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Brief Report

Endoscopic neuroanatomy study using embalmed cadavers

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ABSTRACT

Objectives: A firm understanding of anatomy is foundational for all medical students and residents. As opportunities for cadaveric study dwindle, we propose a simplified perfusion model for formalin fixed cadavers that allow for endoscopic neuroanatomical study and procedural practice. This model is easily accessible, cost effective, and valuable in medical training.

Materials and Methods: Cadavers were fixed through accepted methods that included formalin injection into the cranial vault. The perfusion system was set up using a series of catheters, tubing, and pressurized saline bag that forced saline into the various neuroanatomical spaces chosen for study.

Results: A neuroendoscope was subsequently introduced to explore and identify relevant neuroanatomical structures as well as to perform a 3rd ventriculostomy and filum sectioning.

Conclusion: Using formalin fixed cadavers for neuroendoscopic studies and procedural practice is a cost effective, multipurpose tool that can provide medical trainees with a strong understanding of anatomy as well as procedural practice.

Keywords: Cadaver, Medical education, Neurosurgery, Neuroanatomy

INTRODUCTION

The Accreditation Council for Graduate Medical Education requires medical school and residency programs to educate students on fundamental anatomy through multiple modalities including cadaver dissections, skills laboratories, and simulations.[1,2] However, due to rising costs, cadavers for anatomical training are less frequently used with most programs preferring mannequins, pro-sections, and computer simulations. Fresh cadavers provide the most accurate tissue planes and opportunities for realistic tissue handling.[1] However, these cadavers can cost between $1000 and $3000, have increased handling requirements, and expire quickly.[1-5] Here, we propose methods to use formalin fixed cadavers for neuroanatomical studies through endoscopy to appreciate fundamental anatomy and perform various controlled techniques.

MATERIALS AND METHODS

Multiple cost-effective tools were used to carry out the cadaveric exploration including but not limited to, standard dissection kits, a 3L sterile NaCl solution, 3L pressure bag, 24” pressure tubing and 72” pressure tubing, 4 way stopcock, 16 gauge I.V. Catheter, 30 cc syringe, Stryker® Endoscopy Tower, a Medtronic® Neuroendoscopy Set with disposable expired scope, and a Stryker® camera. A complete list of items used and unit costs are shown in [Table 1].

Preparation of the cadaver

The cadaver was preinjected with a mixture of formaldehyde, methanol, and ethylene glycol with 1.5 gallons of reverse osmosis (RO) water. Subsequently, the body is injected through a mixture of ethanol, formaldehyde, ethylene glycol, phenol, and glutaraldehyde along with 1.5 gallons of RO water. Next, the cranial vault is accessed and 20 cc of formalin is injected in to the cranial vault. The body is then hypodermically treated in strategic areas and injected with the same contents utilized in the second injection. Bodies are then placed in a 10% phenol bath for 24 h.

Perfusion system

A manually pressurized perfusion system was used for the perfusion of necessary structures. A 3L bag of NaCl was placed inside a 3L pressure bag that was pressurized

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to 300 mmHg through a hand pump to produce a forceful inflow of NaCl into the relevant structures and to enhance visualization of structures better than gravity controlled perfusion methods. The pressurized bag was then connected to 24" pressure tubing that led to a 4 way stopcock, as shown in [Figure 1]. Another 24" pressure tubing was used connect from the stopcock to a 16 gauge IV catheter that was placed in the relevant neuroanatomical spaces, as shown in [Figure 1].

Table 1: Costs of supplies and equipment used in cadaveric anatomical study

Material	Cost
3,000 ml Sterile NaCl	$8.86
3,000 ml Pressure Bag	$12.84
24" pressure tubing x 2	$3.25
72" pressure tubing	$2.78
4 way stopcock	$0.91
16 ga I.V. Catheter x 2	$1.62
30cc syringe	$0.21
4-0 Nurolon RB-1 Needle	$11.84
Medtronic Neuro Endoscope Set	n/a*
Stryker camera	*$40,000**
Leksell Ronguer	*$238.00**
#3 Kerrison Ronguer	*$987**
Wiltsie Retractor x 2	*$508**
#3 Knife Handle	$7.00
# 15 Blade	$0.29
# 11 Blade	$0.22
Stryker Endoscopy Tower	*$104,000**

*One time purchase or rental from operating rooms.

RESULTS

The cadaveric exploration was split into two stages to demonstrate the spectrum of utility of fixed cadavers.

Spinal canal exploration

A one level thoracic laminectomy at T12 and 1 cm durotomy was performed, as shown in [Figure 1]. We, then, inserted the 16 gauge IV catheter into the intrathecal space, as shown in [Figure 1]. The catheter was secured to the soft tissue and a watertight seal among the dura, fascia, and skin, was created. In similar fashion, a T4 laminectomy was also performed to provide a release for pressurized fluid introduced to the primary durotomy. While one durotomy served as an access site, the other performed as a drainage site. After identifying pertinent structures, as shown in [Figure 2a], we, then,

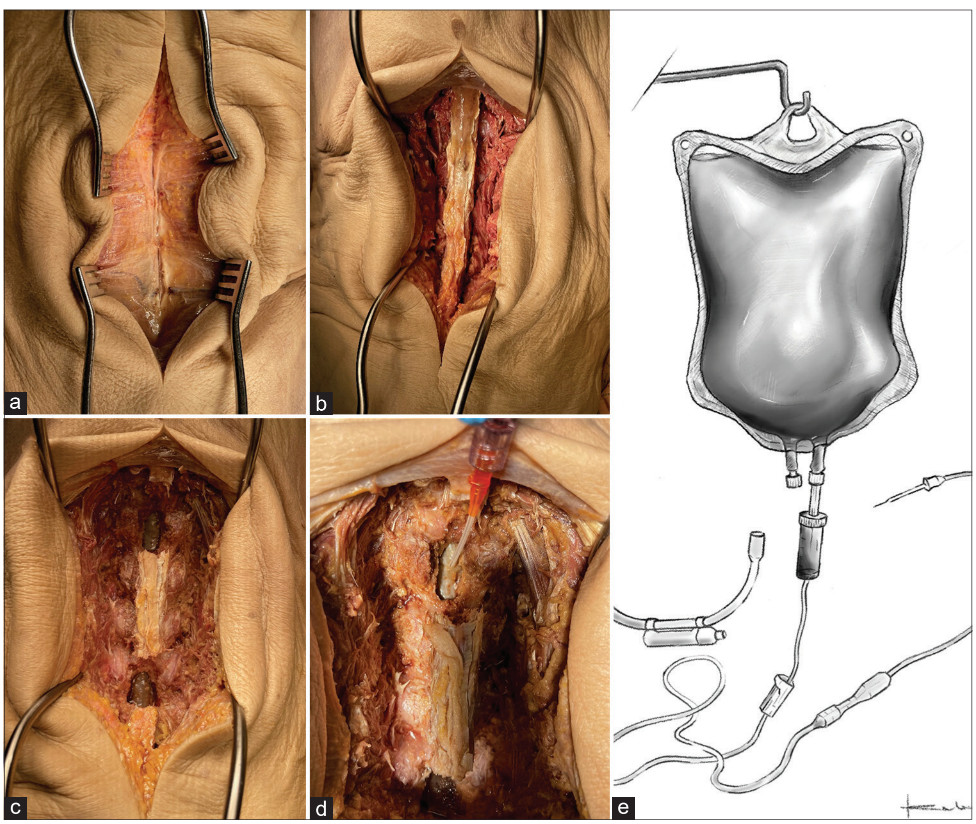

Figure 1: A T4 and T12 laminectomy with 1 cm durotomy was performed on the cadaver (a-c). Placement of the catheter for perfusion was then accomplished (d). The perfusion system was then set up as best depicted in the artistic rendering (e).

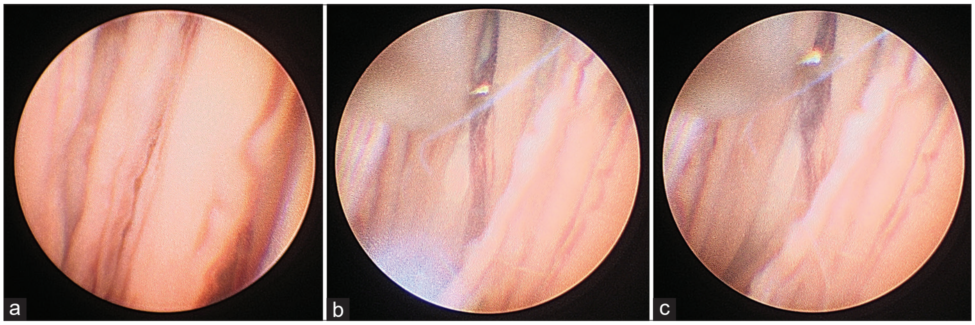

Figure 2: Neuroendoscopic images captured during anatomical survey that demonstrates the ability to identify relevant structures (a), navigate and deploy tools to identify the filum (b), and performance of a tethered cord release (c).

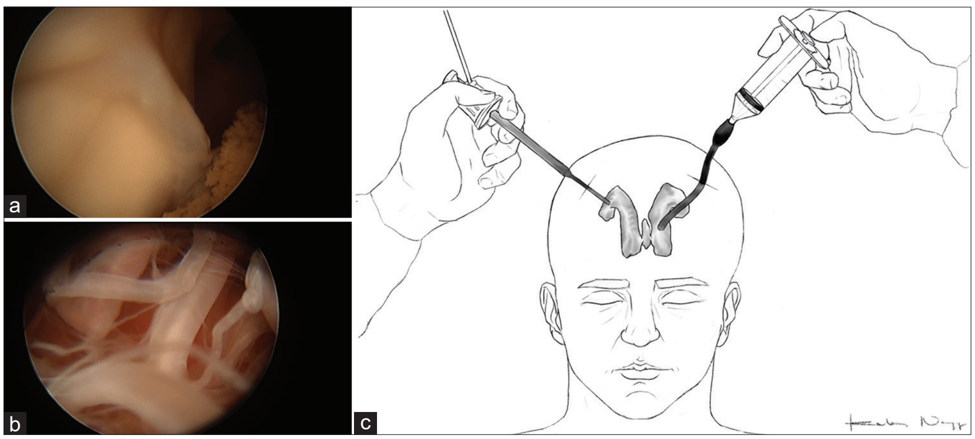

Figure 3: Ventricular exploration was accomplished through two frontal craniectomies followed by insertion of the perfusion system into the interventricular space where we identified the choroid plexus (a). By piercing the floor of the third ventricle, we were given the opportunity to visualize the basilar artery and surrounding nerves (b). An artistic rendering is provided to best capture this exploration (c).

turned our attention toward performing a simple filum sectioning, as shown in [Figure 2b and c].

Ventricular exploration

Two small frontal craniectomies, both 3–4 cm in diameter, were made. Through one of the craniectomies, a 4 cm resection was done to approach the border of the ventricles. The 16 gauge IV catheter was placed into the interventricular space and infused with pressurized saline for irrigation. The secondary craniectomy and the working channel within the endoscope served as outlets for debris cleared during initial irrigation of the ventricular system. Once the structures were cleared through thorough irrigation, the endoscope was introduced into the vital structures for neuroanatomical identification and education, as shown in [Figure 3] and characterized in [Figure 3]. We, then, penetrated the floor of the 3rd ventricle to identify the basilar artery and surrounding nerves, as depicted in [Figure 3].

DISCUSSION

Cadaver training courses, a tool that has been used for a long time to teach both medical students and residents, are becoming increasingly important in the era where there are increased limitations in training for residents in the Operating Room (OR).[3,6,7] A deep understanding of anatomy and controlled exposures to operative challenges is imperative in all surgical specialties as increased practice is the key to successful performance in the OR.[1,6] Furthermore, cadaveric dissection, with the tactile and visual experience that it provides, enhances the textbooks, pro-sections, and computer models based education for trainees.[1]

Developing strong surgical skills, especially using tools such as endoscopy that have a steep learning curve, require extensive practice and repetition.[5,6] While 3D virtual reality as a teaching tool has become more popular recently, it has limitations in its simulation capabilities particularly in the tactile feedback necessary in many neurosurgical procedures.[5,6] One of the goals of endoscopic cadaveric study is to achieve better anatomic orientation while using the endoscope. Depth perception when using an endoscope is difficult to ascertain and requires extensive practice to perfect.[8] These procedures also require a thorough anatomical understanding to safely puncture the floor of the third ventricle without harming the basilar artery.[5]

In the past, plastic replica models and live animals have been used for endoscopic simulation.[9] For cadaveric study, the previous standard noted that fresh cadavers are optimal to avoid the ventricular wall collapse in embalmed cadavers.[8-10] Fresh cadavers can be attached to a host of pumps used according to the Minneti method, and other equipment to achieve such high simulation standards.[2,4,5,9,11-13] However, the equipment alone can be very expensive to acquire with balloon pumps exceeding $1000. In addition, the setup can be time intensive and laborious.[14] On the other hand, when using fresh cadavers, viability of structures greatly affects the cadaver experience. Blood and fluids in the cadaver are the catalyst for desiccation and tissue breakdown. The brain and small structures, such as nerves, desiccate faster than do larger structures. While large structures may remain viable for 4–5 weeks, the brain and nerves have limited viability with optimal neurosurgical educational opportunity in the first 24–48 h. Preparation of fresh cadavers is also met with stringent guidelines as set forth by the state anatomical board. From serology testing to COVID-19 testing, fresh cadavers are highly scrutinized to prevent infection risk which subsequently increases the cost of preparation and maintenance.[13] In addition, the COVID-19 pandemic has noted a decrease in use of fresh cadavers for health concerns and has created a shortage in fresh cadaver learning opportunities.

Fixed cadavers have often been dismissed as sub-par in utility when performing complex neurosurgical procedures due to the ventricular wall collapse issue that arises with the embalming process. Formalin fixation leads to tissue rigidity and impairs the integrity of the tissue such that it no longer approximates living tissue.[1]

With regard to the finances of cadaveric study for medical students and residents on fixed cadavers versus that using fresh cadavers, the potential cost-benefits are great. First and foremost, the recovery costs of fixed cadavers and fresh cadavers are vastly different with regards to preparation costs, maintenance costs, and continued use costs. For fixed cadavers, the embalming process is highly variable across institutions and may lead to varying costs. The cadaver itself can range in prices between $1200 and $2000. These cadavers have a usage expectancy between 2 and 10 years. Additional storage and maintenance costs are minimal and are often included in the initial cost of procurement. Furthermore, students and residents can arrange for regional dissections whereby a cadaver procured for one procedure can be reused for study of a different anatomical area at a fraction of the original cost. Fresh cadavers, on the other hand, have a very limited usage expectancy ranging from 1 to 3 weeks, high maintenance costs to maintain tissue integrity, and offer limited learning opportunities. Overall, the costs and decreased longevity of fresh cadavers present barriers that fixed cadavers can overcome.

While the authors acknowledge the draw backs of fixed cadavers for realistic surgical experiences, they are still valuable tools for learning neuroanatomy. Neuroendoscopic navigation and manipulation in CSF spaces are a skill that requires extensive practice that can be accomplished through the use of revitalized fixed cadavers before the OR experience. In addition, COVID-19 has exposed the shortcomings of fresh cadaver experiences especially with regard to health risk concerns. Utilizing fixed cadavers can also extend the life of the educational tool when there is a fresh cadaver supply shortage as seen during the COVID-19 pandemic and can serve as a viable alternative in resource deficient areas of the world. As accomplished in this study, trainees can use similar setups to practice orientation with neuroendoscopes, identify important structures, perform third ventriculostomy, and much more. After accounting for the cost of procuring a fixed cadaver, the disposable tools used in the study cost $49.82, a much lower cost than any other cadaveric revitalization equipment study. The non-disposable tools are also tools that are commonly found in any well-equipped OR and, thus, are not additional costs incurred specifically for cadaveric exploration like the pumps mentioned in these perfusion model cadaveric studies. These cadavers can then be used for medical student anatomical studies.

This study is limited in that it only outlines the educational experience with a single type of training tool, a fixed cadaver. Thus, without comparative data, it would be unreasonable to make generalizations, of which training tool is better. Future studies should compare performance of fresh and fixed cadavers, along with non-cadaver training devices and their effects on neuroanatomical education and resident preparedness for the OR. While the perfusion model and use of fixed cadavers as described here are by no means a replacement for fresh cadaver experiences, they demonstrate an opportunity to reduce waste and maximize learning opportunities at every step of medical education.

CONCLUSION

While fixed cadaver education does not take the place of fresh cadavers, it enhances trainee experience for better utilization of fresh cadaver experiences and can increase comfortability in the OR by providing trainees with more practice. Such tools are particularly important in procedures that have a steep learning curve, such as neuroendoscopy. Through our model, we note that fixed cadavers can be used as great tools for neuroanatomical study and procedural practice.

Furthermore, our simple perfusion model and tools can be used achieve anatomical study at a lower cost.

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Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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