ABSTRACT

HENDERSON, KAMRYN NICOLE. Study of Absorption Capacity and Absorbency Rate of Woven Cotton Laparotomy Sponges. (Under the direction of Dr. Kavita Mathur).

Laparotomy sponges have long been an indispensable tool within surgical environments for centuries, used to secure organs in place, facilitate body temperature control, and absorb bodily fluids during operation. They are typically made of an open mesh gauze, primarily loosely woven plain weaves from cotton yarns. Crucial attributes, including high wicking rates, exceptional absorbency, and minimal lint or debris generation, define their physical and performance characteristics. While nonwoven sponges have grown in popularity due to greater absorbent properties and high productivity in manufacture, woven cotton sponges maintain dominance over the market despite the performance gap. However, research on laparotomy sponges is greatly limited, and studies have not been conducted to address fundamental redesign of woven cotton laparotomy sponges. Thus, a need for further research was identified to unravel the intricate relationship between the construction parameters and absorbency patterns of woven cotton laparotomy sponges.

This study employs a comprehensive experimental approach, incorporating traditional gravimetric testing and a novel test method design to simulate blood absorption. The research design involved a systematic variation of yarn spinning method, yarn number, and fabric density to create various configurations for the experimental samples. The Gravimetric Absorbency Testing System (GATS) was employed to assess absorbent capacity and absorbency rate, while the novel test method was used to gauge absorbent capacity in the context of simulated blood, using simulated blood that mimics the viscosity of real blood.

Analysis of the experimental results revealed the significant impact that yarn spinning method, yarn number, and fabric density each had on the absorbency of the laparotomy sponges. Gravimetric testing revealed that each parameter played a vital role in absorbent capacity, while fabric density and yarn spinning method had the most impact on absorbency rate. This suggests a complex relationship between the material properties and absorbent performance. However, comparative analysis between the GATS and novel test method revealed contrasts in the results. While GATS was more consistent and reliable, the novel test exhibited greater inconsistency in the results due a higher margin of error. The study concluded that GATS is more suited for analyzing absorbency of laparotomy sponges at this state, although future research should be done on novel test methods, as testing absorbency with a test solution that mimics blood viscosity could provide valuable insights.

Study of Absorption Capacity and Absorbency Rate of Woven Cotton Laparotomy Sponges

by
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DEDICATION

All my work, now and forever, is dedicated to my family. To my grandma, Volree Johnston, who I miss every single day. You are the reason that I have made it so far, and I will never forget our daily phone calls my freshman year that helped me adjust to being away from home. I wish more than anything that you were still here to share these moments with me. To my grandpa, Richard Johnston, who not only afforded me all the opportunities to explore my passions growing up, but has showered me with unconditional love, support, and encouragement over the years. I hope that you know how much I appreciate you. To my older sisters, Kori Henderson and Kaley Henderson Francisco, who have looked after me and spoiled me as the younger sister, and to my Aunt Nicci, who took me in for my internship last summer and has acted as a mother figure to me ever since. You are all some of the strongest women that I know, and I have always wanted to be like each of you. And finally, to all the other family members, and friends who have become my family, who have loved and supported me over the years. I am so appreciative, and truly am the person that I am today because of all the love and support I've been shown.

BIOGRAPHY

Kamryn Nicole Henderson was born and raised in Kernersville, North Carolina. She spent most of her childhood under the care of her grandparents, Richard and Volree Johnston. It was through their love and support that she was provided every opportunity to explore her creative interests. Her interest in fashion, which began as a little girl hand stitching matching outfits with her American Girl Dolls, continued into her adult years. This passion, along with her grandparents' encouragement to do whatever she put her mind to, ultimately led her to pursue a career in fashion and textiles.

Kamryn graduated Summa Cum Laude from NC State's Wilson College of Textiles with a degree in Fashion and Textile Management (Fashion Development and Product Management) in 2021. She remained on the Dean's List all four years, and participated in the Accelerated Bachelor's/Master's program to begin her Master's coursework during senior year. She utilized her master's program to further explore her interest in computer aided design and develop a more thorough understanding of yarn and fabric manufacturing processes and testing methods. Kamryn has begun her career as a Textile Laboratory Specialist at Victoria's Secret & Co. Headquarters in Columbus, OH, and is bringing with her the wealth of knowledge on textile testing that she gained during her graduate studies at the Wilson College of Textiles.

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CHAPTER 1: INTRODUCTION

1.1 Background

Laparotomy sponges are surgical dressings that have been a vital part of operating rooms and austere environments for centuries. They are open mesh, plied gauze pads that are used to keep organs in place and prevent them from entering the field of operation, support body temperature, and absorb blood and other bodily exudates. Classified as a secondary surgical dressing, laparotomy sponges must be sterile, non-toxic, and non-allergenic (Parikh et al.,1999). Vital physical and performance characteristics of laparotomy sponges include a high wicking rate, high absorbency, and minimal lint/debris generation (Choski, Spaeth & Shiff, 1977).

Laparotomy sponges have traditionally been made of a low count, loosely woven plain weave of 100% cotton. Cotton contains suitable properties, such as softness, purity, absorbency, and non-toxicity to the human body, that have long made it preferential for medical use (Chohan et al., 2020). Because cotton yarns are hairy in nature, they must be coated with starch or other sizing mixtures to prevent yarn breakage during the weaving process (Parikh et al.,1999). However, after weaving, the woven gauze must be desized, scoured, and bleached in order to be labeled as “Absorbent Gauze " suitable for sponges. The gauze is plied into four layers with the edges folded in and hemmed and attached to a looped tape with a nontoxic monofilament treated with barium sulfate to make the sponge x-ray detectable in case of a retained sponge. The laparotomy sponge can range in size from 10 x 10 inches to 28 x 24 inches, and must be kept in sterilized, tamper-proof packaging to maintain the integrity of the product and meet standardized regulations (Mohiuddin, 2019).

Absorbent Gauze used to make woven laparotomy sponges is well-defined and regulated by the United States Pharmacopeia (USP). It is described as a “cotton or a mixture of cotton and not more than 53%, by weight, of rayon, and is in the form of a plain weave cloth conforming to the standards set forth in USP," (Parikh et al., 1999). The USP Absorbent Gauze monograph lays out the purity standards that the cloth must adhere to, and the tests include: absorbency, % water extractables, ignited residue, ash, ether extract, alkalinity, acidity, starch and pH range (Parikh et al.,1999). Adherence to these standards allows for the final laparotomy sponge to be labeled as made with USP Absorbent Gauze.

Falling under the medical device category, laparotomy sponges are also explicitly identified and regulated by the Food and Drug Administration (FDA). Under the Code of Federal Regulations (CFR) Title 21--Food and Drugs, woven sponges are regulated by Nonabsorbable gauze for internal use (2001). They are identified as medical devices of open mesh woven fabric of "not less than 50 percent by mass cotton, cellulose, or a simple chemical derivative of cellulose." They should contain x-ray detectable elements and are intended for use inside the body or surgical incisions or applied to internal organs or structures to "control bleeding, absorb fluid, or protect organs or structures from abrasion, drying, or contamination." They are a Class I device of low risk and are exempt from premarket notification subject to limitations (Nonabsorbable gauze for internal use, 2001).

While manufacturing laparotomy sponges from woven absorbent gauze is the most common and well-established method, weaving productivity has presented economic concerns and woven gauze is heavily sourced from developing countries. Because of this, nonwoven meshes have rapidly grown in popularity due to higher productivity rates and versatility in the manufacturing process. They are manufactured on moderately run nonwoven machines at a productivity rate that is several times higher than that of a highly productive weaving machine. These gauzes are frequently manufactured from cotton, polyester, and rayon, and have physical and performance properties that meet or exceed those of woven gauze, including an improved wicking rate, greater absorbent capacity, and less lint generation (Parikh et al.,1999). These increased properties present a notable advantage.

However, despite the recognized and promising advantages of nonwoven gauzes, woven laparotomy sponges remain at the forefront of surgical supplies. This can be attributed to the well-established history of weaving and the long-developed procedures and techniques practiced by surgeons who are reluctant to change (Parikh et al.,1999). Furthermore, nonwoven laparotomy sponges do not have the advantage of a USP label, nor do they fall under the same FDA regulation as woven sponges due to the construction. Nonwoven laparotomy sponges are regulated under Nonresorbable gauze/sponge for external use (1999), and are identified as a "sterile or nonsterile device intended for medical purposes, such as to be placed directly on a patient's wound to absorb exudate" that can be made from an open mesh woven or nonwoven material from cotton cellulose or a simple chemical derivative (Nonabsorbable gauze for internal use, 2001). A notable disadvantage to this regulation is the limitation to external use, which doesn't provide the same functionality in a surgical environment that a sponge approved for internal use does.

While woven laparotomy sponges remain the most common choice by surgeons, changes have not been implemented to increase absorption rate on a most basic level. It is generally thought that absorption is influenced at 3 places: fiber, yarn, and fabric. This includes the fibers themselves, the spaces between fibers in a yarn, and the spaces between weave intersections (Sawazaki, 1964). Therefore, it is reasonable to assume that altering fiber, yarn, and fabric parameters of the already existing design would alter absorption patterns, potentially leading to an increase that would allow them to perform more closely to a nonwoven sponge. While studies have more often analyzed the effect of changing one parameter on laparotomy sponge absorbency, comprehensive research about the impact of altering parameters on all three levels has yet to be conducted. A need for such is identified, with the possibility of reducing OR costs, reducing medical waste, and reducing the amount of space taken up by excess supplies.

Although statistics about the laparotomy sponge market alone are not available, the medical textile device market as a whole has an overall high potential. In 2020, it was forecasted that the global market for medical textiles would be worth 20.23 billion USD by 2022. The rise in demand is driven by the growing population, a rise in standards of living, greater expectations of quality of life, and an aging population. While the market for advanced and novel medical devices is promising, traditional woven medical textiles still play a major role in the healthcare industry (Rajendran & Anand, 2020). Furthermore, the modification of conventional wound dressings is "one of the great matters in medical and biomedical research," (Hajimirzababa et al., 2017). Thus, it is concluded that laparotomy sponges, especially those with improved physical and performance properties, have a promising place in the market and could be both lucrative and solve a need in the industry. However, in order to redesign traditional laparotomy sponges to enhance the performance, comprehensive research is needed to understand the relationship between construction parameters and the absorbency patterns of laparotomy sponges. Such a study would aid laparotomy sponge innovation by identifying trends in sorptive behavior, pointing to optimal values of the parameters studied.

1.2 Statement of Problem

The purpose of this study is to determine the extent to which yarn number, spinning method, and fabric density impact the absorbency of woven cotton laparotomy sponges in order to optimize traditional woven laparotomy sponge design. Quantitative research was conducted by manufacturing and comparing samples via absorbency testing in order to determine patterns in their behaviors in reference to the various fiber, yarn, and fabric parameters. Specifically, the study sought to understand how woven sponges might be redesigned at the most basic level in order to reflect an enhanced performance, but also provided a fundamental look at the significance of fiber, yarn, and fabric system parameters on the sorptive behaviors of woven cotton systems in general.

This study began by deconstructing and conducting physical testing on commercially available woven sponges to determine the current construction parameters of a product currently on the market. The information gathered from this initial testing was used to develop a sample testing plan from which cotton gauze samples were manufactured. Then, the commercial control samples and the developed gauze samples were tested for sorptive behavior and analyzed and compared to understand the significance of the factors altered, how this relates to the current market offering, and how the current product might be redesigned to be improved.

1.3 Research Questions

The following research questions guided this study's investigation of the influence of fiber, yarn, and fabric properties on woven cotton laparotomy sponges:

1. Are commercially available woven sponges optimized for maximum absorbency?
2. Do yarn count, spinning technology, and fabric construction have a significant impact on the absorbency of woven cotton laparotomy sponges?
3. Do one or more variables show a more significant impact on absorbency than the others?

4. Does the introduction of synthetic fiber increase the absorbency of woven cotton laparotomy sponges?

1.4 Limitations of the Study

The limitations of this study were:

- Funding - The research was not funded by outside sources, and therefore, materials and testing capabilities were limited. The materials used to make the samples were collected from available resources at NC State's Wilson College of Textiles. Testing was conducted to fulfill the overarching scope of the project, but further detailed research into the materials was restricted.
- Time - The laboratories are faced with several projects from undergraduate students, graduate students, and industry partners, limiting the availability to utilize lab resources. This provided challenges in sample manufacture, as the amount of time required to get through manufacturing the samples took up a large portion of the time allotted to complete the project. This delay reduced testing capabilities for the samples.
- Limited Samples - Relative to the funding and time constraints was the limited ability to test a wide variety of samples. While sample development reflected differences between a few treatment levels of spinning method, yarn number and fabric density, it was not possible to capture a more thorough look of all sample options.

1.5 Definitions

Woven: A cloth made of interlaced warp and filling yarns.

Nonwoven: A cloth made of directionally oriented or randomly laid fibers.

Yarn Number: The fineness or coarseness of a yarn determined by mass per unit length of yarn (direct system) or length per unit mass of yarn (indirect system).

ASTM: Formerly known as the American Society for Testing and Materials, ASTM International sets forth standards for materials, products, systems, and services.

ISO: International Organization for Standardization

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review is divided into three main sections. The first section (2.2) explores medical waste, specifically as it applies to the use of laparotomy sponges and other disposable medical products. The second section (2.3) explores the research that has been conducted to understand the principles of textile absorbency, with an emphasis on the three fabric levels: fiber, yarn, and system. Finally, the third section (2.4) goes into the current state of research on the performance of laparotomy sponges in terms of absorbency. Overall, the aim of this literature review is to understand the current state of knowledge on textile absorbency, examine the ways in which researchers have gone about studying absorbency, and identify the current state of research on woven and nonwoven laparotomy sponges. However, the current body of research on laparotomy sponges is notably limited, with a lack of comprehensive studies addressing multiple factors such as design, material, and absorbency performance. This gap in literature highlights the need for further research to address these factors, especially as operating room procedures evolve and the need for enhanced sponges grows.

2.2 Associated Medical Waste

The healthcare industry is one of the largest industries in the United States and is known to contribute an overwhelming amount of waste to landfills every year. In 2015, it was estimated that the healthcare industry produces 5.9 million tons of waste annually and is responsible for 8% of the US's carbon dioxide emissions. Despite these monumental numbers, only about 0.03% of the U.S. National Institutes of Health's budget is allocated to sustainability research (Campion et al., 2015).

While the exact amount that laparotomy sponges contribute to medical waste is unknown, it is well understood that disposable materials account for a large portion of healthcare waste. Disposable custom packs are used in almost every single procedure, where a set amount of disposable supplies are packaged and then subsequently thrown out after the procedure, despite whether or not the items are actually used. Oftentimes, these disposable packs lead to a lot of costly and unnecessary waste. In a study conducted with the intent to design a more "green" custom pack, the researchers found that cotton products, including OR towels, gauze, and laparotomy pads, were the second most prevalent material by weight in custom packs used for conventional vaginal birth, but showed the largest environmental impact (Campion et al., 2015). Furthermore, another study found that limiting the use of custom supplies could be a cost-saving opportunity for hospitals (Hoeksema, 2011). This leads to the conclusion that limiting the use of custom packs could not only relieve some of the burden that disposable products have on the environment, but also benefit hospitals as well.

While many disposables are wasted unnecessarily, not all waste can be avoided. One study found that 10-15% of annual waste generated by hospitals is considered infectious. (Crow, 1996). Infectious waste cannot be reused or recycled, and used laparotomy sponges fall under this category, as blood and other bodily exudates contaminate the sponge and make them no longer viable for future use. This emphasizes the need for laparotomy sponges engineered for better performance.

2.3 Understanding and Improving Textile Absorbency in Wound Dressings

While cotton fibers have inherently good absorbent properties, the effect is dramatically reduced once spun into yarns (Prasad et al., 2021). As noted in Chapter 1, woven cotton laparotomy sponges, while preferred, do not perform to the same extent as sponges of manufactured fibers. Thus, several studies have been conducted in an attempt to improve the absorbency of cotton materials. The following paragraphs discuss methods examined by previous researchers, including structure engineering and surface finishes.

The level of compactness of fibers in a yarn has been identified as a principal factor in total yarn absorbency. In a 1995 study by S. L. Paek, it was found that both warp and filling twist levels were highly significant for absorbency of the test fabrics. The samples woven from yarns of lower twist factors absorbed water quicker than the samples woven from yarns of higher twist factors. Furthermore, the study compared the effect of two different spinning methods on absorbency and found that the samples of open-end yarns in both the warp and filling direction were more absorbent than the samples of ring-spun yarns in both directions (Paek, 1995). While the findings from this study are significant to review, it is worth noting that the sample fabrics were woven from cotton/polyester and cotton/Dacron blend yarns. Paek noted the intention for further research that would explore a wider range of twist levels and yarn types, but the need for a comprehensive study is still present.

Tyagi et al., (2010) also compared the effects of twist and spinning methods on absorbency. When comparing woven cotton fabrics of cotton ring- and compact-spun yarns with various twist factors, the fabrics of yarns with higher twist factors exhibited invariably less absorbency than those with lower twist multiples. Furthermore, the researchers also identified the spinning method as playing a notable role in comfort characteristics such as absorbency. The fabrics of ring-spun yarns were found to have a higher total absorbance due to greater capillary size and degree of interconnectivity between the capillaries. The researchers concluded that twist factor, spindle speed, and yarn structure all play a major role in comfort characteristics (Tyagi et al., 2010). A more recent study found that a sample fabric manufactured with vortex yarns showed better absorbency when compared to samples made from ring and compact yarns, however, the harsher hand of the fabric makes it questionable for use in certain applications, especially laparotomy sponges used inside the body (Behera, 2020).

Prasad et al. (2021) conducted a study to engineer the absorbency and antibacterial activity of cotton wound dressings, and found samples woven from yarns with a 2.6 TM resulted in 29% greater water absorption than samples woven from yarns with a 4.0 TM. By observing the yarn cross-sectional area, they noted that the higher twist resulted in fibers more compactly arranged in the cross-section, notably reducing pore volume and porosity. Following the standard IS 13683:2006, the authors reported that 3.0 was the optimum twist multiple for yarns used in cotton gauze fabrics, which presented good absorbency and vertical wicking when compared to the samples of highly twisted yarns.

While altering yarn structure is a proven way to improve absorbency, finishes can also be imparted on fabrics to increase absorbency. One study found that microbial cellulose results in an over 30% increase in water absorption and wicking ability on conventional cotton gauze (Meftahi et al., 2009). Another study utilized chitosan, alginate, PVP-I, and AgNPs in an attempt to enhance woven cotton gauze performance. The researchers found that absorbency was increased by 55%, water holding capacity by 28%, and vertical wicking by 33% (Hajimirzababa et al., 2017). Their findings suggest a promising future for woven cotton gauze, especially in the realm of advanced wound dressings.

2.4 Performance Comparison of Laparotomy Sponges

Despite the long-standing use of laparotomy sponges in operating rooms, research on the performance of traditional laparotomy sponges is few and far between. In 1977, researchers presented a study on the wicking rate and absorbency of woven and nonwoven laparotomy sponge materials at the Association of the Nonwoven Fabrics Industry Symposium in Washington, DC. Their study, which used a novel apparatus, found that the 2-ply spunlace polyester sample wicked water 30% faster and blood 85% faster than spunlace cotton/rayon or woven cotton, but that the woven cotton sample had a 37% greater absorbent capacity than spunlace cotton/rayon and 13% greater than finished spunlace polyester. Furthermore, they stressed the importance of using blood over water to accurately measure absorbency and wicking rate (Choski, Spaeth & Shiff, 1977).

Interestingly, the findings on absorbency of the 1977 paper were contradicted by future research. In 1999, Parikh et al. reviewed the physical characteristics and performance properties of woven absorbent gauze and nonwoven gauze, noting that spunlaced nonwovens are manufactured to have performance advantages over traditional cotton gauze, presenting higher absorbency rates and capacities (Parikh et al., 1999). This likely points to technology improvements over those two decades, allowing for nonwovens to be engineered to meet or exceed woven fabric performance.

More recently, researchers reviewed laparotomy sponges used in small animal surgeries. When comparing typical woven and nonwoven sponges, it was found that a 4x4 inch, 4-ply nonwoven sponge of 70% rayon, 30% polyester had over double the adsorbent capacity of a 4x4 inch, 12-ply woven sponge of 100% cotton. Moreover, the nonwoven sponge had 1.4

micrograms of linting observed, where the woven sponge had 31.2 micrograms (Zeltzman & Downs, 2011).

In a 2015 study, researchers compared samples of 100% woven cotton surgical sponges, 100% rayon chamoix, rayon-polypropylene chamoix, and 20/80 nylon-polyester composite towels (microfiber towels) to evaluate alternatives to cotton sponges for military applications. They found that the 100% rayon chamoix was the most absorbent, and the 100% woven cotton sponges were the least absorbent. Furthermore, the rayon samples presented lower levels of linting, proving to be an overall more effective option than cotton laparotomy pads (Sirkin, Cook & Davis, 2015). Given the enhanced performance properties, rayon, a cellulosic fiber, appears to be a viable alternative to cotton laparotomy pads and would fall under FDA requirements given the fiber's cellulosic origin. However, such studies conclude the extent to which laparotomy sponges have been compared and researched. It is understood that furthering research to understand and improve laparotomy sponge absorbency could improve the product at hand.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The purpose of this study was to investigate the significance of spinning method, yarn number, and filling density on the absorbency of woven cotton laparotomy sponges in order to optimize traditional woven laparotomy sponge design. A quantitative approach was used to manufacture samples, test sorptive properties in a laboratory setting, and analyze the results.

The following research questions guided this study's investigation of the influence of fiber, yarn, and fabric parameters on woven cotton laparotomy sponges:

1. Are commercially available woven sponges optimized for maximum absorbency?
2. Do yarn count, spinning technology, and fabric construction have a significant impact on the absorbency of woven cotton laparotomy sponges?
3. Do one or more variables show a more significant impact on absorbency than the others?

3.2 Goal, Scope, and Hypothesis

The goal of this study was divided into three phases. The first phase was pre-intervention analysis via physical testing on the commercially available woven samples to determine spun yarn type, warp and filling densities, twist, and yarn number. The results from this phase were used to identify the baseline for woven sponge design to develop intervention testing. Cotton was identified as the fiber in the commercial samples and remained the fiber of interest during this study due to its biocompatibility, biodegradability, high natural absorbency, and adherence to the FDA regulation. Furthermore, various combinations of yarn number, yarn spinning method, and filling densities of woven cotton gauzes were developed and used to manufacture samples for testing in Phase II and III. The second phase included gathering absorbency data on the woven gauze samples using the Gravimetric Absorbency Testing System (GATS). Five specimens from each sample type were tested, and the resulting data was analyzed and reported as absorbent capacity (ACap) and absorbency rate (ARate). Finally, Phase III was carried out to gather data on the absorbent capacity of the samples using simulated blood to understand how the ACap is impacted by the viscosity of blood. Five specimens from each sample type were tested by measuring initial dry weight, submerging the samples in simulated blood, and reweighing to measure wet weight. The data generated from Phases 2 and 3 was statistically analyzed to address the research questions previously stated. The scope of this study included various combinations of spinning method, yarn number, and filling densities to better understand the significance of their impact on absorbency.

The null hypotheses for this study are:

$H_0$1: Spinning method will not have a significant impact on the absorbency of the laparotomy sponge gauze.

$H_0$2: Yarn number will not have a significant impact on the absorbency of the laparotomy sponge gauze.

$H_0$3: Fabric density will not have a significant impact on the absorbency of the laparotomy sponge gauze.

The alternative hypotheses are:

H_A1: Spinning method will have a significant impact on the absorbency of the laparotomy sponge gauze.

H_A2: Yarn number will have a significant impact on the absorbency of the laparotomy sponge gauze.

H_A3: Fabric density will have a significant impact on the absorbency of the laparotomy sponge gauze.

3.3 Setting

The yarns for the sample gauze, which were collected from the Wilson College of Textiles' Spinning Laboratory, were primarily manufactured at Parkdale Mills, with the exception of the vortex yarns, which were manufactured at NC State's Wilson College of Textiles. Finally, all sample testing was conducted in the Physical Testing Laboratory and the Textile Protection and Comfort Center at NC State's Wilson College of Textiles.

3.4 Intervention & Experimental Design

The experimental design for this study was 3 x 2 x 2 and the independent variables were spinning methods (3), yarn counts (2), and filling densities (2), with 5 replications of each combination per test method.

3.4.1 Phase I

In this phase, a commercial woven laparotomy sponge of 100% cotton underwent physical testing to determine spun yarn type, warp and filling densities, twist, and yarn count. The purpose of this pre-intervention testing was to deconstruct a sample widely available on the market to better understand the basic material and construction parameters. This was then used to develop a plan of action for new sample development.

3.4.1.1 Materials

The materials used in Phase I include:

1. Woven sponge sample of 100% cotton
2. Pick finder
3. Meter stick
4. Zeroed scale
5. Bausch & Lamp Monozoom-7 Zoom Microscope and Printer
6. Glass plates
7. U.S. Testing Twist Tester

3.4.1.2 Spun Yarn Type

Yarn type was determined using a Bausch & Lamp Monozoom-7 Zoom Microscope and Printer. The commercial sample was seam ripped and unfolded, and warp and filling yarns were extracted. The yarns were laid out flat, individually pressed between glass plates and photographed under the microscope.

3.4.1.3 Warp and Filling Densities

Warp and filling densities were determined following ASTM D3775-17e1 - Standard Test Method for End (Warp) and Pick (Filling) Count of Woven Fabrics. A pick finder was utilized to count ends/picks per inch, repeated 10 times per end and 10 times per pick at various locations on the sample sponge.

3.4.1.4 Twist

Yarn twist of both the warp and filling yarns was determined following ASTM D1422-13R20 - Standard Test Method for Twist in Single Spun Yarns by the Untwist-Retwist Method. A 10 inch specimen was loaded into the U.S. Testing Twist Tester, one end fixed into a rotatable clamp and the other clamped to a weight-pointer. The yarn was then untwisted and retwisted in the opposite direction until contracting back to the original length. Turns per inch was then calculated by dividing the number displayed on the counter by double the specimen length. This process was repeated on a total of 10 specimens of the warp yarns and 10 specimens of the filling yarns.

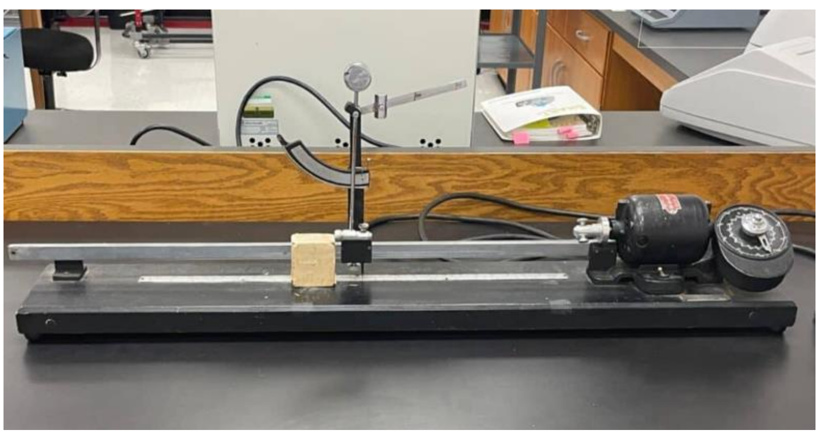


Figure 3.1: U.S. Testing Twist Tester.

3.4.1.5 Yarn Number

Yarn number was determined following ASTM D1059-17 - Standard Test Method for Yarn Number Based on Short-Length Specimens. 10 specimens were taken from both the length and the width of the sample sponge and individually measured and weighed. The length and weight measurements we used to calculate yarn number in the indirect system using eq. (1),

Eq. 1: $$\text{Yarn Number} = [454\,(1 + C)/(G \times L)]\, Y * P$$

where:

G = mass of conditioned yarn

L = number of yards of No. 1 yarn in 1 lb (840 for Ne)

P = number of plies (P = 1 for single yarns)

Y = length of specimen, yd.

C = change in length per unit length of yarn in untwisting (C = 0 for single yarns)

3.4.2 Sample Configurations & Preparation

3.4.2.1 Configurations

Based on the conclusions that past research has shown about textile absorbency, it was decided that the gauze samples should represent alternative conditions at the fiber, yarn, and fabric levels. This was achieved, respectively, by varying yarn spinning method, yarn linear density, and fabric density. Table 3.1 represents the sample configurations developed after concluding the pre-intervention phase. It is important to note that Sample B and Sample C were made with 60/40 cotton/polyester ring spun yarns due to lack of availability of 30/1 100% cotton yarns in the Spinning Laboratory at NC State. While this was not originally within the scope of the project and the intent was to focus on 100% cotton yarns, the cotton/polyester samples were ultimately included in the study to provide a cohesive look at all of the other intervention variables. The subsequent sample gauze was woven in NC State's Weaving Laboratory.

Table 3.1. Sample configurations

Sample ID	Warp Yarn (24 EPI)	Filling Yarn	Filling Density (PPI)
A (Control)	47/1 Ring	47/1 Ring	18
*B	30/1 Ring	30/1 Ring	18
*C	30/1 Ring	30/1 Ring	22
D	30/1 Open-end	30/1 Open-end	18
E	30/1 Open-end	30/1 Open-end	22
F	30/1 Vortex	30/1 Vortex	18
G	30/1 Vortex	30/1 Vortex	22
H	24/1 Ring	24/1 Ring	18
I	24/1 Ring	24/1 Ring	22
J	24/1 Open-end	24/1 Open-end	18
K	24/1 Open-end	24/1 Open-end	22
L	24/1 Vortex	24/1 Vortex	18
M	24/1 Vortex	24/1 Vortex	22

*30/1 Ring samples are 60/40 ring spun cotton/polyester

3.4.2.2 Sample Manufacture

The samples were manufactured at NC State's Wilson College of Textiles Weaving Laboratory. Cones of yarn for each spinning method and yarn number were sized using the IZUMI KS-7 Unisizer and a 14% size solution of PVC and starch. The yarns were then wound onto a warp beam using a CCI single end warper and taken to the drawing-in frame to prepare the beam for the weaving machine. Drafting and denting was done on the drawing-in frame, where each warp end was drawn through a singular dent in the reed with 480 dents across. The prepped warp was then threaded into a CCI positive rapier weaving loom and woven to meet the following specifications: ten yards of 20 inch fabric with 24 ends/inch and 22 picks/inch, and ten yards of 20 inch fabric with 24 ends/inch and 18 picks/inch. This process was repeated for each yarn number and spinning method, creating a total of 12 experimental samples with ten yards of each.

3.4.2.3 Preparation

3.4.2.3.1 Materials

The materials used to prepare the samples include:

1. 3 control samples, listed in Table 3.1 as Sample A
2. 1 yard of each sample gauze type laid out in Table 1
3. Tippmann Clicker 1500 Die Cut Machine
4. Cardboard
5. Circular die with a diameter of 3.5"

3.4.2.3.2 Sample Preparation Procedure

All samples were folded into 4-ply rectangles, with the expectation of the control samples which were already plied and conditioned according to ASTM D1776-20 - Standard Practice for Conditioning and Testing Textiles prior to specimen preparation. Subsequently, each sample was cut using the Tippmann Clicker 1500 Die Cut Machine and a circular die with a diameter of 3.5”. Cardboard was placed underneath the samples to act as a layer of protection for the base of the cutting machine from the die punctures, as seen in Figure 3.3. This process was repeated five times to create five test specimens per sample type.

Figure 3.2: Die cutting the samples to create test specimens.

3.4.3 Phase II

In this phase, the gauze samples were tested using the Gravimetric Absorbency Testing System (GATS) in order to measure the demand wettability, or the ability of a material to rapidly absorb and hold liquid. Key parts to the system include a porous plate, a water reservoir, weigh table and sample holder (cover), and it is pictured in Figure 3.2 below.

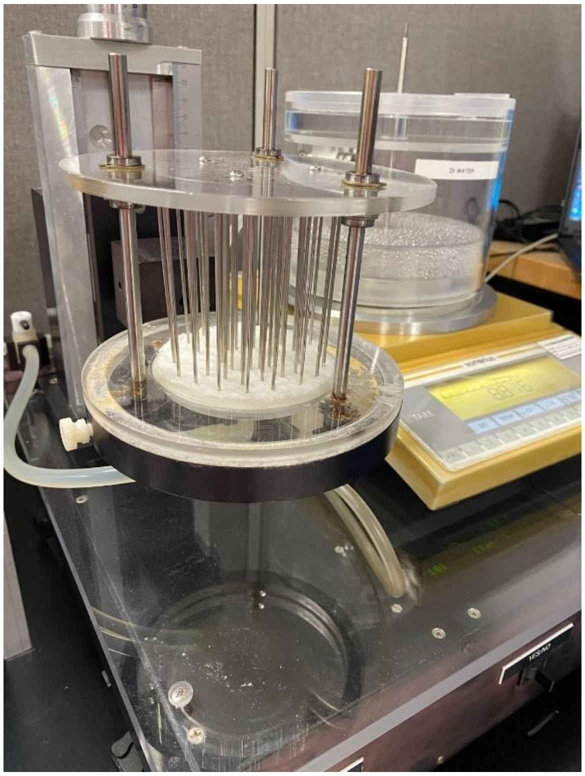


Figure 3.3: Gravimetric Absorbency Testing System.

GATS is able to simultaneously measure absorption rate and capacity, and the measurement parameters reported: include dry weight of the sample specimen (g), wet weight of the sample specimen after the test (g), the amount of water passed from the reservoir during 1000 seconds (g), and time (minutes). The resulting absorption parameters calculated include absorbent capacity (g) (ACap) (eq. (2)) and absorbency rate (g/min) (indicated by the initial high slope in the test). In this use case, a higher demand wettability is desired, as it represents a material that has a higher absorbent capacity and a faster absorbency rate.

Eq. (2): *Absorbent capacity = (wet weight - dry weight)/dry weight*

3.4.3.1 Materials

The materials used in Phase II include:

1. 5 test specimens per sample type laid out in Table 3.1
2. Gravimetric Absorbency Testing System & Associated Computer
3. Testing liquid (distilled water) in accordance with ISO 3696:1991-01
4. Precision balance
5. Tongs
6. Paper towels to dry receptacle between tests

3.4.3.2 GATS Procedure

Testing was performed on the GATS according to the following procedure:

1. Weigh the specimen on a precision balance to obtain initial dry weight and document.
2. Open GATS software on computer associated with the testing system.
3. Select YES to cleaning the plate.
4. Select NO to entering weight.
5. Select YES to changing the settings.
6. Enter the dry weight recorded into the sample weight section.
7. Click enter and allow water reservoir to fill.

8. Start the test and immediately place the specimen on the porous plate and apply the cover.
9. Allow the test to run for 999s.
10. Immediately remove the specimen with tongs and place into the weighing receptacle to measure wet weight and document.
11. Repeat for all specimens of each sample type, thoroughly drying the weighing receptacle in between each test with paper towels.
12. Generate final GATS report with all data and calculations after all testing is complete.

3.4.4 Phase III

In this phase, the gauze samples were tested for absorbent capacity (ACap) using a novel method to implement the use of synthetic blood with the same viscosity as real blood. The intent of this method was to further explore the absorbency behavior of the samples when introduced to a test liquid closer in likeness to real blood, due to the expected end-use of the product. The experimental design of this test was inspired, in part, by a previous study titled Evaluating Alternatives to Traditional Cotton Laparotomy Sponges for Blood Absorption in the Austere and Mobile Surgical Environment, in which the absorbency of laparotomy sponges of alternative materials were compared (Sirkin, Cook & Davis, 2015). Their submersion technique was replicated in this study to soak the samples in test liquid, but the use of real bovine blood was not realized in this study due to material limitations, and secondary and tertiary trials were not conducted, as this was outside of the scope of this research.

3.4.4.1 Materials

The materials used in Phase III include:

1. Precision balance
2. Tongs
3. VATA Inc. Simulated Blood - Same Viscosity as Real Blood
4. Plastic tub
5. Beaker
6. Gloves
7. Towel
8. Paper towels

Figure 3.4: Simulated blood bath and measuring apparatus for Phase III testing.

3.4.4.2 Novel Test Procedure

The specimens were tested according to the following procedure:

1. Weigh the specimen on a precision balance to obtain initial dry weight and document.
2. Remove and place the empty beaker on the precision balance and tare the scale.
3. Submerge the specimen in the tub of simulated blood for 30 seconds, swirling five times, squeezing and releasing five times, and shaking while submerged five times.
4. Immediately remove the specimen from the simulated blood after 30 seconds and swiftly place into the beaker.
5. Weigh the sample in the beaker on a precision balance to obtain wet weight and document.
6. Repeat for all specimens of each sample type, thoroughly cleaning the beaker in between each test with paper towels.

The initial dry weight and wet weight were then used to calculate absorbent capacity (ACap) using eq. (2) listed in Phase II.

3.5 Data Analysis

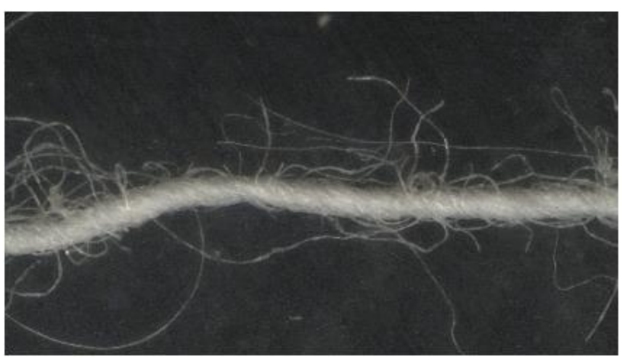
Data analysis was performed on the data collected during Phase II and Phase III using descriptive and inferential statistical analysis in JMP-17. One-way analysis of variance (One-way ANOVA) was used to determine statistical significance between the means of the data, and Dunnett's tests were used to compare the means of each sample against the control (Sample A). Furthermore, the data was grouped and examined by yarn spinning method, yarn number, and fabric density to identify trends amongst the variables. A significance level of $p < 0.5$ was used throughout the analysis.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Commercial Sponge Preliminary Analysis

As stated in the literature review found in Chapter 2, it is known that various yarn manufacturing methods result in various fiber packing assemblies and yarn structures. This is discernible through microscopic imaging. Table 4.1 shows the results of the imaging of a warp and filling yarn taken from the commercial sponge sample provided by Dukal. It was found that ring spun yarns were used throughout the sample, determined primarily by the hairiness of the yarns, orientation of the fibers, and the absence of wrapper fibers.

Table 4.1: Commercial Sponge Yarn Imaging.

Yarn	Image	Yarn Type
Warp		Ring
Filling		Ring

Furthermore, the preliminary testing also resulted in conclusive results on the yarn twist, yarn number, and warp and filling densities, as shown in Table 4.2 below. These parameters were used, in part, to develop the sample configurations shown in Table 3.1 in Chapter 3. However, due to the limitations of the study and availability of supplies for sample manufacture, yarn twist was not factored into the new samples, and yarn numbers chosen for the sample gauzes were based on yarn sizes that were consistently available in the Spinning Laboratory at NC State.

Table 4.2: Commercial sponge yarn and fabric parameters, determined by preliminary testing.

Yarn Manufacturing Method	Twist	Yarn Number	Warp Density	Filling Density
Ring Spinning	29 TPI	48/1	24 EPI	18 PPI

4.2 Phase II Testing - GATS

4.2.1 Absorption Capacity (g)

4.2.1.1 Statistical Analysis of Experimental Samples + Control

The results of the average absorption capacity (ACap) per 1 gram of material was analyzed using one-way analysis of variance (ANOVA). Using Dunnett's Method of means comparison, the means were compared against the control sample (A) to determine significance, with a p-value of > 0.5 considered statistically significant. These results are displayed in Table 4.3 below, where statistical significance against the control is denoted by an asterisk next to the p-value. Despite the variances seen in the ACaps of the samples, the only statistically significant differences were found in Samples B, J, E, G, K, L, and M.

Table 4.3: Average Absorption Capacity (g), Standard Deviation, and P-Value of all Samples Using GATS.

Sample	**Mean**	**Standard Deviation**	**P-Value Against Control**
A (Control)	9.6518	0.4066	1.0000
*B	10.6599	0.2720	0.0002*
*C	10.1600	0.1670	0.1402
D	9.1972	0.2607	0.3709
E	8.5420	0.5615	0.9450
F	9.1887	0.6702	1.0000
G	8.3739	0.1400	0.2334
H	10.0512	0.1479	0.2160
I	9.8629	0.1691	0.0010*
J	8.7604	0.1085	<.0001*
K	8.3596	0.1396	<.0001*
L	8.0171	0.1529	<.0001*
M	6.5059	0.4575	<.0001*

*Samples B and C are made from 60/40 ring spun cotton/polyester

It is seen that most of the samples performed worse than the control sample in terms of ACap during Phase II testing. The samples that did perform better than the control were Sample B (30/1 Ring Spun, 18 PPI, 60/40 cotton/polyester), Sample C (30/1 Ring Spun, 22 PPI, 60/40 cotton/polyester), Sample H (24/1 Ring Spun, 18 PPI), and Sample I (24/1 Ring Spun, 22 PPI). Although Sample B was the only sample in the outperforming group to show a significant difference against the control sample according to Dunnett's Method, it is nonetheless noteworthy to observe that all of the samples in this group were, like the control, made of ring spun yarns.

Furthermore, the two samples with the highest ACap were the samples made of 40% polyester. Interestingly, polyester is known for being a hydrophobic fiber, generally less absorbent than cotton due to its tendency to repel liquids. Despite this, polyester is still frequently seen in absorbent surgical products, often mixed with rayon and used in nonwoven surgical sponges for external use. In the nonwoven fiber blend case, it is thought that the sponges gain most of their absorbent advantage from the rayon fibers, not the polyester. Nonetheless, in this study, the results show that the cotton/polyester blend performed better than the control. While it would be ill considered to assign correlation between the higher ACap and the polyester fibers without having a 100% cotton sample of the same interventions to test against, it is interesting to note the positive trend despite the presence of hydrophobic fibers in the samples. It is believed that this is likely seen due to uncontrolled yarn variables that also influence absorbency, such as the twist imparted into the yarns.

4.2.1.2 Graphical Analysis of Experimental Samples

Graphing the data of the experimental samples presented trends in the results, as seen in Figure 4.1 below.

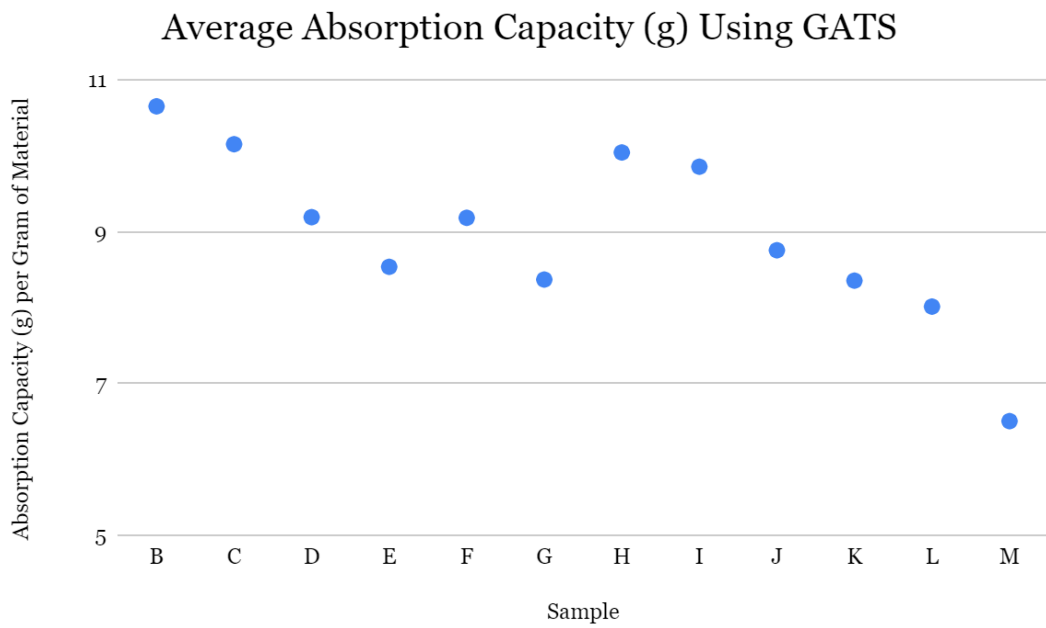


Figure 4.1: Scatter plot of average absorption capacity (g) by sample using GATS.

Immediate observations based on the graph include:

- The ring spun samples (Samples B, C, H, and I) had higher ACaps than the open end and vortex samples of corresponding yarn numbers due to the yarn structure resulting from the spinning method;
- Each sample had a higher ACap when the filling density was at 18 PPI versus the samples of corresponding spinning method and yarn numbers at 22 PPI;
- And the samples made with 30/1 yarns had a higher ACap than the corresponding samples made with 24/1 yarns.

To further explore these trends, the data was isolated into smaller groups to look at the findings in relation to the intervention conditions applied to the samples. Scatter plots of the findings isolated by yarn spinning method are seen in Figures 4.2, 4.3, and 4.4.

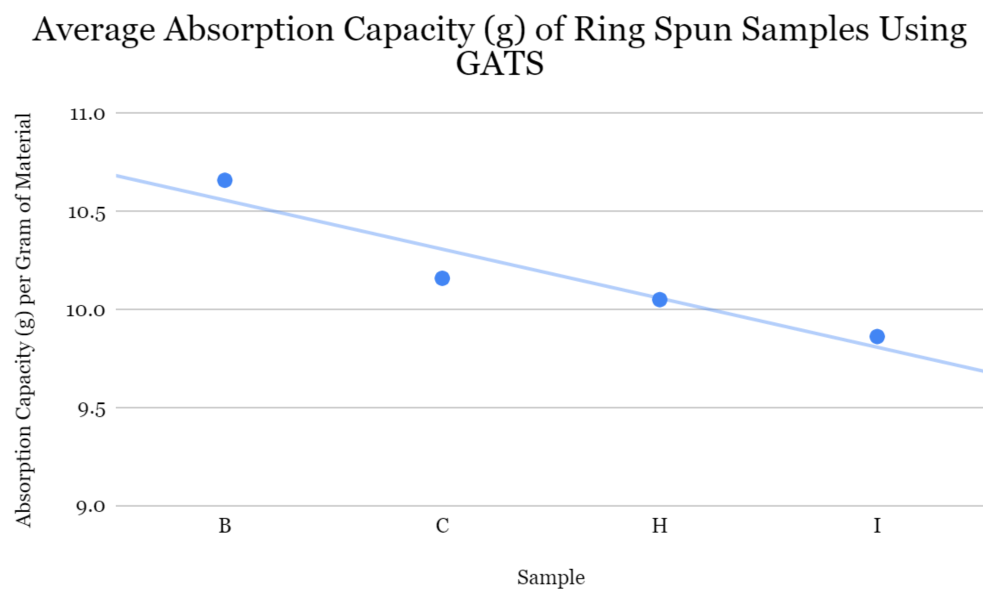


Figure 4.2: Scatter plot of average absorption capacity (g) of ring spun samples using GATS.

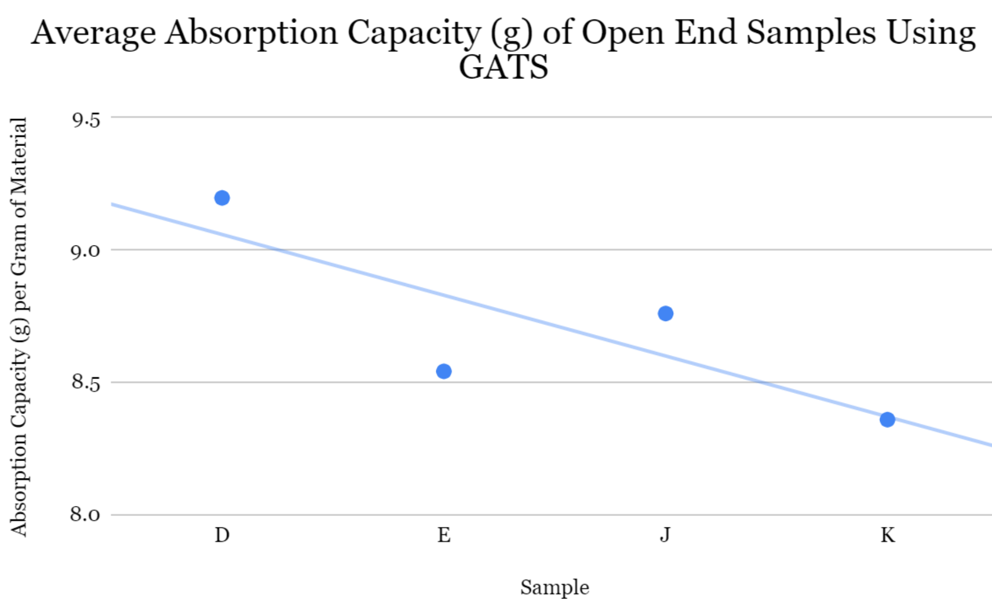


Figure 4.3: Scatter plot of average absorption capacity (g) of open end samples using GATS.

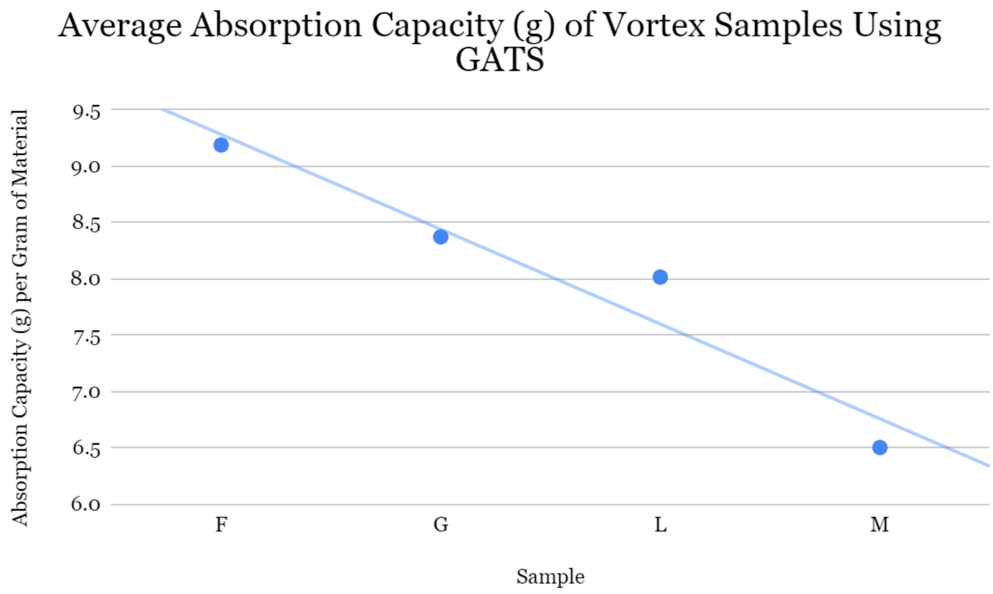


Figure 4.4: Scatter plot of average absorption capacity (g) of vortex samples using GATS.

By isolating the data into groups by yarn spinning method, it is seen that the alternating yarn numbers and filling densities presented trends in the ACaps of the samples. The samples made with ring spun and from vortex yarns were the most consistent out of the three spinning methods, showing a decrease in ACap when the yarns were coarser (i.e. samples from 20/1 yarns), and when the filling densities were higher (i.e. samples with 22 PPI). This is seen clearly in Figures 4.2 and 4.4.

While the samples made with open end yarns follow similar trends, Figure 4.3 shows that Sample E behaved slightly differently. The average ACap of Sample E (30/1 open end, 22 PPI) was marginally lower than the third sample type (Sample J: 24/1 open end, 18 PPI), while in the other spinning systems, the second sample type typically performed marginally better than the third sample type (coarser yarn with a lower fabric density).

Overall, when looking at the three key factors studied in the graphs above, it was seen that the utilization of ring spun yarns, finer yarns, and lower fabric densities revealed an enhancement in the ACap of the experimental samples, confirming the significance of each parameter on the ACap of laparotomy sponges. This can be attributed to each parameters' influence on surface area, capillary action, and porosity of the fibers, yarns, and fabric system, as discussed in the paragraphs below.

By varying the yarn spinning method, differences in the ACap were seen, pointing towards a correlation between spinning method and the ability of the samples to hold liquid. A trend in the increased ACap in the samples of ring spun yarns can be attributed to the structural characteristics of the yarns resulting from the ring spinning process, such as the compactness and organization of the fibers more parallel to the yarn axis. The resulting yarn structure shows an increased surface area and enhanced capillary action between the fibers, which allows for greater liquid movement throughout the pores of the yarns. This is opposed to the structures seen in open end and vortex yarns, which are known to be more irregular and present fewer opportunities for liquid transport throughout the yarn (Tyagi et al., 2010).

Similarly, a trend in the yarn numbers observed was noted, as the utilization of finer yarns in the samples presented noteworthy improvements in the ACap when compared to the corresponding samples of coaster yarns. This is attributed to the higher porosity found in finer, having greater inter-yarn spaces for liquid to move through. The behavior seen correlates with the findings from Sharma et al. (2016).

Finally, fabric density was found to be significant, as the lower fabric density samples demonstrated higher ACaps when compared to the higher fabric density samples. This is attributed to the more open fabric structure with greater pore spaces, allowing liquids to move more freely. The looser fabric system ultimately presents less resistance to liquid transport and in turn, results in a more absorbent fabric.

4.2.2 Absorbency Rate (g/min)

4.2.2.1 Statistical Analysis of Experimental Samples + Control

One-way ANOVA and Dunnett's Method of means comparison was utilized to analyze the results of the average absorbency rate (ARate) in g/min. Table 4.4 below represents the resulting data. Significance against the control sample is documented by an "*" beside the p-value.

Table 4.4: Average Absorbency Rate (g/min), Standard Deviation, and P-Value of all Samples Using GATS.

Sample	Mean	Standard Deviation	P-Value Against Control
A (Control)	6.1230	0.5400	1.0000
*B	12.4354	2.4926	<.0001*
*C	9.2780	0.8744	0.0256*
D	8.5290	1.7358	0.1498
E	5.1078	0.7965	0.9442
F	11.0542	2.3997	<.0001*
G	9.7170	1.1076	<.0077*

Table 4.4: (continued).

H	15.1844	2.7853	<.0001*
I	11.9556	0.9884	<.0001*
J	8.2638	1.2161	0.2514
K	6.0832	1.2407	1.0000
L	9.4344	1.0774	0.0169*
M	7.1128	1.4750	0.9523

*Samples B and C are made from 60/40 ring spun cotton/polyester

The average ARates and their p-values show significant variation between the experimental samples and the control group. Most of the samples had a higher ARate than the control, except for Samples E (30/1 open end, 22 PPI) & K (24/1 open end, 22 PPI). In terms of statistical significance, it is seen that the means of Samples B, C, F, G, H, I, and L are all statistically significant when compared against the control.

4.2.2.2 Graphical Analysis of Experimental Samples

Similarly to the results of the absorbent capacities, the ARates of the experimental samples were graphed in order to look for trends in the data, shown in Figure 4.5 below.

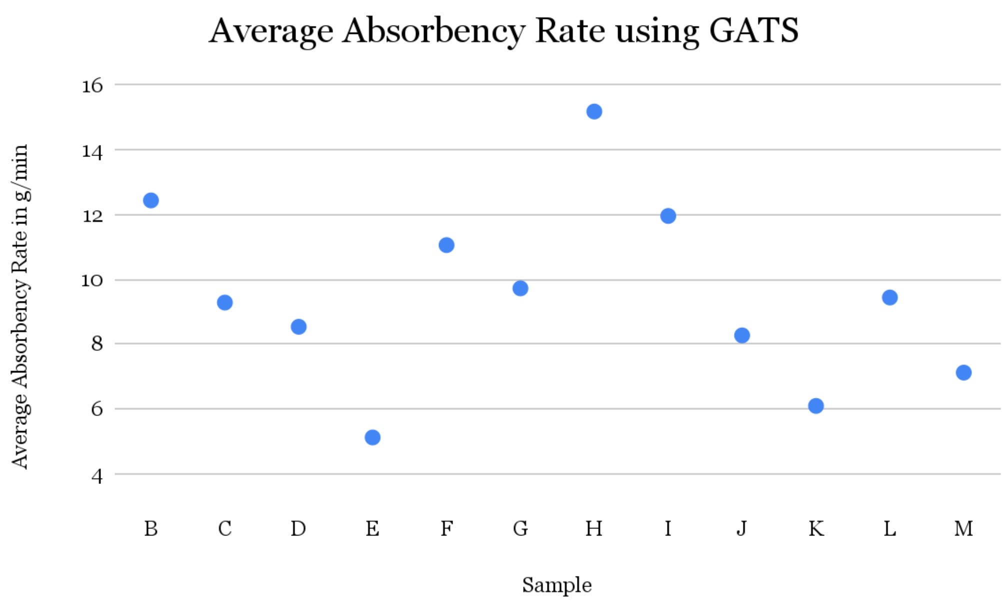


Figure 4.5: Scatter plot of average absorbency rate (g/min) by sample using GATS.

Graphical representation of the data shows that samples of the same spinning method and yarn number followed a similar pattern. The samples containing lower filling densities had higher ARates than their higher density counterparts. This analysis supports the theory that fabric density has an inverse relationship with ARate (the higher the density, the lower the absorbency rate). This is explained by the greater pore size in the fabric system, as it allows for more rapid liquid absorption as the water moves throughout the material. Furthermore, it is shown that samples of ring spun yarns had the highest ARates when compared to samples containing yarns of the same number and filling density. This is attributed to the capillary action resulting from the unique yarn structure, as discussed in the previous subsection.

4.2.3 ACap and ARate by Sample

To capture an entire look at the absorbency of the experimental samples, absorbent capacity and absorbency rate were looked at together for each sample in Figure 4.6. It is shown that the samples of ring spun yarns (Samples B, C, H, and I) and the samples of vortex yarn (Samples F, G, L and M) have an average ARate that is higher than their average ACap, whereas the samples of open-end yarns (Samples D, E, J, and K) have average ARates lower than their average ACap.

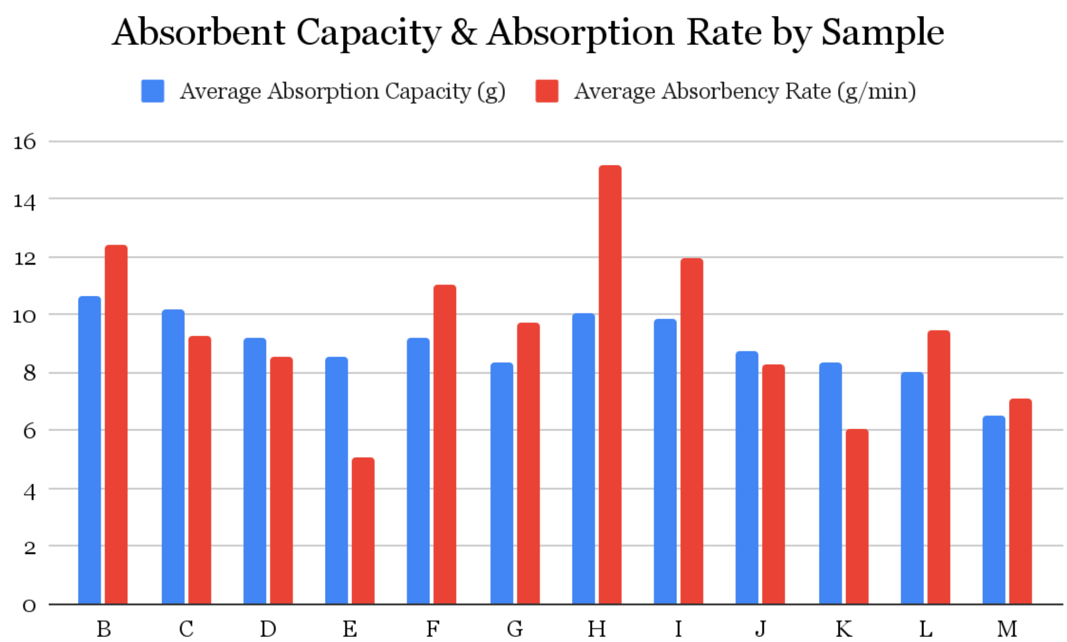


Figure 4.6: Average ACap and ARate by sample.

4.2.4 Implications of Results from GATS

Through the analysis of the data gathered from the GATS trials, the following conclusions can be drawn:

- The ACap of the water solution tends to be greater when samples are made from ring spun yarns;
- The ACap of water tends to be greater when samples are made with open end yarns versus vortex yarns;
- As the yarn gets coarser, the ACap of water decreases;

- And as fabric density increases, the ACap and ARate of the water solution decreases.

Although the results often showed marginal differences between the ACaps of the samples, significance was established when the variables were grouped by yarn spinning method, and it was found that each variable treatment showed a correlation to the absorbent capacity of the samples. Furthermore, the ARate results further proved the significance of fabric density on the overall absorbency of the samples. These findings lead to the rejection of the null hypotheses, and in turn support the following alternative hypotheses:

H_A1: Spinning method will have a significant impact on the absorbency of the laparotomy sponge gauze.

H_A2: Yarn number will have a significant impact on the absorbency of the laparotomy sponge gauze.

H_A3: Fabric density will have a significant impact on the absorbency of the laparotomy sponge gauze.

4.3 Phase III - Novel Testing of ACap with Simulated Blood

4.3.1 Statistical Analysis of Experimental Samples + Control

The following table shows the results from the ACap novel test method using simulated blood as the testing solution. Similarly to what was done with the GATS, one-way ANOVA & Dunnett's method were used to observe the means, their variances, and significance against the control sample. Significance against the control sample is documented by an "*" beside the p-value.

Table 4.5: Average Absorbent Capacity (g), Standard Deviation, and P-Value of all Samples Using Novel Testing with Simulated Blood.

Sample	Mean	Standard Deviation	P-Value Against Control
A (Control)	15.7572	0.7366	1.0000
*B	17.2028	1.3042	0.3609
*C	17.1854	2.3535	0.3748
D	14.1984	1.4774	0.2786
E	13.0478	0.9509	0.0071*
F	13.1586	1.0724	0.0108*
G	13.2186	0.7884	0.0135*
H	14.2048	1.2045	0.2829
I	13.3170	0.7996	0.0193*
J	14.9838	0.8832	0.9377
K	14.0624	0.9163	0.1985
L	13.7628	0.9764	0.0851
M	13.5130	1.0741	0.0382*

*Samples B and C are made from 60/40 ring spun cotton/polyester

4.3.2 Graphical Analysis of Experimental Samples

Figure 4.7 below represents the results of the ACap of the experimental samples plotted on a scatter plot.

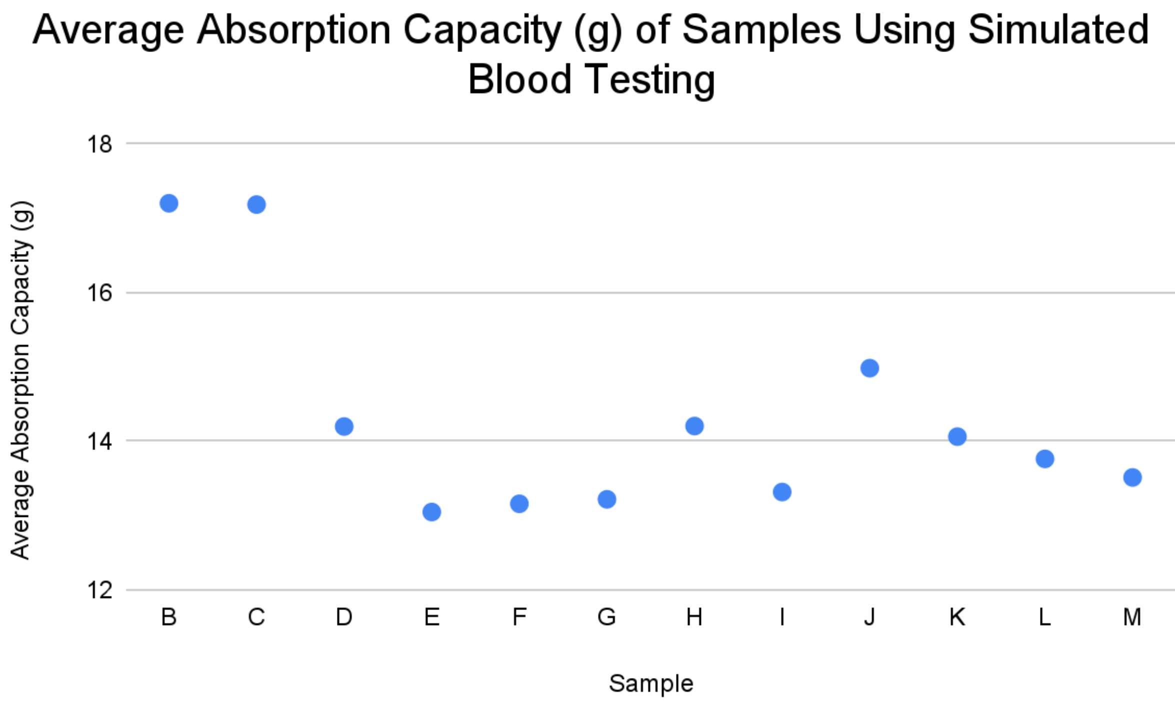


Figure 4.7: Scatter plot of average absorbent capacity (g) by sample using a novel test method with simulated blood.

The initial observations of this graph are as follows:

- In many cases, it is seen that ACap decreased in the samples with higher filling density when compared to the corresponding sample with a lower filling density, except for in Samples E and F. Overall, the findings generally correlate with what was reported about the influence of fabric density on ACap in Section 4.2.1.1, as greater pore size in the fabric system allows for greater liquid transport through the material;

- The ring spun samples made with 30/1 yarns (Samples B and C) had a significantly higher ACap than all other samples. These findings confirm what was reported about the significance of yarn linear density on absorbency in Section 4.2.1.1, where finer yarns have a higher absorbency rate largely due to capillary action;
- And the trends were not consistent across spinning methods, filling densities, and yarn numbers.

While some of the trends seen in this data align with what was found in the ACap results of the GATS testing, they were not consistent across the board. For the samples made with ring spun yarns (Samples B, C, H and I), the trends were the same: ACap was higher in the samples with finer yarns and a lower filling density. However, the samples made with open end and vortex yarns (D, E, J and K, and F, G, L, and M) both presented higher ACap when the yarns were coarser, and Samples F and G contradicted what was seen with the relationship of filling density and ACap in all other sample types.

It is clear by the data above that the results of the novel testing with simulated blood were more inconsistent and inconclusive than the testing done with GATS. While it is generally useful to test samples with a simulated blood solution in order to mimic the real life use case, the lack of standardization in test methods presented a challenge in the subsequent data collection. Procedural and human error are thought to be the two main contributing factors to the inconsistent results with the novel test method, with potential problem areas being the simulated blood rapidly expelling from sample upon removal of the tub before making it into the beaker and varying pressure applied to the samples upon removal. Overall, the results lead to the conclusion that the data collected from GATS was more representative of the true behavior of the samples.

4.4 Recommendations for Future Research

The limitations of this study greatly restricted the parameters of the samples and the amount of treatments tested. While many of the samples from the GATS test method were not able to perform better than the control in terms of ACap, the data showed significance among the studied variables and their sorptive behaviors. Further studies would need to be conducted to redesign the current control to increase the ACap, however, the data from this study could assist researchers in determining the appropriate interventions to test. This study points to using ring spun yarns of finer yarn counts to create gauze with a lower fabric density. Furthermore, it would be recommended that, when possible, future studies control all yarn parameters (including twist level, direction, etc.) in order to get a fully cohesive look at the samples and eliminate any variations in the test data caused by uncontrolled variables. Finally, alternative yarn styles (such as plied yarns) and alternative fabric constructions should be looked at to determine viability in the product and their potential impact on absorbency.

Furthermore, it is recommended that research be done to continue the exploration of effective test methods for gauze material using simulated or real blood. This would ensure that the data tested reflects results that are realistic to the product end use. Standardization of such a test method would be valuable to the future of laparotomy sponge research.

CHAPTER 5: CONCLUSION

This study sought to investigate the influence of various construction parameters on laparotomy sponge absorbency, with a focus on three key factors: yarn spinning method, yarn number, and fabric density. By taking a holistic approach to study fiber, yarn, and fabric parameters collectively, the results presented contribute to a deeper understanding of how the factors collectively influence the absorbent properties of laparotomy sponges. This study was able to determine that yarn spinning method, yarn number, and fabric density are all significant variables to the absorption capacity (ACap) and absorbency rate (ARate) of laparotomy sponge gauze samples. It was seen that the ACap was higher in samples with ring spun yarns, in samples with finer yarns, and in samples with lower filling densities. Furthermore, it was seen that ARate was higher in samples with lower filling densities across all samples. When the intervention studied was the spinning method and all other variables were controlled, it was also found that the samples made from ring spun yarns presented the highest ACaps, followed by the samples made from vortex yarns. Overall, the results of the study concluded that when redesigning the fabric specifications of laparotomy sponges to increase the absorbency, the sponge should contain finer ring spun yarns with a lower fabric density. The implications of these findings are significant for applications requiring high absorbency, such as in surgical supplies, wound care, and hygiene products.

Furthermore, the research was able to determine that the Gravimetric Absorbency Testing System (GATS) is a viable method for testing the water absorbency of gauze, with consistent results presented throughout most of the study. When compared to the novel test method using simulated blood with the same absorbency as real blood, the results produced more identifiable and logical trends in the data. Nonetheless, it is important to continue exploring test methods that include testing solutions with the same viscosity as blood to further the understanding of the sorption properties of laparotomy sponges when used in the field.

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