Anthropometric Dynamics of Pregnant Women and Their Implications on Apparel Sizing

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Abstract

Anthropometric changes of pregnant women possess interesting dynamics that are mostly non-linear. These changes can be studied effectively with the use of 3-dimensional digital representations of their body at different time periods following gestation. This research discusses (a) a systematic evaluation of the non-linear changes observed in three key measurements of pregnant women – the bust, the waist, and the hip circumferences, and (b) comparison of these changes in terms of their compliance with the maternity wear sizing standard ASTM, D7197-13. Three-dimensional scanned data of 20 subjects from the study by Perkins et al [1] that include scans at six time periods along the span of gestation to post-delivery were imported into Polyworks for measurement. For each subject the levels for the bust, waist, and hip circumferential measurements were determined first for the scan at 4-16 weeks of gestation; measurements at all other time periods were taken at the same respective levels from the floor. Differential changes in the measurements between the periods of time windows are non-linear within a given measurement and also between the measurements. Subsequently, these changes were compared with the estimated changes recommended by the ASTM standards, i.e., an incremental increase of 9 inches at the waist, 4 inches at the hip and 3 inches at the bust during the 7th month after gestation. Wilcoxon signed-rank test ($\alpha = 0.05$) results showed that the actual measurement changes are significantly different from the ASTM's estimated changes in the cases of the waist ($p = 0.025$) and the hip ($p = 0.0001$), while the bust measurement is in agreement with the ASTM's estimate. If the observed differences between the actual and the estimated measurements are taken into consideration, a more reliable and robust sizing chart would result.

Keywords: 3D body scanning, pregnant women anthropometrics, digital apparel sizing

1. Introduction

Distinguishable anthropometric changes occur during the period of pregnancy. Body measurements and shapes tend to change significantly within the first three to four months of gestation. Anthropometrical changes of pregnant women should be carefully studied to fulfill the ergonomic requirements of products targeted for that population. Fewer studies are found in the literature regarding anthropometrical changes of pregnant women. Pheasant [2] attempted to predict the changes in the anthropometrics of expectant mother from a population in UK. However, the model was predominantly based on Japanese pregnant women. Another study by Fluegel, Greil, and Sommer [3] found that German pregnant women showed an average increase of 17% in weight, 27% in waist circumference, 6% in chest circumference and 4% in hip circumference between the fourth month and before delivery. Similarly, a study by Perkins and Blackwell (1998) found the most apparent changes in the waist, abdominal protrusion and weight for American women. They reported an average increase of 21% in weight, 35% in waist circumference, 10% in chest circumference and 7% in hip circumference between the 8^{th} and 37^{th} week of pregnancy.

Products designed for pregnant women should be reflecting these changes. In the apparel sector, maternity wear have a niche market and the garments are specially designed to fit and accommodate the altered measurements encountered by pregnant women. It is estimated that by 2015, the maternity apparel market in US will reach approximately 4.5 billion dollars [4]. Study by Ho et al [5] regarding the garment needs for pregnant women reported that the maternity support wear should possess functionality, comfort, safety, aesthetics and safe to put on and off. Further study by Ogle et al [6], reported that pregnant women are not finding well fitted maternity wear and are not satisfied with the maternity apparel. Working pregnant women want maternity wear which fulfill their attire requirements without compromising the self-image. However, whether the current maternity wear accurately represents the anthropometric changes for proper fit and comfort is still unknown. The purpose of this study is to analyze (1) the anthropometric changes of pregnant women and (2) to check whether the maternity wear apparel sizing standard (ASTM) is reflecting the original changes in the pregnant women body.

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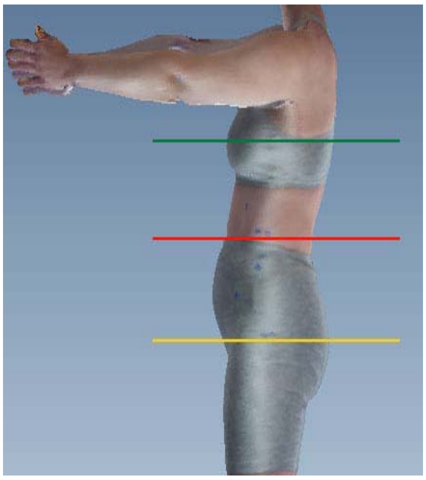
2. Methodology

Data from 3D body scans obtained by Perkins et al [1] were used in this study to assess the longitudinal anthropometric changes. The subjects were scanned using a Cyberware WB4 whole-body scanner at five different sessions throughout their gestation period (see Table-1) and one post-delivery session not exceeding 30 days from the delivery. The base-line scan was completed during the early periods of gestation, before any anthropometric changes had occurred. A total of 20 subjects present in sessions 1 and 4 were chosen for size migration assessment, and a subset of 13 subjects present in all the six sessions were chosen for the longitudinal assessment. Polyworks® v-12 was used to extract the body measurements at three chosen locations along the 3D scan data (see Table-2). The chosen locations carry the key measurements in maternity apparel sizing. These measurements were extracted to be in congruence with the standards for maternity wear suggested by ASTM.

Table 1. List of sessions in the scanning and the corresponding time period of pregnancy

Session	**1**	**2**	**3**	**4**	**5**	**6**
Period	Baseline Session (4-16 weeks)	20 weeks	28-29 Weeks	32-33 Weeks	37-38 Weeks	Post Delivery

Table 2. Measurement locations chosen for assessing the anthropometric changes



Measurement	**Definition**
Bust	The horizontal circumference around the body taken under the arms and across the fullest part of the chest/bust apex
Waist	The minimum horizontal circumference around the body at waist.
Hip	The maximum horizontal circumference around the torso taken at the greatest protrusion of the buttocks as seen from the side

Scans for each subject were aligned with reference to the ground plane, and measurement locations identified from the base-line scan were propagated through the scans obtained from the rest of the sessions. Subsequently, the cross-sections and the corresponding circumferential data were extracted, with the mean and standard deviation computed. Figure-1 shows the cross-section of the three locations (bust, waist and hip) across different periods of gestation.

Based on the computed measurements, each subject was assigned apparel sizes according to the actual measurements from session-1 and session-4, independently. Assignments were derived from (a) the Standard Table of Body Measurements for Adult Female Misses Figure Type Sizes 2–20-D5585-2001 [7] and (b) the Standard Table of Body Measurements for Misses Maternity Sizes Two to Twenty-Two -D7191-13 [8]. Simultaneously, the measurements from session-1 were incremented by a constant factor (4 inches increase at the hip; 9 inches at the waist and 3 inches at the Bust) recommended by ASTM (D7191-13) to generate a set of new *expected* measurements. A Wilcoxon signed-rank test was performed to compare the *expected* measurements with the *actual* measurements obtained from session-4.

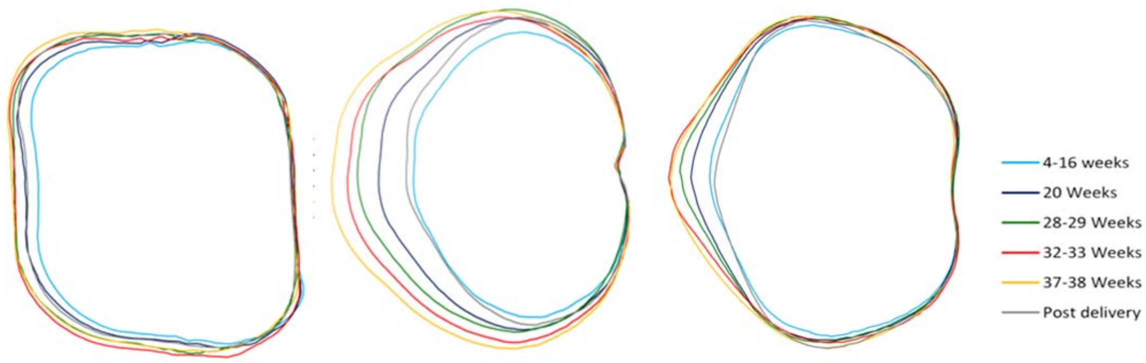


Figure 1. Cross-sections of the bust, waist, and hip (left to right) at different time periods of gestation.

3. Results

The mean and standard deviations of the three measurement locations for the 13 subjects are shown in Figure-2. Waist showed the most dynamic changes while bust measurements modulated the least. The changes in the measurement between subsequent sessions were calculated for sessions 1 through 5. Figure 3 shows the mean and the standard deviation of the differential changes across these sessions. Additionally, the differences in the size assignments between the *expected* measurement obtained via ASTM recommendations and the *actual* measurement obtained from the 3D scans is shown in Figure-4. A Wilcoxon signed rank test was conducted to determine whether the *expected* and *actual* measurements differ significantly. Results showed that the actual measurement changes are significantly different from the ASTM's estimated changes in the cases of the waist ($p = 0.025$) and the hip ($p = 0.0001$). The size estimates based on the expected measurements were predominantly larger than the actual size.

4. Discussions

Affective fit of maternity wear is greatly influenced by proper fit and sizing of the product. According to the convention used by ASTM for maternity wears, each sizing number in the maternity wear corresponds to the same sizing number in the regular wear, i.e., a pregnant end user falls under the same size category as that of the normal wear. However, since the sizing charts for the maternity wear are based on an expected increment, which is significantly different with the actual increment, there is a possibility of inadequate fit with the current ASTM convention. The Wilcoxon signed rank test showed that the actual measurements differ significantly with the ASTM's expected measurements for the waist and the hip. However, the bust measurements are statistically coherent with the standard changes. Out of the 20 subjects, only one subject was in agreement with the ASTM standards for all the three measurements, three subjects were in agreement for any of the two measurements, 10 subjects matched with ASTM for only one of the measurements and the rest six subjects did not follow the *expected* measurement changes in any of the measurements. Furthermore, the changes in the body measurements do not follow a linear increment, rather follow dynamic increments. This may suggest that when a sequel of maternity wears is manufactured for different periods of pregnancy, a non-linear grading system should be appropriate. It is also shown that different regions of the body changes to different apparel sizes during pregnancy. The ASTM standard chart has attempted to address this issue with different constants for incrementing at different locations of the body. Nevertheless, the actual changes observed in this sub-population showed that the changes in measurements lead to different sizing choices when selected from a particular measurement. For example, the body measurement might suggest a size to be compatible when chosen based on hip measurement, but suggest a different size when selected with waist size as the criterion. These discrepancies caused by the dynamic changes in anthropometry due to pregnancy are not sufficiently addressed in the present sizing systems, in general. The 3D body scan data can be of particular advantage to estimate the dynamics exhibited longitudinally, thereby would allow to redefine the basis of the sizing standards. Concluding, the two key observations that can be made from the analyses are (i) the anthropometric changes do not follow a linear change across different periods of pregnancy, and (ii) these changes are significantly different from the *expected* changes recommended by ASTM standards.

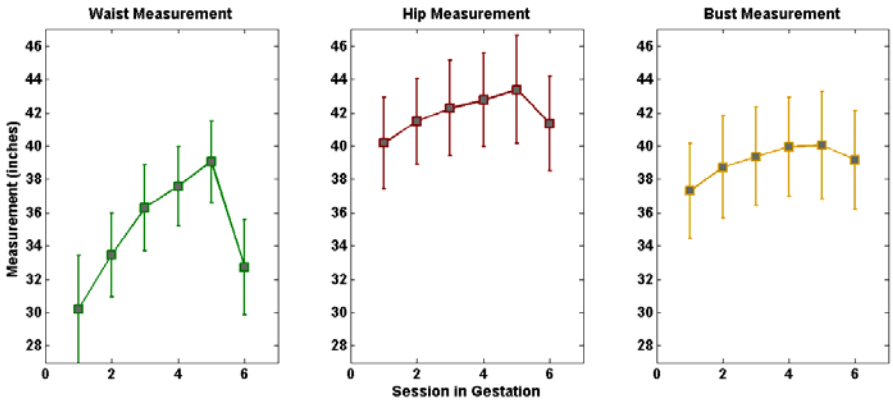


Figure 2. Statistics of the three key measurements obtained over the six sessions. Waist showed the maximum change.

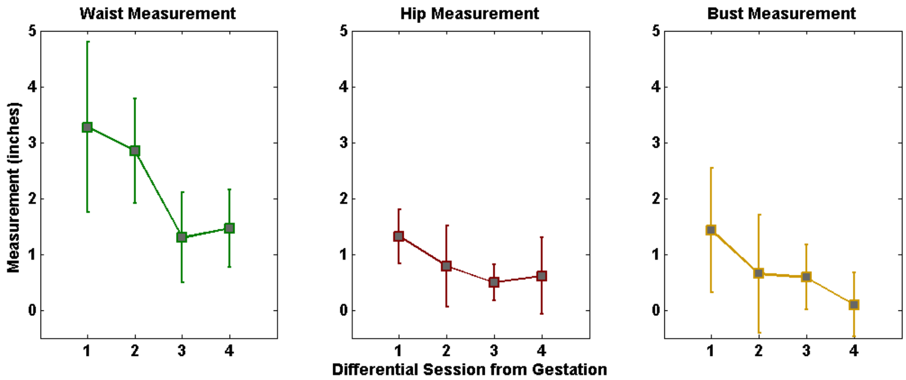


Figure 3. Change is measurement in each session is shown for sessions 1 through 5. The change would be constant if it changes linearly. The actual anthropometric changes are shown to be non-linear.

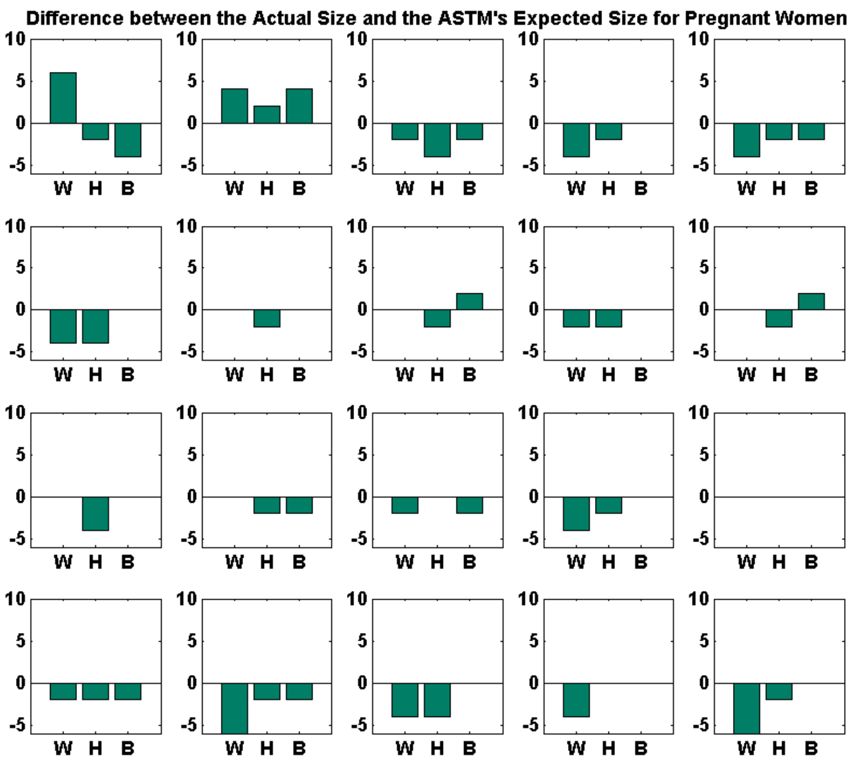


Figure 4. Difference in size categories as estimated by the measurement-based actual size and the ASTM-based expected size for waist (W), hip (H), and bust (B). The difference is given as an even number because the considered ASTM standard uses even numbers as size designation. The number is positive when the ASTM-based expected size is smaller than the measurement-based actual size.

Figure 4 shows the results from each of the 20 subjects. For example, for subject 1 in the upper left corner the ASTM predicted size was 6 sizes smaller than the actual size for the waist measurement, one size larger for the hip measurement and two sizes larger for the bust measurement. Except one subject, the rest were in disagreement with the ASTM sizing in at least one of the three locations.

5. Conclusion

We used 3D body scanned data of pregnant women to study the anthropometric changes at different landmarks along the pregnancy period. A total of 20 subjects along six sessions were studied to assess the changes in body measurements at three key locations, i.e., the bust, waist and hip. We showed that the changes in anthropometric measurements are non-linear and are statistically different from the maternity standards of ASTM.

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