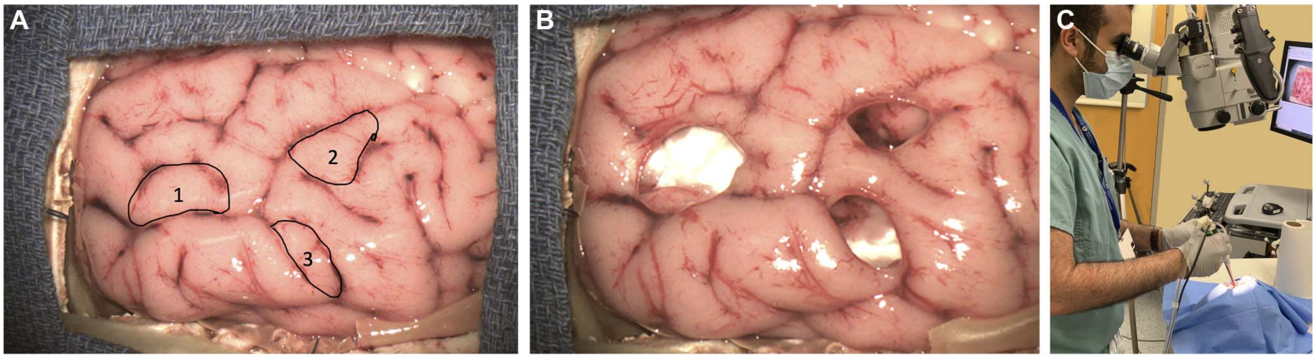

FIGURE 2. *Subpial resection operative procedure.* **A**, *Two-dimensional microscopic image outlining the location of the three subpial resections to be performed.* **B**, *View through the operating microscope after completion of the three subpial resections. The white mater and pial membranes can be seen at the depth of the subpial resection cavities.* **C**, *Participant performing the corticectomy procedure. The fiducials can be visualized attached to the instruments being used.*

TABLE 1. Demographics of Participants Performing the Simulated Subpial Resection Procedure

Demographics	Group A—skilled	Group B—less skilled
Number of participants	12	11
Mean age in years (range)	42.7 (32-58)	32.9 (26-39)
Sex		
Female	3 (25%)	3 (27.3%)
Male	9 (75%)	8 (72.7%)
Level of training		
Neurosurgeons	8	-
Pediatric neurosurgeon	3	-
Neurosurgical oncologist	2	-
Skull base/vascular neurosurgeon	2	-
Spine neurosurgeon	1	-
Mean number of years in practice (range)	11.4 (2-27)	-
Mean number of subpial resections performed in practice (median, range)	513 (150, range 20-3000)	-
Neurosurgical fellows		
Epilepsy	1	-
Oncology	1	-
Pediatrics	2	—
Spine	—	2
Functional	—	1
Mean number of subpial resections performed in fellowship (median, range)	66 (50, range 50-100)	10 (10, range 8-12)
Residents (PGY[a] 4-6)	—	8

[a] PGY: Postgraduate year.

TABLE 2. **Face Validity**

Validity statement	Group A—skilled Median (range) Mean ± SD	Group B—less skilled Median (range) Mean ± SD	*P* value
The preoperative setup was realistically reproduced	5.5 (2.0-7.0) 5.2 ± 1.2	5.0 (1.0-7.0) 4.6 ± 1.9	.44
Overall, the simulated operation setting was realistic	6.0 (3.0-7.0) 5.5 ± 1.1	5.0 (1.0-7.0) 5.2 ± 1.6	.83
The overall appearance of the simulated tissues was realistic	6.0 (5.0-7.0) 6.0 ± 0.7	6.0 (3.0-7.0) 5.6 ± 1.2	.52
The overall tactile feeling was realistic	6.0 (3.0-7.0) 5.3 ± 1.3	6.0 (2.0-7.0) 5.5 ± 1.6	.52
The sensory realism of the “feel” of the simulated pia was realistically similar to a human pia	6.0 (3.0-7.0) 5.7 ± 1.1	6.0 (1.0-7.0) 5.2 ± 1.9	.78
The sensory realism of the “feel” of the simulated brain tissue was realistically similar to a human brain tissue	6.0 (3.0-6.0) 5.4 ± 1.1	6.0 (1.0-7.0) 5.1 ± 2.0	.83
The visual realism of the simulated pia was realistically similar to a human brain pia mater	6.0 (4.0-7.0) 6.0 ± 0.9	6.0 (3.0-7.0) 5.8 ± 1.5	1.0
The visual realism of the simulated brain tissue was realistically similar to a human brain tissue	6.0 (4.0-7.0) 6.2 ± 0.8	5.0 (3.0-7.0) 5.4 ± 1.2	.13
Related to the use of the microscissors, the instrument handling was similar to the microscissors used in the operating room	4.0 (1.0-7.0) 4.0 ± 1.6	5.0 (2.0-7.0) 5.0 ± 1.8	.26
Related to the use of the bipolar, the instrument handling was similar to the bipolar used in the operating room	5.0 (2.0-6.0) 4.5 ± 1.5	5.0 (2.0-7.0) 4.8 ± 1.7	.83
Related to the use of the ultrasonic aspirator, the instrument handling was similar to the ultrasonic aspirator used in the operating room	6.0 (4.0-7.0) 6.1 ± 0.9	6.0 (5.0-7.0) 6.0 ± 0.8	.74

would use this simulator to practice subpial resections (skilled; median 6.0, range 1.0-7.0, less skilled; median 7.0, range 1.0-7.0). Overall satisfaction with the simulator had a median score of 6.0 (range 2.0-7.0). Seventy-five percent (9/12) of the skilled along with 91% (10/11) of less skilled responded “yes” to recommending the integration of simulation training into the curriculum during neurosurgery residency training as a mandatory block.

DISCUSSION

A high-fidelity ex vivo corticectomy model replicating the subpial resection technique has been developed, and this investigation has outlined face and content validity of this platform. This justifies investment in assessing construct validity, the incorporation of AI-powered tutor platforms, and studies to demonstrate the utility of ex vivo models into residency training curriculums. Calf brains have consistent anatomy including intact pia, presence of cortical grey, and subcortical white matter fibers and provide an excellent model to assess and train subpial resection bimanual skills.

The subpial resection technique, initially described in epilepsy surgery,[19] follows normal anatomic boundaries,[3] allowing safe maximal resection of an epilepsy focus. In brain tumor surgery, the extent of surgical resection is associated with a survival benefit and subpial techniques are used when performing wide tumor resections beyond the visible tumor boundary.[3,20] As of 2019, neurosurgery residency programs in Canada incorporated a competency-based educational framework. Assessment of specific technical and nontechnical skills is performed by supervising neurosurgeons through entrustable professional activity checklists.[21,22] One of the educational platforms available to improve surgical performance and skill level is practicing real-life scenarios in simulated settings.[23-25] In one survey of 99 neurosurgery programs, over 70% of program directors stated that simulation could augment traditional training and potentially improve patient outcomes.[26] Simulation platforms include cadaveric, ex vivo, VR, and augmented reality, along with 3-dimensional (3D)–printed models.[12] Each simulator faces challenges related to reproducibility, realism, cost, and availability of objective performance data. Cadaveric simulations possess high fidelity and realistic anatomic representation, yet availability and cost make

TABLE 3. Content Validity

Validity statement	Group A—skilled Median (range) Mean SD	Group B—less skilled Median (range) Mean SD	*P* value
This exercise is appropriate to train hand-eye coordination	6.0 (5.0-7.0) 6.1 ± 0.8	6.0 (1.0-7.0) 5.9 ± 1.7	.88
This exercise is appropriate to train the use of both hands	6.0 (3.0-7.0) 5.9 ± 1.2	6.0 (1.0-7.0) 5.8 ± 1.7	.88
This exercise is appropriate to train the use of microscissors	4.0 (2.0-6.0) 4.2 ± 1.4	6.0 (1.0-7.0) 5.2 ± 1.8	.09
This exercise is appropriate to train the use of a bipolar	3.5 (2.0-6.0) 3.5 ± 1.3	5.0 (1.0-7.0) 4.5 ± 2.0	.19
This exercise is appropriate to train the use of an ultrasonic aspirator	6.0 (4.0-7.0) 6.2 ± 0.8	7.0 (2.0-7.0) 6.1 ± 1.4	.69
This exercise is appropriate to train the subpial resection technique	6.0 (1.0-7.0) 5.9 ± 1.6	7.0 (2.0-7.0) 6.0 ± 1.6	.69
The simulated task is useful for training residents	7.0 (2.0-7.0) 6.3 ± 1.4	7.0 (2.0-7.0) 6.1 ± 1.5	.83
The simulated task is useful for training junior residents with little to no knowledge of the subpial resection	7.0 (4.0-7.0) 6.3 ± 1.2	7.0 (1.0-7.0) 6.0 ± 1.8	.69
The simulated task is useful for training senior residents who have some knowledge of the subpial resection	6.0 (1.0-7.0) 5.7 ± 1.7	6.0 (1.0-7.0) 5.0 ± 2.0	.41
The simulated task is useful for training fellows	6.0 (1.0-7.0) 5.6 ± 1.6	5.0 (1.0-7.0) 4.5 ± 2.1	.23

these models challenging to provide for resident training.[27,28] Printed 3D models lacked the ability to replicate high-fidelity neurosurgical dissections.[29-32] VR and augmented reality simulators are costly and lack realism. However, quantitative data from VR instrument movement can assess skill level.[7,33-35]

Neurosurgical simulation models have demonstrated visual and tactile realism, yet many lack the ability to measure performance metrics through instrument tracking.[12,16,18,36,37] Developing the ex vivo calf brain simulator involved 3D-printed mounts on the surgical instruments used. The employment of these modified instruments did not significantly detract from face or content validity. These results demonstrate the feasibility in continuous tracking of real surgical instruments and the possibility of generating further performance metrics that may differentiate levels of expertise using various ex vivo model simulation platforms (construct validity).

The second objective of this study was to outline if statistically significant differences in face and content validity were present between skilled and less skilled participants, and none were identified. These results suggest that when dealing with small expert groups, the inclusion of others such as senior residents and fellows in other specialties may provide valuable input.

The ex vivo simulation model developed in this study may be considered a hybrid model because it provides a realistic reconstruction of a surgical operative environment and provides an educational platform derived from VR instrument tracking for surgical training involving the subpial resection technique. The model has the potential of generating large data sets for training and testing machine learning algorithms. Our group has used instrument tracking data and AI methodology such as classifying algorithms and artificial neural networks along with deep learning to understand and prioritize specific novel metrics able to improve the granularity of participants classification based on the expertise level.[6,7,38-40] Quantitative data from instrument movement tracking from ex vivo models have the potential to be used in outlining surgical trainee learning curves[41] and developing and testing of AI-powered tutoring systems to prevent surgical error like the Virtual Operative Assistant[6] and the Intelligent Continuous Expertise Monitoring System.[7,9,42] The use of calf brains providing high tissue fidelity and realism along with quantitative metrics may enhance trainee engagement and learning, whereas AI tutors encourage focus on safety and efficiency in performing neurosurgical procedures.[43]

The ultimate goal of these projects is the development and testing of equivalent AI-powered tutoring systems in the human operating room to develop an "Intelligent Operating Room" capable of continuous learner assessment, training, and mitigating surgical errors.

Limitations

Although the calf brain simulation platform used in this study allows detailed and continuous quantitative assessment of bimanual psychomotor skills, it fails to capture the complete set of competencies such as interdisciplinary teamwork required in neurosurgical procedures. Blood vessels are visible in calf brains, but blood flow and bleeding were not simulated in this model. Some studies have described the use of porcine brains with an intact vascular structure where intracranial and capillary blood flow was achieved;[44,45] however, these models involve extensive preparation.[46]

CONCLUSION

A novel hybrid ex vivo calf brain simulation model was developed for this study, which achieved face and content validity in simulating the subpial resection technique.

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VIDEO. Video through the operating microscope showing the use of the microscissors to incise the pia along with the bipolar elevating the pial membrane while the ultrasonic aspirator is being used for subpial resection.