A Pattern Adaptation for Body Changes during Pregnancy: A Single Case Study

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by

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Abstract

Pregnant women experience dramatic body changes during their pregnancy. With the wide variety of body shapes and sizes, physical changes occur differently for every pregnant woman; thus, these variations lead to problems of comfort, fit, and sizing of ready-to-wear maternity apparel. Therefore, this study examined the changes in body measurements and shapes during pregnancy and analyzed the relationship between these changes and pattern measurements and shapes.

A single case study method was used to observe one participant's body measurement and body shape changes during pregnancy, and the relationship between these body changes and related pattern changes. Findings were analyzed by the changes in body measurements and body shapes and the relationship between the body changes and pattern changes. The entire pattern adjustment process represents the analysis of the relationship of body changes to pattern changes.

The findings of this study suggest that consideration of body shape during apparel pattern development offers valuable information related to fit that goes beyond standard linear measurements. In addition, the results indicated that body measurements and patterns did not increase proportionally to each other. The pattern changes were not necessary due to body measurement or shape changes. The patterns were adjusted not only to accommodate body changes but also to maintain the garment style.

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CHAPTER 1: INTRODUCTION

Pregnancy is one of the most exciting times in a woman's life; however, it also can be a time of uncertainty and worry. In particular, pregnant women experience dramatic body changes during their pregnancy. Some women have reported that pregnancy triggered negative feelings no matter how satisfied they were with their bodies before pregnancy (Leifer, 1977). In Fairburn and Welch's (1990) study of 50 pregnant women, they found that that 40% reported fears about weight gain during pregnancy.

With the wide variety of body shapes and sizes, physical changes occur differently for every pregnant woman. For example, pregnant women who have a low Body Mass Index (BMI) tend to gain more weight than those who have a high BMI. In addition, depending on the position of the fetus, abdominal shapes vary from person to person. Another reason for variations in body change is that a subsequent or multiple pregnancies may lower the abdomen. For example, a pregnancy usually does not become obvious until about week 20 with the first baby but by week 14 in subsequent pregnancies (Stone & Eddleman, 2003). These variations lead to problems of comfort, fit, and sizing of ready-to-wear maternity apparel.

Matthias, president and chief creative officer at Destination Maternity, says that maternity wear is fashion that fits women when they are pregnant ("Ooh la la, MAMA," 2009). Today's trend in maternity apparel is stylish and fashionable compared to maternity wear 20 years ago when "tent" dresses were the norm. The change reflects consumers' need to feel better about themselves and their desire to have garments that fit well even though they are pregnant.

With the increasing need for well-fitted maternity wear, today's market has grown rapidly. According to the National Center for Health Statistics, more than 4.3 million babies were born in the U.S. in 2007, which resulted in American women spending more than $1.2 billion on maternity apparel. According to the National Product Diary (NPD) Fashionworld AccuPanel^{SM}, purchases of maternity clothing were up 3.6% from 2007 to 2008, compared to purchases of total women's apparel, which declined 5.6%.

Despite the important need for maternity wear, little research on maternity wear has been conducted. The purpose of this study was to examine the changes in body measurements and shapes during pregnancy and to analyze the relationship between these changes and pattern measurements and shapes. This study will improve our understanding of how to fit maternity wear based on the body shape and measurement changes. This study is also innovative in that it was conducted using advanced 3D technologies to obtain body measurements related to clothing size and fit changes during pregnancy. This study was guided by the following objectives.

- To examine changes in body measurements during pregnancy
- To examine changes in body shapes during pregnancy
- To understand how these body changes affect the pattern measurements and shape

CHAPTER 2: REVIEW OF THE LITERATURE

The purpose of this study was to examine the changes in body measurements and shapes during pregnancy and to analyze the relationship between these changes and pattern measurements and shapes. A single case-study method was used for this study. By understanding how to collect and interpret the data, better fitting maternity wear can be developed, but to develop such a method, a review of literature was necessary. This review will help us understand body changes during pregnancy, general body measurement methods, pattern development, assessment of garment fit, and maternity wear.

Body Changes during Pregnancy

Body changes during pregnancy have been well documented in the literature from the medical and apparel field. Four changes are presented: changes in the body silhouette, measurements, posture and weight.

Body Silhouette Changes

Pregnancy trimesters are divided into three stages of three months each. The first pregnancy trimester is from conception to 12 weeks. The second pregnancy trimester starts from the 13th week to the 28th week. The last trimester is from the 28th week until the birth of the baby. During pregnancy, women experience rapid changes in their body size and shape over a relatively short period of time. The first external physical changes occur at about four months (Gersh & Gersh, 1981) and are prominently seen only in the bust and abdomen. Although women's experiences vary, most pregnant women experience the most dramatic external physical changes throughout the last two trimesters of pregnancy. For the purpose of studying clothing, the last two trimesters can be considered together because pregnant women will need maternity garments during these two periods. Due to the more dramatic body changes during the last two trimesters, the pregnancy cannot be hidden and clothing must accommodate the changes.

Body Measurement Changes

Most women will note an increase of eight to ten inches at the waistline during pregnancy (Sadler, 1974). Manley (1991) found that the largest increases over time (4-5 in.) occurred in the waist and abdominal extension, and bust and hip measurements directly related to the waist and abdominal extension (vertical trunk, crotch length, and crotch depth) increased. Abdominal extension varies the most among pregnant women; some women carry their babies high in their abdominal cavity and others carry their babies lower in the pelvis. Breasts also expand in size during pregnancy with an average increase of two or three inches in bust circumference (Sadler, 1974).

Posture Changes

Regardless of the type of abdominal expansion women experience, body balance must be maintained, resulting in a temporary curvature of the spine. This curvature changes the posture and creates a swayback appearance that results in lengthening the front of women's figures (Fite & Roberts, 1984). Nicholls and Grieve (1992) found that a posture change in the lower back markedly increases in the second and third trimesters of pregnancy. Many studies have shown that body changes occurring in posture and bilateral symmetry affect the fit of clothing (Goldsberry, Shim & Reich, 1996; Lunn, 1983).

Weight Changes

A typical pregnant woman gains approximately 13 kilograms (29 lbs) in weight during a 40-week pregnancy (Girandola, Khodiguian, Mittlemark & Wiswell, 1991).

All of these physical changes during pregnancy require special consideration for comfort, fit and sizing when developing ready-to-wear maternity garments.

Body Measurements and Shape

Slight changes in human body measurements are important when developing an apparel pattern for well-fitting garments, so body measurements are critical. Body measurement methods vary from simple to complex. The standard body measurement methods used for apparel are based on traditional anthropometry, which is "the science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body" (Roebuck, 1995, pg. 1).

Body measurement methods related to apparel can be divided into three categories: (a) linear methods (b) multiple probe methods, and (c) body form methods (Bye, LaBat & Delong, 2006). Linear methods are used to measure length along the body surface between landmark points including circumferences and curvatures. Linear methods only indicate body length, so they cannot quantify surfaces, shapes, or volume

(Bye et al, 2006). These traditional body measurement methods have three limitations (Hwang & Istook, 2001). First, traditional body measurement methods for apparel may differ from person to person. Measurements based on the individual only work when the measurers are trained to know what they are measuring or when the body is not too padded to cover important landmarks. Second, to measure some lengths, positioning is important. For example when measuring elbow circumference, shoulder to elbow length, and arm length, the arm should be bent. Different measurement methods and lack of consensus of terminology appear in all traditional standard measurements for apparel because the length can be obtained in different positions. Third, ambiguous landmarks that are not visible on the body are used for measurements. Imaginary lines such as "side seam to side seam" are unclear descriptions for abdomen width in the American Society for Testing and Materials (ASTM). Therefore, linear measurements may not accurately predict fit in apparel. Moreover, the wide range of different body proportions, body shapes and body postures, and interactions among measurements may result in misfits that cannot be identified by comparing single linear measurements (Ashdown & Connell, 2006).

Researchers (Beazler, 1997; Woodson, 1985) have experimented with capturing more information about body contours, posture, and body angles by using multiple probe methods. There are many body form methods, including draping, casting and body scanning. In particular, as an innovative measurement method, the development of three-dimensional (3D) body scanning technologies may have significant potential for use in the apparel industry. 3D body scanning is capable of extracting an infinite number of data types and measurements. Body shapes, angles, and relational data points are easily obtained with 3D-scanning technology, in addition to the linear measurements on which the apparel industry has historically relied.

Consideration of body shapes is very important during apparel pattern development. The problem, however, is that body shapes vary among people. A pattern constructed on the basis of a limited number of key measurements often needs to be altered to accommodate individuals whose shapes deviate from the shape for which the pattern was originally drafted. According to Watkins (1995), bodies with the same circumferential proportions may differ in width/depth proportions, or in some other shape-defining measurements, such as lengths, heights, or angles, rendering the circumferential description unable to differentiate shapes completely. Several apparel studies have been conducted on body shapes. Mossiman (1988) claimed that size is not related to shape, and proposed that shape should be used for classification of organisms within a species whether small or large. Application of this theory to the analysis of body types for apparel suggests that (a) all persons who wear a specific size category cannot be assumed to be the same shape, and (b) individuals who range from small to large or short to tall within one apparel size category may have similar shapes or very different shapes. Hwang and Istook (2007) studied sizing systems based on understanding of body shape differences among ethnic groups. They pointed out that it is important to establish standards that account for different body shapes and dimensions as a result of ethnic variations.

Studies on body shape type have also been conducted by several apparel researchers. In Gazzulo's study (1985), dimensions of female body shape variations were mapped using front and lateral views. More recently, Istook, Simmons and Devarajan

(2002) developed shape sorting software in Visual Basic using mathematical criteria, and sorted the female figure from a front view into the following shape categories: hourglass, spoon, rectangle, oval, and triangle. Additionally, Connell, Ulrich, Brannon, Alexander and Presley (2006) developed nine scales for assessing body shape from the front and side views. Three scales (body build, body shape, and posture) were used for the whole body analysis, and six scales (front torso shape, hip shape, shoulder slope, bust shape, buttock shape, back curvature) were used for analysis of component body parts.

Consideration of body shape has also been studied for pregnant women. The Standard Table of Body Measurement for Misses Maternity Sizes 2-22 ("D 7197-06 standard", 2007) was built to assist manufacturers in the development of patterns and garments that are consistent with the current anthropometric characteristics of pregnant women. The chart was developed to fit garments for women during the seventh month of pregnancy, but does not include changes in body measurements or body shapes during pregnancy.

Pattern generation based on body measurements is the starting point of garment manufacturing, but it has traditionally presented several challenges including cost and time. Traditional pattern development is typically performed by highly skilled patternmakers. In order to make an optimum pattern, they gather anthropometric information by careful measurement and draft-specific flat patterns based on accumulated knowledge and experience. Then they make a test garment to evaluate fit and repeatedly adjust it on the model's body by trial and error methods. Thus, this process is relatively expensive and requires extensive time. A bigger problem with this traditional pattern development is that it does not consider the width and depth of the body. "Traditional pattern development relies on circumferential and arc body measurements rather than on width (side-to-side in front view) and depth (front-to-back in side view) measurements. Therefore, width/depth body shape categorization would be less related to patternmaking than would be circumference/arc shape categorization" (Petrova & Ashdown, 2008). Thus, ignoring the width/depth of body shape during the pattern generation process can lead to fit problems.

Bye, LaBat, Mckinney, and Kim's study (2008) highlighted the role of body shape variations in individuals with the standard ASTM measurements for bust, waist, and hip circumference and height measurements across the Misses size range. Pattern grading is developed to translate the body changes that occur from size to size to the corresponding garment master pattern pieces; however, current grading practices do not consider change in body shape across a size range. They suggested that changes in both body measurements and shape must be considered to determine the fit of a garment. In spite of the known need to focus on body shape, few apparel studies have focused on the relationship of body shape variations and pattern shape.

Garment Fit

Apparel design and production experts believe that the fit of a garment is one of the most important factors for individuals (Minott, 1978). Garment fit involves multiple factors including the wearer's size, proportions, and posture and the garment's dimensions and drape, so good fit requires a proportional balance between the body and the garment. Fit has been defined as "A correspondence in 3-dimensional form and in placement of detail between the figure and its covering to suit the purpose of the garment, to provide for activity, and to fulfill the intended style." (Berry, 1963, p. 314). Fit problems occur when garments are made with deficiencies in pattern development, grading sizing, and improper construction; thus, good fit can be achieved with the appropriate development and implementation of effective patternmaking techniques and proper sizing and grading systems.

Assessment of fit involves physical and psychological comfort and satisfaction. Koblyakova (1980) evaluated minimum ease values for comfort of movement for upper-body garments based on the changes in body circumferences during breathing. Apparel researchers have also developed additional methods for judging apparel fit based on the wearer's response to the look and feel of the garment, and on responses of expert judges to a visual analysis of the garment on the wearer (McConville, 1986). Traditionally, two methods have been used to test the fit of a garment: live models and dress forms (Yu, 2004). Live models are commonly used for evaluating clothing fit because real human bodies and real human movements are involved. The problem with live models is that judgments based on subjective and qualitative preferences tend to vary from one person to another and from time to time. The other method, dress forms, are more static and convenient to use, but the assessment still relies on the evaluator's personal judgment.

With the development of 3D-scanning systems and 3D technology, it is now possible to assess garment fit in a 3D digital environment. Specifically, 3D technology makes it possible to digitally drape garments directly onto 3D body scans or virtual models. Several studies on visualization and development of 2D patterns in a 3D environment have been conducted (Fozzard & Rawling, 1991; Fozzard & Rawling, 1992;

Okabe, Imaoka, Tomiha, & Niwaya 1992). However, using this technology demands a new approach to evaluating patterns and to assessing fit. Such a system would provide the tools to develop a 3D simulation of a prototype garment which can be viewed and evaluated from any angle prior to making a physical sample. This 3D simulation combined with the ability to develop the corresponding 2D pattern shapes and evaluate the fit of the virtual garment, make the prospect of such a system extremely enticing. For example, 2D/3D pattern-making software by Optitex makes it possible to drape a 2D pattern onto a 3D model by setting the maximum tolerable pressure of the garment and fabric parameters (May-Plumlee, Eischen, & Bruner, 2004). However, 3D software for fit and testing is still in the experimental stages.

Currently, few studies on the use of scan visualization for fit analysis have been conducted. Ashdown, Loker, Schoenfelder and Lyman-Clarke (2004) stated that visual fit analysis of a 3D model is an effective method for categorizing and analyzing the complex relationship between clothing and the human body. In their study, fit analysis based on the classic fit elements of ease, grain, line, balance, and set were used to analyze the relationship between clothing and the human body. Fit was evaluated on the basis of a body scan to observe the smoothness or distortion of the hang of the garment on the body, the angle of the seams or edges, areas of constriction of the body, stress folds, and garment and body proportions. This 3D visualization provides objective 3D data for fit analysis.

Maternity Clothing

Due to body changes during pregnancy, pregnant women need to wear maternity clothing, but they are unsure how the garments should fit so that it is comfortable during their whole pregnancy. For example, proper fit for the fourth month can be quite different than that needed for the ninth month. Clothing purchased during the second trimester may become tight and uncomfortable during the third trimester. According to Burggraf (1987), due to physical changes of enlarging breasts and abdomens, a woman's regular wardrobe becomes tight during their fourth or fifth month, and most women must seek maternity wear that is comfortable and compatible with their lifestyles.

Shopping for garments that are comfortable and fit properly often leads to frustration for consumers (Cotton Inc., 1998). Pregnant consumers have even more difficulty finding well-fitting garments because for women experiencing their first pregnancy, it is common to be unaware of the changes that their bodies will undergo during pregnancy. Moreover, body changes during pregnancy vary widely among women. For example, it is very often difficult or impossible for petite size and large size women to acquire maternity clothing that fits their body size and meets their unique needs (Greer, 1988).

Proper fit should be a strong consideration when designing maternity clothing (Sadler, 1974) since it is a major factor when consumers purchase maternity wear; however, to date, little research has been conducted on maternity clothing. In ergonomic studies, several studies have been conducted on fit and comfort of maternity support garments as functional clothing (Ho, Yu, Lao, Chow, Chung & Li, 2008; 2009) However, research on everyday maternity clothing is scarce and there are no studies on maternity wear focusing on body shape changes during pregnancy.

CHAPTER 3: METHODS

This research focuses on the changes in body measurements and shape during pregnancy and the relationship between these body changes and pattern measurements and shapes. A single case study research method was used and discussed in the following order: case study research design, case study data collection, and data analysis procedure.

Case Study Research Design

Yin (1989) defined a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (p. 23). Case study research emphasizes how conceptual frameworks operate in practice (Merriam, 1988).

Single case studies have been suggested as an alternative method worth exploring because many evaluators have expressed frustrations with group comparison studies (e.g., Bryk and Weisberg, 1978; Snow, 1977; Stanford Evaluation Consortium, 1976). A single case study is "the intensive statistical study of the individual" (Chassan, 2006, p. 248) to overcome the limitations of the extensive model, which is a 0.5 level statistical study. The influence of various participant characteristics on the outcome can be studied with a directness which cannot possibly be achieved with an extensive model. This approach can be regarded either as complementary to one in which degrees of freedom for statistical inferences depend entirely on the number of subjects in a study, or can be based on its own merits.

Chassan (2006) highlighted the importance of intensive statistical study of a single case with respect to the use of a drug. To implement such a design, he assumed that the researcher should deal with a variable or a symptom which has a degree of variability within the individual patient over time. He stated, “if one observes the subject over sufficiently long periods, then the one can, in general, over a sufficient period of time, obtain a sufficiently large number of observations to achieve statistical significance, if, in fact, a true difference does exist” (p. 249). The researcher also can obtain an accurate measure of this difference–that is, a relatively precise estimate of the parameters.

This method is particularly well-suited to the present study because this study explored the effect of body changes on garment pattern changes. In other words, the impact of body changes on patterns was thoroughly considered rather than generalizing body measurement changes and shape changes during pregnancy. In addition, the changes observed during pregnancy provide a sufficient period of time with a sufficiently large number of observations to provide statistically significant results. Thus, intensive observation of one subject was meaningful for this study.

Case Study Data Collection

The goal of this study was to examine the changes in body measurements and shapes during pregnancy and to analyze the relationship between these changes and pattern measurements and shapes. Body scans of the participant were prepared and patterns for well-fit garments were created for each month of the pregnancy.

Participant

For this study, an average-sized participant was recruited. According to Gioello and Berke (1979), average-size customers are those who wear Misses size 10 or size 12. They are approximately 5’5” to 5’7” tall. Their forms are characterized by fully developed figures that are well proportioned. Their hips are approximately two inches larger than the bust. The average-sized participant for this study was a 26-year-old Caucasian female, 5’5”, 160 lbs, and she was pregnant for the first time. The participant was scanned seven times throughout her pregnancy. Table 1 shows the month of pregnancy for each of the seven scans.

Table 1 Scan Data and the Week of Pregnancy

	Scan date	Month of Pregnancy	Trimester
Scan 1	07/23/2007	1st month	First trimester
Scan 2	08/19/2007	2nd month	
Scan 3	10/01/2007	3rd month	
Scan 4	10/31/2007	5th month	Second trimester
Scan 5	12/06/2007	6th month	
Scan 6	01/04/2008	7th month	Third trimester
Scan 7	02/12/2008	8th month	

Body Scanning and Weight Measurement Procedures

A Human Solutions VITUS/SMART 3D scanner in the Human Dimensioning© Lab (HDL) was used to scan the participant to obtain body measurements and body shapes. The lab includes a 3D body scanner and related computer equipment, a changing room, and apparel production equipment.

The participant was scanned seven times during the study using the following procedures. She was first given a consent form and participant information form to complete before she was scanned for the first time. After completing the forms, the participant was given a scan suit, socks and a robe. The participant wore her own bra and panties under the scan suit for this study. For body scanning, the participant stood on a platform with her feet on the foot markings and maintained a relaxed pose. The participant was asked to stand in the same position each time during for each of the scans during the scanning process.

To position the participant in the scanner, the following statement was read to make sure her positioning was correct:

> Please stand on the platform with your feet on the foot markings. Back up until your heels touch the back of the footprint. Maintain a relaxed, natural posture. Do not expand your chest, suck in your stomach, or stretch your back or neck. Turn your palms toward your body about 6 inches away from your legs. Bend your elbows slightly without raising your shoulders. Once the scan is started, red lights will move down your body in about 12 seconds. Stand still, look forward, and breathe normally.

The researcher closed the scanner curtain, and the participant was told when the scan was about to start. When the participant was ready, the researcher scanned her body. After scanning, the scan was checked for quality, and rescanned if necessary. In order to check for quality, the ScanWorX™ AutoMeasure™ program was used to automatically extract body measurements from the participant’s scans. After each body scanning, she was weighed using a digital home scale. Finally, before the participant left, she was allowed to see the scans if she desired.

Apparel Pattern Selection for Study

A sleeveless sheath dress was used to investigate the relationship between body changes during pregnancy and apparel patterns. This style of dress skims the body from neckline to mid-leg, conforms to the base of the neck and armcye, and reflects overall body posture. The sheath dress had no waistline seam, and was shaped using side seam front bust darts, two-ended darts in the front and back waist, and back shoulder darts. The sheath dress was also used in an earlier study on pattern grading to evaluate fit for sizes ranging from Misses 6-20 (Bye et al., 2008).

Data Analysis Procedure

Data analysis consisted of four parts: data preparation, analysis of the changes in body measurements, analysis of the changes in body shape, and an analysis of the relationship between the body changes and pattern changes. Measurement and shape data were prepared for this study including body data, pattern data, and the body-to-pattern relationships. To examine these relationships, pattern adjustments and fit evaluations were analyzed using visual analysis. Procedures for data preparation and case analysis follow.

Data Preparation

Measurement and shape data were prepared for analysis in a form applicable to pattern development. To analyze the changes in body measurements, this study used body surface measurements that were extracted by ScanWorx ™ software used in combination with the VITUS/SMART 3D body scanner. This software automatically determines body surface measurements and dimensions. For an analysis of body shape changes, body shape data was extracted using ScanWorx ™ and Polyworks™ software. Polyworks™ is a point cloud inspection software program. The body scan from a 3D body scanner can be imported into Polyworks™ as a polygonal model which allows body shape and volume to be measured. Body shape slices at the midriff, waist, maximum belly and hip, and anterior, posterior and lateral views of the participant's seven body scans were prepared.

Based on the changes in body measurements and shape of the body scans, patterns were developed using OptiTex™ 2D and 3D software. OptiTex™ can create a 2D digital apparel pattern and virtually drape the pattern on the 3D model in the 3D Model Window which can then be used to display any .stl or .mdl file to create an animation of the file. The pattern adjustment process used body measurements and body shape to explore the relationship between body changes and pattern changes. During the development of the patterns, fit was evaluated in a 3D digital draping. As changes were made, new patterns were evaluated on a 3D virtual model (VM) until the fit criteria were met. Armstrong's fit criteria (2000) were used and are presented below in the "Pattern adjustment procedure" section. Seven 3D VMs were developed from the seven body scans imported from the body scanner. Each 3D VM was displayed and then the adjusted patterns were draped onto the 3D VMs in the 3D Model Window using OptiTex™ software.

Body Measurement Data Preparation

Body measurements were obtained from the 3D body scanner and the ScanWorX™ software, and exported as a spreadsheet. Nine measurements of the torso area were selected and examined including breast circumference, chest band, midriff circumference, waist circumference, waist band circumference, high hip circumference, hip circumference, belly circumference and maximum belly circumference, as these areas typically increase during pregnancy. In addition, bust, waist and hip circumferences are key traditional measurements in developing garment patterns. The body measurement data for each of the seven scans was added to the body measurement data spreadsheet. Figure 1 and Table 2 define each of these selected areas.

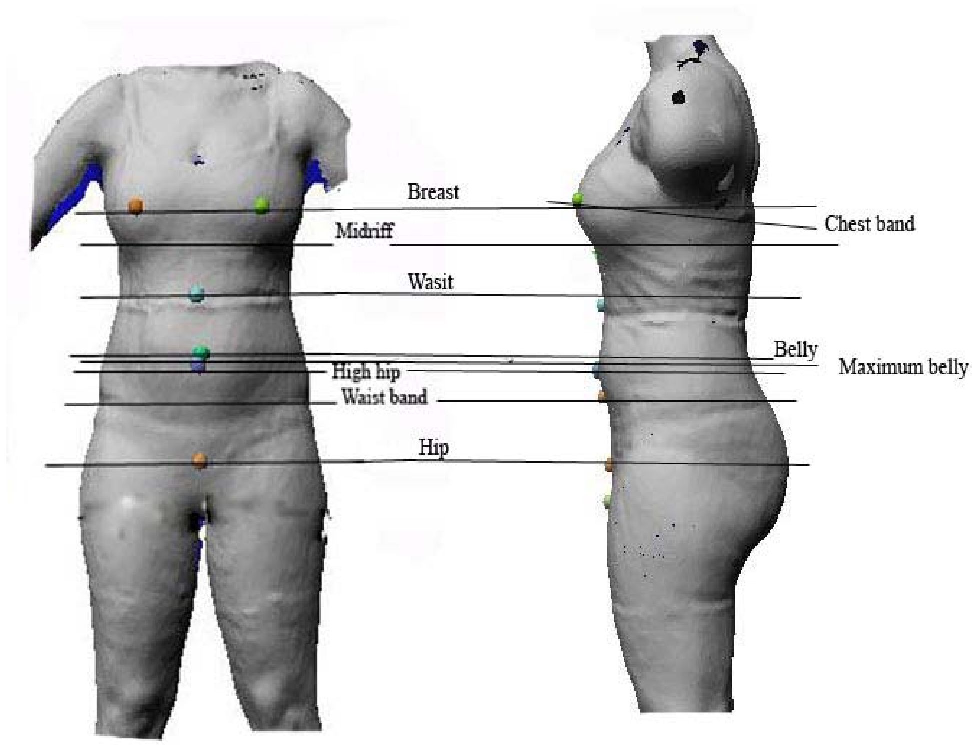


Figure 1 ScanWorx ™ Body Landmarks.

Table 2 Selected Body Measurement and Definition

Measurement Name	Definition
Breast circumference	The circumference of the chest is measured across the bust point landmarks. The circumference is measured parallel to the standing surface.
Chest band	The circumference of the chest is measured across the bust point landmarks. The circumference is measured perpendicular to the axis of the torso.
Midriff circumference	The circumference of the chest is measured just under the bust parallel to the standing surface.
Waist circumference	The circumference of the waist is measured in the height of the natural waist.
Waist band	The waistband location is calculated as a simulation of a physical waist belt on a pair of trousers.
High hip circumference	Horizontal circumference upper hip girth is measuremed at the location of the iliac crest.

Hip circumference	The circumference of the buttock is measured in a front-to-back plane with the tape passing just above the most protruding point of the buttock.
Belly Circumference	The belly circumference is placed horizontally around the torso in the region of the belly.
Maximum belly circumference	Horizontal circumference is in the region of the belly circumference, but in the height of the maximum circumference.

(**ScanWorx** TM)

Body Shape Data Preparation

The changes in body shape were analyzed from the anterior, posterior, lateral and transverse views of the seven body scans. The lateral silhouette is the shape of the body surface, starting at the neck and concluding at the thigh. To investigate the changes in abdomen shape during pregnancy, the anterior, posterior and right lateral views of each body scan were arranged in the order that they were taken and saved as a .jpg file. In the ScanWorX™ software, .jpg files of each body scan were created. These seven lateral contour views of body scans were then digitally overlaid at the curve from the back waist point to the hip, using PolyworksTM software, and they were also saved as .jpg files (see Figure 2). Additionally, the measurement changes of anterior-posterior abdominal depth, and the waist and hip width were presented to examine these changes numerically. An anterior-posterior abdominal depth was measured to quantify the shape changes in the abdomen area in the lateral view. The waist and hip width were measured to quantify the shape changes in the anterior and posterior hip and waist views (see Figure 9).

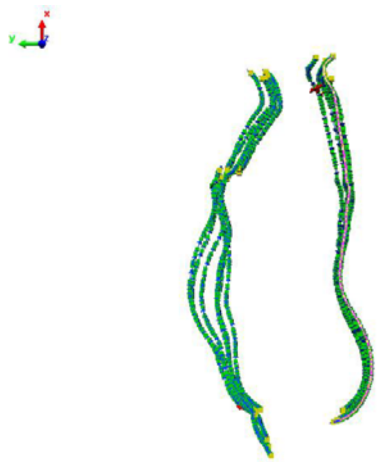


Figure 2 Example of overlaid contour views of body scans, using Polyworks™ software.

In addition to the lateral silhouette changes, the contours of the midriff, waist, maximum belly and hips changed during pregnancy. Seven transverse contours of the midriff, waist, maximum belly and hips were also overlaid using PolyWorks**™** software to investigate how the body shape changed. The following procedure was followed to extract the lateral silhouettes, and transverse contours of the midriff, waist, maximum belly and hips from each scan.

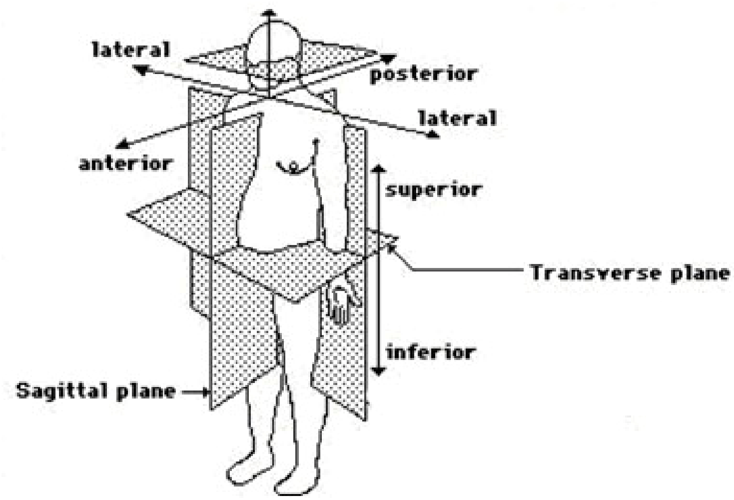


Figure 3 Anthropometric planes of reference.

1. Create a plane through the center of the anterior-to-posterior along the sagittal plane and extract the contour.
2. Create a transverse plane at the hip and extract the contour.
3. Create a transverse plane at the maximum belly and extract the contour.
4. Create a transverse plane at the waist and extract the contour.
5. Create a transverse plane at the midriff and extract the contour.
6. Overlay the seven contours of each area.
7. Create a .jpg picture file of the image.

Data Preparation for Pattern Adjustment

To investigate the relationship between body changes and pattern changes, 3D digital draping was used to adjust patterns and test the fit of the virtual sheath dress. The seven body scans were prepared for use as 3D VMs and then were exported with the ScanWorX™ software as a .bsf file and imported into the PolyWorks™. Throughout this process, each body scan was prepared to be imported into the 3D Model Window in Optitex™ software, and each was ready to be used as a 3D VM in a .stl file. These 3D VMs functioned as virtual 3D body forms.

Analysis of Body Measurement Changes

Body surface measurements were used to analyze the changes in body measurements during pregnancy. Measurements of the selected areas (breast circumference, chest band, midriff circumference, waist circumference, waist band, high hip circumference, hip circumference, belly circumference, and maximum belly circumference) were organized in a table to examine the changes in the body measurements and the range of the changes. The areas that increased or decreased were examined.

Analysis of the Changes of Body Shapes

Visual images of the anterior, posterior, transverse views and lateral views of the participant's body scans, and the measurement changes in the anterior-posterior abdominal depth, waist width, and hip width during pregnancy were used to analyze the changes in body shape. Visual analysis focused on the changes in contour, size, and shape. Lateral views of the seven body scans were arranged chronologically and the measurements of anterior-posterior abdominal depth were used to quantify the changes in side silhouette. In addition, overlaid contours of sagittal sections of the seven body scans were used to study the shape changes in the midriff, waist, maximum belly, and hip from the lateral view. These contours were evaluated to determine the progression of shape changes in a specific area. Posture changes were also observed from these contours. The transverse views of the midriff, waist, maximum belly, and hip were analyzed (see Figure 8).

Relationship Analysis of Body Changes to Pattern Changes

The next step was to analyze how the body measurements and shapes corresponded to the pattern measurements and shapes for this case. To analyze the relationship between the two, the patterns were adjusted through multiple fit trials on the 3D VM. Analysis was done during the process of developing the seven custom fit patterns including virtual fit assessments. Throughout the pattern adjustment process, the pattern changes were related back to the body changes. After developing the finalized patterns for each VM, the seven 2D front and back fit-to shape patterns were overlaid to analyze the changes in pattern shapes. Visual analysis was used to study the relationship between pattern changes and body changes.

Pattern adjustment procedure

The sheath dress patterns were custom fit to each of the seven 3D VMs, using OptiTex™ PDS, 2D and 3D pattern making software (see Figure 4).

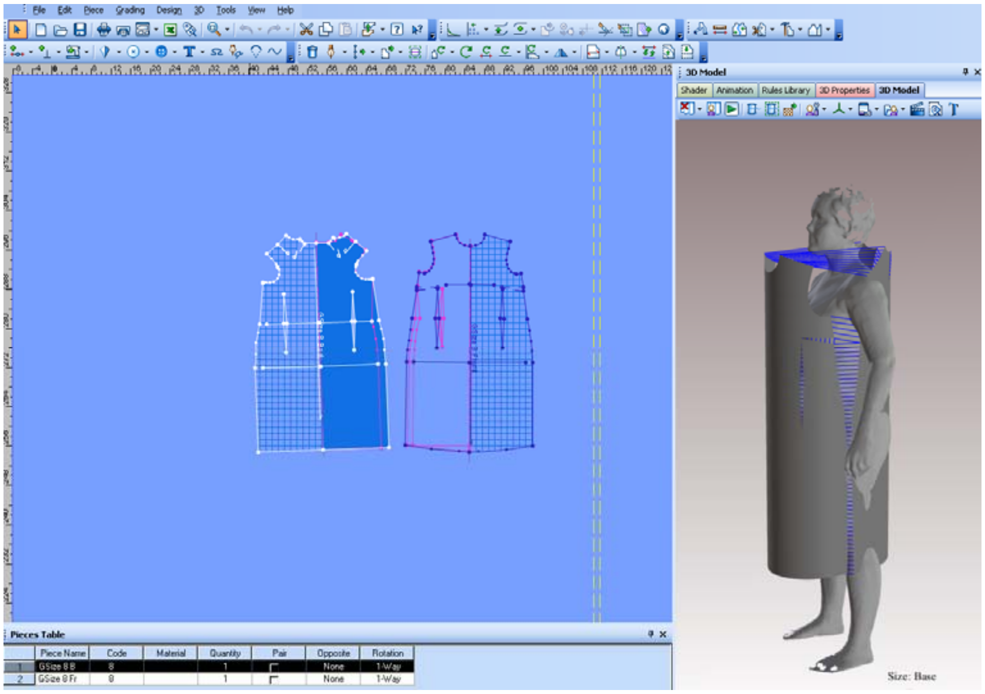


Figure 4 The process of the sheath dress pattern adjustments in OptiTex™

The basic pattern was a sleeveless sheath dress pattern, size 8 (see Figure 5).

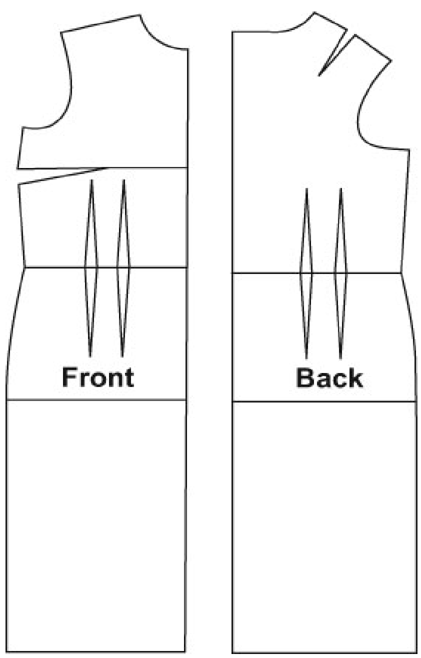


Figure 5. Sleeveless sheath dress pattern, size 8

The following procedure was used to adjust the patterns for each month's VM and to investigate how body changes affected the pattern changes.

1. Dress pattern size 8 was virtually fit to the VM month 1. The 3D digital draping in Optitex^{TM} was used to make the pattern adjustments. The 3D VM was uploaded in a 3D model window. The front and back of the sheath dress pattern was positioned on the 3D VM and the two pieces were virtually seamed to fit the body. If the size was too small, they separated and could not be seamed together. If the size was too large, the dress hung loosely on the 3D VM.
2. To develop each pattern, digital draping and a fit assessment in a digital environment were conducted by the researcher. A visual evaluation was done with the 3D VM using the established fit criteria and the tension map. Between each fitting, patterns were corrected, and multiple fittings were required to perfect the fit of the dress. For example, tension appeared across the bust, so the pattern was enlarged using the body shape information as a guide until the fit was correct. The following fit criteria (Armstrong, 2000) were used:
   a. Center front and center back aligns with the body center.
   b. Armscye fits smoothly.
   c. Waist level aligns with body waist.
   d. No stress or gapping at neckline.
   e. Side seam hangs perpendicular to the floor.
   f. Shoulder seam centered on the shoulder.

In addition to Armstrong's fit criteria, the tension map tool in OptiTex™ was used for the fit evaluations. This tool inspects simulated cloth objects as a colored map depicting amounts of stretching, tension, and distance between the cloth and the 3D VM (see Figure 6). The color display bar shows the tension UV (fg/cm) which measures the amount of physical tension influencing the cloth. The range of colors represents the scope of values. Red and blue are constant colors, and will always appear (Optitex, n.d), but if a dominant area of red appears, it must be interpreted with care because this indicates high physical tension leading to discomfort of the clothing. If red became dominant in an area, and the area looked too tight on the 3D VM, more ease was added to the pattern to reduce the red area and correct the fit.

Figure 6 Example of Virtual Fit Evaluation with the Tension Map Tool in OptiTex™

3. Pattern alterations and virtual fit evaluations were interactively conducted back and forth. Several versions of the dress patterns and fittings were completed before the patterns were finalized by meeting all of the fit criteria. This process was done, based on the body shape and body measurement. An in-depth analysis is discussed in Chapter 4.
4. Each subsequent pattern alteration was done with the final pattern for the previous month's VM.
5. Location and type of adjustments for each pattern, such as the bust, waist, and hip circumferences and the front length of the dress and dart length were recorded.
6. The seven final front and back fit-to-shape patterns were nested within the software and saved as .jpg picture files to investigate how pattern changes corresponded to body changes during pregnancy.

CHAPTER 4: CASE REPORT

This chapter presents the case report findings from the analysis of changes in body measurements and shapes during pregnancy and the analysis of the relationship between body changes and pattern changes. Body change analysis includes body surface measurements, body shape, and weight. The relationship analysis of body changes to pattern changes is conducted by adjusting patterns based on body shape and measurement changes during pregnancy. The pattern adjustments were evaluated and completed using 3D digital draping and virtual fit assessment. Pattern change analysis is associated with dart location, length, and width changes and pattern shape changes.

Analysis was conducted across the seven virtual models (VMs); thus, body and pattern changes through the entire pregnancy are described as one case.

Analysis of Body Measurement Change

Measurements were obtained by applying the ScanWorx™ automated measurement software to the seven 3D body scans. The main measurement changes occurred in the participant's torso. The torso consists of the chest, abdomen, and pelvis. Waist circumference, high hip circumference, belly circumference, and maximum belly circumference increased markedly between Body Scan 1 and Body Scan 7. Measurements related to the abdomen area had the most dramatic increases of more than five inches: waist circumference (7.47 in.), belly circumference (5.74 in.), high hip circumference (5.53 in.) and maximum belly circumference (5.48 in.). The waist band (4.29 in.), midriff circumference (3.52 in.), chest band (1.75 in.), breast circumference (1.64 in.) and hip circumference (1.3 in.) also increased during this pregnancy. The participant's weight increased from 162 lbs to 187.2 lbs. From the sixth month of pregnancy (Body Scan 5), body measurments and weight rapidly increased. Table 3 and Table 4 show the weight change and the body surface measurement changes through the eighth month of the partipant's pregnancy.

Table 3 Weight Change through 8 months of the Participant's Pregnancy

	Month of Pregnancy	Weight
Scan 1	1^{st} month	162.0 lb
Scan 2	2^{nd} month	165.0 lb
Scan 3	3^{rd} month	163.8 lb
Scan 4	5^{th} month	162.0 lb
Scan 5	6^{th} month	173.0 lb
Scan 6	7^{th} month	183.6 lb
Scan 7	8^{th} month	187.2 lb

Table 4 Body Surface Measurements Change through the 8 months of the Participant's Pregnancy
*unexpected measurement reduction, possibly due to different undergarments

		bust points width (in)	chest band circumference (in)	breast circumference (in)	midriff circumference (in)	waist circumference (in)	waist band circumference (in)	hip circumference (in)	high hip circumference (in)	belly circumference (in)	maximum belly circumference (in)
Scan 1	2 week	7.71	39.85	39.72	33.91	31.30	36.16	42.93	37.12	36.15	36.83
Scan 2	6 week	7.80	39.94	39.74	34.24	32.41	36.45	42.93	36.92	36.40	36.79
Scan 3	12week	7.82	39.39	39.67	33.60	32.96	37.11	43.11	37.96	37.23	37.75
Scan 4	18 week	7.66*	38.53*	38.58*	33.57*	33.61	37.08*	43.39	37.88*	36.89*	37.52*
Scan 5	23 week	7.97	39.69	39.80	34.99	37.32	38.21	43.61	39.88	39.25	39.46
Scan 6	27 week	8.17	40.77	41.23	38.01	38.56	39.96	45.69	41.85	41.12	41.50
Scan 7	33 week	8.03	41.60	41.36	37.43	38.77	40.45	44.23	42.65	41.89	42.31
Total Difference		0.32	1.75	1.64	3.52	7.47	4.29	1.30	5.53	5.74	5.48

Analysis of Body Shape Changes

To investigate the changes in body shape, anterior, posterior, and right lateral views of the participant's body, scans during her pregnancy were organized in chronologic order. In addition, the measurement changes of anterior-posterior abdominal depth, and the waist and hip widths were presented to quantify these changes numerically because there were no obvious visual changes (see Figure 10).

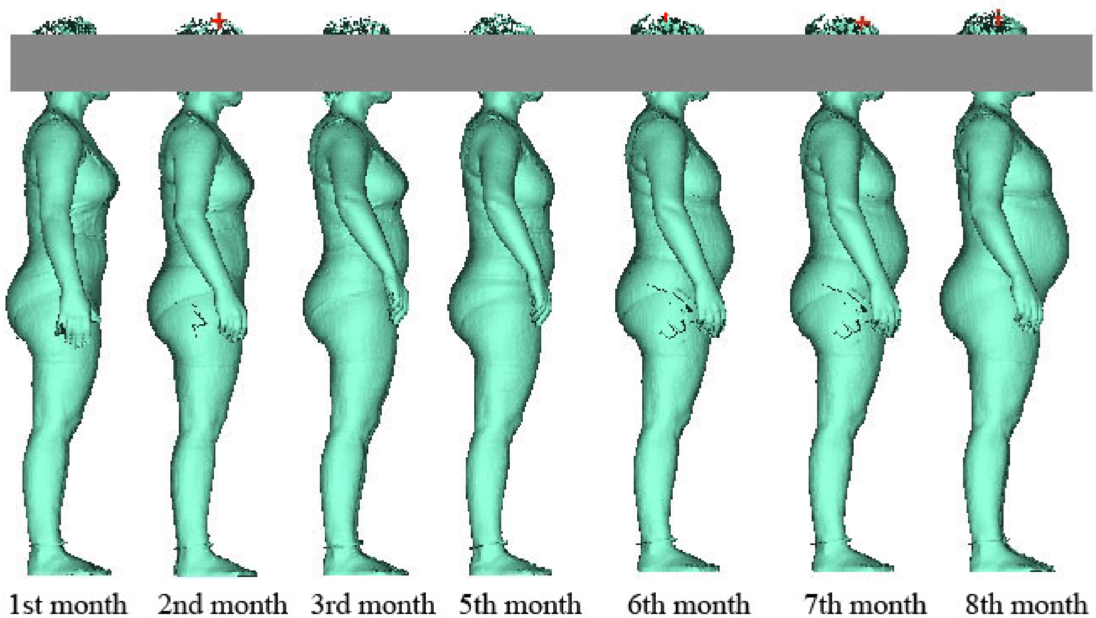


Figure 7 Lateral Views of the Seven Body Scans

Figure 7 illustrates a visible difference in the shape of each lateral view of the body during pregnancy. It shows that there is no externally visible indication of pregnancy until the third month (Body Scan 3). After the 3rd month, the abdomen starts to protrude. The abdomen is the most visible external change, and starting in the sixth month, the abodominal shape begins to grow rapidly. The measurements of the anterior-posterior abdominal depth increased by 3.69 (see Table 5).

Table 5 Measurement Changes of Anterior-Posterior Abdominal Depth, and Waist and Hip Widths
*unexpected reduction of measurement, possibly due to different undergarments

	Month of Pregnancy	Anterior-posterior abdominal depth	Waist width	Hip width
Scan 1	1st month	8.93	11.02	15.79
Scan 2	2nd month	9.43	11.34	15.80
Scan 3	3rd month	10.02	11.20	15.96
Scan 4	5th month	9.84*	11.20	15.41*
Scan 5	6th month	11.14	12.17	15.90
Scan 6	7th month	11.50	12.57	16.84
Scan 7	8th month	12.62	12.80	16.39

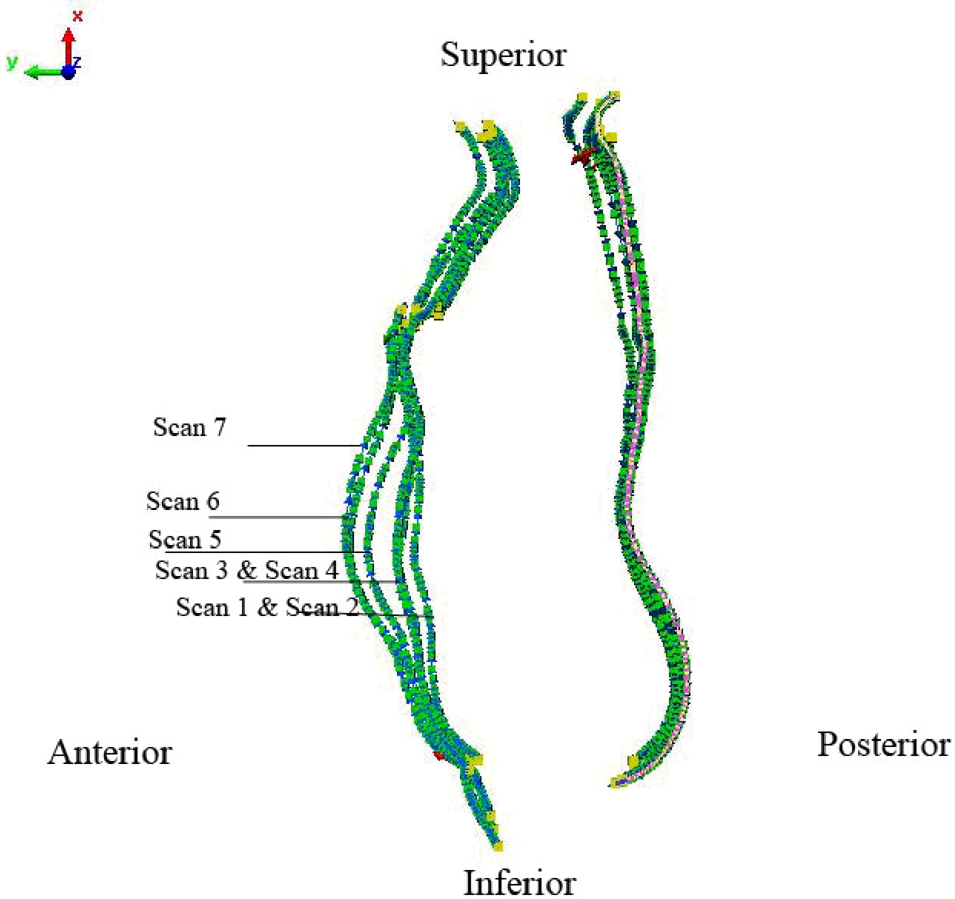
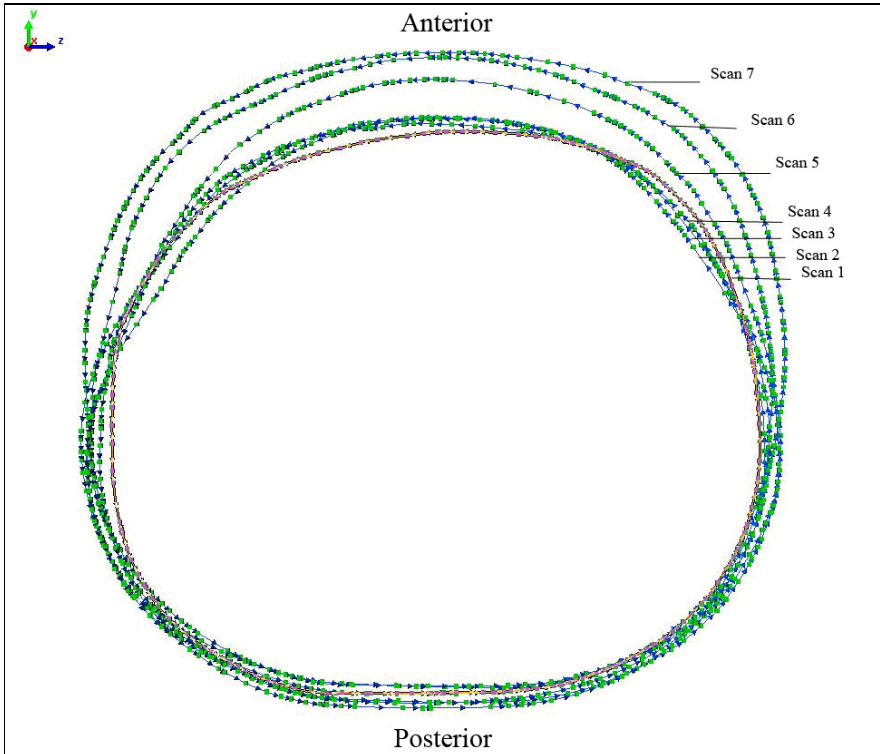


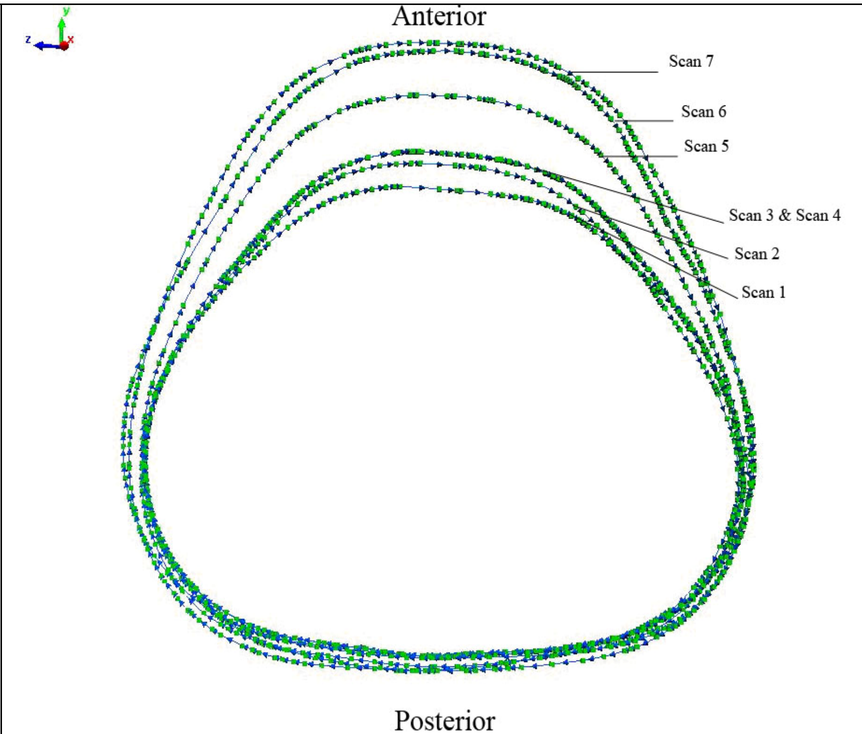
Figure 7 Overlaid Lateral Views of the Seven Body Scans

Seven lateral sections of the body scans were overlaid at the curve from the back waist point to the hip to provide a more detailed comparison of the silhouette changes in the midriff, waist, belly, and hips during pregnancy (see Figure 8). Each scan shows progressive body shape changes in the belly, hips, and midriff. The first month (Body Scan 1) and the second month (Body Scan 2) of pregnancy had a flat abdomen shape from the midriff to the hips, and the outline of the back was flat. The third month (Body Scan 3) and fifth month (Body Scan 4) of the pregnancy presented similar abdomen shapes but had a greater protrusion in comparison to Body Scan 1 and Body Scan 2. However, the abdomen shape change in the sixth month (Body Scan 5) of pregnancy was significant, and the lower abdomen shape under the belly began to expand along with the abdomen protrusion. In the seventh month (Body Scan 6) of pregnancy, the midriff shape expanded along with the earlier increases in the abdomen and hips. The difference between the midriff circumference and breast circumference was about 3.00 in. between Body Scan 6 and Body Scan 7, compared to the 6.00 in. difference in Body Scan 1 through Body Scan 5. In the eighth month (Body Scan 7) of pregnancy, the center front midriff point expanded more as the abdomen continued to enlarge. Even though it was not visually notable, a change in body posture can be detected; the posture gradually slanted to the back to balance the larger belly. According to Nicholls and Grieve (1992), trunk inclination increases significantly during pregnancy.



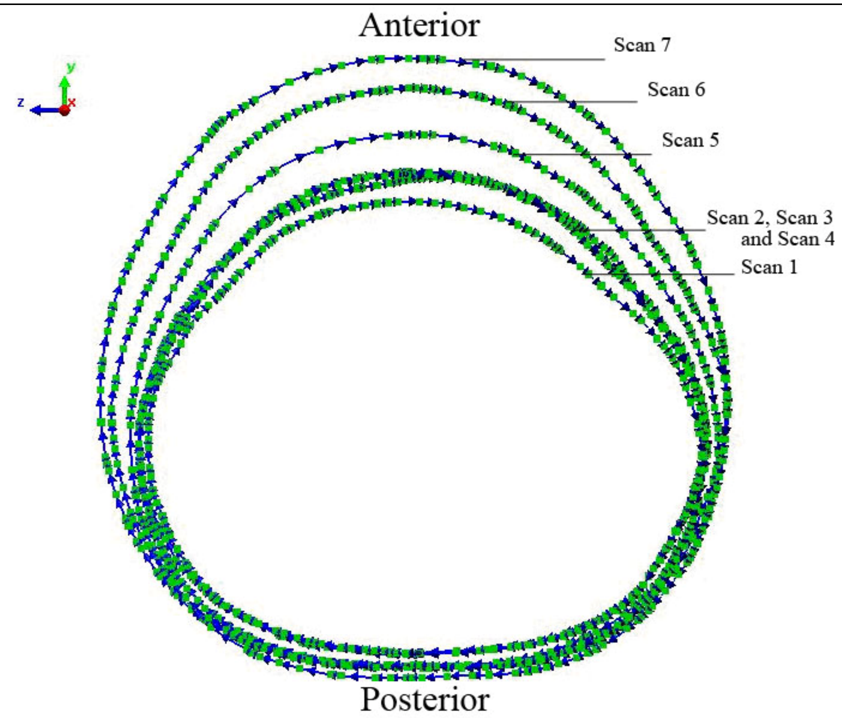
Midriff

- The midriff circumfernece increased during pregnancy.
- The contours changed; the dimension increased, and the shape became more rounded.



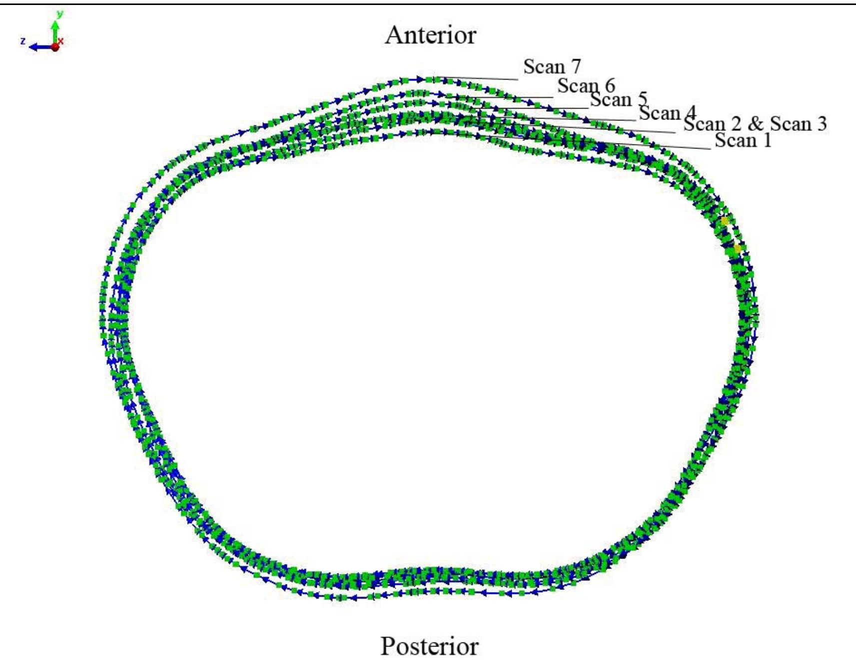
Maximum belly

- The maximum belly increased.
- The contours changed; the shape became more elliptical, and the side angles became sharper.



Waist

- The waist circumference increased.
- The contours changed; the shape became more rounded (but less rounded than the midriff) and more pointed (but less pointed than the maximum belly)



Hip

- The hip shape did not change as much as the midriff, maximum belly, waist, and hips.
- The outlines changed slightly; the contour shape remained constant with the center front bulging out slightly.

Figure 8 Contour Changes of the Transverse Views of the Midriff, Waist, Maximum Belly and Hips with Descriptions

Figure 8 illustrates the contour changes of the transverse views of the midriff, waist, maximum belly and hips. In general, there were notable changes between the fifth month (Body Scan 4) and the sixth month (Body Scan 5) of pregnancy. From the sixth month of pregnancy, the shape changes were clearly visible.

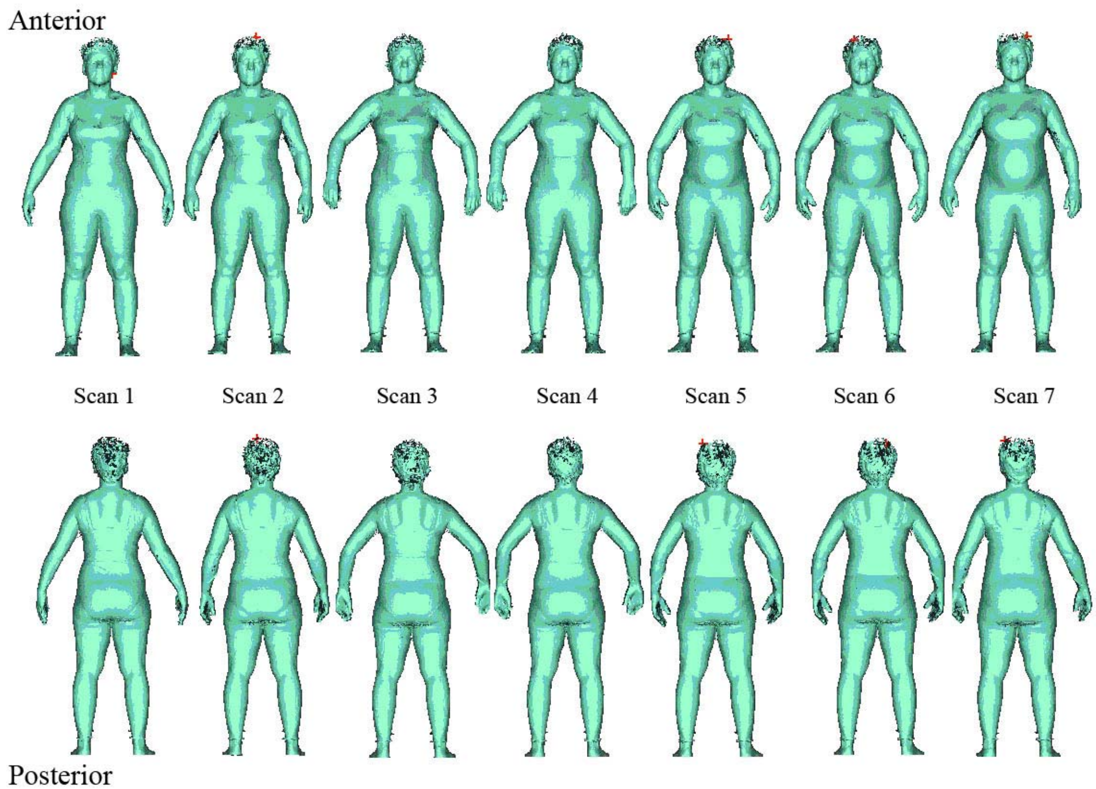


Figure 9 Anterior and Posterior Views of the Seven Body Scans

Figure 10 shows little visible difference in the anterior and posterior views of the participant's body scan. The seven body scans were arranged chronologically from the 1st, 2nd, 3rd, 5th, 6th 7th and the 8th month. The silhouetted outlines of each month's body scan did not markedly change even though the waist and hip width increased slightly. The waist width increased by 1.78 in., and the hip width increased by 0.60 in. (see Table 5).

However, due to the visual contrast created by shading in the abdominal areas throughout the body scan images, the participant's abdominal shape change was visible.

Analysis of the Relationship between Body Changes and Pattern Changes

To explore the relationship between changes in body measurements and shapes during pregnancy and changes in pattern measurements and shapes, virtual fit-to-shape dresses were developed using digital 2D pattern adjustments based on multiple 3D digital draping and virtual fit assessments in a digital environment. The fit-to-shape dresses reflected the pattern adjustments needed to fit each body scan.

A sleeveless sheath dress, size 8, 100% cotton, plain-woven fabric was fit to VM month 1 and used as the test garment for this study. Each pattern alteration was done using the final pattern from the previous month's VM. For example, the pattern for VM month 6 was used as the starting point to alter the pattern for VM month 7. In order to evaluate the accuracy of adjustments, a fit test on the 3D VM was done each time an adjustment was made. For the virtual fit assessment, the 2D digital patterns were digitally draped onto the VM. The virtual fit assessment and the 2D pattern-making process were interactively used to manipulate the patterns, leading to better garment fit for each VM. According to Zangrillo (1990), garment fit can be improved "when flat pattern designs are made from a sloper and then draped on a dress form." The 2D pattern adjustment process was guided by the visual results from the digital draping, but numeric inputs were needed to adjust the 2D patterns in Optitex™. This entire process illustrates how body shape affects the pattern shape.

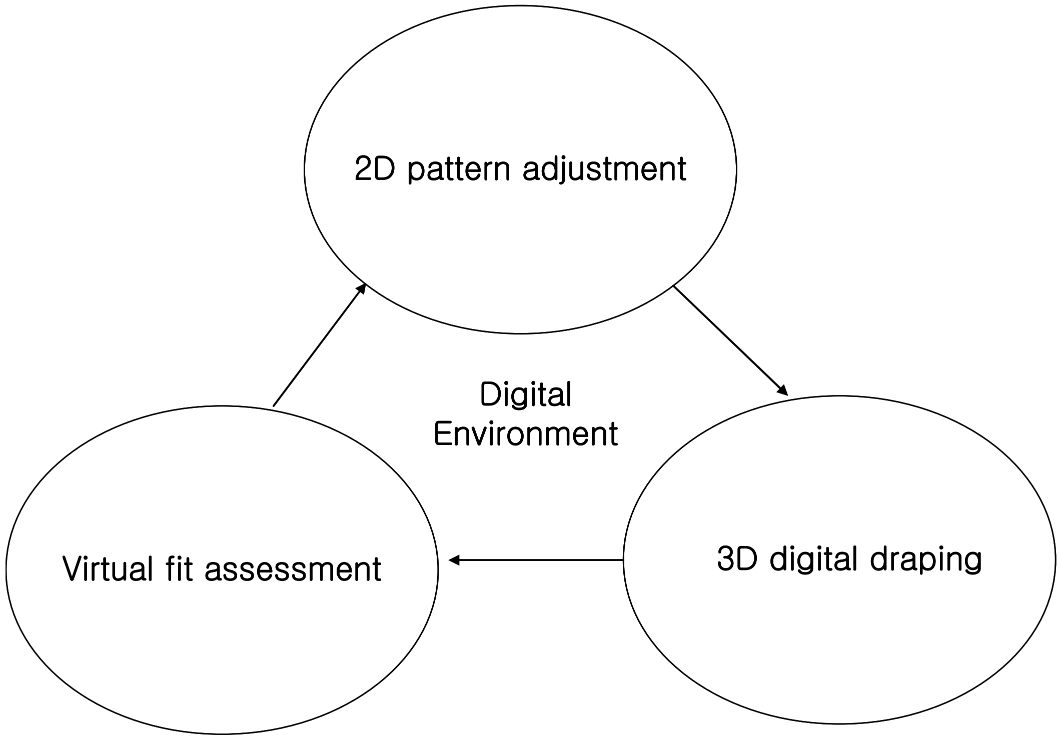


Figure 10 Pattern adjustment process

Pattern adjustment

Visible external body changes occured after the third month (Body Scan 3); thus, the pattern was manipulated for VM month 3 through VM month 8. The first pattern was adjusted to fit VM month 3 and VM month 5. Adjustments for VM month 1 through VM month 5 were minor and included a dart location manipulation on the neck area, one front dart elimination, and an increased length of the front pattern. Notable body changes occurred beginning with VM month 6, and are visible in the lateral view. There was a 6.00 in. increase in waist circumference and a 3.00 in. increase in belly circumference (see Table 4).

When fit problems occurred during a virtual fit test, the pattern was adjusted using the 2D pattern making tools in Optitex™. Each pattern was adjusted for the subsequent

VM based on changes in shape. According to Minott (1978, p121), “poor fit results from a pattern length or width.” Thus, the patterns were mainly adjusted in length and width in this study.

The size 8 sheath dress pattern, fit well on VM month 1 and 2, except for the neck area, so the shoulder dart was moved to the neck, to improve the fit in the neck area. This was likely a standard alteration for this individual pre-pregnancy

Figure 11 Illustration of Final Pattern on VM month 1

Figure 12 Illustration of Final Pattern on VM month 2

The abdomen began to protrude and its shape became more elliptical in VM month 3, which required the elimination of the front dart located closer to the center front, and an increase in the front length until the hemline hung evenly. A total of ½ in. was added at the center front hemline and blended to 0 at the side seams. There were few measurement and shape changes in VM month 5; thus, the same pattern was used for VM month 5 as no adjustments were necessary

Figure 13 Illustration of Final Pattern on VM month 3

Figure 14 Illustration of Final Pattern on VM month 5

The final pattern for VM month 3 was simulated on VM month 6. However, it did not fit well because of the expanding shape of the abdomen. The visual results of the virtual fitting showed that the waist area on the back was too tight and the side seams were tilted. Additionally, the front lengh of the dress was short and the hemline of the dress was not parerall to the floor. Thus, one back dart located next to the side seam was eliminated to give more ease to the back and sides. Still, the dress was too tight, but the remaining front and back darts were not eliminated to maintain the original fit and style of the sheath dress. Instead, the front and back waist and hip widths were increased until the tightness and tension pulls disappeared. The front length was then increased to make the hem line parallel to the floor, a total of 1.00 in.

Figure 15 Illustration of Final Pattern on VM month 6

The final pattern for VM month 6 was simulated on VM month 7. It was tight at the waist and hips on the back and on the abdomen. The same fitting and adjustment procedure was applied to the pattern adjustment for VM month 7. One front and back dart were maintained for the garment style. The waist circumference was increased by adding width to the front and the back waist until the side seams hung vertically. Then, the front length was increased to make the hem line parallel to the floor. Along with the increase in the waist and hips, the front and back hemline width was also increased an equal amount to maintain the style of the pattern.

Figure 16 Illustration of Final Pattern on VM month 7

The final pattern for VM month 7 was then simulated on VM month 8. It was too tight at the hips and waist on the back and the abdomen. The tension map also indicated that the garment was too tight at the bust. The same fitting and adjustment procedure was applied; the front and back waist width, the front and back hip width, and the front and back hemline width were adjusted until the pulls around the torso disappeared and the hem was parallel to the floor. The depth and width of the bust dart was increased to accommodate a fuller, rounder bust. VM month 8 had the largest abdomen, and the abdominal shape was elliptical rather than rounded. Thus, the front dart needed to be moved closer to the side seam for a smooth fit.

Figure 17 Illustration of Final Pattern on VM month 8

Pattern shape changes

Pattern shape refers to the contained outline of any pattern piece that creates a form. Traditionally, a two-dimensional pattern is used to make a garment that should fit the three-dimensional body shape. In this study, the body shape was used to fit the 2D pattern on the 3D body digitally. Body measurements were not used in this study because pattern dimensions were not used – the changes in shape guided the pattern adjustments. However, to discuss pattern changes, specific measurements were used for clarity in addition to descriptions of body shape changes.

Analysis of the visual data from the fit-to-shape 2D pattern nest is presented in the following section. Figure 19 shows the changes in pattern shape, which corresponded to changes in the body. Specifically, the shape changes at the bustline, waistline, hipline, hemline, and length are described.

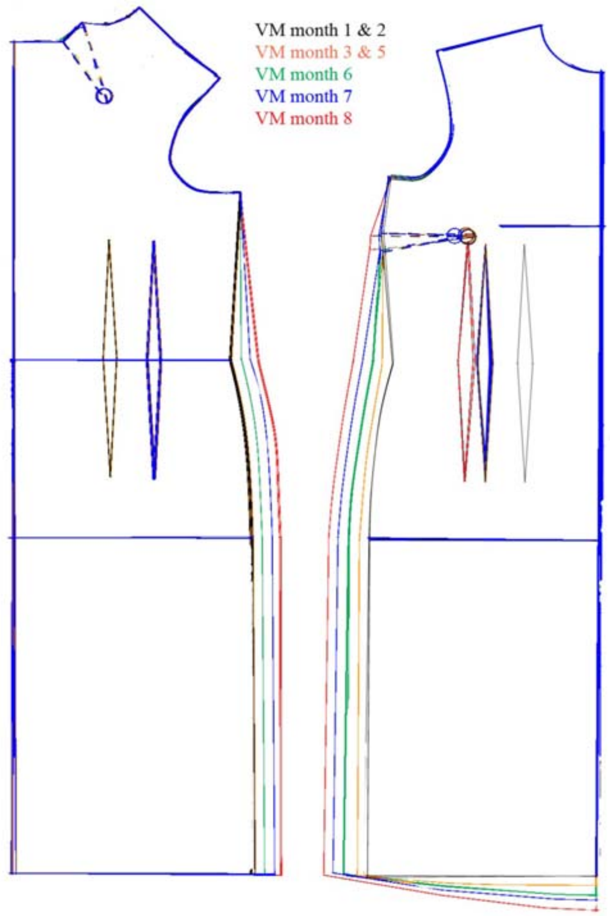


Figure 18 Fit-to-shape 2D pattern nest

Analysis of the pattern nest indicates that the width of waist, hip, and hem and the front length gradually increased in an even progression even though the body did not grow in this way. However, the contours of the side seam and hemline did change, corresponding to the body changes. While the patterns for VM month 1 and VM month 2 clearly show the location of the waistline with an indentation, the side seam of the pattern for VM month 8 does not include an indentation for the waistline. The hemline of the pattern for VM month 1 and VM month 2 is flat, but it becomes more rounded at the center front each subsequent month because the center front length increased while the length of the side seam was maintained. Both contour changes in pattern shape reflected the abdomen extension during pregnancy.

Relocation or elimination of the darts was directed by changes in the body. One front dart located in the closest-to-center position was eliminated in the pattern for VM month 3 and VM month 5 because of the increasing roundness of the abdominal shape. In the pattern for VM month 8, the front dart moved toward the side seam to accommodate the increased abdomen circumference and more elliptical abdominal shape. In addition, due to the fuller and more rounded bust shape, the bust dart was increased by ¼ in. in width and decreased by ¼ in. in length in the pattern for VM month 8.

The patterns were adjusted not only to accommodate body changes but also to maintain the garment style. For example, one back dart located in the closest-to-center position was eliminated in the pattern for VM month 6 to help maintain the balance between the dress front and back. Increased hip and hem widths of the patterns increased in proportion to growth at the bust and waist to maintain the original garment style as closely as possible, but these pattern changes were not necessary due to body measurements or shape changes.

Bust

Dramatic changes were not observed in the bust circumference. Only a 1.64 in. total increase in the bust circumference was observed in this case study. The pattern alteration to the bust dart was only required on VM month 8; the bust dart length was decreased by ¼ in. and its width was increased by ¼ in. Thus, the bust circumference of the pattern was increased by ½ in.; this amount of change did not correspond to the amount of the bust circumference increase (1.64 in.) However, the change in the bust dart length and width accommodated the participant's bust shape changes. Manley (1997) stated that the bust typically increases 7 to 12 cm (2.76 in. to 4.7 in.) during pregnancy. An average increase of two or three inches in bust circumference is usually expected (Sadler, 1974). There is evidence, however, that the scansuit may have compressed the bust area, making the measurement smaller than the actual size. In a study by Kim, Sohn, LaBat, & Bye (2009), the results showed that the scansuit significantly affects the body scan data. Because the soft bust tissue compresses easily, the measurements in the bust area were found to be most affected.

Waistline

Changes in the abdominal measurements and shape beginning at the third and fifth month of pregnancy required that the front waist width of the patterns for VM month 3 and VM month 5 through VM month 8 increased by ½ in. each. A total of 2.0 in. was added to the waist on each front pattern. The back waist width of patterns for VM month 6 through VM month 8 increased by ½ in. each (1.5in. total). The waist darts are associated with the waist width, but are also connected to shape. In the pattern for VM month 3 and VM month 5, one front dart, which was located in the closest-to-center position, was eliminated because of the increasing roundness of the abdominal shape. In the pattern for VM month 6, one back dart located in the closest-to-center position was also eliminated to help to maintain balance between the dress front and back. In the pattern for VM month 8, the front dart moved 1.00 in. toward the side seam to accommodate the increase in abdomen circumference and the abdominal shape. The abdomen shape became more eliptical during the pregnancy, thus the dart needed to be moved to accommodate the sharper angle of the abdomen.

Hips

Along with the waist width changes, the front hip width of the patterns for VM month 3 and VM month 5 through VM month 8 also increased by ½ in. each (2.0 in. total), and the back hip width of the patterns for VM month 6 through VM month 8 increased ½ in. each (1.5 in. total), even though the hip circumference changed less than this amount. Specifically, a total hip circumference measurement change from VM month 1 to VM month 8 was 1.30 in. In terms of hip shape, the lower abdomen protruded toward the front, and the hip width also increased by 0.60 in. The pattern changes were not due to the body measurement changes, but were to meant maintain the garment style. The sheath dress is not fitted close to the body through the hips; thus, changes in the hip measuremnts and shape had little impact on the final pattern measurements and shape.

Length

The length of the front dress pattern should correspond to the abdomen extension and the posture changes. During the pregnancy, the abdomen dramatically increased and the posture was slanted more to the back; thus, the vertical length of the front pattern required increased length. From the pattern for VM month 3 and VM month 5, the front length was increased by 1/2 in. each which also led to changes in the hem shape. The hemline that connects the center front and the side seam increased in length and curved at the center front to avoid a pointed shape (^).

Hemline

In order to balance the waist and hip width alterations and maintain the final garment style, the front and back hem circumference of the patterns for VM month 6 to VM month 8 was also increased by ½ in. each.

CHAPTER 5: Summary and Conclusion

The purpose of this investigation was to examine the changes in body measurements and shapes during pregnancy and to analyze the relationship between those changes and pattern measurements and shapes. A single case was used in this study with one participant who was scanned seven times during eight months of her pregnancy. This chapter summarizes the procedures and the findings of this study, presents conclusions, and makes suggestions for future research.

Summary of Research Procedure

A single case study method was used to observe one participant's body measurement and body shape changes during pregnancy, and the relationship between these body changes and related pattern changes. A Human Solutions VITUS/SMART 3-D scanner was used to scan the participant to obtain body measurements and body shapes. The participant was scanned and weighed seven times from the first month of her pregnancy to the eighth month. Seven body scans were prepared for use as 3D virtual models for pattern adjustments. For this study, a sleeveless sheath dress was used as the test garment because it skims the body from the neckline to mid-leg, conforms to the base of the neck and armcye, and reflects overall body posture. The dress pattern was developed to fit the participant without a waistline seam, and with fullness controlled by side seams, front bust darts, two-ended front and back waist darts, and back shoulder darts. Findings were analyzed by the changes in body measurements and body shapes and the relationship between the body changes and pattern changes. The entire pattern adjustment process represents the analysis of the relationship of body changes to pattern changes.

Nine areas including breast circumference, chest band, midriff circumference, waist circumference, waist band, high hip circumference, hip circumference, belly circumference and maximum belly circumference were measured and examined to analyze the changes of body measurements. These body surface measurements were then extracted by ScanWorx ™. For the analysis, the areas that markedly increased or decreased were examined. The body shapes changes were analyzed from the anterior, posterior, lateral and transverse views of the seven body scans, in addition to the measurement changes of anterior-posterior abdominal depth, waist and hip width. Additionally, seven lateral sections of the body scans were overlaid and analyzed to provide a more detailed comparison of the silhouette changes in the midriff, waist, belly and hips during pregnancy. Visual analysis focused on the changes in contour, size and shape. Finally, virtual fit-to-shape patterns were adjusted to fit each Virtual Model (VM). Three-dimensional digital draping was used to adjust patterns and test fit, and the seven body scans were used to create a 3D virtual fit model for each month. The patterns were adjusted through multiple trials of fitting on the 3D virtual fit model. Then, the seven 2D front and back fit-to shape patterns were overlaid in order to analyze the pattern shape changes.

Summary of Findings

The results of this study indicated that body measurements and patterns did not increase proportionally to each other. The measurements of the participant's torso (i.e., chest, abdomen and pelvis), were the main areas that changed during pregnancy. The largest increase was more than five inches in the abdomen. From the sixth month of pregnancy to the final scan at the eighth month, body measurments and weight rapidly increased.

In terms of body shape changes, from the third month of pregnancy, body changes were visible. Although the abdomen began to protrude in the third month of pregnancy (Body Scan 3), the abodominal shape grew much larger in the sixth month (Body Scan 5) of pregnancy. Belly circumference (2.36 in.) and the maximum belly circumference (1.94 in.) increased from the fifth month to the sixth month, while they only increased by 0.18 in. and 0.92 in. each from the first month to the third month. In the overlaid lateral views of the seven body scans, it was possible to conduct a more detailed comparison of the silhouette changes in the midriff, waist, belly, and hips during pregnancy. The second month (Body Scan 2), third month (Body Scan 3) and fifth month (Body Scan 4) of the pregnancy presented similar abdomen shapes. When compared to Body Scan 1, the abdomen protruded slightly. However, the abdomen shape change in the sixth month (Body Scan 5) of pregnancy was dramatic. In general, from the sixth month (Body Scan 5) of pregnancy, the shape changes were very visible. The midriff shape began to change along with an enlarged abdomen and hips in the seventh month (Body Scan 6) of pregnancy. In the eighth month (Body Scan 7) of pregnancy, the midriff point moved out as the abdomen continued to protrude more. In addition, a posture change was observed even though it was slight. The contour changes of the transverse views of the midriff, waist, maximum belly, and hips showed dramatic increases between the fifth month (Body Scan 4) and the sixth month (Body Scan 5) of pregnancy. Thus, both the body shapes and measurements dramatically increased from the sixth month on; however, there was little visible difference in the anterior and posterior views of the participant's body scan. Most importantly, shape changes vary during pregnancy. In the transverse views of the midriff, the shape became more rounded, but in the transverse views of the maximum belly, the shape became more elliptical, and the side angles became sharper. However, the shape became more rounded (but less rounded than the midriff) and more pointed (but less pointed than the maximum belly). At the hips, the outlines changed slightly; the contour shape remained constant with the center front bulging out slightly.

Pattern changes corresponded to the body changes. Because visible external body changes occured after the third month (Body Scan 3), the pattern was manipulated for VM month 3 through VM month 8. However, most noticeable body changes occurred beginning with VM month 6. Thus, alterations were necessary for each dress pattern for the sixth month, seventh month, and eighth month of pregnancy.

Specifically, due to the dramatic changes in abdominal measurements and shapes from the sixth month (Body Scan 5) of pregnancy on, the front and back waist widths of the patterns for VM month 6 – VM month 8 increased by 1/2 in. each. Along with the increases of waist width, the hip and hemline width were increased to maintain the garment style. The front and back hip width of patterns for VM month 6 – VM month 8 were also increased by 1/2 in. each and the front and back hem sweep of the patterns for VM month 6 – VM month 8 were also increased by 1/2 in. each. Because the abdomen began to increase from the third month (Body Scan 3), the front vertical length increased by 1/2 in. each for the pattern for VM month 3 and VM month 5.

Relocation or elimination of the darts was directed by changes in the body. One front dart, which was located in the closest-to-center position was eliminated in the pattern for VM month 3 and VM month 5, and the front dart moved toward the side seam to accommodate the increase in abdomen circumference and more elliptical abdominal shape The breast circumference had increased by 1.64 in. over the entire pregnancy in this study, so the bust dart width was increased by 1/4 in.

The patterns were adjusted not only to accommodate body changes but also to maintain the garment style. Analysis of the pattern nest indicates that the width of waist, hip, and hem and the front length gradually increased in an even progression even though the body did not grow in this way. An increase in hip and hem widths of the patterns increased in proportion to growth in the bust and waist to maintain the original garment style as closely as possible. The pattern changes were not necessary due to body measurement or shape changes.

Conclusion

The findings of this study suggest that consideration of body shape during apparel pattern development offers valuable information related to fit that goes beyond standard linear measurements. The consideration of body shape provides details about the variation of the body surface, volume, or data from body slices, contributing to a better-fitting garment pattern. For example, there might be a unique shape variation that is not evident from a linear circumference because the human body is three dimensional. Darts are very important to make a 2D pattern fit onto a 3D body. The location, width, and the number of darts were closely related to the fit of the garment in this study. For example, because the abdominal shape became more pointed during the pregnancy, one front dart located in the closest-to-center position needed to be eliminated and moved toward the side seam for a better fit. Shape information guided the pattern changes in a way that linear measurements could not.

Many individuals need alterations to accommodate shape variations that differ from the shape for which the pattern was drafted originally. However, body changes during pregnancy vary from month to month. For example, changes in the transverse views of the midriff, waist, maximum belly, and hips were different from month to month in this study. The shape of the maximum belly became more pointed and the side angles became sharper during the pregnancy. In contrast, the shape of the midriff became more rounded. Thus, the maternity wear pattern development process should consider body shape changes as well as body measurement changes.

One of the most significant and innovative characteristics of this study was the use of 3D technologies to evaluate the fit of maternity wear. The use of ScanWorx™ and Polyworks™ provided details about body shape changes as well as linear measurements. The vertical slices of the torso and the various transverse views provided shape information that has not previously been applied to pattern development. Thus, this case study documents the application of shape information gained through visual analysis to the pattern development and fit process.

A virtual fitting method in a 3D virtual try-on simulation was used as the method of fitting in this study. Traditional fitting methods have limitations. They require extra time and effort, and increased financial expense because a new trial garment must be constructed for each fit revision (Liechty, Pottberg, & Rasband, 1986). However, a 3D virtual model and 3D virtual try-on simulation made it possible to remove these limitations. These 3D technologies can provide computer-generated visual displays of how garments will look on the body without the use of fabric and live fit models and reproductions of trial garments. The pattern alteration for this study was done without any actual fabric, so it did not require extensive time or expense. The interactive adjustment and fit simulations allow quick experimentation and visual results that are not dependent on specific measurements.

In this study, body scans from a 3D body scanner were used as virtual models to adjust the patterns and test fit. These virtual models can be permanently recorded and used anytime. An advantage of the permanent record of the virtual models is that it allows researchers to explore fit on bodies that are under constant change with little inconvenience to the participants.

Limitations

This study was limited to one participant. More participants are required before any generalized conclusions can be made. Further research on body changes during pregnancy will require more subjects to obtain more diverse data.

This study was also limited to the times when the participant was available to be scanned. Depending on the participant's health, the scanning schedule was changed or canceled. In this study, scans for the fourth month and ninth month could not be completed.

Another limitation of this study was that it was limited to one style of garment and the fabric variable that existed in the software. As fabric parameters, this study used the sleeveless sheath dress and 100% cotton plain-woven fabric available in the OptiTex™ software.

Finally, this study was limited by the use of the scansuit, so body surface measurement data from the 3D body scanner might be inexact. For modesty purposes, a scansuit was used for scanning, but there is evidence that the scansuit may compress the soft bust tissue, compromising the accuracy of the measurements.

Recommendations

Future research should focus on expanding the number of participants to investigate changes in body measurements and shape during pregnancy and to develop better fitting maternity wear for more women because people have a variety of body shapes and body characteristics. Furthermore, more diverse populations of pregnant women such as Asians, Hispanics, or African American populations with different body types should be studied. Future research could also consider the use of a 3D virtual model for developing garments for different populations who are likely to have difficulty participating in traditional fit evaluations, such as the elderly.

This study considered two factors that contribute to garment fit on the body: the garment pattern and fabric. Future research should consider more variations in garment style and fabric type. Consumers' individual fit perceptions can also contribute important information to improving garment fit.

The sleeveless sheath dress was chosen as a test garment because it skims the body from the neckline to mid-leg, it conforms to the base of the neck and armcye, and it reflects overall body posture. This garment style, however, did not reflect the body shape changes from abdomen to hip because it was not fitted close to the body in those areas. Thus, in future research, garments that fit close through the hips, such as pants, would further illustrate the body changes in the pattern.

A future focus might compare the reliability of visual analysis of a 3D virtual simulation with the actual fit evaluation on live fit models. A study on accuracy of the fit evaluation during a 3D virtual simulation is recommended. The realism of a reproduction of the mechanical features of fabric materials must also be studied.

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