Comparative Analysis of Body Measurement and Fit Evaluation between 2D Direct Body Measuring and 3D Body Scan Measuring

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Abstract

This study purposed to analyze differences in body measurement between the 2D direct body measuring method and the 3D body scan measuring method and to perform the appearance evaluation and cross-sectional evaluation of the fit of pants to which body measurements obtained by each measuring method were applied. Body measuring was conducted in 10 women in their 20s-30s using 2D direct body measuring and 3D automatic measuring with Hamamatsu body scanner. Among the 10 women, 3 participated in experimental garment wearing. Experimental pants were made using their 2D direct body measurements and 3D automatic measurements, and wearing tests were performed through expert evaluation and cross-sectional evaluation. The results of the experiment were as follows.

According to the results of comparative analysis on differences between 2D direct body measurements and 3D scan measurements, 3D automatic measurements were significantly larger in bust circumference, ankle circumference, armscye circumference, shoulder length, scye depth, and arm length. As circumferences measured with the 3D body scanner were somewhat larger than directly measured ones, it is suggested to adjust ease when using existing pattern making methods. We prepared experimental garments by the same pattern making method through applying body measurements obtained with the two measuring methods, and assessed the fit of the garment comparatively through expert evaluation and 3D scan cross-sectional evaluation. According to the results, 2D-pants using 2D direct body measurements was slightly tighter than 3D-pants using 3D measurements in waist circumference, hip circumference, and abdominal circumference. In the results of comparing appearance in terms of the fit of the experimental garment in each subject, significant difference was observed in most of the compared items. This result suggests that 3D automatic body measuring data may show different accuracy according to body shape and therefore it is necessary to examine difference between 2D direct body measurements and 3D automatic measurements according to body shape.

Key words: 3D body scan measurement(3차원 인체스캔측정), 2D direct body measurement(2차원 직접인체측정), fit(맞음새), body shape(체형).

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I. Introduction

In response to rapid changes in the clothing market, countries throughout the world including developed countries are developing body measuring systems using 3D body scan data and 3D body measuring data obtained using 3D body scanners are being used in increasingly diverse areas. As a result, the 3D scan body measuring method, which can obtain accurate measurements quickly, is replacing body measuring methods that measure lengths and circumferences on body surface using a measuring tape and methods measuring body surface angles, etc.\(^1\)

Various types of 3D body scanners have been developed and being used including light-based systems such as NX16 System of [TC]\(^2\), TriForm Body-Scan of Wicks and Wilson Limited, and SYMCAD 3D Virtual Model of Telmat, and laser-based systems such as WBX/WB4 of Cyberware, Vitus Smart of TecMath, and VOXELAN of Hamano. Moreover, there is Intellifit Scanner using radio wave.\(^2\)

A 3D body scanner is advantageous in that it obtains body measurements quickly and provides data on cross-sectional shapes and changes in lengths on body surface resulting from body movement. However, it has difficulty in measuring body parts that are folded and therefore invisible and there can be variations depending on the scanner’s mechanical characteristics, the subject’s posture during scanning, and the measuring program’s characteristics.\(^3\)

There have been active studies on clothing construction using 3D body measuring including research on the patterns of tight clothes using the accurate measurements of body surface\(^4\)\(^-\)\(^6\) and on the fit analysis of clothes using 3D body scanner.\(^7\)

Many studies are being conducted on body measuring using 3D body scanning systems\(^8\)\(^-\)\(^13\) and studies on differences according to body measuring method include comparatives studies on 3D body scanners,\(^14\) on differences between automatic body measuring scanners are expected to be used in various industries including games, animations, and movies as well as apparel industry.

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using a 3D body scanner and 2D direct body measuring, on the accuracy of automatic body measurements obtained through repeated measuring among 3D body scanner systems, and on difference between body measurements obtained from 3D body measuring systems and 2D direct body measuring.

However, most of previous studies compared measuring methods or comparatively analyzed 3D body measuring data that measured dummies rather than real human bodies. Accordingly, it is necessary to conduct comparative analysis and garment wearing tests of 3D body measuring systems and 2D direct body measurements using real human bodies.

In addition, the use of 3D scan anthropometric data is expected to increase in the development of mass customization clothing patterns fit for consumers’ body type. Thus, this study purposed to analyze difference in body measurements between 2D direct body measuring and 3D body scan measuring using a 3D body scanner (Hamamatsu body scanner), to make pants patterns based on the body measurements obtained by 2D direct measuring and 3D scan measuring and compare the fit of the patterns, and ultimately to determine the applicability of 3D scan anthropometric data in the future clothing industry.

### II. Research Methods and Procedures

#### 1. Measured Subjects and Measuring Equipment

In this study, body sizes were measured for 10 women in their 20s-30s who belonged to the normal body type (N) according to drop value suggested in KS K0051 (Sizing Systems for Female Adult’s Garments). They wearing a measurement garment and hat were measured in May 2010 through 2D direct body measuring and 3D automatic measuring using a Hamamatsu body scanner. For 3D body measuring, we used Bodyline Scanner (BLS) of Hamamatsu. In 2D direct body measuring, R. Martin measuring instrument, stickers for reference point marking, measuring tapes, etc. were used. The 3D and 2D body measuring methods followed the ISO 8559 Standard.

#### 2. Measuring Method and Measured Items

Measured items were 3 height items, 12 circumference items, 6 length items and 3 breadth items based on ISO 8559 and previous studies as in Table 1. In measuring, the subject posed with an interval of 18cm between the right and left feet, a distance of 17-19cm between the body and the wrist, and the eyes looking straight ahead.

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3. Experimental Garment Making and Wearing Test

The pants patterns of experimental garments were made according to the method of Armstrong (2001). Also, 2D-pants based on 2D direct body measurements and 3D-pants based on 3D body scan measurements were prepared for each subject.

From those who participated in scanning experience, we selected 3 subjects whose body size was close to the average size for wearing tests. Based on previous studies, items related to the appearance and fit of experimental pants were selected for evaluation, and they were assessed on a 5-point scale. The expert evaluation team (n=11) included graduate students and professors at the Department of Clothing and Textiles who had expert knowledge about clothing construction.

For objective evaluation, moreover, 3D scanning data were obtained for each body part from the subjects in 2D-pants and 3D-pants, and cross-sectional views of 3D data were compared and analyzed.

4. Analysis Methods

In this study, data were analyzed using SPSS 12.0 and the contents of analyses were as follows.

First, differences between 2D direct body measurements and 3D body measurements using the Hamamatsu body scanner were analyzed through t-test.

Second, the results of wearing appearance evaluation for 2D-pants and 3D-pants were analyzed comparatively through t-test. Differences in appearance evaluation for each subject were examined through one-way ANOVA and Tukey’s post hoc test.

| Table 1 | Body Measuring Items - ISO 8559 Standard |
|---------|----------------------------------------|
| Height  | Measuring Items | ISO No. | Measuring Items | ISO No. | Measuring Items | ISO No. |
| (3)     | Hip height       | 2.2.4    | Waist height    | 2.2.3    | Knee height     | 2.2.6    |
| Girth   | Neck girth      | 2.1.2    | Bust girth      | 2.1.8    | Waist girth    | 2.1.11   |
| (12)    | Hip girth       | 2.1.12   | Thigh girth     | 2.1.18   | Mid thigh girth| 2.1.19   |
|         | Knee girth      | 2.1.20   | Calf girth      | 2.1.22   | Ankle girth    | 2.1.24   |
|         | Armscye girth   | 2.2.20   | Elbow girth     | 2.1.14   | Wrist girth    | 2.1.15   |
| Length  | Shoulder length | 2.1.4    | Scye depth      | 2.2.9    | Back waist length| 2.2.10 |
| (6)     | Arm length      | 2.2.22   | Waist to hips   | 2.2.17   | Total crotch length | 2.2.19 |
| Width   | Bust width      | 2.1.9    | Shoulder width  | 2.1.5    | Back width     | 2.1.6    |
| (3)     |                          |          |                 |          |                 |          |

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Third, the fit of experimental garments was analyzed comparatively through cross-sectional analysis between the body and the garment.

### III. Results and Discussion

#### 1. Comparison of Body Measurements between 2D Direct Body Measuring and 3D Body Scan Measuring

Table 2 shows the results of t-test on differences in measurement items between 2D direct body measuring and 3D body scan measuring (Hamamatsu). At a significance level of 0.05, Bust girth, Ankle girth, armscye girth, shoulder length, scye depth and arm length were significantly different between the measuring methods. The other items were not significantly different between the two methods.

Among circumference (girth) items, bust circumference \((p<.05)\), ankle circumference \((p<.05)\) and armscye circumference \((p<.01)\) were significantly different between the measuring methods, and 3D scan measurements were generally larger than 2D measuring.
direct body measurements.

In case of bust circumference, the 2D direct body measurement was smaller than the 3D measurement probably because the bust has a thick subcutaneous layer and it is pressed during 2D direct body measuring. As to ankle circumference, the oblique line passing through the medial malleolus and the lateral malleolus should be measured, but 2D direct body measuring tends to measure horizontally without passing the points and this may be the reason for the smaller value of the 2D direct body measurement. In case of armscye circumference, it is not easy to measure the armpit with a 3D scanner and 3D data have a hole and noise in this part. Because of data noise in 3D scan measuring, the armpit point is inaccurate and this may cause a difference from the 2D direct body measurement.

Among the length items, shoulder length \((p<.05)\), scye depth \((p<.01)\), and arm length \((p<.05)\) were significantly different between the measuring method. Shoulder length and scye depth were higher in the 3D scan measurements than in the 2D direct body measurements. Arm length was longer in 2D direct body measuring than in 3D scan measuring. That is, it is difficult to find the acromion accurately in 3D scan measuring and therefore the acromion tends to be marked slightly outward, and this is probably the reason for the shorter value in 3D scan measuring.

The height and width items did not show any significant difference between the measuring methods. Also, the measurements of items such as waist circumference, hip circumference, hip length and waist height used for experimental garment making were not significantly different between the measuring methods.

These results suggest that the same measurement method of the ISO 8559 standard is used to the 2D direct body measuring and 3D body scan measuring (Hamamatsu), but automatic body measuring using a 3D body scanner has a difficulty in marking the accurate position of landmarks such as acromion, armpit point, and ulnar styloid.

These results suggest that this is believed to cause differences in the positions of landmarks designated for body measuring and in body measurements between the measuring methods.

### 2. Experimental Garment Wearing Test

(Fig. 1) shows the appearance of the 3 subjects in 2D-pants made with 2D direct body measurements and 3D-pants with 3D automatic measurements.

In the results of comparative analysis on the appea-
rance of 2D-pants and 3D-pants, some items showed a significant difference as in Table 3. 3D-pants had a more horizontal front waist line than 2D-pants \((p<.01)\), and more adequate overall ease in waist circumference \((p<.05)\).

Compared to 2D-pants, 3D-pants was found to have a more horizontal front hip line \((p<.05)\) and more ease in the hip line and the crotch line on the side seam \((p<.01)\). In addition, 3D-pants was evaluated to have adequate ease in waist circumference \((p<.05)\) but much ease in the hip \((p<.01)\). What is more, 2D-pants was found to be tighter than 3D-pants in the abdominal part below the front waist line \((p<.05)\), the hip line and the crotch line on the side seam \((p<.05)\), and the part below the back waist line \((p<.05)\). Moreover, 2D-pants was evaluated to be

**Table 3** Appearance Evaluation of Experimental Garments made with 2D Direct Body Measurements and 3D Body Scan Measurements

| Appearance Evaluation Item                                      | 2D-pants |            | 3D-pants |            | Sig.  |
|-----------------------------------------------------------------|----------|------------|----------|------------|-------|
|                                                                 | Mean     | SD         | Mean     | SD         |       |
| **Front**                                                       |          |            |          |            |       |
| The waist line is horizontal.                                   | 3.70     | 1.015      | 3.79     | .781       | .685  |
| The hip line is horizontal.                                     | 3.09     | .914       | 3.73     | .876       | .005**|
| The position of the waist line is adequate.                    | 3.39     | 1.171      | 3.58     | .969       | .494  |
| The position of the hip line is adequate.                      | 3.52     | 1.121      | 3.52     | 1.004      | 1.000 |
| The abdominal part below the front waist line is tight.        | 2.70     | 1.262      | 1.97     | 1.075      | .014* |
| **Lateral**                                                     |          |            |          |            |       |
| The side seam is vertical.                                     | 2.88     | 1.219      | 3.39     | 1.088      | .075  |
| The position of the size seam is adequate.                     | 3.55     | 1.003      | 3.79     | .781       | .277  |
| The waist line is horizontal.                                   | 3.21     | 1.193      | 3.15     | 1.417      | .851  |
| The hip line is horizontal.                                     | 3.61     | 1.197      | 3.36     | 1.432      | .458  |
| The hip line and crotch line of the side seam are tight.       | 2.06     | 0.827      | 1.55     | .564       | .004**|
| The hip line and crotch line of the side seam have enough ease.| 2.58     | 1.226      | 3.79     | 1.219      | .000**|
| **Back**                                                        |          |            |          |            |       |
| The waist line is horizontal.                                   | 3.42     | 1.146      | 3.15     | .939       | .294  |
| The hip line is horizontal.                                     | 2.15     | 0.939      | 2.12     | 1.023      | .901  |
| The position of the waist line is adequate.                    | 3.15     | 1.176      | 3.30     | .951       | .567  |
| The position of the hip line is adequate.                      | 3.12     | 1.193      | 3.15     | 1.349      | .923  |
| The part below the back waist line has enough ease.            | 2.36     | 1.194      | 2.91     | 1.331      | .085  |
| The part below the back waist line is tight.                   | 3.06     | 1.273      | 2.45     | 1.175      | .049* |
| The back hip crotch is tight.                                   | 2.36     | 1.141      | 1.85     | 1.034      | .059  |
| The back hip crotch has enough ease.                           | 2.85     | 1.302      | 3.42     | 1.370      | .085  |
| **Overall**                                                     |          |            |          |            |       |
| The pants fit the model as a whole.                            | 2.70     | 1.334      | 2.42     | 1.226      | .39   |
| Overall ease is adequate.                                      | 2.88     | 1.341      | 2.58     | 1.347      | .363  |
| Overall silhouette is adequate.                                | 2.73     | 1.257      | 2.55     | 1.201      | .55   |
| Ease in waist circumference is adequate.                       | 2.36     | 1.270      | 3.00     | 1.225      | .042* |
| Ease in hip circumference is adequate.                         | 2.85     | 1.253      | 2.64     | 1.319      | .505  |
| The hip has enough ease as a whole.                            | 2.12     | 1.053      | 3.52     | 1.326      | .000**|
| The hip and the crotch are tight.                              | 2.52     | 1.349      | 1.82     | 0.917      | .017* |

*p<.05, **p<.01
tighter in the hip and the crotch \( (p < .05) \).

In the results of comparing appearance evaluation on the fit of pants among the 3 subjects, all the subjects belonged to the one same group among body type groups classified according to drop value and low drop value, but they showed significant difference in almost every item of appearance evaluation. The appearance of the lateral side was different among the subjects in all of items ‘verticality of side seam’ \( (p < .01) \), ‘adequacy of side seam position’ \( (p < .01) \), ‘horizontality of waist line’ \( (p < .01) \) and ‘horizontality of hip line’ \( (p < .01) \). The appearance of the back was different among the subjects in all of items ‘horizontality of waist line’ \( (p < .01) \), ‘horizontality of hip line’ \( (p < .01) \), ‘adequacy of waist line position’ \( (p < .01) \), and ‘adequacy of hip line position’ \( (p < .01) \). As to overall appearance, the subjects were different in ‘overall fit’ \( (p < .01) \), ‘adequacy of overall ease’ \( (p < .01) \), ‘adequacy of general silhouette’ \( (p < .01) \), ‘adequacy of ease in waist circumference’ \( (p < .01) \)

**Table 4** Differences in Appearance Evaluation of Experimental Garments among the Subjects

| Appearance Evaluation Item                                                      | \( F \)  | Sig.    |
|--------------------------------------------------------------------------------|--------|--------|
| Front                                                                          |        |        |
| The waist line is horizontal.                                                   | .800   | .454   |
| The hip line is horizontal.                                                     | .656   | .523   |
| The position of the waist line is adequate.                                    | 4.099  | .021   |
| The position of the hip line is adequate.                                      | 6.845  | .002   |
| The abdominal part below the front waist line is tight.                        | .800   | .454   |
| The side seam is vertical.                                                     | 5.378  | .007** |
| The position of the size seam is adequate.                                     | 14.935 | .000** |
| The waist line is horizontal.                                                   | 19.577 | .000** |
| The hip line is horizontal.                                                     | 25.902 | .000** |
| The hip line and the crotch line of the side seam are tight.                   | .425   | .656   |
| The hip line and the crotch line of the side seam have enough ease.            | 3.535  | .035*  |
| Lateral                                                                        |        |        |
| The waist line is horizontal.                                                   | 8.061  | .001** |
| The hip line is horizontal.                                                     | 17.536 | .000** |
| The position of the waist line is adequate.                                    | 9.794  | .000** |
| The position of the hip line is adequate.                                      | 30.229 | .000** |
| The part below the back waist line has enough ease.                            | 1.777  | .178   |
| The part below the back waist line is tight.                                    | 6.224  | .003** |
| The back hip crotch is tight.                                                   | 2.727  | .073   |
| The back hip crotch has enough ease.                                            | 5.604  | .006** |
| Back                                                                           |        |        |
| The pants fit the model as a whole.                                            | 20.175 | .000** |
| Overall ease is adequate.                                                      | 16.12  | .000** |
| Overall silhouette is adequate.                                                 | 14.233 | .000** |
| Ease in waist circumference is adequate.                                       | 8.006  | .001** |
| Ease in hip circumference is adequate.                                         | 11.136 | .000** |
| The hip has enough ease as a whole.                                            | 4.282  | .018** |
| The hip and the crotch are tight.                                               | 2.463  | .093   |

*\( p < .05 \), **\( p < .01 \)
and ‘adequacy of ease in hip circumference’ (p<.01).
In the evaluation of detailed appearance, the subjects were different in items ‘excessive ease in side seam, hip line, crotch line’ (p<.05), ‘pulling wrinkle caused by the tightness of the part below the back waist line’ (p<.01), ‘excessive ease in back hip crotch’ (p<.01) and ‘excessive ease in overall hip’ (p<.05).

### 3. Experimental Garment Wearing Evaluation through Cross-sectional Analysis

When experimental garment wearing was evaluated by comparing the cross-sectional lengths of waist circumference, hip circumference, and abdominal circumference through cross-sectional analysis of each body part in the subjects and experimental garments, 2D-pants (red) was tighter than 3D-pants (green) in the front, back and lateral sides as in (Fig. 2).

### IV. Conclusion

This study purposed to analyze differences in body measurements comparatively between 2D direct body measuring and 3D scan measuring using real human bodies and to compare wearing evaluation of pants made based on body measurements obtained by the two measuring methods in order to provide basic

|       | Subject 1                          | Subject 2                          | Subject 3                          |
|-------|------------------------------------|------------------------------------|------------------------------------|
| Waist | Body: 82.5, 2D-Pants: 83.0, 3D-Pants: 84.7 | Body: 75.5, 2D-Pants: 75.7, 3D-Pants: 76.7 | Body: 80.6, 2D-Pants: 79.1, 3D-Pants: 82.1 |
| Hip   | Body: 98.0, 2D-Pants: 100.4, 3D-Pants: 101.2 | Body: 92.2, 2D-Pants: 94.6, 3D-Pants: 96.5 | Body: 90.8, 2D-Pants: 92.8, 3D-Pants: 95.8 |
| Abdominal | Body: 90.0, 2D-Pants: 92.1, 3D-Pants: 94.1 | Body: 82.2, 2D-Pants: 84.5, 3D-Pants: 86.2 | Body: 83.0, 2D-Pants: 82.4, 3D-Pants: 85.3 |

(Fig. 2) Cross-sectional Analysis by Body Part of 2D-pants and 3D-pants
(Red: 2D-pants, Green: 3D-pants, Blue: Body) (Unit: cm)
The results of this study are summarized as follows.

First, in the results of analyzing differences in the measurements of items between 2D direct body measuring and 3D scan measuring, significant difference was observed between the measuring methods in bust circumference, ankle circumference, armscye circumference, shoulder length, scye depth and arm length. The other items were not significantly different between the measuring methods.

Second, in the results of evaluating the appearance of experimental garments made with 2D direct body measurements and 3D scan measurements, no significant difference was observed in the fit of the two experimental garments, but 2D-pants based on 2D direct body measurements was slightly tighter than 3D-pants based on 3D scan measurements in waist circumference, hip circumference and abdominal circumference. In addition, 3D-pants was found to have adequate ease in waist circumference but much ease in hip circumference. Moreover, in the results of comparative analysis of cross-sectional data obtained from 3D scanning of experimental garment wearing, 2D-pants was tighter than 3D-pants in waist circumference, hip circumference and abdominal circumference. This was consistent with the results of evaluating the appearance of experimental garment wearing. The results of this study show that when pant patterns are drafted with automatic measurements obtained using a 3D scanner, ease should be smaller than that based on 2D direct body measurements. In addition, because the result of comparing the 3D cross-section of each part before and after wearing were similar to that of evaluation by an expert evaluation team, we may evaluate the fit or adequacy of patterns through 3D cross-sectional evaluation if there is no expert evaluation team available.

Third, the subjects participating in the wearing test belonged to the same body type group but showed significant difference in most of the appearance evaluation items. However, this study could not explain the difference of fit resulting from delicate variation in the body shape of the subjects. Thus, future research needs to examine the effects of subjects' body type on the accuracy of 3D automatic measuring.

In this study, the evaluation of garment fit was limited to subjects who belonged to the one same group among body type groups classified according to drop value and low drop value, but future research needs to diversify body type groups as well as subjects.

This study was conducted as an effort to develop strategies for coping with global clothing and fashion markets developing in connection to 3D digital technologies. For higher competitiveness in mass customization markets, moreover, research should be made continuously on pattern making for individual fit reflecting data on 3D parametric body form and body shape obtained with 3D body scanners.

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