Minimizing cotton retention in neurosurgical procedures: which imaging modality can help?

Raphael Bechtold[1], Niki Tselepidakis[1], Benjamin Garlow[1], Sean Glaister[1], William Zhu[1], Renee Liu[1], Alexandra Szewc[1], Arushi Tandon[1], Zachary Buono[1], James Pitingolo[1], Cristina Madalo[1], Isabella Ferrara[1], Collin Shale[1], Thomas Benassi[1], Micah Belzberg[2], Noah Gorelick[3], Brian Hwang[3], Camilo A. Molina[3], George Coles[4], Betty Tyler[3], Ian Suk[3], Judy Huang[3], Henry Brem[1,3], and Amir Manbachi[1,3]

[1] Department of Biomedical Engineering, Johns Hopkins University, Baltimore, MD
[2] Department of Plastic Surgery, Johns Hopkins University, Baltimore, MD
[3] Department of Neurosurgery, Johns Hopkins University, Baltimore, MD
[4] Johns Hopkins Applied Physics Laboratory, Laurel, MD

Abstract

Cotton balls are used in neurosurgical procedures to assist with hemostasis and improve vision within the operative field. Although the surgeon can reshape pieces of cotton for multiple intraoperative uses, this customizability and scale also places them at perpetual risk of being lost, as blood-soaked cotton balls are visually similar to raw brain tissue. Retained surgical cotton can induce potentially life-threatening immunologic responses, impair postoperative imaging, lead to a textiloma or misdiagnosis, and/or require reoperation. This study investigated three imaging modalities (optical, acoustic, and radiographic) to find the most effective method of identifying foreign bodies during neurosurgery.

First, we examined the use of dyes to increase contrast between cotton and surrounding parenchyma (optical approach). Second, we explored the ability to distinguish surgical cotton on or below the tissue surface from brain parenchyma using ultrasound imaging (acoustic approach). Lastly, we analyzed the ability of radiography to differentiate between brain parenchyma and cotton.

Our preliminary testing demonstrated that dark-colored cotton is significantly more identifiable than white cotton on the surface level. Additional testing revealed that cotton has noticeable different acoustic characteristics (eg, speed of sound, absorption) from neural tissue, allowing for enhanced contrast in applied ultrasound imaging. Radiography, however, did not present sufficient contrast, demanding further examination. These solutions have the potential to significantly reduce the possibility of intraoperative cotton retention both on and below the surface of the brain, while still providing surgeons with traditional cotton material properties without affecting the surgical workflow.

Keywords: Retained Foreign Object, Textiloma, Gossypiboma, Cotton balls, Brain Surgery, Ultrasound, Optics, X-ray, Medical Imaging, Contrast, Detectability

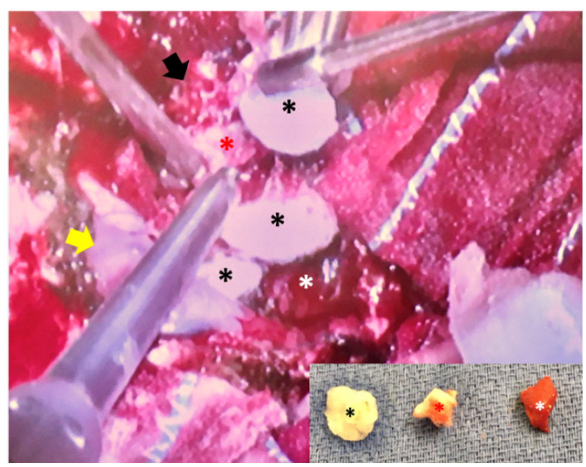

Figure 1. Intraoperative photo of brain tumor resection demonstrating the challenges of identifying cotton balls in the surgical field. Normal brain tissue (yellow arrow) and brain tumor (black arrow) are visible. Unlike the fresh cotton balls (black asterisk), partially and completely blood-soaked cotton balls are difficult to distinguish (red and white asterisks, respectively). Cotton balls are removed from the surgical field for comparison (inset).

1. Introduction

Neurosurgical procedures typically entail lengthy, meticulous dissection through complex, highly sensitive anatomy. Maintaining unobstructed visualization throughout a neurosurgical procedure is therefore critical.

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Many instruments and materials may be used to clear away obstructions (including blood and fluid) from the surgeon's view. Cotton balls are a particularly useful and inexpensive tool for this purpose, especially because a surgeon has the flexibility to pull and re-shape cotton balls for a multitude of intraoperative applications. However, the customizability and scale that make cotton balls such valuable surgical tools also increase the likelihood that they are misplaced and difficult to identify in the operative field (*Figure 1*). Moreover, individual pieces of cotton balls are typically not formally counted during surgery.[10] Approximately 22.6 million people worldwide suffer from a neurological injury or disorder every year, and 13.8 millions of these patients require surgery.[1] Each of these 13.8 million procedures presents opportunities for cotton balls to be left in the brain or spine. It's estimated that there are 1500 to 2000 retained surgical items cases a year in the US.[14] It is likely that the magnitude of the problem is underestimated because of underreporting—clinicians and hospitals are reluctant to disclose these types of errors.[11,12] In addition, retained foreign body data are often hampered by the confidentiality requirements of insurance and legal claims.[13]

Surgical cotton unintentionally left in the brain can induce a potentially life-threatening immunologic response, impair postoperative imaging, lead to a misdiagnosis, require reoperation, or some combination of these scenarios.[2,3,4] Symptoms of retained cranial cotton include seizures, epilepsy, memory loss, and headaches.[2,3,4] There have been 50 recorded cases of intracranial textilomas or gossypibomas since 1973.[3] As sequelae of retained cotton may not present for months or years postoperatively, and because incidences of retained cotton are likely underreported, the true frequency of these events is unknown.[5,6] Retained cotton may require an additional operation, which places the patient at greater risk. These incidents may cost hospitals and healthcare providers millions of dollars from malpractice lawsuits.[7] At present, there is no means to reliably detect retained cotton balls before surgical closure. The lone exception—radiofrequency-tagged surgical sponges—have not been accepted by hospitals and cannot provide exact spatial location information.[15]

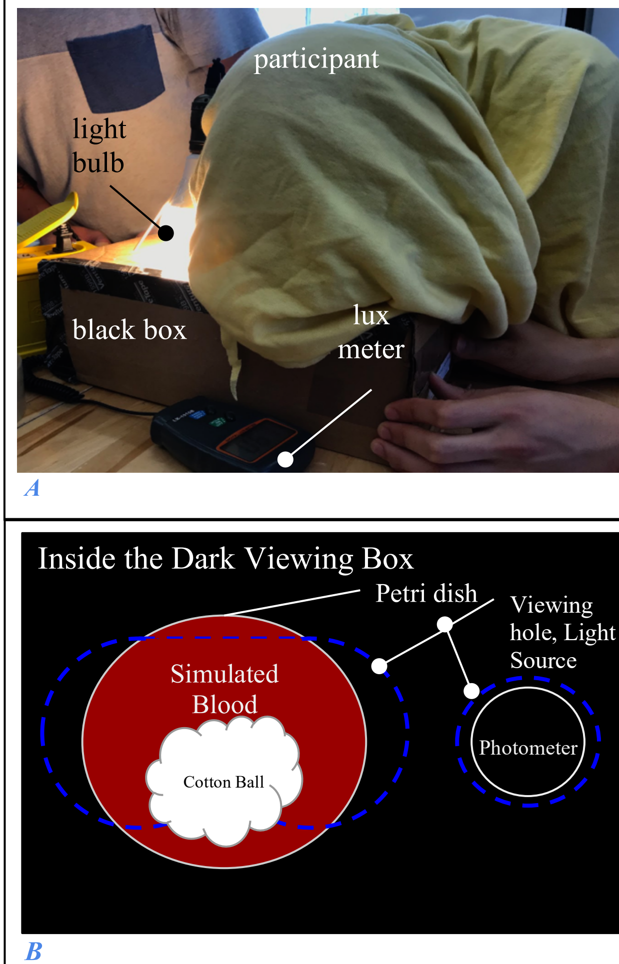

Figure 2. Dark Viewing Box Test Setup. (A) The interior is painted black; a small hole allows a controlled amount of light into the box. A petri dish with artificial blood and cotton is placed in the box, and the light level is increased until the cotton is identifiable in the blood. (B) Inside view of the dark viewing box. The dotted blue lines represent the shapes of the holes cut into the top of the box (left: represents where the participant would look into the box, right: placement of the adjustable light source).

Optical, acoustical, and radiographic imaging modalities may each have the potential to distinguish cotton from brain tissue. This study pursued *ex vivo* experimental approaches to develop a method to detect cotton balls during neurosurgery. We explored the ability to distinguish surgical cotton from brain parenchyma using visual, ultrasound, and radiographic approaches.

2. Methods

2.1: Dyed Cotton (Optical Approach)

To control our experiments and to minimize unwanted background ambient noise, a testing rig involving a dark viewing box was developed (*Figures 2-3*). We sought to quantitatively measure the detectability of the different colored cotton against a background color intended to mimic the color of blood (pink/light red, wavelength=722nm). The interior of the box was painted black and sealed so that no light could enter. A large viewing hole was cut and standard chemistry lab goggles were attached over the hole for the participant to look through. A smaller light hole (approx. 50mm diameter) was cut on the top of the box, and a brightness-adjustable light (Seaside Village, MN: CECOMINOD047576) was used to allow for controlled illumination into the inside of the box. A photometer (CityFarmer, MN: 8595745782) was then placed inside the box to measure the relative levels of light that entered. Finally, a piece of colored cotton was placed in a petri dish filled with a blood-mimicking fluid (Kangaroo, IN: 10207), and the petri dish was placed inside the box. During the test, 10 participants looked into the box (one time per color) while the light intensity was raised until the participant indicated that the cotton was distinguishable from the blood mimicking background. The measured brightness was then recorded, and the procedure was repeated for each different dyed color of cotton. Results were normalized compared to an initial "control" test using undyed white cotton.

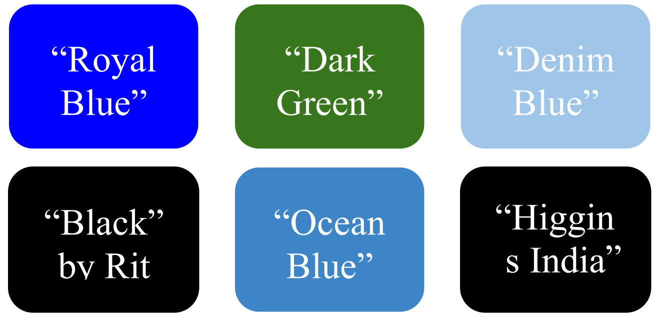

Figure 3. List of dyes used to color the cotton during testing. The lighter and darker shades were created by varying the duration for which the cotton balls were soaked in the dye.

Figure 4. Ultrasound Testing Setup. Soaked surgical cotton balls were placed above, within, and beneath a section of swine brain and imaged with a wireless ultrasound transducer.

2.2: Ultrasound Imaging (Acoustic Approach)

A segment of fresh swine brain (used within 6 hours of euthanasia) was obtained from a local butcher (Wagner Meats, Mt Airy, MD, USA). Initial ultrasound imaging was performed using a 4-13MHz linear, wireless handheld ultrasound probe (Clarius L7 HD, Burnaby, BC, Canada).

A control ultrasound image was obtained of the swine brain parenchyma without cotton. Sterile surgical cotton balls were

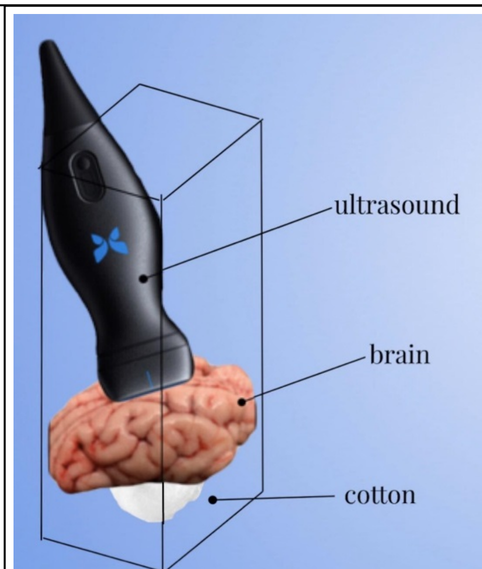

Figure 5. Depth test setup with cotton at the base of the box and swine brain layered on top to create the desired depth.

obtained, and a 2cm-diameter piece of cotton was soaked in saline. The brain was held by hand and white cotton that had been soaked in water was then placed in a variety of positions, both superficially as well as within and beneath the swine brain. The presence of air was assessed, and saline was added as needed to remove air pockets. Still and video ultrasound images were recorded. The experimental setup is seen in *Figure 4*.

In order to remain neutral to one specific commercial system and to avoid any bias in our results, further assessment was performed using a portable Butterfly IQ ultrasound probe that operates at 1-5 MHz (Butterfly Network, Guilford, CT). Size and depth evaluation were performed to measure the smallest detectable size of cotton and the maximum depth of detecting cotton.

For size testing, we used a similar setup as in the above-described experiment, except the brain was placed on a hard plastic surface with cotton under the brain. Six different-size cotton balls were imaged, with diameters of 20mm, 15mm, 10mm, 5mm, 3mm, and 2mm.

The depth test used a box (15cm x 15cm x 20cm) with a 15mm-diameter cotton ball under layered porcine brain hemispheres. By changing the number of stacked brains, we were able to test with varied cotton ball depths (*Figure 5*). Depth was measured from the cotton ball to the top of the stack of brains. Cotton ball depths were measured in the range of 0cm (brain surface) to 8cm beneath brain tissue, in 2cm increments. This range was chosen to be compatible with operating ranges for neurosurgical procedures.

2.3: Radiographic Imaging (Radiological Approach)

An ULTRA High Res Canon CT scanner (Aquilion Precision, Canon, Tustin, CA) was used to identify the visibility of cotton using radiography. Similar to the ultrasound approach, surgical cotton balls as well as fresh porcine brain hemispheres were obtained. Brain tissue, cotton balls, and saline were all placed in a radiolucent plastic bucket (*Figure 6*).

For the first set of images, the pig brains were partly submerged with a saline-soaked cotton ball inserted into the exposed brain matter. Images were taken with and without cotton balls. In the next set of images and in accordance with standard neurosurgical procedures, a 20mm-diameter ball of saline-soaked cotton was fully wedged into a sulcus on the top face of the completely submerged porcine brains. Similar to the first iteration, images were taken with and without cotton. The position of the cotton relative to the top surface of the porcine brains was generally kept constant.

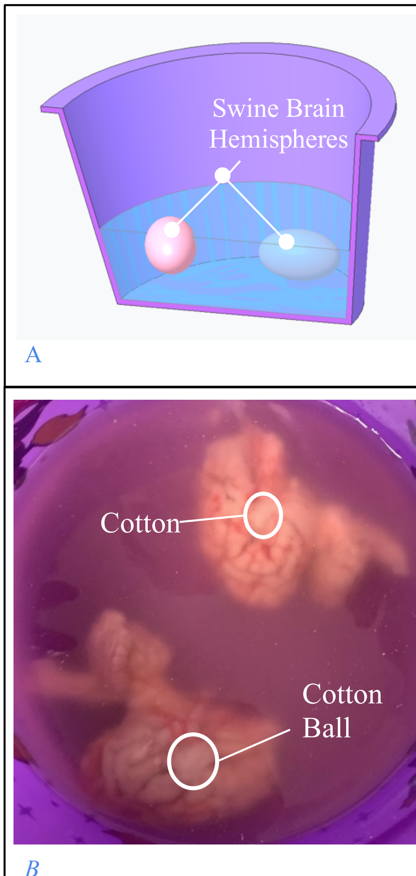

Figure 6 Radiographic Testing Experimental Setup (A) Simulated 3D model of the experimental setup, illustrating the brain placement inside the container. (B) Top view of the setup. Pig brains with cotton placed below the top surface of the brain. Cotton balls are circled in white.

3. Results

3.1: Dyed Cotton (Optical Approach)

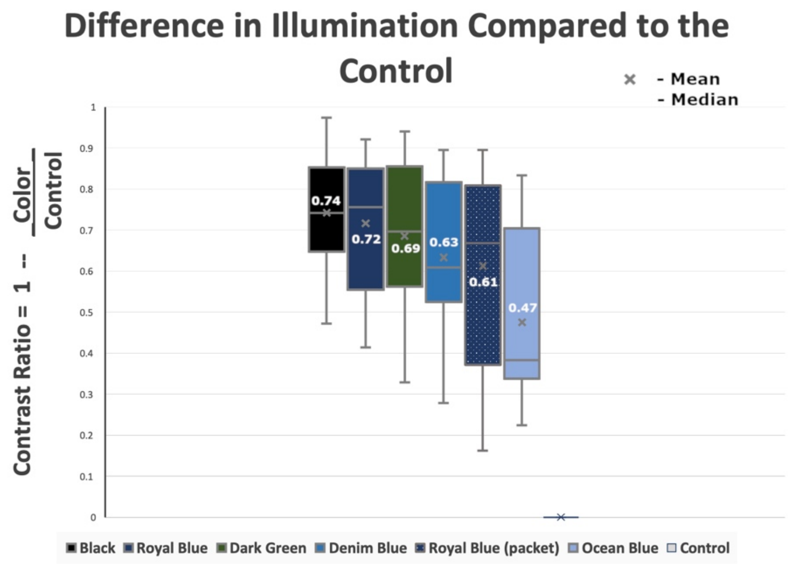

Figure 7. The results from the "black box" color contrast experiment. The values were achieved by taking the proportion of light needed to reach visibility as compared to the control (white cotton). Then, the final values with valued as 1-x in order to display that larger bars had increased proportional contrast.

The experimental results obtained from the dyed cotton balls placed inside the dark viewing box are displayed in *Figure 7*, with black, dark royal blue, and dark green as the colors with the most detectability/contrast (determined by lowest illumination levels required to reach the visibility threshold). Importantly, we observed that all dyed colors of cotton scored significantly better than the control (white cotton). Even though black scored highest, royal blue may have an advantage in practical applications due to its change in color as it absorbs blood and fluid, whereas black stays a consistent color. This color contrast gradient could indicate to surgeons the cotton will not further absorb blood and should be replaced with a fresh piece. These results strongly support our hypothesis regarding altering the appearance of cotton to increase detectability, as colored cotton was shown to increase contrast against a blood background. Ongoing studies are examining this effect *in vivo*.

3.2: Ultrasound Imaging (Acoustic Approach)

As presented in *Figure 8*, surgical cotton balls were successfully identified in swine brain parenchyma using ultrasound imaging. The cotton presented with a hyperechoic proximal margin with uniquely identifiable distal acoustic shadowing. This appearance contrasted significantly from the structure of the swine brain parenchyma. The cotton ball appearance remained consistent regardless of cotton position within, above, or beneath the brain tissue.

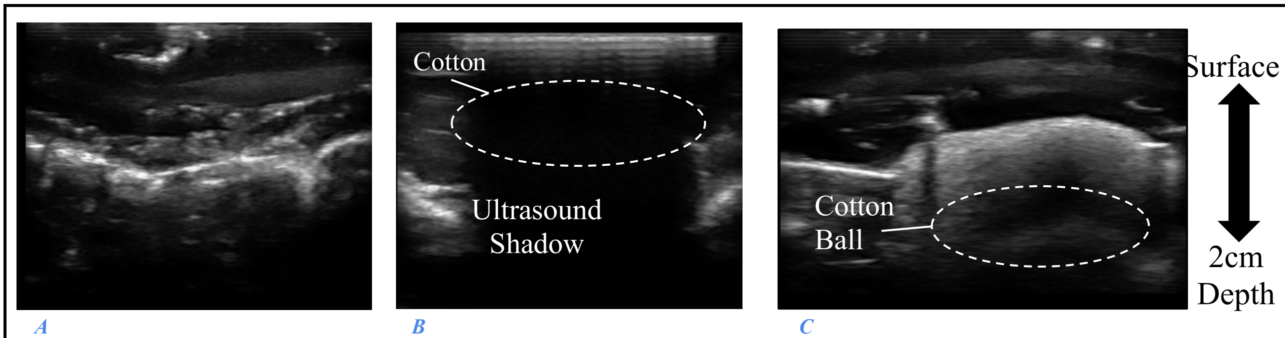

Figure 8. (initial/POC) Ultrasound scans (Clarius) of fresh porcine brains (A) control image of a swine brain (B) image of cotton on the surface of the brain (C) image of cotton 2cm beneath the surface of the brain. Dashed circles indicate locations of cottons. Dark regions under the circles are acoustic shadowing, characterized by a signal void behind cottons strongly absorbing ultrasonic waves.

Cotton ball size analysis further quantified the efficacy of ultrasound to detect cotton balls in neurosurgical procedures. Cotton was successfully detected using ultrasound from a size of 20mm diameter to a size of 2mm diameter at a depth of 1 cm (*Figure 9*).

This cotton ball detectability depth investigation demonstrated effective detection up to 8cm deep within fresh swine brain tissue. This shows that ultrasound is able to detect cotton balls of 15mm diameter within brain tissue at least up to 8cm deep, which is the standard maximum depth required in a neurosurgical operation (*Figure 10)*.

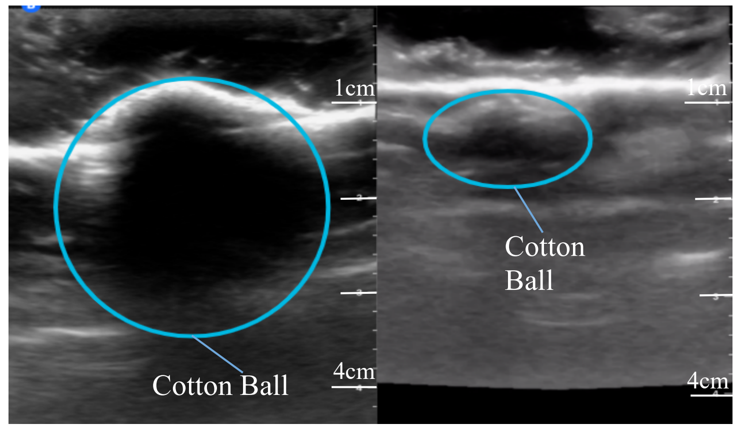

Figure 9. The image on the left is a 15mm-diameter sized cotton ball imaged at a depth of 1cm. It is easily visually distinguishable from the surrounding swine brain tissue. The image on the right is a 2mm-diameter cotton ball at 1.5cm depth. It is less noticeable, but still distinguishable from brain tissue due to its darker color.

Ultrasound studies demonstrated feasibility in locating cotton within the brain intraoperatively. Moreover, the distinct appearance of the cotton balls as well as the acoustic shadowing associated with them creates a unique visual identifier for cotton. This could allow for an algorithm to automatically detect retained cotton balls. Ongoing experiments are evaluating the appearance of surgical cotton *in vivo* and the effect of multi-hour soaking, as many neurosurgical procedures often last hours.

3.3: Radiographic Imaging (Radiological Approach)

An initial experiment (*Figure 11*) provided insight into the efficacy of using radiography to detect potentially retained cotton balls in neurosurgical procedures. In *Figures 11A* and *11B*, it is easy to identify cotton on the surface of the brain due to a slight dark discoloration on the cotton. *Figures 11C* and *11D, however,* show a different result: the cotton is almost impossible to identify and appears nearly indistinguishable from the surrounding black background. Further testing of radiography with cotton in varying locations is needed to fully determine the efficacy of using radiography to detect cotton in neurosurgical procedures.

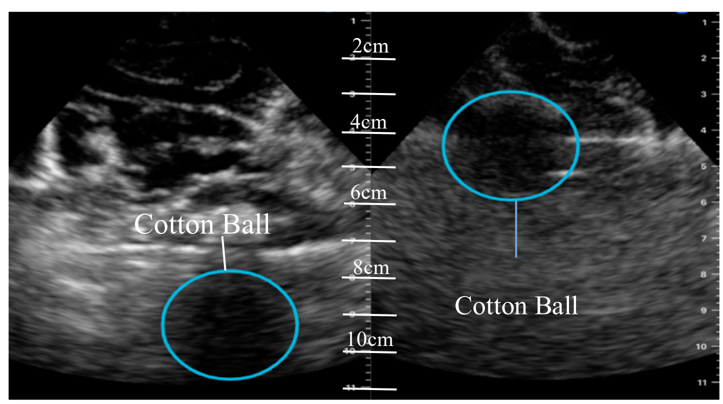

Figure 10. The image on the left is a cotton ball at 8cm deep in the brain. The image on the right is a cotton ball at a depth of 3cm. Cotton is distinguishable at a multitude of depths in the brain, with ultrasound being able to detect cotton at least 8 cm deep.

4. Discussions

Published studies of retained surgical cotton in neurosurgery focus on drawing attention to the problem and analyzing specific cases, but few have offered actual solutions to this problem.[5,7,8,9] Most authors advise surgeons to be aware of the possible dangers of an intracranial textiloma.[3,8] Thus, a method to locate cotton before closing is paramount to preventing textiloma. Our study investigated whether optical, acoustic, and radiological approaches could distinguish cotton from brain parenchyma.

All of the dyed cotton colors tested demonstrated improved contrast compared to white cotton. Black cotton is the most visible, but royal blue cotton has the added advantage of providing information on the blood saturation level of the cotton, as it shows when blood is no longer being absorbed and a fresh piece should be introduced.

Radiographic imaging techniques were conflicting in their ability to identify cotton in the brain. However, these techniques hold promise in identifying cotton in the operative field. Further testing of cotton in various locations, under various conditions, is warranted to fully determine efficacy of radiography for this purpose.

Ultrasound imaging has proven to be the most effective method of determining cotton ball retention compared with visual and radiographic techniques. The unique acoustic signature of the cotton balls (eg, the acoustic shadowing under the cotton material) suggests the opportunity to develop an image-based algorithm to automatically detect cotton, or potentially all foreign body material, intraoperatively. Ongoing *in vitro* and *in vivo* experiments are examining the effects of different experimental parameters, including soaking duration, soaking substances, and ultrasound parameters. Thus, these results strongly suggest that the optimal solution may be to use a visual approach to search for dyed cotton on the brain's surface and to use ultrasound technology to identify subsurface cotton balls and other foreign body materials in neurosurgical procedures in order to reduce the risk of these life-threatening events.

5. Conclusion

Surgical cotton unintentionally left in the brain can induce life-threatening immunologic response, impair postoperative imaging, lead to a misdiagnosis, require reoperation, or some combination of these scenarios. Optical, acoustical, and radiographic imaging modalities may each have the potential to distinguish cotton from brain tissue. This study pursued *ex vivo* experimental approaches to compare the applicability of visual, ultrasound, and radiographic modalities for this purpose.

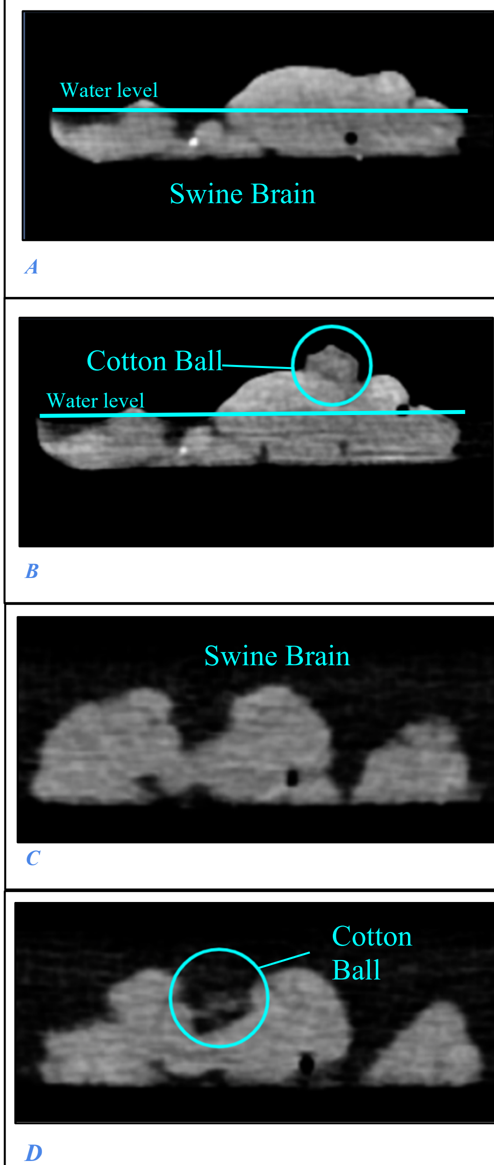

Figure 11 Radiography testing results. (A) Swine brain partially submerged in water **without** cotton. (B) Swine brain partially submerged in water **with** cotton (blue circle). The cotton has a slightly darker color and was discernible from the surrounding tissue. (C) Swine brain fully submerged **without** cotton. Fully submerged brain more closely mimics a surgical setting in which the operative field is filled with blood and fluid. (D) Swine brain fully submerged in water **with** cotton (blue circle). The cotton appears much darker in the fully submerged case and is difficult to distinguish from the surrounding water.

6. Publication History: None

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