3D Body Scanning for Examining Active Body Positions: An Exploratory Study for Re-Designing Scrubs

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Abstract

In this pilot study, we used 3D body scans to investigate range-of-motion issues associated with one of the most frequently used scrub top and bottom design. By conducting a focus group interview, we investigated problems and inconveniences occurred when wearing scrubs. Based on the focus group interview data, five active positions were determined. One participant was scanned with a $[TC]^2$ NX-16 3D whole body scanner to capture anthropometric standing and active body positions. The 3D body scanner was used as a visual tool for identifying and examining fit of a set of scrubs when mimicking active postures. The findings of this study showed that the white light based 3D body scanner can be used as a fit evaluation tool when used with a powerful visualization software to process scan data. Visual fit analyses showed that the areas such as back, shoulder, underarm, crotch and knees should be redesigned to improve the movement capacity in the scrubs.

Keywords: 3D body scanning, protective clothing design, scrubs, active body positions

1. Introduction

According to the Centers for Disease Control and Prevention data, healthcare sector in the U.S. employs more than 18 million workers and is one of the fastest-growing sectors of the U.S. economy [1]. Comprising an increasing percentage of the health care sector, the nursing workforce is the largest part of hospital staff and is the main source for providing care for patients [2, 3]. As a part of their work, nurses do lots of physically demanding tasks such as lifting patients, moving equipment, pushing, pulling, carrying, bending, and stretching [4, 5].

Scrubs are protective clothing (shirts, trousers, and gowns) used mainly in the health care sector. These can be described as specialized garments worn by healthcare workers to protect themselves from a wide range of hazardous agents in their workplaces. Bacteriological protection and providing comfort to wearer are two basic functions expected from scrubs [6]. When designing a scrub, providing mobility to wearer is as important as clothing material's type and its barrier properties against pathogens, tear, and puncture. The proper fit of protective clothing is important in a way that it does not restrict the movements of its wearer or decrease the level of protection by providing more ease, thus bulk, than necessary [7].

Functional designers of protective clothing should know what particular movements happen in different activities and how to incorporate these movements to their designs [8, 9]. Although medical companies have been introducing scrubs with various cut and fit options, these scrubs are ready-to-wear items and their sizing range does not usually accommodate all body types. When a wearer uses scrubs that are restrictive, don't fit well and keep up with movements, this might lead to tears, exposing uncovered areas to certain pathogens and even injuries when taking active postures. There is a large room for improving scrub designs for fit and ease of movement. However, only a few studies have been conducted in this particular area [6, 10].

When identifying and evaluating problems with existing clothing designs, assessing the fit of the clothing visually is an essential part of the process. Although visual fit analysis is inherently a subjective process, expert eyes can recognize complex optical patterns of improper fit, such as stress folds, direction of wrinkles, excess/ sagging fabric, seam lines at a wrong angles, and imbalance in garments [8, 11, 12]. 3D body scan data can be very helpful to better understand the issues related to mobility and restrictions imposed by the clothing and be especially useful for the designers of protective clothing when proper fit is crucial for increased mobility in clothing [11]. 3D whole body scanning has been used in various studies to analyze dimensional changes in body measurements, fit analysis and garment-body interaction when taking active postures [11, 13-15]. These studies demonstrated that the 3D body scanner is a reliable and valid instrument to take number of various anthropometric measurements within 10-12 seconds and it can be used as a visual tool for assessing fit of the clothing. Fit experts can access this data at any time and examine it in detail by rotating the images to look at them from different angles, and zoom in/out [11, 15].

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Laser based and white-light based 3D scanners are the two main types of the scanners used in 3D body scanning research. Both systems capture surface details of the body by gathering its XYZ coordinate data, which are represented as dots. Laser-based scanners (e.g. Human Solutions Vitus XXL) use moveable cameras and eye-safe lasers to capture about 300,000 data points for each scan [13]. A white-light based scanner (e.g. $[TC]^2$ NX-16) works on a moiré-based light projecting system and uses a white light source to project stripes of light on the three dimensional surface. Distorted stripes of light are detected by non-moving sensor cameras and then translated to an accurate 3D body model within eight seconds. The body model is generally created in the form of a point cloud. To visualize this data, dots are connected by triangulation and then this area is filled with a surface [11, 16,17].

It should be noted that these technologies has some limitations when it comes to capture surface information. Especially when a participant wears dark colors, blocks camera views, exceeds boundaries of the scan volume when taking poses other than anthropometric standing; the resulting scan data lacks some important data points. In addition to these factors, some horizontal body surfaces such as top of the head and shoulder, and other areas such as armpits and crotch cannot be captured well during scanning, resulting holes, or image loss, in the final scans. These scans can be improved further by smoothing their surfaces and holes in them by using additional visualization software such as Geomagic, PolyWorks, RapidForm, and MeshLab [11, 15, 16].

$[TC]^2$ 3D body scanners are installed in more than 40 universities and institutions [18]. These scanners have been widely used in studies such as sizing surveys, body shape analysis and custom clothing design [19- 21]. However it has never been used as a tool for visual fit analysis. In this study we wanted to explore this by expanding its capacity for visual fit assessment tool.

Therefore, the purpose of this exploratory study was two-fold: 1) to investigate range-of-motion and design issues of existing scrubs and 2) to use a white-light based 3D body scanner as a visual tool for identifying and examining the fit of scrubs when taking active body positions.

2. Method

2.1. Data Collection

Upon obtaining a human subject approval from the IRB office, we conducted a focus group interview with a group of nurses at a Midwest hospital. Main discussion topics were problems and inconveniences occurred when wearing scrubs, wearing practices, likes and dislikes about scrubs, fit issues, the most frequent and extreme working positions and design suggestions. The focus group interview took approximately one hour and was audio recorded.

Upon establishing scan protocols and postures and before starting our study of the different postures used in the medical profession while wearing scrubs, we also tested scanner cameras' ability to capture enough data for effective analysis by experimenting with how a person would stand in the scanning booth. To examine the scrub and body relationship while performing various movements, one participant was recruited. Upon arrival, the participant was informed about the study, the 3D body scanner, protocols and the consent form. For scanning, a $[TC]^2$ NX-16 white-light 3D body scanner was used. For each scan position, the participant was provided with foot positions marked on the scanner platform and hand positions marked on the scanner walls. Moreover, the participant wore a bouffant scrub cap to get as much surface information from the head as possible to create a unified scan of a person. The participant was first scanned in anthropometric standing pose with a t-shirt and a pair of tight fitting shorts worn over underwear. Then, we took scans of five active poses of the participant in the scrub set, which was worn over a t-shirt. For each posture, three repetitions were taken. The set of best scans were visually analyzed by zooming in and out and rotating scan images.

2.2. Participants

Three male and three female nurses between the ages of 25 and 40 were recruited from a Midwest hospital to participate in the first part of the study. They were registered nurses and four of them were working in the cardiac catheterization lab.

For the exploratory 3D body scanning part, one male student, age 30, was recruited. The scan participant was wearing a regular size small scrub set in US sizing and a bouffant scrub cap.

2.3. Scrubs

A reusable scrub set consisted of a V-neck scrub top with a left chest pocket and short set-in sleeves and a pair of drawstring pants was used for the body scanning. Both scrub top and bottom fibers were composed of 65 % cotton 35% polyester. This particular scrub design was selected based on the focus group interview data. The color of the scrub set was chosen as white to maximize the number of data points captured by the scanner.

2.4. 3D scan data processing

The raw 3D body scan data from the NX-16 3D body scanner, which were in RBD format by default, were converted to the avatar mesh files (OBJ). The OBJ files were imported to Geomagic Studio 11 to clean the wrapped surface around the point cloud, do a very few hole patching and repair some surface data by flipping normals. The visual fit analyses were conducted in Geomagic Studio 11 as this software allowed rotating and zooming in/out the body model.

2.5. Data analysis

The focus group interview audio recording was transcribed for data analysis. The interview transcript was read through many times to obtain familiarity with the data and to identify issues regarding some important active positions for the scanning protocols. First, five of the most frequent and extreme movements were determined based on the interview data analysis and the literature review. Then, we performed 3D body scanning.

The exploratory visual fit analysis of the 3D body scan data was conducted for each scan posture. When evaluating fit, we looked at the areas where stress folds, wrinkles, excess fabric, strain in the crotch area were visible on the scrubs and discussed each indicator of improper fit in problematic areas before making our final conclusion.

3. Results

3.1. Focus group interview findings

The focus group interview findings indicated that the participants were all wearing scrub tops and bottoms. The most frequent postures used most in the day were walking, stretching, pushing, lifting, bending, bending arms, and squatting. In the profession, there was very little standing still. Male participants expressed that they were wearing scrub sets on a daily basis and those were provided by the hospital, as well as laundered by the hospital. Because their scrubs were selected by the hospital, male participants were having more fitting problems than female nurses, who had freedom of choice when purchasing their own scrub sets.

Common fit problems with male's scrub sets were the length of the pants and tops. Some of them were choosing one size bigger scrubs to have more room and eliminate back showing when bending or pushing. However, when they do that, they suffer from excessive amount of fabric in other areas-ending up being uncomfortable. One participant addressed that he would need more room across the back when bending. The male participants indicated that their scrubs are unflattering, shapeless and not fashionable at all.

One of the female participants was a petite woman and she explained the fact that it was difficult to find perfectly fitting ready-to-wear scrubs for her and she needs to alter her scrubs each time she purchase a new set. Another female participants mentioned that her scrubs were usually tight in the shoulders, restricted the shoulder movement and she wished that they were out of a more flexible fabric.

All participants agreed they would pay more for the scrubs that provide customized sizing, give improved ease of movement and have athletic cut, which would look good on them. Elastic waistbands and drawstrings in pant were preferred for ease of use. The participants also wanted to see more pockets on their scrubs for their personal items. The participants also wanted to have lighter weight, softer, flexible and durable fabric materials for their scrubs.

3.2. 3D scans of anthropometric standing and active postures

To better understand the relationship between scrub wearers' body positions and the fit of the scrubs, we conducted a second study by using the white light 3D body scanning technology. Based on the interview and literature data, five active positions (stretching, bending, squatting with arms reaching forward, lifting and pushing) were determined. One participant was scanned with a $[TC]^2$ NX-16 3D body scanner to capture anthropometric standing and five active body positions. Geomagic 11 software was used to process these scans further for image analysis purposes. In the following images,

blue color shows the useable surface information whereas yellow areas indicate missing surface information and reveal the inside of the scan model.

3.2.1. Anthropometric standing

For this posture, the scan participant is seen in the standing position (see figure 1). Horizontal folds in the pants legs show the excess length in the legs. The vertical lines on the front and back of the scrub top specified that the top was slightly loose as well. Side view of this posture showed the loose fit of the top around hip area.

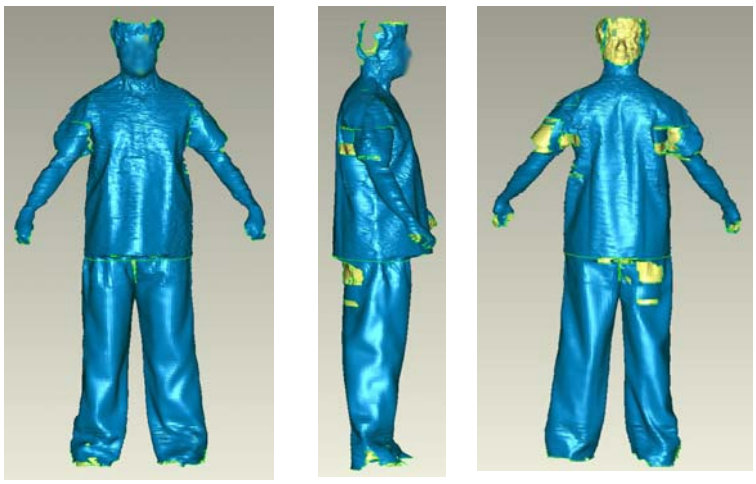


Fig.1 Anthropometric standing position captured by the [TC]^2 NX-16 3D body scanner (front, side and back views).

3.2.2. Stretching

The 3D scan was captured with the scan participant standing in the booth and reaching/stretching straight over his head (see figure 2). This posture showed the movement of the scrub set on the body. The scan data revealed that, when both arms are raised, the hemline of the scrub top, which was once located on the hip during standing, shifted upward and stayed on the waistline, revealing the waistband of the scrub pants. Because of the loose fit of the scrub top, direction of the fold lines on the back were visible. Especially the folds started in the underarm region and continued across the back indicated the possible direction of tightness/restriction that might have occurred when the top was half size smaller. In this particular case, the v-folds originated in the underarm area and continued around the waist area pointed out the areas with excess fabric. Moreover, some amount of fabric at the back neck was slightly bunching up.

As for the scrub pants, horizontal folds at the legs were lesser when stretching than standing, indicating that they shifted up during that action as well.

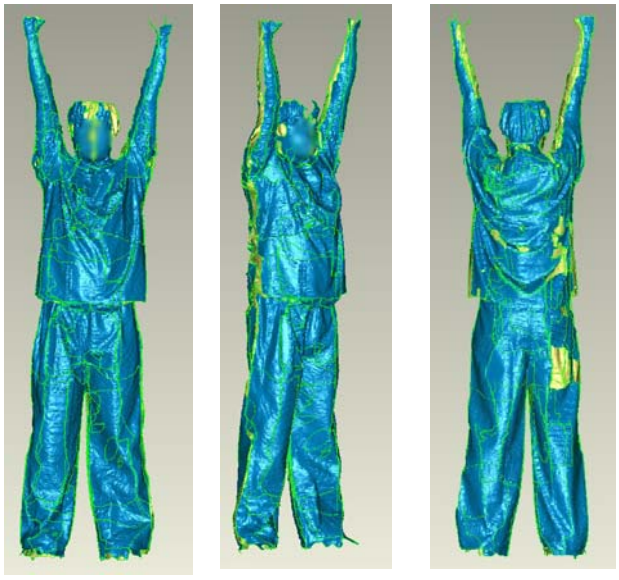


Fig. 2. Stretching captured by the [TC]^2 NX-16 3D body scanner (front, 3/4 and back views).

3.2.3.Bending

When bending over from the waits to touch the ground, some important information at the back was lost as the scanner was not able to successfully capture that area (see figure 3). It was impossible to see if the back neckline was being pulled down because of this posture or not. The only visible excess fabric folds were the ones over the thigh area to the outseam at the back knee. Horizontal fold lines at the pants hemlines were not visible in this most extreme posture as well.

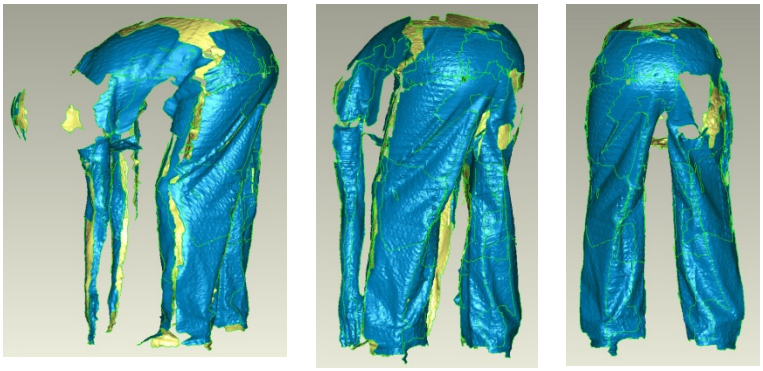
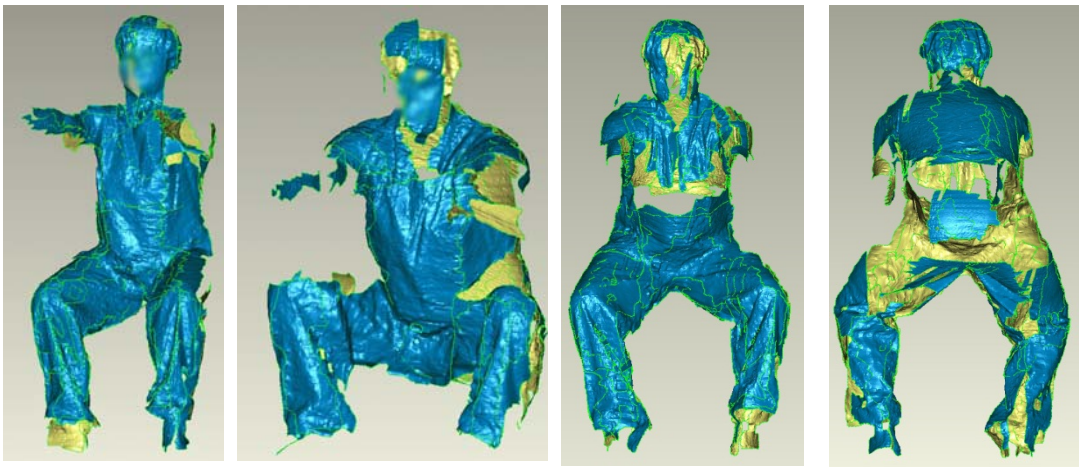


Fig.3. Bending captured by the [TC]^2 NX-16 3D body scanner.

3.2.4. Squatting with arms reaching forward and lifting

As the focus group interview data indicated, nurses also spend a great deal of time squatting or in some cases, lifting. These postures are very important to a nurse in the profession because he/she does a lot of work with patients. The job also depends on arm use to properly fulfill the duties. For these postures, the scan participant was facing towards one of the corners of the body scanner (see figure 4). Two versions of squatting were tested. For the lifting stance, both arms were bent in the front and the participant was squatting. Therefore we evaluated both squatting and lifting postures together.

The scanner data did not provide clear information on the lower back and around hip, especially for the lifting posture. Also, arms were very difficult to obtain. However, these scans still showed the strain of the pants on the upper back as well as the knees and legs. There was a noted strain on the shoulders of the participant as well. Although the back showed some signs of stress folds, there was excess fabric in the front of the scrub top.



a. *b.* *c.* *d.*

Fig.4. Squatting with arms reaching forward (a. squat, b. deep squat) and lifting (front and back) postures.

3.2.5. Pushing

The last posture (see figure 5) was mimicking pushing. For this posture, too, the scan participant was facing towards one of the corners of the scanner. However, his arms were cut off in the scan data, indicating that this positioning did not work for maximizing the captured surface area. Scan data for the scrub top indicated some excess fabric folds in the front and a bunching up at the back neck. In the back view, some stress folds on the thigh area when the participant was stepping forward were visible.

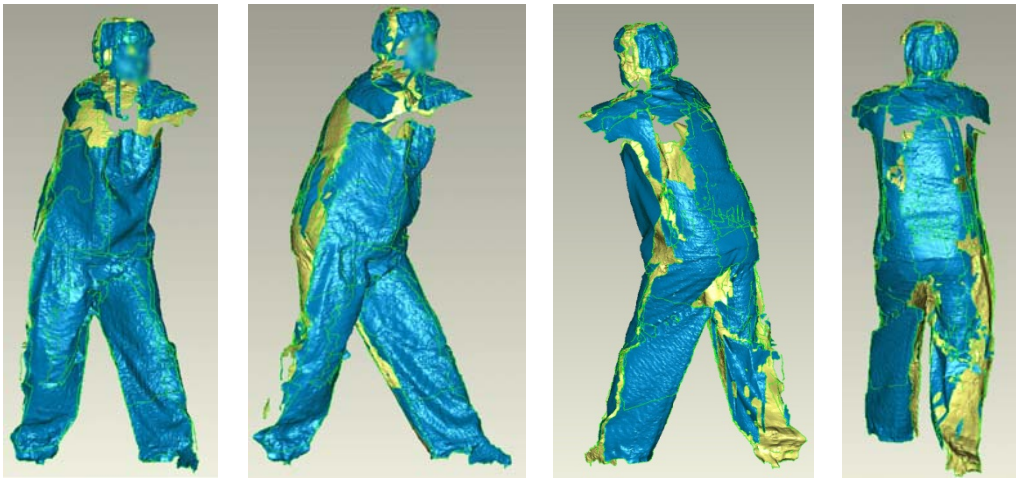


Fig.5. Pushing captured by the [TC]^2 NX-16 3D body scanner (front, 3/4 and back views).

4. Discussion and Conclusion

Workers in health care facilities routinely wear scrubs and spend their entire day wearing them. Therefore feeling comfortable in their work attire is crucial to maintain work efficiency. It is a very hands-on job, and they need their scrubs to move with ease to provide the most comfort possible during their workday. However, designers of scrubs have been still paying lack of attention toward comfort of scrub wearers. To understand the underlying problems with the scrub fit, we have investigated the problems with scrubs and examined various body positions. The white-light 3D body scanner was used to explore its usability as a visual fit assessment device.

The findings of this study supported other studies which stressed the importance of fit for protective clothing. The focus group interview results identified stretching, bending, squatting, lifting and pushing as the most frequent and extreme postures that the nurses expressed were commonly used in their profession. Visual analysis of the 3D scan files provided some rich information regarding how to improve the design of a conventional scrub set. The ready-to-wear scrub bottom was slightly long on the scan participant when standing, but the length seemed better when the participant was reaching up or bending. Overall, we were able to detect some areas on the scrub top and pants that need some improvement. For the particular scrub design we used in this study, the back, shoulder area, underarm, crotch and knees would need some improvements for better fitting and more comfort. Using a gusset in the crotch area and underarms might be a part of the solution. Expansion pleats can be built into the shoulder area. Based on the interview data, the cut of the scrubs should be re-designed to give them a more athletic and modern look.

Although we made several suggestions for a better fitting scrub design, providing any specific pattern design or fabrics was not the scope of this exploratory study. Our future work will include conducting multiple focus group interviews and observation of nurses in their work environments, experimenting with various visualization software to process [TC]^2 scans to create smoother surfaces without holes, taking cross sections of the scan data to examine the body-scrub relationship at certain postures, designing various prototypes and developing a fit rating scale for objective evaluation of the fit of the existing scrubs as well as redesigned scrub prototypes.

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