Designing a Scrub Cap to Meet Clinical Needs in a Sterile Environment

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Abstract

Healthcare activities account for 8% of the United States' national greenhouse emissions, and hospitals alone generate more than 3.5 million pounds of waste annually.[1,2] A large amount of this solid waste comes from the $40.3 billion disposable medical supply industry.[3] As a result, the use of disposable medical devices impedes a hospital's ability to operate sustainably. One example of a common disposable medical device is the scrub cap, which is used to cover healthcare professionals' hair when in a sterile environment. In contrast to scrubs, which are laundered between uses, these pieces of protective equipment become waste after a single use. Furthermore, despite their ubiquity, these devices have many design flaws that make them uncomfortable to wear and threaten to contaminate sterile environments. The goal of this project was to design a reusable scrub cap that addresses the design flaws found in the current disposable scrub caps used within the University of Virginia (UVA) Health System. Through interviews with potential users and an iterative design process, a scrub cap was designed using reusable, launderable material. The designed product provides for a more ergonomic fit for a wide variety of users, ensures sterility by containing all hairs, and allows for personnel identification in sterile environments. It also provides healthcare workers with increased protection by including a pocket where a RADPAD® No Brainer® may be inserted. An economic analysis was performed to prove the cost-saving potential of this design. With future work, this product may replace disposable caps in hospitals, making healthcare systems more sustainable and resilient.

Keywords: scrub cap, sustainability, sterility

Introduction

In recent years, many hospitals within the United States have created sustainability goals in order to address the significant carbon footprint of the healthcare industry.[4] However, many hospitals currently rely on single-use, disposable medical devices for the majority of patient care.[5] These products generate millions of pounds of waste annually, significantly increasing hospitals' environmental impact.[2] In particular, non-hazardous medical waste from devices such as personal protective equipment (PPE) used in infection control make up 85% of all medical waste produced by hospitals.[6] Consequently, using reusable PPE would significantly decrease the waste produced by hospitals and aid them in becoming more sustainable.

Professional guidelines mandate that operating room personnel wear hair coverings in order to maintain the sterility of the operating room environment and prevent surgical site infections (SSIs).[7,8] Few controlled clinical studies have been conducted evaluating the relationship between hair coverings, such as scrub caps, and SSI incidence.[9] As a result, the relationship between the use of surgical hair covering attire and SSI incidence has never been clearly defined.[10] However, experimental data shows that live microorganisms can be shed from the hair of operating room personnel.[11] In addition, hair contamination has been linked to surgical site infection outbreaks in hospitals.[12,13] Thus, although the exact relationship between scrub cap use and SSI prevention is unknown, the use of surgical hair coverings as a form of PPE remains a prudent preventative measure in operating rooms.

Currently, a large number of hospitals around the country use single-use, disposable scrub caps in order to meet operating rooms standards for hair covering.[14] This contrasts with scrubs, which are generally reused and laundred.[15] Manufacturers of disposable scrub caps advertise disposable scrub caps as being more sterile and cost-effective than reusable alternatives.[16] In addition, these caps are convenient for healthcare professionals, as they can easily dispose of the caps when unneeded or unclean.

However, despite these claims, many studies have revealed flaws in the current disposable cap design. According to a study by Markel et al., disposable scrub caps may actually be worse at preventing

airborne microbial contamination in the operating room than reusable cloth caps.[17] In addition, life cycle assessments (LCAs) of reusable surgical supplies has demonstrated their potential to save hospitals money in the long term.[18] Additionally, these disposable caps contribute to the aforementioned problems of medical waste. As a result, reusable scrub caps offer many benefits over their disposable counterparts.

Furthermore, preliminary research performed prior to the start of this project revealed many issues with the current physical design of common scrub caps. Many healthcare professionals with long hair report difficulty containing all their hair within disposable scrub caps. No studies investigating the relationship between surgeon hair length and SSI incidence could be found, however the inability to effectively fit longer hair within a scrub cap may also reduce the sterility of operating rooms. Secondly, because of the uniformity of disposable scrub caps, operating room personnel occasionally report difficulty identifying other personnel in the operating room. The prevalence of this problem can be seen by the popularity of a news story surrounding an anesthesiologist's use of identifiers on his scrub cap.[19,20] Consequently, the design of a novel scrub cap may also help improve the quality of life of healthcare professionals, reduce the exposure of patients to hair contamination, and increase the ability to identify healthcare professionals in the operating room.

As a result, the goal of our project was to design a novel, reusable scrub cap that could be used in a sterile setting and improves upon current disposable cap designs to appeal to a more diverse audience. We did this by analyzing current scrub cap designs and interviewing healthcare practitioners, designing and testing prototypes, and iterating using feedback. We also performed a sample economic analysis in order to prove the economic viability of reusable alternatives to disposable scrub caps. By doing this, we hoped to improve patient health and operating room efficiency, increase healthcare practitioners' quality of life and comfort, and reduce the overall costs and waste produced by the healthcare industry.

Results

Analysis of Current Scrub Cap Designs

There are currently three main types of scrub caps used in the healthcare industry: the disposable bouffant cap, the disposable skull cap, and the ponytail skull cap. Each of these caps has their own strengths and weaknesses that will be detailed below.

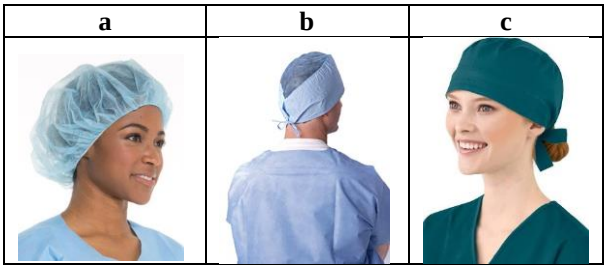


Figure 1: Most Common Scrub Caps. a) Disposable bouffant cap used by people with a long and/or voluminous hair. **b)** Disposable skull cap used primarily by males with short hair. **c)** Ponytail skull cap used by people with long hair that can be tied back.

The disposable bouffant cap (**Figure 1a**) is made of spunbonded polypropylene and has an elastic band that allows the cap to fit to the user's head.[21] This cap is often used by healthcare workers with long and/or voluminous hair, as the user is able to contain more of their hair within the excess fabric. However, the elastic band around the user's head can cause undesirable skin irritation and leave temporary skin indentations. Additionally, longer and heavier hair can slip out of the bottom of the cap, creating a potential risk for contamination.

The disposable skull cap (**Figure 1b**) is made of two different materials: scrim around the head and spunbonded polypropylene on the top of the cap.[22] The polypropylene fabric on the top of the cap allows for better heat transfer, ensuring that the user does not get too hot. The tie back feature allows the cap to fit to a variety of head shapes and sizes. However, the lack of extra fabric means that this cap design is only effective for users with extremely short hair.

The ponytail scrub cap (**Figure 1c**) is very similar to the disposable skull cap. Unlike its disposable counterpart, the ponytail scrub cap is made of a durable and reusable cotton and polyester fabric blend. However, unlike the disposable skull cap, the ponytail scrub cap does not have a thinner fabric on the top that allows for effective heat transfer. The ponytail scrub cap has a tie back feature, similar to that of the disposable skull cap, but this cap also has a hole a ponytail can protrude out of the cap. However, this leaves some hair exposed, so many workers who wear this cap often must wear a disposable bouffant cap on top of the ponytail skull cap to cover all their hair.

The strengths and weaknesses of these various designs were considered when designing our prototypes. In addition, we looked to combine elements from each of these caps so that our scrub cap could appeal to all potential users and eliminate the need for hospitals to distribute different kinds of scrub caps for users with different hair.

Interviewing Healthcare Professionals

We conducted a total of 21 interviews with various healthcare professionals within the University of Virginia Health Systems, including doctors, nurses, technicians, and medical students (**Table 1**). We then quantified trends in the interviews by tallying the number of respondents who mentioned that a specific concern was relevant to them (**Table 2**). From this data, we confirmed that the initially identified issues of operating room recognition, scrub cap fit for those with longer hair, and sterility were relevant concerns to our target users. In addition, we identified two additional considerations to incorporate in our new design: scrub cap thermodynamics and the option for radiation protection.

We also observed the workflow of hospital scrub laundering and distribution within the UVA Health System and talked to several employees involved in the process. Seeing these processes helped us recognize the logistic possibilities and challenges involved in the implementation of our project. For example, we found that due to the way scrubs sets are distributed, scrub caps would need to be uniform in design and must fit all users if distributed in scrub machines. We also concluded that the scrub caps should be able to be laundered with the rest of a scrub set, in order to avoid significant changes to the hospital workflow. Several professionals outside of the healthcare industry who worked with hair coverings were also interviewed. The interviewees consisted of one hairdresser and four Aramark employees working in the Fresh Food Company at Newcomb Hall. From these interviews, we gained a better idea of other devices used to contain hair, giving us new ideas and style choices to explore when designing our novel cap.

Role	Number of Responses	Avg. Years of Experience
Doctor	3	22.3
Nurse	8	1.5
Technician	5	4.8
Fellow	1	5
Medical Student	2	3.2
PCA	3	3.7

Table 1: Summary of Interviewee Experience Level. This table shows the frequency of responses for each relevant position in the healthcare field. The average years of experience is also shown for each position, as this may also affect the interviewee's responses.

Issue	Number of Responses	Response Rate (%)
Identification	14	66.7
Sterility	6	28.6
Fit of the cap	11	52.4

Table 2: Frequency of Reported Issues. This table shows the frequency of each issue reported, as well as the corresponding response percentage for each of the issues.

First Design and Feedback

We created and discussed several design drawings and low-tech prototypes (**Appendix A and B**) within our group before manufacturing our first usable prototype (**Figure 2**). This prototype aimed to address all the major design flaws and considerations made apparent by our initial interviews (**Table 3**).

We choose to use a 60% cotton-polyester blend as the material for our cap. This blend is the same material used for scrubs within the UVA Health System and can withstand the high heats of industrial washing. As a result, the cap can be washed under the same conditions as scrubs. Furthermore, we found the blend of cotton and polyether to be ideal, as cotton is a more breathable material, while polyester is highly elastic and durable.

Five interviews were conducted post user-testing in order to collect feedback on the first design prototype. From these interviews, we concluded that the large amount of mesh in the back of our prototype was unused and disliked by men with short hair. This feedback was incorporated into our next, and final, design iteration.

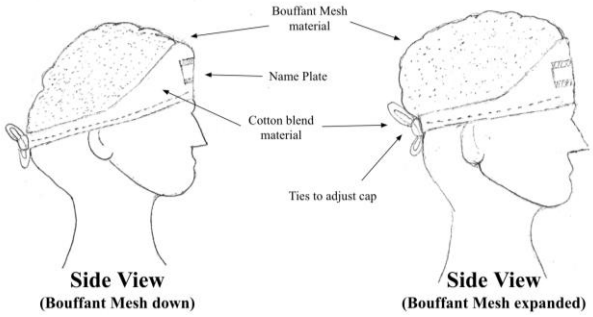
Figure 2: First Prototype. This prototype incorporated feedback from previous designs and interviews. This served as the basis for the final design.

Concern	Design Feature to Address Concern
Containing long hair	Excess mesh fabric was added so that longer and more voluminous hair can be effectively contained within the cap.
Issues with identification	Added a place to display a name badge on the front of the cap.
Thermodynamics of the cap	The mesh fabric on the top of the cap is a looser weave, allowing more heat to escape from the cap.
Desire for radiation protection	Added a pocket in the inner lining of the cap that could fit a RAD-PAD “No Brainer” radiation protection pad.

Table 3: Addressing Design Concerns. The first column shows the concerns raised by healthcare professionals during the initial interviews. The second column shows how the new hybrid cap effectively addresses these concerns.

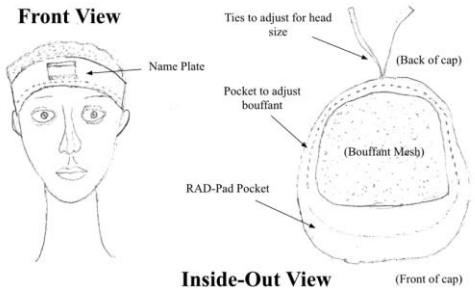
Final Cap Design

As with the first cap, we created several preliminary design drawings (**Appendix C**) before settling on the final design (**Figure 3, Figure 4**). This prototype retained all the features and materials from our first iteration prototype, however it reduced the total amount of mesh, and added a pocket on the inside of the cap where the bouffant mesh could be retained if desired. This feature allowed users to better adjust the mesh based on their head shape and size. In addition, stabilizing folds were added to better frame the ID badge on the front of the cap, as well as a plastic covering to protect it from potential contamination.



a **b**

Figure 3: Side View of Hybrid Cap. a) The excess bouffant mesh can be compressed down into a pocket on the outside of the cap. **b)** The excess bouffant mesh can be expanded in order to contain longer and more voluminous hair.



a **b**

Figure 4: Front and Inside-Out Views of the Hybrid Cap. a) This view shows the location of the nameplate on the user's forehead. **b)** This view shows the pocket in the inner lining for the RAD-PAD, as well as the pocket on the outside of the cap that allows the expansion of the bouffant mesh to be adjusted.

Sample Economic Analysis of the Hybrid Cap

In order to demonstrate the feasibility of the new reusable scrub cap, a sample economic analysis was performed (**Table 4**). The total cost per unit was estimated for both the disposable cap option and our new reusable cap. These estimates considered the cost to purchase the cap, waste management costs, and sterilization costs. The total cost of one disposable cap ($0.32) was much cheaper than the total cost of one reusable cap ($13.54), meaning that the cost of one reusable scrub cap is approximately equivalent to 43 disposable scrub caps.[23,24] However, the single-use nature of the disposable caps means that the hospital must continue to reorder disposable caps on a regular basis. It was estimated that the hospital ordered 1000 disposable caps per month. At this rate, it would be approximately 23 months before the investment in a reusable cap would be realized. Since the reusable cap will be made from the same cotton-polyester blend that typical scrub sets are made of, it is assumed that the durability will be approximately the same. The average scrub

Category	Item	Unit Cost
Disposable Cap	Cost to purchase	$0.14
	Avg. waste management cost	$0.18
	Total Cost (per unit)	**$0.32**
Reusable Cap	Cost to purchase	$7.00
	Cost of a RadPad "No Brainer" pad	$6.50
	Cost to launder caps ($0.44/lb; 0.1lb)	$0.04
	Total Cost (per unit)	**$13.54**
Breakeven Calculation	(Cost/reusable cap) ÷ (Cost/disposable cap) = *Disposable Caps per Reusable Cap*	42.3125 → **43**

Table 4: Economic Analysis. This table shows the average total cost of production for both the disposable and the reusable cap. The breakeven point is the point at which the cost of approximately 43 disposable caps is equivalent to the cost of one reusable cap.

set is replaced every 3-4 years, which is longer than the 23 months it takes to realize the investment, so reusable scrub caps would be a worthwhile purchase for the hospital.

Discussion

Following the completion of our first design prototype, our project experienced multiple setbacks that limited our results. Originally, we intended to have our first prototype professionally manufactured by a tailor and tested by healthcare professionals within the UVA Health System before iterating upon our design. However, due to complications finding a tailor and the COVID-19 pandemic, we were unable to fulfill this goal. Instead, we asked family members to test our first prototype and compare it to the disposable caps that are currently distributed at the hospital. Their lack of experience in the healthcare industry greatly diminished the quality and amount of feedback we were able to receive on our first design, making it difficult to identify design flaws and improve in our second iteration. In addition, a lack of appropriate materials and sewing skills prohibited us from fully manufacturing our second design, making the feasibility of certain design decisions unknown.

Despite these limitations, our final design addresses all the major issues initially identified by healthcare professionals within the UVA Health System and improves upon current scrub cap designs. The hybrid skull cap and bouffant design increases the comfort and ergonomics of the cap, regardless of head shape or hair style. The bouffant mesh in combination with the adjustable ties ensures that all hair is covered within the cap and cannot escape into sterile environments. The name plate at the front of the cap allows for personnel identification, and pockets inside the cap give users the option for radiation protection. Overall, our cap is reusable, increases healthcare workers' quality of life, increases hospital sterility and efficiency, and provides workers with radiation protection. Thus, our results fulfill the initial goal for the project.

Future work is necessary to ensure that our designed scrub cap will be useful and desirable to healthcare professionals. Firstly, samples of our final design should be manufactured professionally and given to healthcare professionals for user-testing. This will allow us to collect higher quality feedback on the design and ensure that the cap is fulfilling all the intended needs. Several iterations of designs and user-testing will most likely be necessary before a marketable product is created. From there, a market analysis of potential users could be performed to ensure that doctors and hospitals are willing to adopt the new cap. Once a more accurate production cost has been determined by a manufacturer, further economic analysis could be performed to ensure that our cap is cost-effective. In order to complete an environmental analysis, the amount of waste produced at a specific test location, such as the UVA Hospital, could be tracked in order to ensure that our cap is fulfilling the goal of being sustainable. If these studies are successful, our product can be patented and sold to hospitals and adopted nationwide as a replacement for disposable caps.

Lastly, current events across the globe demonstrate the need for reusable alternatives to disposable medical products. COVID-19 has shed light on the need for reusable personal protective equipment (PPE) as the pandemic’s pressure on global supply chains has caused major shortages of essential, disposable equipment.[25] This highlights the vulnerability of the disposable medical equipment industry and the risks that hospitals face when supply chains are disrupted. As a result, developing reusable PPE alternatives for hospitals would help improve hospitals’ resilience during a crisis while simultaneously helping the world’s environment.

Materials and Methods

In order to distinguish desirable features and design flaws of the current scrub caps, current scrub cap designs were analyzed, and interviews were conducted with healthcare workers within the UVA

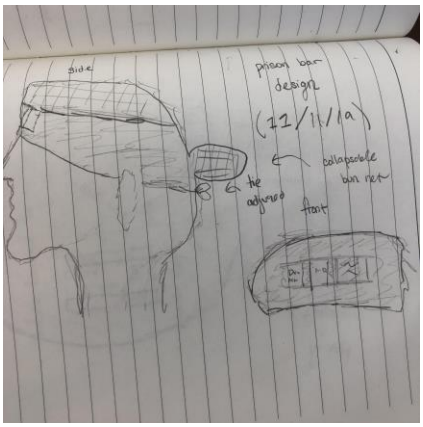
Health System. Interviews were performed using an iCore questionnaire which consisted of a series of standardized, open-ended questions surrounding operating room identification, scrub cap comfort and fit, as well as hair contamination in sterile environments (**Appendix D**). The results of these interviews were aggregated, and trends in the responses were quantified by tallying the number of responses which mentioned a specific issue. Several other interviews were conducted with hospital employees in charge of scrub laundering and distribution, hairdressers, and employees within Newcomb Dining Hall's Fresh Food Company to gain further perspective on design constraints and ideas. However, these interviews were not quantified and incorporated in the data.

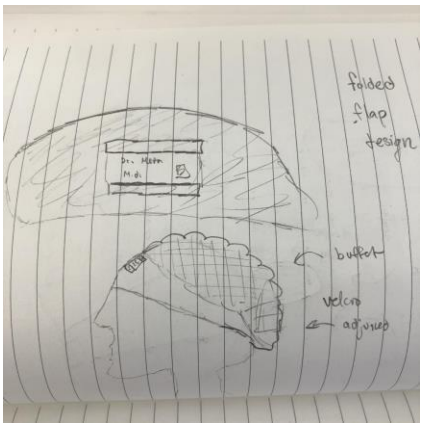
During the prototyping phase, preliminary designs were drawn and discussed by the team and their advisor, Dr. Nishaki Mehta. Desirable features from the survey results were incorporated into these designs, as well as features that address identified design flaws. Several rounds of low-tech prototyping and design drawings were done before deciding on the final design and fabricating the first usable prototype.

The first viable prototype was created using fabrics from the disposable bouffant and disposable skull caps provided by the UVA Hospital, as well as scrap cotton fabric. This design was used in user-testing, and five post-use interviews were conducted using a second modified iCore survey (**Appendix E**). This round of feedback was used to design the second, and final, iteration prototype.

Appendix

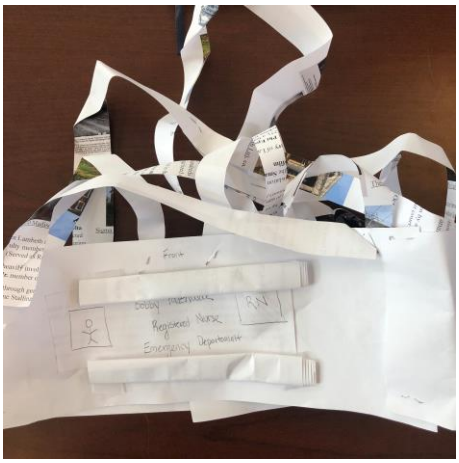
A. Preliminary Design Drawings





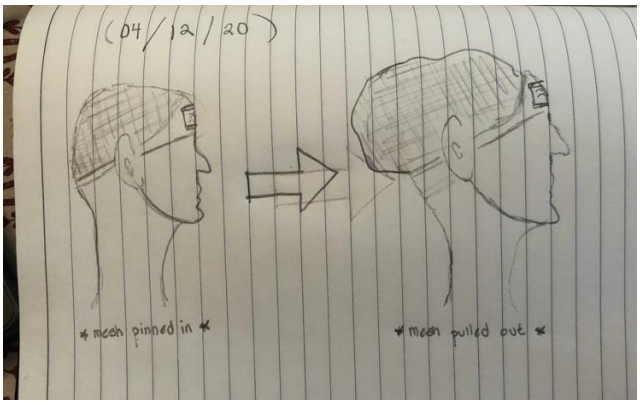
Important design features, such as an ID display and long hair containment emerged from these early drawings.

B. Preliminary Prototypes Presented to Dr. Mehta.



Various methods for incorporating features were tested and the feedback received on these prototypes were refined in future prototypes.

C. Second Prototype Design Drawings



From this drawing, the idea of an expanded cap emerged that was used in the final design.

D. Initial iCore Questionnaire

Operating Room Identification

1. How do you currently identify unknown team members in a critical setting or in an operating room?
2. How do you feel your ability to identify people in a surgical operating room impacts your understanding or ability to perform your role?
3. Do you see a need or have a desire for better methods of identification in the operating room? If so, what information is more important and how can it be displayed?

Scrub Cap Design

1. Have you ever had any issues with the fit of a scrub cap? If so, what were they?
2. How would you rate the following in order of importance: comfort, aesthetics, customizability, feel, material?
3. Would you be comfortable wearing a scrub cap that is made out of the same material that scrubs are currently made out of?

Scrub Cap Sterility

1. Has hair contamination ever been a problem in the operating room for you or any other team member?
2. How often do you change your scrub cap during the day and why?
3. What features would you like your dream scrub cap to have?

E. iCore Survey Used to Collect Feedback on Initial Prototype

Comparison with Traditional Caps:

1. What is your opinion of the redesigned scrub cap in comparison to the cap you typically wear?
2. What features do you like about the redesigned scrub cap?
3. What concerns do you have about the new scrub cap?

Questions about Features:

1. What do you think of the nameplate on the front of the cap? Do you think it would be useful for identification?
2. What do you think of the tightening mechanism? Does the cap seem adjustable enough?

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