Evaluating Alternatives to Traditional Cotton Laparotomy Sponges for Blood Absorption in the Austere and Mobile Surgical Environment

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ABSTRACT

Background: The operative control of noncompressible hemorrhage is the single largest impact that could be addressed in reducing the mortality on the battlefield. Laparotomy pads, traditionally used for hemorrhage evacuation, are made of woven cotton, and, while effective, their use requires a substantial amount of space and adds weight. This poses no concern in traditional operating rooms but is a hindrance for mobile providers and providers in austere environments. We sought to compare different absorptive compounds to ascertain their utility as alternatives for traditional laparotomy pads. Methods: Samples of cotton laparotomy pads, pure rayon sheets, rayon-polypropylene composite sheets, and nylon-polyester composite “microfiber” sheets were weighed and submerged in heparinized whole bovine blood. After saturation, the fabrics were weighed, wrung dry, reweighed, and resubmerged. This process was performed for a total of three sequential submersion. The saturated weights and dry weights of each fabric were used to calculate how much blood each fabric could absorb initially and after multiple repeated uses. The initial densities of the four fabrics was calculated and compared. Results: The initial submersion demonstrated that 1g each of cotton, rayon, rayon-polypropylene, and nylon-polyester were able to absorb 7.58g, 12.98g, 10.16g, and 9.73g of blood, respectively. The second and third sequential trials, which were statistically similar, demonstrated that 1g of cotton, rayon, rayon-polypropylene, and nylon-polyester were able to absorb 1.73g, 2.83g, 2.3g, and 2.3g of blood, respectively. The calculated densities of cotton, rayon, rayon-polypropylene, and nylon-polyester were 0.087g/cm³, 0.12g/cm³, 0.098g/cm³, and 0.093g/cm³, respectively. Conclusion: Per gram, rayon absorbed approximately 1.7 times more blood than cotton and used three-quarters the amount of the storage space. Rayon also retained its superior absorption abilities on repeated uses, demonstrating the potential for reuse in remote and austere environments. Thus, rayon could serve as a viable alternative to traditional cotton laparotomy pads in the austere forward surgical environment.

Keywords: hemorrhage; laparotomy; cotton; rayon; sponge; austere; surgery; packing; combat casualty care; absorption; density

Introduction

The operative control of noncompressible hemorrhage is the single largest factor that could be addressed in reducing mortality on the battlefield. There is a demonstrated improvement in survival the sooner the combat injured patient undergoes surgical evaluation and treatment. In an attempt to impact these patients, equipment and personnel are situated closer to the point of injury in both combat and in austere medical environments. This movement of resources forward requires mobility. Two factors that limit this mobility are the space and the weight of the necessary equipment. Both of these factors play a critical role in what providers can bring with them and, therefore, what is available to the injured patient.

Medical providers in austere, remote, or hostile environments must carefully assess the equipment they bring and each item must demonstrate that it is a vital tool in the mission to come. Items that can serve dual purposes should be chosen; if an item can be reused, it is more beneficial than one that cannot.

Hemorrhage remains the most common preventable cause of death in all austere, hostile, or mobile theaters. Tourniquets and packing material are the two mainstays of treating hemorrhage in the field. Tourniquets are very effective for extremity hemorrhage, while packing material is used for large soft-tissue or cavity injuries that are not amenable to tourniquet placement. For cavity injuries, hemostasis relies on a combination of direct pressure and the patient’s coagulation properties. It is these injuries that could be impacted by earlier surgical intervention.

The primary tool used for surgical hemorrhage evacuation is the laparotomy pad. It is impossible for the surgeon to visualize and attempt to repair an injury until
the large amount of liquid and clotted blood is removed. Laparotomy pads are bulky and the amount needed to effectively prepare for multiple hemorrhaging patients can be substantial. According to one study by Cichon et al. that evaluated blunt trauma patients requiring surgical intervention, the average amount of blood found within the peritoneal cavity was 4,500mL. The laparotomy pads required to absorb this amount of blood would be excessive for the provider attempting to bring equipment with them. Advanced Trauma Life Support doctrine holds that an average range of 750–2,000mL of blood is lost either on scene or within a target body cavity when class 1–3 shock has occurred. While the weight of the necessary laparotomy pads may not be a significant burden, the space necessary to carry this much cotton is. Providers would need to devote an entire bag or large portion of a rucksack just to carry enough cotton laparotomy pads. This limits any additional equipment they can bring into the field.

Our objective was to evaluate alternative materials to traditional laparotomy pads and test not only their ability to absorb blood but also their occupation of space. The hope was to find a fabric with similar or superior absorption to cotton that also occupies less space. This would allow the forward provider to provide the same or improved care with less equipment.

Methods

Model Development
This study was reviewed by and approved by our institutional review board. Fresh whole bovine blood was obtained during euthanasia procedures that were performed for food processing; thus, no animals were harmed for the sole purpose of collecting blood. Three gallons of fresh whole bovine blood was collected and combined with 500mL of normal saline and 25,000 units of heparin.

Five untested samples were obtained for each of the following fabrics: 100% woven cotton laparotomy pads (lap pads) (Figure 1); 100% rayon chamoix (Figure 2); rayon–polypropylene chamoix; and 20/80 nylon–polyester composite towels (microfiber towels).

Figure 1  Cotton laparotomy sponges currently used in most operating rooms.

A zeroed scale with an attached receptacle was used to contain any blood spilled during the weighing process. The fabric samples in each of the four groups were weighed to obtain dry initial weights. It was not necessary to have all initial fabrics weigh the same, because the absorption coefficients we calculated are natural properties specific to each fabric. Regardless of the starting weights, the coefficient will always be identical and is expressed in grams of blood absorbed by 1g of fabric.

Absorbance Coefficient
The absorbance coefficient (ACo) is defined as the amount of target fluid that 1g of target fabric is able to absorb. The ACo for each fabric is different when the fluid being absorbed is changed (i.e., a given fabric has a different ACo for each type of fluid). This is due to intrinsic properties of both the fabric and fluid, such as the charge of the fluid and material, porosity of the material, and particular content of the fluid. This measurement is used by industry to measure and compare the ability of fabrics to absorb fluids. This coefficient is also referred to absorbance capacity and is calculated using the following equation: 

\[
\frac{\text{wet weight of material used} - \text{dry weight of material used}}{\text{dry weight of material used}} = \text{absorbance capacity}
\]

This coefficient allows for side-by-side comparison of materials and their ability to absorb given fluids.

Study
The fabric samples were saturated in whole blood by submerging the fabric for a total of 30 seconds; each was swirled five times, squeezed, and released five times, and shaken while submerged five times. The fabrics were then removed from the whole blood and immediately transferred to the receptacle on the scale to obtain an initial wet weight. The fabrics where then manually wrung dry until no more blood could be expressed. The fabrics were then placed back on the scale to obtain a secondary dry weight. They were then replaced in the whole blood and saturated using the same technique, to obtain secondary dry and wet weights. This process was repeated a third time to obtain tertiary dry and wet weights.

The equation given above was used to calculate the ACo for each of the five samples of fabrics for the four fabrics...
used. Initial, secondary, and tertiary weights were used to calculate initial, secondary, and tertiary ACos, respectively (Table 1). These ACos were compared.

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<tr>
<th>Sample No.</th>
<th>Absorption Coefficient, g</th>
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The mean ACos of the five samples from each fabric from each trial were obtained to yield initial, secondary, and tertiary mean ACos for each fabric. The means were used for graphical comparison.

The weight of five 10mL syringes of whole bovine blood was then subtracted from the dry weight of each of the five syringes to obtain the average mass of 10mL of whole bovine blood. This allowed us to convert mass to volume of bovine blood.

The density of each material was calculated by measuring the weight and volume of new samples of fabric straight from the factory packaging. This allowed not only comparison of absorption of the given fabrics but also the amount of weight and/or volume they would occupy.

Statistical Analysis

We performed multiple two-tailed, unpaired, t tests, with \( p < .05 \) considered statistically significant. We compared the initial ACos of rayon–polypropylene to initial ACos of cotton, initial ACos of rayon to initial ACos of cotton, and initial ACos of microfiber to initial ACos of cotton. This gave us three \( p \) values for the initial trial: one for each comparison of target fabric to cotton. Similarly, we compared the secondary and tertiary ACos of the same combinations, obtaining three \( p \) values for each of these (Table 2).

Results

The mean initial ACo for rayon was 12.96g of bovine blood absorbed per gram of fabric, 2.83g for the second trial, and 2.57g for the third trial. The mean ACos for rayon–polypropylene were 10.16g, 2.16g, and 2.3g for the initial, second, and third trials, respectively. Mean ACos for microfiber were 9.73g, 2.28g, and 2.3g, respectively; and those of cotton were 7.58g, 1.73g, and 1.74g, respectively (Figure 3).

The mean weight of the five 10mL syringes of whole bovine blood was 10.3g. Rayon was the densest fabric, with a mean density of 0.12g/cm³ (Table 3); cotton was the least dense (mean density, 0.087g/cm³). The mean densities of rayon–polypropylene and microfiber towels were 0.098g/cm³ and 0.093g/cm³, respectively.

Discussion

The surgical provider in the remote and austere environments is faced with many obstacles to optimal patient care. One of the biggest obstacles is the access, transport, and storage of surgical equipment (e.g., surgical instruments, surgical equipment, lap pads, and hemostatic devices and agents).
In established operating rooms around the world, the storage and procurement of lap pads are not issues. When a small team or solo provider is forced to bring their medical supplies with them, multiple new problems arise. The austere or remote provider must now consider the weight, ease of procurement, and ease of storage of every item of equipment. They must also look for items that can serve multiple uses or be safely reused or used for longer periods of time. This study demonstrates that 100% rayon and rayon composite materials offer potential alternatives to traditional lap pads in the remote and austere environment by maximizing the ability to absorb blood and control hemorrhage, while decreasing the space needed to carry such supplies.

The benefit of rayon-based laparotomy sponges over cotton can be seen in the following example. Based on our research, a 30cm³ brick of cotton (about 125 lap pads) would weigh 2.35kg and be able to absorb 17.29L of blood on initial use and 3.95L of blood for each use afterwards. An equivalent mass of rayon (2.35kg) would be a brick roughly 27cm³ (about 28 extra-large sheets; about three-quarters the size of the cotton brick) and absorb 29.57L of blood on initial use and 6.4L of blood for each use afterward.

A typical scenario that demonstrates the potential benefits of rayon is nonobtunded patients with class 3 shock and averaging 2L of blood loss, excluding extremity wounds. The aforementioned 125 cotton lap pads would be able to evacuate hemorrhage for eight or nine patients, while the equivalent mass of rayon would be able to control hemorrhage for 14–15 patients. The equivalent mass of rayon is nearly twice as effective as cotton on both initial and repeated uses and takes up three-quarters the amount of space.

Rayon lap pads and surgical sponges are not a new concept and patents for rayon-based sponges date back to the 1970s.7 The benefits of rayon over cotton—decreased lint, leading to fewer adhesions and microgranulomas; and better absorptive properties—have been described in surgical literature dating back to the 1940s.8 Rayon is a natural, regenerated cellulose fiber made from wood pulp and has been referred to as artificial silk, bamboo silk, bamboo cotton, or artificial cotton. Although it is manmade, it is entirely natural and biodegradable, and can be easily sterilized. Since its invention in the mid 1800s, it has been a strong competitor of cotton in many fields, but mostly in the clothing industry. A major advantage of rayon over cotton, besides those demonstrated in this study, is cost. Rayon is cheaper than cotton by $1.65 per yard, enough to cause major shifts in marketplace and textile economics.10

Although rayon has existed for hundreds of years, it has some limitations. Because of the way rayon is manufactured, the strands that compose the fabric are not as long as cotton strands. Thus, rayon has a much lower tensile strength than cotton. Rayon lap pads are sold both with and without cotton mesh nettings and, based on our search for these products, seem to be more popular in Eastern countries.

Rayon has been shown to have significantly lower levels of lint than cotton and to cause a much lower level of inflammation. The adhesive properties of cotton have been well described and have led to the disuse of many cotton surgical devices, such as cotton sutures.11,12 Because of their lower potential to cause inflammation and lower “lint emboli,” rayon sponges seem to be finding a niche in specialized surgical fields.13

Based on our data on cotton’s density and its absorptive properties, one can calculate the amount of cotton needed to care for eight surgical casualties with class 3 hemorrhage. For example, our data indicate 2,111g of cotton would be needed to absorb about 16L of blood. With our measured weight of roughly 18–20g per lap
Moisture flow through Belen, New Mexico, for their assistance with this study. We thank Mathews Custom Meat Processing from sponges could positively impact surgical patient care at while using less space in their medical kits. Rayon-based care to a greater number of hemorrhaging patients low providers in austere and remote locations to give cotton for both initial and repeated uses in absorbing blood. Because of the larger pore and tensile size of cotton, there may be a theoretical advantage of cotton over rayon in its ability to absorb clotting blood but this has not yet been demonstrated. Again, live-tissue studies in nonheparinized animals would allow investigation to see if this difference exists.

**Conclusion**

An equivalent mass of rayon is more effective than cotton for both initial and repeated uses in absorbing blood. This, coupled with a decrease in space, could allow providers in austere and remote locations to give care to a greater number of hemorrhaging patients while using less space in their medical kits. Rayon-based sponges could positively impact surgical patient care at the point of injury.

**Acknowledgments**

We thank Mathews Custom Meat Processing from Belen, New Mexico, for their assistance with this study.

**Study Limitations**

This is a preliminary study that evaluated the absorption of heparinized blood. When using sponges in the operating room to control hemorrhage, the sponges must not only be absorb but also provide effective exposure and visualization of the injury to prevent further blood loss and allow for surgical correction of the problem. While it is not entirely certain what aspects of a sponge allow for better tamponade of blood flow, the only way to compare this characteristic would be side-by-side live tissue studies, which are being established. Live-tissue studies would allow creation of an injury and use different packing material to see if rayon could absorb more blood with less fabric than cotton and also create a superior tamponade effect.

While similar to human blood, bovine blood is not identi
cal to human blood and the results of our study should take this into consideration. While we do not foresee this being a major limitation, it should be mentioned and hu
man whole-blood studies should be performed to confirm our findings. Heparin, on the other hand, prevented the blood from clotting and made our study easier to perform without time limitations. This being said, unless there is substantial loss of coagulation factors, which is common in massive hemorrhage, blood in a live patient will clot. Thus, we were unable to compare the fabrics’ ability to absorb clotted or clotting blood. Because of the larger pore and tensile size of cotton, there may be a theoretical advantage of cotton over rayon in its ability to absorb clotting blood but this has not yet been demonstrated. Again, live-tissue studies in nonheparinized animals would allow investigation to see if this difference exists.

**Disclosures**

The authors have no financial interests related to this project. No outside funding was acquired or used for this study.

**References**


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