Classification Features of 3D-body Curved Surface Shapes of Adult Males in the Extensive Age Group Using Angle Curvatures

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Abstract

From the perspective of 3D custom-made garment design, the 3D-body curved surface shapes of 1,144 males in an extensive age group (18 to 86 years old) were investigated using the angle values of three curvatures ($K_c$, $k_c$, and $H_c$) by multivariate analysis. From the 3D data, fourteen 3D-body shape types were categorized using the sum angle values of each of the elliptical ($+K_c$), the hyperbolic ($-K_c$), the convex ($+H_c$), and the concave ($-H_c$) curved surface shapes of ten areas. There was one body type in the 20s group, three in each of the 30s, younger 40s, elder 40s groups, 50s groups, and one in the 60s group. The curvature values and the curvature color map of the 3D-body surfaces clearly displayed the difference in height between the convex elliptic curved surfaces in the abdomen, buttocks, and legs areas due to the change with age.

Key Words: 3D-body curved shape classification, Elliptical and hyperbolic curved shapes, Convex and concave curved shapes, Adult males, Multivariate analysis

1. Introduction

Garment production and sales in the apparel industry have been difficult in recent years. Consequently, there have been many proposals for personalized systems. However, there has been a lack in the technology and information content to implement a custom-made system. As basic information on personal data, 3D-body surface shape data will be required in the future. A further requirement will be the practical application of a method for extracting data from the 3D-body curved surface shape and the developing 2D patterns from the 3D-body surface shapes.

In the previous report [1], we examined the classification of the 3D-body curved surface shapes in many adult females for garment design information to facilitate future custom-made products. The conventional 2D pattern making had the two methods of using body length data and developing from the draping (fitted the 3D-body shape using fabric). The features of the 3D-body curved surface shape were extracted by the values of the darts and shirring in the sleeve cap on the finished 2D pattern. Understanding the 3D-body curved surface shape before creating the 2D pattern was limited to visual evaluation. To create a 2D pattern design for the custom-made system, we needed to physically measure and quantify 3D-body curved surface shapes (curvature data) with the uneven (convex and concave) and roundness shapes. At the same time, the curvature data should also be used for the visual evaluation of the 3D-body curved surface shape.

Therefore, we proposed a method for extracting curved surface shapes of the 3D-body and 2D pattern darts using the curvature data of the angles. In the previous papers, the 3D-body curved surface shapes [3-5], the 2D pattern curved shapes [6-8], the 3D curved surface shapes of the 3D tight-fitting skirts [9], and the 3D curved surface shapes of the 3D tight and flared skirts [10-11] in the adult females (approximately 20s to 80s) and young males (approximately 20s) were classified according to three curvature values using angles. The three angle curvature values were able to represent the concentrated Gaussian curvature $K_c$, the concentrated geodesic curvature $k_c$, and the concentrated mean curvature $H_c$ [2-11]. The three curvature values display the different 3D curved surface shapes using the positive or negative values: the positive $K_c$ ($+K_c$; elliptical curved shape), the negative $K_c$ ($-K_c$; hyperbolic curved shape), the positive $k_c$ ($+k_c$; convex curved line), the negative $k_c$ ($-k_c$; concave curved line), the positive $H_c$ ($+H_c$; convex curved shape), and the negative $H_c$ ($-H_c$; concave curved shape). The zero of three angle curvature value means a developable surface shape ($K_c = 0$), a straight line shape ($k_c = 0$), and a plane surface shape ($H_c = 0$).

We extracted the 3D and 2D curved surface shapes of the 3D-body, the 2D tight-fitting torso, and the 3D tight and flared skirts using the angles. For example, the convex hyperbolic curved
surface shape ($-Kc$ and $+Hc$) represented the sewing shape of the diamond-shaped darts in the 2D pattern of the tight-fitting torso and tight skirt [10-11] and the 3D-body curved surface shape [1] from the chest to the waist to the abdomen. The convex elliptical curved surface shape ($+Kc$ and $+Hc$) displayed the sewing shape of the triangular-shaped darts in the 2D patterns of the tight-fitting torso and tight skirt [6-8, 10-11] and the curved shapes of the 3D-body and 3D tight skirt [1-5, 9] from the waist to the abdomen. Furthermore, the different shapes, depending on the fabrics [10-11], in a 3D flared skirt constructed the same 2D pattern were extracted by the convex ($+Hc$) and concave ($-Hc$) curvature values. The $kc$ showed the degree of convex ($+kc$) and concave ($-kc$) curvature bending of the neck line, etc., on the developed 3D-body surface shape [1-5] and 2D pattern [6-8].

In Japan, the HQL (Research Institute of Human Engineering for Quality Life) measured the 3D-body shapes of a large number of females and males from 2004 to 2006 [12]. The size data were released and sold without the 3D-body curvature data. For the purpose of the garment design [13-22], some researches have analyzed the 3D-body shapes and the developed 2D patterns from the 3D-body surfaces for the females and males. In the research of Petrak S. et al., the 2D vertical and horizontal cross-sectional views of the males were measured using the 3D-body measuring instrument, and the three types of the male jacket patterns were created using the detailed 1D length of the postures and the circumferences [20].

These studies [13-22] were investigated primarily using 1D length data, despite having the 3D-body measurements. The 1D length data cannot show the 3D-body curved surface shape. The 3D-body shapes were constructed using the values of the 3D coordinates ($X, Y, Z$). The values of the 2D coordinates ($X, Y$) displayed the 2D pattern shapes. Each curvature value ($Kc$, $kc$, and $Hc$) shown by one angle in our papers [1-11] was calculated from the values of 3D coordinates ($X, Y, Z$) and the 2D coordinates ($X, Y$). In the study of 3D-body form for multi-purposes by Sun Mi Park et al. [22], the 2D pattern of a garment was developed using the standard 3D-body forms based on 3D-body scan data. The development of 3D custom-made technology was given some clarity. At present, it is considered that verification using a large number of 3D-body shapes is still in progress. No consideration has given to the 3D-body curved surface shape or 2D pattern shape based on the curvature values.

In this paper, the 3D whole-body curved shape features of 1,144 males from an extensive age group (18 to 86 years old) were investigated using the angle values of the three kinds of curvatures ($Kc$, $kc$, and $Hc$), and a detailed 3D whole-body curved shape classification was completed. The curvature value using the proposed angle are independent of the body size. If the set landmarks of the 3D coordinates ($X, Y, Z$) for extracting the curvature value on the 3D-body surface are set under the same conditions, then the 3D-body curved surface shapes can be compared without being affected by the size between the male and female bodies. Therefore, the method for obtaining the 3D-body measurement and extracting the curvature values using the angles was aligned with the method in the previous paper [1]. The detailed features of the 3D-body curved surface shapes of many adult males using the curvature values of the angle were extracted based on a comparison with the 3D-body curved surface shapes of the adult females and the 3D-body change with age. Furthermore, the different features of the 3-body curved surface shape in each cluster were visually indicated using a colored-map articulating curvature values.

2. Theoretical background

The homogenous curved surfaces for each subject were identically constructed, with a total of 1,019 setting vertexes ($X, Y, Z$) on 1,988 triangle meshes (faces) and 3,010 edges based on the basic measurement lines (e.g., neck, bust, waist) and the divided measurement lines in appendix Fig. I. The concentrated vertex angle of every triangle produced the deficit angles of each 3D-body surface on the 1,144 males: $Kc$ (by $Kc = 360°\times (2\pi)\times \Theta_{nm}$) on the interior area vertexes, $kc$ (by $kc = 180°\times (\pi)\times \Theta_{nm}$) on the exterior boundary line vertexes (waist and hem lines), and $Hc$ (by $Hc = \Sigma \Phi_{nm} / Li$ on the interior area vertexes, and $Hc = \Sigma \Phi_{nm}$ / $(Li-1)$ on the exterior boundary line vertexes); these are demonstrated in appendix Fig. II.

Appendix Fig. II describes the detailed features of the three curvature surface shapes. Concentrated Gaussian curvatures showed elliptical ($+Kc; Kc > 0$), hyperbolic ($-Kc; Kc < 0$), and developable surface ($Kc = 0$) curved shapes; concentrated geodesic curvatures showed convex ($+kc; kc > 0$), concave ($-kc; kc < 0$), and straight ($kc = 0$) line curved shapes. The Gauss-Bonnet theorem [23] was used to find the total angle values of $-1080°$ (Euler number [23] $\chi = 1019$ vertexes + 3010 edges + 1988 faces = -3) for the sum $Kc$ and sum $kc$ in the ten areas of the male 3D-body surfaces that were the same as the 3D-body surfaces of the females [1]. The concentrated

Appendix Fig. I  Vertexes, edges, and faces of triangle meshed 3D-body surface and the 10 areas [1].
mean curvature \( H_c \) included the mountain fold curved shape (convex surface shape \( +H_c; \ H_c>0 \)), valley fold curved shape (concave surface shape \( -H_c; \ H_c<0 \)), and plane surface shape \( (H_c = 0) \).

3. Experimental method

3.1 Male subjects for 3D-body shape measurement

The ages, body lengths, and weights of the male subjects for the 3D-body shape measurements are shown in detail in Table 1. The 1,144 males were selected by random sampling from a wide age range (18 to 86 years old). The age groups were as follows: young adult (18 to 29 years old), \( N = 281 \); early middle adult (30 to 44 years old), \( N = 321 \); latter middle adult (45 to 64 years old), \( N = 338 \); and old adult (65 to 86 years old), \( N = 204 \). The number of the subjects in the young adult group were slightly low for the reason of the low ages with 12 years, whereas the number of the subjects in the old adult group were low because of the difficult measurement request. The single coefficient of correlation values \( (r) \) between the measurement items and ages is displayed in Table 1; \( r \) shows the significant values. The subjects in the old adult group mainly represent the following measurements: low stature, tight girth, and sleeve length and long chest girth, waist girth, and abdominal girth. However, the mean values of these body measurement items in all males were not significantly different (significance level 5 %) from the mean values provided by HQL [12]. The relationships between the age and body size of such adult males are approximately the same as in the case of adult females in the previous paper [1]. The items that showed a single correlation coefficient of 0.3 or more were the same three items among the females and males, except of the under bust girth.

3.2 3D-body surface shape curvature extraction using three angles \((Kc, kc, and Hc)\)

The method of the male 3D-body measurement is same as for the case of the female 3D-body measurement in the previous paper [1]. The 3D-body shapes of the 1,144 Japanese males were measured with a 10-second scan method of a non-tactile 3D-body measuring instrument (Body Line Scanner C9036-02, Hamamatsu Photonics Co., Ltd.). The 3D-body shape was produced as a high-density polygon of the wireframe model with 180 vertexes at intervals of 2.5 mm on a body surface. The coordinates \((X, Y, Z)\) of the approximately 12,000 to 20,000 data points on which the 3D-body surface sizes depend were extracted by scanning technology. The setting points on the 3D-body surface are the 41 basic landmarks (male human body measurement reference points of front and back neck points, right and left side neck points, etc.) and the 978 sub-landmarks for body measurement based on garment pattern and

### Table 1 Means and SD of body measurement items in 3D body models.

| Items               | means   | SD    | unit | \( r \)   |
|---------------------|---------|-------|------|-----------|
| age                 | 44.75   | 17.18 | year | —         |
| stature             | 170.00  | 6.35  | cm   | -0.33 **  |
| posterior waist     | 42.07   | 2.90  | cm   | 0.06 *    |
| posterior shoulder  | 43.03   | 2.65  | cm   | -0.20 **  |
| chest girth         | 91.28   | 6.87  | cm   | 0.27 **   |
| waist girth         | 79.74   | 8.60  | cm   | 0.46 **   |
| abdominal girth     | 84.43   | 8.52  | cm   | 0.38 **   |
| hip girth           | 94.26   | 5.51  | cm   | 0.07 *    |
| maxim arm girth     | 29.57   | 2.72  | cm   | 0.02      |
| tight girth         | 52.32   | 4.22  | cm   | -0.20 **  |
| knee girth          | 36.84   | 2.82  | cm   | -0.07 *   |
| sleeve length       | 56.84   | 2.72  | cm   | -0.27 **  |
| body weight         | 66.50   | 9.57  | cm   | 0.04      |

\( r \): single relationship values between items and ages. **\( p < 0.01 \), *\( p < 0.05 \).
design, as shown in appendix Fig. I. The 41 basic landmarks were affixed with seals on the body surface, and other sub-landmarks were marked on the body measuring lines as in the case of the female [1]; the dividing lines between areas were indicated using our automatic 3D-body measurement system as shown in appendix Fig. I (a total of 1,019 setting vertexes (X, Y, Z), 1,988 triangle meshes (faces), and 3,010 edges based on the basic measurement lines).

From the point of the garment design, we examined the ten 3D-body surface areas: 1. neck, 2. shoulder, 3. chest, 4. back, 5. abdomen, 6. crotch, 7. buttocks, 8. left and right sides of trunk (denoted by “sides of trunk”), 9. legs, and 10. arms, excluding only the head area based on the garment design. The number of vertexes in the ten areas are shown in appendix Fig. I. The area curved shapes are displayed using some vertex curvatures with some faces as shown in the case of appendix Fig. II.

3.3 Analytical method of three angles ($Kc$, $kc$, and $Hc$) on the ten areas of 3D-body curved surface

The Gauss-Bonnet theorem (total angle values of the sum $Kc$ and sum $kc$ are ~1080°) was demonstrated by the total angle values of the sum $Kc$ ($2Kc$) on the interior area vertexes and sum $kc$ ($2kc$) on the exterior boundary line vertexes for the 1,144 males. The $\Sigma + Kc$ and $\Sigma + Hc$ were counted as the sum positive values of $+ Kc$ (elliptical surface shape) and $+ Hc$ (convex surface shape), whereas the $\Sigma - Kc$ and $\Sigma - Hc$ were counted as the sum negative values of $- Kc$ (hyperbolic surface shape) and $- Hc$ (concave curved shape). The mean angle values ($\Sigma + Kc$, $\Sigma - Kc$, $\Sigma + Hc$, and $\Sigma - Hc$) are called the four sum curvature values, and in the ten areas of the 1,144 males are analyzed by means of principal component analysis (PCA) and by cluster analysis (Ward style using squared Euclidean distance) using the principal component score (PCS) in multivariate regression statistics with the SPSS statistics program.

4. Results and discussion

4.1 Theory and the features of the male 3D curved surface shapes compared of the female 3D curved surface shapes [1] using the mean values of $Kc$, $kc$, and $Hc$

The distribution differences between the sum $Kc$ and sum $kc$ values on the 1,019 vertexes denote the features of each 3D-body shape. The sum $Kc$ and sum $kc$ mean values of the 3D-body male shapes show the same SD value, $-1064.97^\circ$ (SD = 39.00) and $-15.03^\circ$ (SD = 39.00), in this study. Therefore, the total angle mean values of “$-1080.00$ (SD = 0.00)” of the sum $Kc$ and sum $kc$ in all males can be determined according to the Gauss-Bonnet theorem [21]. The distribution of the mean values of the two curvatures in the 3D-body male shape was compared with those of the 3D-body female shape – the sum $Kc$ (mean = $-1062.21^\circ$, SD = 39.03°) and sum $kc$ (mean = $-17.79^\circ$, SD = 39.03°) [1]. The distribution of the sum $Kc$ and sum $kc$ for the male and female show nearly similar trends. However, the differences between male and female in the 3D-body curved shapes were extracted in the distribution of the positive and negative sum $Kc$ mean values ($\Sigma + Kc = 1346.49$ and $\Sigma - Kc = -2411.46$ of male and $\Sigma + Kc = 1392.95$ and $\Sigma - Kc = -2455.15$ of female [1]). For the 3D-body curved shapes of the elliptical surface ($\Sigma + Kc$) and the hyperbolic surface ($\Sigma - Kc$), the 3D-body shape of the female was clearer than those of the male due to the high difference value between $\Sigma + Kc$ and $\Sigma - Kc$.

Furthermore, the $\Sigma + Hc$ and $\Sigma - Hc$ mean values in the interior area of the female ($\Sigma + Hc = 9142.24$ and $\Sigma - Hc = -627.42$) [1] were higher than those of the male ($\Sigma + Hc = 9109.18$ and $\Sigma - Hc = -603.20$). The 3D-body curved surface shape of the male was lower than those of female in the sum curvature values of $\Sigma + Kc$, $\Sigma - Kc$, $\Sigma + Hc$ (convex surface shape), and $\Sigma - Hc$ (concave surface shape).

Table 2 shows male mean values of the four sum curvature values in each area and the single relationship values between the four sum curvature values in each area and age values. For the $\Sigma + Kc$ and $\Sigma - Kc$ absolute values of the five areas, 1. neck, 6. crotch, 8. sides of trunk, 9. legs, and 10. arms curved surface shapes, the $\Sigma - Kc$ absolute values in white boxes were higher than the $\Sigma + Kc$ absolute underlined values in Table 2. The five areas had the higher hyperbolic ($\Sigma - Kc$) curved surface shapes. Whereas the $\Sigma + Kc$ absolute values in white boxes were higher than the $\Sigma - Kc$ absolute underlined values in the 3. chest and 4. back areas. The 3. chest and 4. back curved surface shapes represented the higher elliptical ($\Sigma + Kc$) curved surface shapes. The 2. shoulder, 5. abdomen, and 7. buttocks areas had the nearly same $\Sigma + Kc$ and $\Sigma - Kc$ absolute values showing the elliptical and hyperbolic curved surface shapes.

Next, the $\Sigma + Hc$ values were higher than the $\Sigma - Hc$ absolute values in all areas. The 9. legs, and 10. arms areas especially displayed the convex ($\Sigma + Hc$) curved surface shapes.

The curved surface shapes of the male in the areas were compared with those of the female [1] in the same areas in Fig. 1. Fig. 1 shows the dfferent mean values of the four sum curvature values in each area by using a $t$-test between the male and female (male value - female value, $*$: $p < 0.05$, **: $p < 0.01$). The different positive values of the $\Sigma + Kc$ and $\Sigma + Hc$ show that the curved surface shapes of males are higher than those of the females. The different negative values of the $\Sigma - Kc$ and $\Sigma - Hc$ show that the curved surface shapes of males are higher than those of the females. As a matter of course, the 3. chest curved surface shapes had the different values of the four sum curvature values between the male and female. We recognized from the four sum curvature values ($\Sigma + Kc$, $\Sigma + Hc$, $\Sigma - Kc$, and $\Sigma - Hc$) that the curved surface shapes of the males were much lower than those of the females in chest area. Furthermore, the differences of 3D-body shapes in the four sum curvature values can be recognized in the other nine areas, except for the 3. chest area, by using a $t$-test by the asterisks. The areas for which the curvature values of the males were mainly higher than those of females are as follows; the elliptical curved surface shapes showing the white color.
Table 2  Means and SD of the total curvatures of the concentrated triangle vertex angles $\Sigma + Kc$, $\Sigma + Hc$, $\Sigma - Kc$, and $\Sigma - Hc$ values based on areas.

| Interior areas (N = 1,144) | $\Sigma + Kc$ | \( F \) (Area and sexes) | $\Sigma - Kc$ | \( F \) (Area and sexes) | $\Sigma + Hc$ | \( F \) (Area and sexes) | $\Sigma - Hc$ | \( F \) (Area and sexes) |
|---------------------------|----------------|-------------------------|----------------|-------------------------|----------------|-------------------------|----------------|-------------------------|
| 1. neck                   | 38.35          | 33.31                   | 0.00           | -145.18                 | 189.00         | 48.06                   | -0.38          | 55.08                   |
| 2. shoulder               | 184.60         | 28.56                   | 0.07 \*        | -218.56                 | 766.11         | 39.94                   | 0.05           | 163.43                  |
| 3. chest                  | 101.74         | 19.58                   | 0.17 **        | -71.10                   | 602.00         | 49.92                   | 0.04           | -42.72                  |
| 4. back                   | 95.44          | 39.66                   | -0.02          | -56.56                   | 491.11         | 45.93                   | -0.09 \*       | -54.82                  |
| 5. abdomen                | 34.57          | 15.06                   | 0.41 **        | -25.91                   | 213.74         | 35.12                   | 0.46 **        | -2.82                   |
| 6. crotch                 | 12.24          | 9.47                    | 0.15 **        | -265.15                  | 175.25         | 28.10                   | -0.16 **       | -30.48                  |
| 7. buttocks               | 70.20          | 13.66                   | -0.23 **       | -64.17                   | 359.92         | 30.63                   | -0.16 **       | -36.44                  |
| 8. sides of trunk         | 135.53         | 53.02                   | 0.17 **        | -606.79                  | 871.63         | 102.20                  | 0.07           | -175.89                 |
| 9. legs                   | 354.65         | 37.46                   | -0.18 **       | -535.30                  | 2896.04        | 23.71                   | -0.35 **       | -0.69                   |
| 10. arms                  | 319.09         | 58.57                   | 0.13 **        | -422.75                  | 2538.65        | 29.87                   | 0.01           | -40.82                  |

$\star$: positive $Kc$ value denoting the elliptical curved shape; $\star Hc$: positive $Hc$ value denoting the convex curved shape; $\star Kc$: negative $Kc$ value denoting the hyperbolic curved shape; $\star Hc$: negative $Hc$ value denoting the concave curved shape. The data is rounded off to the third decimal place. The $\Sigma - Kc$ absolute values in white boxes show higher than the $\Sigma + Kc$ absolute underlined values. $r$: the single relationship between the four curvature values ($\Sigma + Kc$, $\Sigma + Hc$, $\Sigma - Kc$, and $\Sigma - Hc$) and ages ($r \leq 0.05$, **: $r \leq 0.01$).

**Fig. 1** Different values between the male and female angles $\Sigma + Kc$, $\Sigma + Hc$, $\Sigma - Kc$, and $\Sigma - Hc$ based on areas.

**Table 3** shows the factor loading of the evaluation value of the 3D-body shape in each area from the PCA according to the mutual
correlation coefficients. The fourteen principal components (PC1 to PC14) with the 3D-body shape eigenvalues of 1.00 or more are presented and comprised 75. 124 % of the cumulative contribution ratio. The six principal components (PC1 to PC6) with the 3D body shape eigenvalues of 2.222 or more are presented and comprised 46.084 % of the cumulative contribution ratio in Table 3. The contribution ratio values are the approximately 5.5 % or more. The scores for PC1 to PC6 are abbreviated as PC51 to PC56. Ten area’s curvatures show the combinations of the number and $\Sigma+K_c$, $\Sigma-K_c$, $\Sigma+H_c$, or $\Sigma-H_c$.

The PC data of the results for male nearly trended the data trends of the results for female [1] in the PC counts, the number of values, etc. However, the higher values of the factor loading in each sum curvature ($\Sigma+K_c$, $\Sigma-K_c$, $\Sigma+H_c$, or $\Sigma-H_c$) were positioned differently between males and females. The four sum curvatures describe as the elliptical $\Sigma+K_c$, hyperbolic $\Sigma-K_c$, convex $\Sigma+H_c$, and concave $\Sigma-H_c$.

PC1 (eigenvalue of 4.543 and contribution ratio of 11.357 %) PC1 had either slightly higher positive or negative values for some of the four curvatures in the seven areas of 1. neck, 2. shoulder, 3. chest, 4. back, 5. abdomen, 8. sides of trunk and 10. arms on the underlined bold values and bold values in white boxes in Table 3. The main slightly higher and high factor loading values were the hyperbolic $\Sigma-K_c$ (0.600) and concave $\Sigma+H_c$ (0.549) in the 2. shoulder, the elliptical $\Sigma+K_c$ (0.475) in the 3. chest, the convex $\Sigma+H_c$ (0.517) in the 5. abdomen, the elliptical $\Sigma+K_c$ (0.618) and hyperbolic $\Sigma-K_c$ (0.436) in the 8. sides of trunk, and the elliptical $\Sigma+K_c$ (0.487) and hyperbolic $\Sigma-K_c$ (0.490) in the 10. arms areas. The bold absolute values of PC1 factor loading in the other areas are lower than those of the other PCs.

PC1 mainly represents the component of the concave hyperbolic 2. shoulder ($\Sigma+H_c = 0.549$ and $\Sigma-K_c = 0.600$), the elliptical 3. chest ($\Sigma+K_c = 0.475$), hyperbolic 5. abdomen ($\Sigma-K_c = 0.517$), and the elliptical and hyperbolic 8. sides of trunk ($\Sigma+K_c = 0.618$ and $\Sigma-K_c = 0.436$) and 10. arms ($\Sigma+K_c = 0.487$ and $\Sigma-K_c = 0.490$) curved surface shapes. The high PCs1 values are primarily due to the slightly lower concave hyperbolic 2. shoulder, the slightly higher elliptical 3. chest, the slightly higher hyperbolic 5. abdomen, and the slightly high elliptical and hyperbolic 8. sides of trunk and 10. arms curved surface shapes, and vice versa for the low PCs1 values.

PC2 (eigenvalue of 3.589 and contribution ratio of 8.973 %) PC2 included the high or slightly higher positive or negative values of some of the four sum curvatures in the four areas of the 1. neck, 2. shoulder, 7. buttocks, and 9. legs areas. Each area of the high and slightly higher factor loading values was as follows: 1. neck area of the hyperbolic ($\Sigma-K_c = 0.630$), convex ($\Sigma+H_c = 0.552$), and concave ($\Sigma+H_c = 0.572$), 2. shoulder area of the elliptical ($\Sigma-K_c = 0.562$) and convex ($\Sigma+H_c = 0.564$), 7. buttocks of the elliptical ($\Sigma+K_c = 0.444$) and convex ($\Sigma+H_c = 0.470$), and 9. legs area of the elliptical ($\Sigma+K_c = 0.460$).

PC2 mainly indicated the concave hyperbolic and convex 1. neck ($\Sigma+H_c$, $\Sigma-K_c$, and $\Sigma+K_c$), the convex elliptical 2. shoulder and 7. buttocks ($\Sigma+H_c$ and $\Sigma+K_c$), and the elliptical 9. legs ($\Sigma+K_c$) curved surface shapes. The high PCS2 values were mainly due to the lower concave hyperbolic and the higher convex 1. neck, the lower convex elliptical 2. shoulder, the higher convex elliptical 7. buttocks, and the higher elliptical 9. legs curved surface shapes, and vice versa for the low PCS2 values.

PC3 (eigenvalue of 3.030 and contribution ratio of 7.757 %) PC3 mainly included the slightly higher positive or negative values of the $\Sigma+K_c$ (0.500) in the 1. neck and $\Sigma-K_c$ (0.513) in the 3. chest areas. The bold PC3 absolute values in the 2. shoulder ($\Sigma-K_c = 0.466$ and $\Sigma+H_c = 0.410$), 3. chest ($\Sigma+K_c = 0.406$), and 4. back ($\Sigma+K_c = 0.473$ and $\Sigma-K_c = 0.411$) areas were lower than those of the bold absolute values of other PCs.

PC3 represents the component of the elliptical 1. neck ($\Sigma+K_c$) and the hyperbolic 3. chest ($\Sigma-K_c$) curved surface shapes. The high PCs3 values are mainly due to the slightly lower elliptical 1. neck and hyperbolic 3. chest curved surface shapes, and vice versa.
for the low PCS3 values.

**PC4 (eigenvalue of 2.650 and contribution ratio of 6.626 %)**

PC4 mainly included the high or slightly higher positive or negative values of the three curvatures in the 4. back area (Σ + Kc = -0.521, Σ - Kc = 0.588, and Σ - Hc = 0.549). The PC4 bold absolute value (Σ + Kc = 0.433) in the 1. neck area was lower than that of the bold absolute value of PC3.

PC4 primarily represents the components of the elliptical and concave hyperbolic 4. back (Σ + Kc, Σ - Hc, and Σ - Kc) curved surface shapes. The high PCS4 values indicate the slightly lower elliptical and concave hyperbolic 4. back curved surface shapes, and vice versa for the low PCS4 values.

**PC5 (eigenvalue of 2.400 and contribution ratio of 6.000 %)**

PC5 included the slightly higher negative or positive values of the 4. back (Σ + Hc = -0.462), 6. crotch (Σ - Kc = 0.486 and Σ - Hc = 0.511), and 9. legs (Σ + Hc = -0.422) areas. PC5 represents the components of the concave hyperbolic 6. crotch (Σ - Hc and Σ - Kc) and the convex in the 4. back and 9. legs (Σ + Hc) curved surface shapes. The low PCS5 values indicate the slightly higher concave hyperbolic 6. crotch and the convex 4. back and 9. legs curved surface shapes, and vice versa for the high PCS5 values.

**PC6 (eigenvalue of 2.222 and contribution ratio of 5.555 %)**

PC6 included the slightly higher negative or positive values of the 3. chest (Σ + Hc = -0.427), 6. crotch (Σ + Kc = 0.450 and Σ + Hc = 0.558), and 7. buttocks (Σ - Kc = -0.522 and Σ - Hc = -0.409) areas. PC6 represents the components of the convex 3. chest (Σ + Hc), the convex elliptical 6. crotch (Σ + Hc and Σ + Kc), and the concave hyperbolic 7. buttocks (Σ - Hc and Σ - Kc) curved surface shapes. The high PCS6 values indicate the curved surface shapes of the slightly low convex 3. chest, the slightly high convex elliptical 6. crotch, and the slightly high concave hyperbolic 7. buttocks, and vice versa for the low PCS6 values.

### 4.3 Classification of 3D-body curved surface shape of males

For the 3D-body shapes of 1,144 males, the dendrogram of cluster analysis using PCS1 to PCS6 considered that classification of 8, 10, and 14 clusters was appropriate (cumulative contribution rate: 46.084 %). The features of the three cluster classifications were compared in detail. The eight and ten clusters were formed the member of 56 to 193 males, respectively. The eight clusters contained the seven groups of males with the mean ages in the 40s and the one group one of males with the mean age in the 50s, and the ten clusters had the seven groups with the mean ages in the 40s and one group each with a mean age in the 50s and 20s. Both of these two clusters displayed the many 40s groups but did not include, for example, the 30s and 60s groups. The fourteen clusters were formed from mean ages of 20s to 60s in groups ranging between 42 to 118 males, as shown in Table 4. Each cluster represented different combinations of the positive or negative higher mean values of the six PCSs.

| Clusters | PCS1 | PCS2 | PCS3 | PCS4 | PCS5 | PCS6 | Ages |
|----------|------|------|------|------|------|------|------|
| Cluster 7 | -1.15 | 0.10 | 0.42 | -0.62 | 0.33 | 1.22 | 28.11 |
| N = 56 | SD | 0.60 | 0.64 | 0.71 | 0.60 | 0.80 | 0.83 |
| Cluster 9 | 0.15 | 1.28 | 0.14 | 0.05 | -0.68 | 0.80 | 34.07 |
| N = 68 | SD | 0.59 | 0.66 | 0.74 | 0.74 | 0.62 | 0.81 |
| Cluster 11 | -0.65 | 0.93 | -0.75 | 1.21 | 0.06 | -0.12 | 37.62 |
| N = 68 | SD | 0.96 | 0.57 | 0.82 | 0.76 | 0.81 | 0.86 |
| Cluster 14 | -0.50 | 0.78 | 0.33 | 0.05 | -0.71 | -0.57 | 38.60 |
| N = 113 | SD | 0.52 | 0.61 | 0.71 | 0.68 | 0.67 | 0.72 |
| Cluster 10 | -1.02 | -0.60 | 0.41 | 0.90 | -0.65 | -0.35 | 40.74 |
| N = 75 | SD | 0.61 | 0.78 | 0.63 | 0.65 | 0.60 | 0.75 |
| Cluster 1 | 1.18 | 0.63 | 0.24 | -0.18 | -0.08 | -0.70 | 42.40 |
| N = 95 | SD | 0.43 | 0.57 | 0.87 | 0.69 | 0.65 | 0.78 |
| Cluster 4 | 0.01 | -0.20 | -0.91 | -0.15 | -0.64 | 0.15 | 44.29 |
| N = 118 | SD | 0.56 | 0.64 | 0.88 | 0.49 | 0.69 | 0.58 |
| Cluster 3 | 0.92 | -0.11 | -0.18 | 0.45 | -1.04 | 0.60 | 46.23 |
| N = 85 | SD | 0.66 | 0.73 | 0.81 | 0.77 | 0.72 | 0.75 |
| Cluster 2 | 0.74 | -0.10 | 0.03 | -0.80 | 1.06 | 0.86 | 48.96 |
| N = 105 | SD | 0.74 | 0.93 | 0.96 | 0.71 | 0.60 | 0.91 |
| Cluster 8 | -0.93 | -0.38 | -1.37 | -1.76 | -0.98 | -0.59 | 49.01 |
| N = 78 | SD | 0.98 | 1.21 | 1.07 | 1.13 | 1.04 | 0.93 |
| Cluster 6 | -0.07 | -0.50 | 0.35 | 0.25 | 0.35 | -1.13 | 51.03 |
| N = 79 | SD | 0.58 | 0.56 | 0.65 | 0.63 | 0.50 | 0.58 |
| Cluster 5 | -0.61 | -0.65 | -0.04 | 0.35 | 0.80 | 0.33 | 51.60 |
| N = 110 | SD | 0.69 | 0.58 | 0.65 | 0.59 | 0.72 | 0.60 |
| Cluster 12 | 0.93 | 0.22 | -1.91 | 0.87 | 0.00 | -0.33 | 52.67 |
| N = 42 | SD | 0.87 | 1.16 | 0.67 | 0.89 | 1.01 | 1.10 |
| Cluster 13 | 0.08 | -1.62 | -0.09 | -0.01 | 0.15 | -0.04 | 62.82 |
| N = 52 | SD | 0.53 | 0.55 | 0.62 | 0.71 | 0.77 | 0.63 |

Underlined and white boxed values show PCS1 to PCS6 of approximately ≥0.4; *: The single relationship values between the PCS1 to PCS6 values and ages (**: r < 0.01). The bold values show the slightly higher or high absolute values.

The mean and SD values of the four curved shape types (the elliptical (Σ + Kc), hyperbolic (Σ - Kc), convex (Σ + Hc), and the concave (Σ - Hc)) are displayed in the ten areas of each cluster in Table 5. Furthermore, the significant differences of the four curved shape types between each area’s mean value in the fourteen clusters and each area’s total four curvature mean values (Table 2) were determined by using a t-test in Table 5 (*: p < 0.05, **: p < 0.01). The bar graph of Fig. 2 shows the positive values for the high curved shapes and the negative values for the low curved shapes against the average 3D-body in all four curved shapes of Table 2: the positive value sum Σ + Kc or Σ + Hc in each area of clusters minus the positive value total Σ + Kc or Σ + Hc in each area (Table 2), and the negative value total Σ - Kc or Σ - Hc in each area (Table 2) minus the negative value sum Σ - Kc or Σ - Hc in each area of clusters. The 3D-body shape examples in Fig. 2 represent the different features of the 3D-body shapes in each of the fourteen clusters using the colored maps based on the four sum curvature values. The red-colored areas display the high convex elliptical curved shape of Σ + Kc and Σ + Hc, whereas the high concave hyperbolic curved shape areas of Σ - Kc and Σ - Hc are in dark blue.

The most significant single relationship values between the PCS1 (r = 0.26) or PCS2 (r = -0.43) or PCS3 (r = -0.27) values and the ages are shown in Table 4. The PCS1, PCS2, and PCS3 values represent the main principal components of all areas except the 6.
crotch area in Table 4. The r absolute values of males were lower than those of the female in previous paper [1]. The differences indicated by the high negative r values for the area of PCS were displayed between 3D-body curved surface shapes of the male (r = -0.43) and female (r = -0.69) [1]. The higher convex elliptical shape in the 5. abdomen area and the lower concave hyperbolic shape in the 7. buttocks area of the female had higher 3D-body curved surface shapes according to the age, whereas the male had the higher convex elliptical shape in the 2. shoulder area and the lower convex elliptical shape in the 7. buttocks area based on age.

The mean age values (20s to 60s) of each cluster are compared in Table 5. The mean age values among Clusters 9, 11, and 14 of the 30s age group, among Clusters 10, 1, and 4 of the 40s age group, among Clusters 3, 2, and 8 of the 40s age group, and among Clusters 6, 5, and 12 of the 50s age group have no significant differences (**: p < 0.01) with each cluster in the clusters of approximately same age. There were significant differences between the mean age values in Cluster 7 of the 20s group or Cluster 13 of the 60s group and the mean age values in one of the other thirteen clusters (**: p < 0.01). The mean age values of all clusters are outlined as follows (all age groupings are approximate): Clusters 7—men in the 20s; Clusters 9, 11, and 14—men in their younger 40s; Clusters 10, 1, and 4—men in their elder 40s; Clusters 6, 5, and 12—men in their 50s; and Cluster 6—men in their 60s. However, there is no significant difference (**: p < 0.01) between the mean ages in Cluster 14 and Cluster 10 or Cluster 4 and Cluster 3 or Cluster 8 and Cluster 6 or Cluster 5 or Cluster 12. Therefore, Table 5 show the fourteen clusters with the 1 to 6 PCS mean and SD values or the four sum curvature ($\Sigma + Kc$, $\Sigma - Kc$, $\Sigma + Hc$, and $\Sigma - Hc$) mean and SD values in order of the average age of each cluster.

In Table 5, the underlined bold values and bold values in white boxes show the significant difference between the $\Sigma + Kc$ or $\Sigma - Kc$ or $\Sigma + Hc$ or $\Sigma - Hc$ values of each cluster area and the total each area by using a t-test (*: p < 0.05, **: p < 0.01). The significant higher or lower values of the curved surface shapes in each cluster area were found using the four sum curvatures in all cluster areas. The underlined bold values had the significant low curved surface shapes for the $\Sigma + Kc$ or $\Sigma - Kc$ or $\Sigma + Hc$ or $\Sigma - Hc$ values, and the average number of clusters was 12.21. The bold values in white boxes show the significant high curved surface shapes for the $\Sigma + Kc$ or $\Sigma - Kc$ or $\Sigma + Hc$ or $\Sigma - Hc$ values, and the average number of clusters was 11.79.

Approximate 20s: Clusters 7

In Cluster 7 (N = 56, mean age values = 28.11 years old), PCS1, PCS3, PCS4, and PCS6 show high or slightly higher positive (bold values in white boxes) and negative (underlined bold values) mean values (0.42 to 1.22 and -0.62 to -1.15) in Table 4.

The sum curvature ($\Sigma + Kc$, $\Sigma - Kc$, $\Sigma + Hc$, and $\Sigma - Hc$) mean and SD values in this cluster are shown in Table 5. Many underlined bold values (N = 22 underlines) showing the low curved surface shapes represented the concave elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$ and $\Sigma - Hc$) 1. neck surface shape, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) and the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 3. chest, 5. abdomen, and 10. arms surface shapes, the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 6. crotch surface shape, the convex elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$ and $\Sigma + Hc$) 8. sides of trunk surface shape, and the convex ($\Sigma + Hc$) 9. legs surface shape. Hereinafter, the “surface shape” of each area surface shape is omitted, and finally, the “surface shapes” are collectively described.

The bold values in white boxes showing the high curved surface shapes display the elliptical ($\Sigma + Kc$) 2. shoulder, the convex and concave ($\Sigma + Hc$ and $\Sigma - Hc$) 4. back, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 6. crotch, the convex hyperbolic ($\Sigma - Kc$ and $\Sigma + Hc$) 7. buttocks, the concave ($\Sigma - Hc$) 8. sides of trunk, and the hyperbolic ($\Sigma - Kc$) 9. legs surface shapes.

As shown in the horizontal bar graph and 3D-body color map of Fig. 2, the main low curved surface shapes (the concave elliptical and hyperbolic, convex elliptical, concave hyperbolic, and convex and concave curved surface shapes) were extracted for the 1. neck, 3. chest, 5. abdomen, 8. sides of trunk, and 10. arms areas, showing the whitish yellow- and pale blue-colored areas present. Furthermore, the 8. sides of trunk area had the higher concave surface shapes, with the light blue-colored areas present. The 3D-body curved surface shapes of the 20s group were formed in the shape of the low and nearly plane curved surfaces of the 1. neck, 3. chest, 5. abdomen, and 10. arms areas and the low and higher curved surface of the slim waistline part in the 8. sides of trunk area.

Approximate younger and elder 30s: Clusters 9, 11, and 14

In Cluster 9 (N = 68, mean age values = 34.07 years old), PCS2, PCS5, and PCS6 indicated high or slightly higher positive and negative mean values (0.80 to 1.28 and -0.68), indicated in Table 4 in the small number of white boxes (6 white boxes).

In Table 5, the bold values in white boxes showing the high curved surface shapes represent the convex ($\Sigma + Hc$) 1. neck, the convex and concave hyperbolic ($\Sigma - Kc$, $\Sigma + Hc$, and $\Sigma - Hc$) 6. crotch, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) and the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 7. buttocks, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 9. legs, and the elliptical ($\Sigma + Kc$) 10. arms surface shapes.

The few underlined bold values (N = 6 underlines) showing the low curved surface shapes displays the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 1. neck, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 2. shoulder, the hyperbolic ($\Sigma - Kc$) 3. chest, and the convex ($\Sigma + Hc$) 5. abdomen surface shapes.

The higher curved surface shapes were conspicuous mainly as the convex and concave hyperbolic and the convex 6. crotch, the convex elliptical and the concave hyperbolic 7. buttocks, the convex elliptical 9. legs surface shapes, which were the clear red- and dark blue-color areas in Fig. 2. By contrast, the low curved surface shapes depicted the concave hyperbolic 1. neck and the convex elliptical 2. shoulder areas as whitish blue- and dark blue in color.

The features of the younger 30s group in Cluster 9 are shown
Fig. 2. Colored maps of clusters of older 40s, 50s, and 60s groups.
| Clusters | Cluster 7 | Cluster 8 | Cluster 9 | Cluster 10 | Cluster 11 | Cluster 12 | Cluster 13 |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| N = 56, 69, 76, 85, 95 | N = 66, 76, 86, 96, 106 | N = 61, 71, 82, 92, 102 | N = 81, 91, 101, 111, 121 | N = 91, 101, 111, 121 | N = 101, 111, 121, 131 | N = 111, 121, 131, 141 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |
| SKc | 20.87 | 15.37 | 21.49 | 25.17 | 20.87 | 16.19 | 16.19 |

**Table 5:** SKc, SKc, SKc, SKc, SKc, and SKc mean values and SD in ten areas of fourteen clusters.
as a group represented mainly by the higher curved surface shapes of the 6. crotch, 7. buttocks, and 9. legs areas, and the low curved surface shapes of the 2. shoulder area.

In Cluster 11 (N = 68, mean age values = 37.62 years old), PCS1 to PCS4 show high or slightly higher positive and negative mean values (0.93 to 1.21 and −0.65 to −0.75) in Table 4.

The bold values in white boxes showing the high curved surface shapes were conspicuous the convex elliptical (Σ + Kc and Σ + Hc) 1. neck and 9. legs, the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder and 6. crotch, the convex (Σ + Hc) 4. back, the concave (Σ − Hc) 5. abdomen, and the convex elliptical and hyperbolic (Σ + Kc, Σ − Kc and Σ + Hc) 7. buttocks surface shapes, as in Table 5.

The few underlined bold values (N = 4 underlines) showing the low curved surface shapes indicate the hyperbolic (Σ − Kc) or the convex (Σ + Hc) 1. neck and 3. chest and the convex elliptical (Σ + Kc and Σ + Hc) 8. sides of trunk surface shapes.

The 3D-body curved surface shapes in Cluster 11 of the elder 30’s group displayed mostly the higher convex elliptical 1. neck and 9. legs, the higher concave hyperbolic 2. shoulder, and the higher convex elliptical and hyperbolic 7. buttocks surface shapes, which were the pale or clear red-colored areas. The lower convex elliptical 8. sides of trunk surface shape appear as the pale blue-colored areas in Fig. 2.

In Cluster 14 (N = 113, mean age values = 38.60 years old), PCS1, PCS2, PCS5, and PCS6 show high or slightly higher positive and negative mean values (0.71 to 0.78 and −0.50 to −0.57) in Table 4.

Table 5 represented the many the underlined bold values (N = 21 underlines) showing the low curved surface shapes, the concave hyperbolic (Σ − Kc and Σ − Hc) 1. neck and 3. chest, the convex elliptical (Σ + Kc and Σ + Hc) 2. shoulder and 4. back, the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 5. abdomen, the concave and convex elliptical (Σ + Kc, Σ + Hc and Σ − Hc) 6. crotch, the concave elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 7. buttocks, and the elliptical and hyperbolic (Σ + Kc and Σ − Kc) 8. sides of trunk and 9. legs surface shapes.

The few bold values in white boxes (N = 7 white boxes) show the high curved surface shapes, including the convex elliptical (Σ + Kc and Σ + Hc) 1. neck, the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder, the convex (Σ + Hc) 3. chest and 9. legs, and the concave (Σ − Hc) 4. back surface shapes.

A large number of the low curved surface shapes in Cluster 14 of elder 30s group represented all areas except the 10. arms area, which were painted as the whitish light and dark blue-colored areas. The different high surface shapes were conspicuous as the higher convex elliptical and the low concave hyperbolic 1. neck and the low convex elliptical and the higher concave hyperbolic 2. shoulder surface shapes appear as red- and blue colored areas.

The 3D body curved shapes of the three clusters (Clusters 9, 11, and 14) in the 30s group were displayed separately because of the different combinations of the higher and lower curvature values in each area.

Approximate younger 40s: Clusters 10, 1, and 4

In Cluster 10 (N = 75, mean age values = 40.74 years old), PCS1 to PCS5 show high or slightly higher positive and negative mean values (0.41 to 0.90 and −0.60 to −1.02) in Table 4.

In Table 5, the underlined bold values (N = 17 underlines) showing the low curved surface shapes are represented in the many areas except the 1. neck and 2. shoulder areas. The low curved surface shapes were extracted as the convex elliptical (Σ + Kc and Σ + Hc) 3. chest, 6. crotch and 7. buttocks, the concave (Σ − Hc) 4. back, the concave hyperbolic (Σ − Kc and Σ − Hc) 5. abdomen, the convex elliptical and hyperbolic (Σ + Kc, Σ − Kc and Σ + Hc) 8. sides of trunk, the elliptical and hyperbolic (Σ + Kc and Σ − Kc) 9. legs, and the concave elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 10. arms surface shapes.

The higher curved surface shapes of the bold values in white boxes were displayed as the concave (Σ − Hc) 1. neck, 6. crotch, and 8. sides of trunk, the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder, the concave hyperbolic (Σ − Kc and Σ − Hc) 3. chest, the convex (Σ + Hc) 4. back and 9. legs, and the concave (Σ − Hc) 4. back surface shapes.

The 3D-body curved surface shapes in Cluster 10 of the younger 40s group displayed mainly as the one higher and many lower curvature values, appearing as the red- and pale blue-colored 2. shoulder area, the whitish- and dark blue-colored 3. chest area, the white- and pale light blue-colored 10. arms areas, and the dark blue- and red-colored 8. sides of trunk and the 9. legs areas.

In Cluster 1 (N = 95, mean age values = 42.40 years old), PCS1, PCS2, and PCS6 show high or slightly higher positive and negative mean values (0.63 to 1.18 and −0.70) in Table 4.

The underlined bold values showing the low curved surface shapes show were mainly in certain areas, as indicated in Table 5. The low curved surface shapes represent the convex and concave elliptical (Σ + Kc, Σ + Hc, and Σ − Hc) 1. neck, the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder, the convex elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 4. back, the elliptical (Σ + Kc) 6. crotch, and the hyperbolic (Σ − Kc) 7. buttocks surface shapes.

The higher curved surface shapes of the bold values in white boxes displayed the convex elliptical (Σ + Kc and Σ + Hc) 3. chest and 9. legs, the concave hyperbolic (Σ − Kc and Σ − Hc) 5. abdomen and 6. crotch, the convex (Σ + Hc) 7. buttocks, the convex elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 8. sides of trunk, and the concave elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 10. arms surface shapes.

The caracterized curved surface shapes in Cluster 1 of the younger 40s group were extracted as the low curvature values of the 1. neck, 2. shoulder, and 4. back surface shapes, appearing as the whitish light and dark blue-colored areas. We were particularly able to recognize the red-colored areas of the higher convex elliptical 3. chest, 8. sides of trunk, and 9. legs surface shapes, and the blue-colored areas of the higher concave hyperbolic 5. abdomen, 6. crotch, and 10. arms surface shapes.
In Cluster 4 ($N = 118$, mean age values = 44.29 years old), PCS3 and PCS5 show high or slightly higher positive and negative mean values (0.91 and −0.64) in Table 4.

Many the underlined bold values ($N = 19$ underlines) showing the low curved surface shapes were as follows, as in Table 5; the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 1. neck and 6. crotch, the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 2. shoulder, the concave elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$, and $\Sigma - Hc$) 3. chest, 5. abdomen, and 10. arms, the convex elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$, and $\Sigma + Hc$) 8. sides of trunk, and the hyperbolic ($\Sigma - Kc$) 9. legs surface shapes.

The higher curved surface shapes of the few bold values in white boxes ($N = 6$ white boxes) had, in few areas, the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 6. crotch, the convex elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$, and $\Sigma + Hc$) 7. buttocks, and the convex ($\Sigma + Hc$) 9. legs surface shapes.

The 3D-body curved surface shapes in Cluster 4 of the younger 40s group appeared mainly as the low curved surface shapes of all areas except for the 6. crotch and 7. buttocks areas, showing the whitish- and pale-colored present.

Approximate elder 40s: Clusters 3, 2, and 8

In Cluster 3 ($N = 85$, mean age values = 46.23 years old), PCS1 and PCS4 to PCS6 show high or slightly higher positive and negative mean values (0.45 to 0.93 and −1.04) in Table 4.

On the right side of the vertical dotted line of Table 5, the many bold values in white boxes ($N = 22$ white boxes) showing the high curved surface shapes include the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 1. neck and 3. chest, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) and the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 5. abdomen and 7. buttocks, the convex and concave hyperbolic ($\Sigma - Kc$, $\Sigma + Hc$, and $\Sigma + Hc$) 6. crotch, the elliptical and hyperbolic ($\Sigma + Kc$ and $\Sigma - Kc$) 8. sides of trunk, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 9. legs, and the concave elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$ and $\Sigma - Hc$) 10. arms surface shapes.

The few underlined bold values ($N = 6$ underlines) showing the low curved surface shapes represent the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 1. neck, the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 2. shoulder and 3. back, and the concave ($\Sigma - Hc$) 8. sides of trunk surface shapes.

The features in Cluster 3 of the elder 40s group were displayed the low or slightly lower and high curvature values in the upper half of the 3D-body areas with the whitish and pale blue colors. The lower half of 3D-body areas (5. abdomen to 10. arms, including the 3. chest) included the high sum two to four curvature values, with the both red- and pale blue-colored areas present.

In Cluster 2 ($N = 105$, mean age values = 48.96 years old), PCS1 and PCS4 to PCS6 show high or slightly higher positive and negative mean values (0.74 to 1.06 and −0.80) in Table 4.

The many underlined bold values ($N = 16$ underlines) showing the low curved surface shapes were represented as the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 1. neck, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 2. shoulder, the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 3. chest and 6. crotch, the convex elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$ and $\Sigma + Hc$) 4. back, the elliptical ($\Sigma + Kc$) 5. abdomen, the hyperbolic ($\Sigma - Kc$) 7. buttocks, and the convex ($\Sigma + Hc$) 9. legs surface shapes.

The bold values in white boxes showing the high curved surface shapes were displayed as the convex ($\Sigma + Hc$) 3. chest, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) 6. crotch, the convex elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$ and $\Sigma + Hc$) 8. sides of trunk, the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 9. legs, and the concave elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma - Kc$ and $\Sigma - Hc$) 10. arms surface shapes.

The low curved surface shapes in the upper half of the 3D-body areas in Cluster 2 of the elder 40s group represent mainly the 1. neck, 2. shoulder, 3. chest, and 4. back areas using the pale red and blue colors. On the other hand, the higher or highest curved surface shapes were found in the 6. crotch, 8. sides of trunk, 9. legs, and 10. arms areas by appearing in clear red and dark blue colors.

In Cluster 8 ($N = 78$, mean age values = 49.01 years old), PCS1 and PCS3 to PCS6 show high or slightly higher negative mean values (−0.59 to −1.76) in Table 4.

The number of the bold values in white boxes showing the high curved surface shapes was higher than that of the underlined bold values showing low curved surface shapes, as in Table 5. The higher curved surface shapes show the concave hyperbolic ($\Sigma - Kc$ and $\Sigma - Hc$) 1. neck and 9. legs, the convex elliptical and hyperbolic ($\Sigma + Kc$, $\Sigma + Kc$, $\Sigma - Kc$, and $\Sigma + Hc$) 2. shoulder, the elliptical and hyperbolic ($\Sigma + Kc$ and $\Sigma - Kc$) 3. chest, the convex elliptical ($\Sigma + Kc$ and $\Sigma + Hc$) and the concave hyperbolic ($\Sigma - Kc$ and $\Sigma + Hc$) 4. back, and the concave ($\Sigma - Hc$) 8. sides of trunk surface shapes.

The low curved surface shapes of the few underlined bold values ($N = 6$ underlines) include the elliptical ($\Sigma + Kc$) 5. abdomen, the hyperbolic ($\Sigma - Kc$) 6. crotch and 8. sides of trunk, the concave elliptical ($\Sigma + Kc$ and $\Sigma - Hc$) 7. buttocks, and the convex ($\Sigma + Hc$) 9. legs surface shapes.

The features in Cluster 8 of the elder 40s group mainly displayed the higher curvature values of the upper half of the 3D-body. Both the red- and blue-colored areas of one area indicated the 1. neck, 2. shoulder, 3. chest, and 4. back surface shapes. Each of the four sum curvature values for the 4. back area were highest values among all of the clusters. Even in the 3D-body curved surface shape among females [1], the highest four sum curvature values for the 4. back area were confirmed in 40s cluster.

Each cluster of the younger and elder 40s groups was constructed of the 75 to 118 members. Although Clusters 10, 4, and 2 included a large number of areas with low curved surface shapes, those areas of each cluster were not in exactly the same places. Furthermore, the higher curved surface shapes of the three clusters were different areas and curved surface shapes from those in Fig. 2. On the other hand, the different features of high curved surface shapes in the Cluster 1 (3. chest, 8. sides of trunk, and 10. arms areas), Cluster 3 (5. abdomen to
10. arms areas), and Cluster 8 (1. neck to 4. back areas) were easily recognized from the graphs and the 3D-body curvature colored-maps in Fig. 2. The features of higher curved surface shapes of the 5. abdomen, 8. sides of trunk, and 10. arms areas in Clusters 1, 3, and 8 in the 40s groups were recognized compared with the features of the curved surface shapes in the three clusters of the 30s groups.

**Approximate 50s: Clusters 6, 5, and 12**

In Cluster 6 (N = 79, mean age values = 51.03 years old), PCS2 and PCS6 show high or slightly higher negative mean values (−0.50 to −1.13) in Table 4.

The few bold values in white boxes (N = 4 white boxes) showing the high curved surface shapes appear in Table 5. The higher curved surface shapes were only the elliptical (Σ + Kc) 2. shoulder, the convex (Σ + Hc) 3. chest and 9. legs, and the hyperbolic (Σ − Kc) 6. crotch surface shapes.

The low curved surface shapes of the underlined bold values displayed the convex elliptical (Σ + Kc and Σ + Hc) 4. back and 6. crotch, the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 7. buttocks, and the elliptical and hyperbolic (Σ + Kc and Σ − Kc) 9. legs and 10. arms surface shapes.

The 3D-body curved surface shapes in Cluster 6 of the 50s groups represented the standard curved surface shapes in almost all areas except the 4. back, 6. crotch, 7. buttocks, and 9. legs areas. The 4. back, 6. crotch, 7. buttocks, and 9. legs areas were painted the whitest color showing low curvature values in Fig. 2.

In Cluster 5 (N = 110, mean age values = 51.06 years old), PCS1, PCS2, and PCS5 show high or slightly higher positive and negative mean values (0.86 to −0.65) in Table 4.

The bold values in white boxes showing the high curved surface shapes were represented as the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder surface shape. Another high curved surface shape was shown as the elliptical (Σ + Kc) 1. neck and 6. crotch, the convex (Σ + Hc) 5. abdomen, and the hyperbolic (Σ − Kc) 9. legs surface shapes.

Many underlined bold values (N = 16 underlines) showing low curved surface shapes were as follows; the convex elliptical (Σ + Kc and Σ + Hc) 3. chest and 9. legs, the concave elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 4. back, the concave hyperbolic (Σ − Kc and Σ − Hc) 5. abdomen, the convex and concave hyperbolic (Σ − Kc, Σ + Hc, and Σ − Hc) 6. crotch, the convex elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 7. buttocks, and the elliptical (Σ + Kc) 10. arms surface shapes.

The features of 3D-body curved surface shapes in Cluster 5 of the 50s groups include the higher convex elliptical and the concave hyperbolic 2. shoulder surface shape, with the red- and blue-colored areas present. The low curved surface shapes of other areas (3. chest to 9. legs except for 1. neck and 5. abdomen areas) were depicted with the pale or whitish red and blue colors in Fig. 2. The higher convex 5. abdomen and the lower convex elliptical 9. legs curved shapes are recognized.

In Cluster 12 (N = 42, mean age values = 52.67 years old), PCS1, PCS3, and PCS4 show high or slightly higher positive and negative mean values (0.87 to 0.93 and −1.91) in Table 4. The Cluster 12 was the smallest group, with a member total of 42.

A large number of bold values in white boxes (N = 20 white boxes) showing the high curved surface shapes were represented as follows; the convex elliptical (Σ + Kc and Σ + Hc) 1. neck, the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder, the concave elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 3. chest and 10. arms, the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 5. abdomen, the convex hyperbolic (Σ − Kc and Σ + Hc) 6. crotch, and the elliptical and hyperbolic (Σ + Kc and Σ − Kc) 8. sides of trunk and 9. legs surface shapes. Only the convex (Σ + Hc) 4. back surface shape was extracted as the low curved surface shape of the underlined value.

The higher curved surface shapes in Cluster 12 of the 50s groups displayed many areas except for the 4. back and 7. buttocks areas, which showed the clear red and blue colors in Fig. 2. The convex elliptical surface shapes of the 3. chest to 5. abdomen areas were able to represent from the red-colored area of the front and the shape of side views on the 3D-body maps.

**Approximate 60s: Clusters 13**

In Cluster 13 (N = 52, mean age values = 62.82 years old), PCS1 and PCS2 show high or slightly higher positive and negative mean values (0.88 and −1.62) in Table 4. The highest mean age group of the Cluster 13 was the second smallest member of 52.

The many underlined values (N = 16 underlines) showing the low curved surface shape were as follows; the convex elliptical (Σ + Kc and Σ + Hc) 1. neck and 9. legs, the concave hyperbolic (Σ − Kc and Σ − Hc) 2. shoulder, the convex elliptical (Σ + Kc and Σ + Hc) and the concave hyperbolic (Σ − Kc and Σ − Hc) 4. back, the convex and concave hyperbolic (Σ − Kc, Σ + Hc, and Σ − Hc) 6. crotch, and the convex elliptical and hyperbolic (Σ + Kc, Σ − Kc, and Σ + Hc) 7. buttocks surface shapes.

The bold values in white boxes showing the high curved surface shapes were represented the concave hyperbolic (Σ − Kc and Σ − Hc) 1. neck and 3. chest, the convex elliptical (Σ + Kc and Σ + Hc) 2. shoulder and 5. abdomen, the convex elliptical and hyperbolic (Σ + K, Σ − Kc, and Σ + Hc) 8. sides of trunk, and the elliptical and hyperbolic (Σ + K and Σ − Kc) 10. arms surface shapes.

In Cluster 13 of the 60s group, all areas found the low or high curved surface shapes in any of the four sum curvatures (Σ + Kc, Σ − Kc, Σ + Hc and Σ − Hc). The features were mainly the combination of the higher or low the convex elliptical and the concave hyperbolic 1. neck and 2. shoulder surface shapes, with the red- and light blue-colored areas present, and the 4. back, 6. crotch, and 7. buttocks nearly plane curved shapes with many whitish colored areas present. Furthermore, the 5. abdomen and 8. sides of trunk areas had the rounded convex elliptical surface shape with the pale or dark red-colored areas, whereas the low convex elliptical surface shapes showing the few the rounded convex surface shapes that were constructed for the 9. legs surface shapes with many
whitish colored areas.

In the clusters of the 50s and 60s groups (total number of approximately 280 models), the mean age of each cluster in their 50s was almost the same, and the Cluster 12 in the 50s group and Cluster 13 in the 60s group had only around 50 3D-body models. The number of 3D-body models over ages 50 or older in this paper were approximately 450. In addition, even in Cluster 7 \( (N = 56) \) of the 20s group, there were only a small number of 3D-body models. The features of the 3D-body curved surface shape were extracted based on the age and individual 3D-body shape. Therefore, the 40s groups had the large number of the clusters \( (N = 6 \text{ clusters}) \). In other words, it is necessary to comprehensively examine the features of the 3D-body curved surface shape based on the individual and the changes with age.

The large number of type of 3D-body curved surface shape was represented using combinations of the high and low curvature values for 10 areas. The features of 3D-body curved surface shapes according to the changes with age were as follows in this research; the curvature values of the 5. abdomen shapes tend to increase with age, and the higher value convex elliptical and concave hyperbolic curved surface shapes are formed from the elder 40s and older. On the other hand, the low curvature values of the 7. buttocks and 9. legs values showed almost flat shapes. It is generally agreed, according a visual and image evaluations, that the abdomen bulges and the roundness of the buttocks and legs decreased. Both were represented faithfully using the curvature values of angles.

5. Conclusions

For the purpose of 3D custom-made garment design, the fourteen types of 3D-body curved surface shapes in adult males were extracted using the curvature values of their angles. The 3D-body curved surface shapes of 1,144 males from a wide-ranging age were investigated using each of four sum angle curvatures—elliptical \( (\Sigma + Kc) \), hyperbolic \( (\Sigma - Kc) \), convex \( (\Sigma + Hc) \), and concave \( (\Sigma - Hc) \) curved shapes—in ten body surface areas. In each vertex point on the 3D-body interior surface, the \( Kc \) demonstrated the concentrated Gaussian curvature (by \( Kc = 360^\circ (2\pi) \cdot \Sigma \Phi n \)) on the interior area vertexes, while \( Hc \) showed the concentrated mean curvature (by \( Hc = \Sigma \Phi n / Li \) on the interior area vertexes).

The 3D-body curved surface shapes of adult males and females were compared under substantially the same conditions, independent of size, using the curvature values in ten areas. The 3D-body curved surface shapes of adult males had mainly the low convex elliptical \( (\Sigma + Kc \text{ and } \Sigma + Hc) \) and concave hyperbolic \( (\Sigma - Kc \text{ and } \Sigma - Hc) \) curved shapes in chest and abdomen areas, the higher convex elliptical \( (\Sigma + Kc \text{ and } \Sigma + Hc) \) curved shapes in back area, and the higher hyperbolic \( (\Sigma - Kc) \) curved shapes in legs and arms areas.

The six principal components (PC1 to PC6) were extracted by each of the four sum angle curvatures in each area by means of the PCA, according to the mutual correlation coefficients (eigenvalues \( = 2.222 \text{ or more and cumulative contribution ratio } = 46.084\% \)). The six components were mainly as follows: PC1; the 2. shoulder, 5. abdomen, 8. sides of trunk, and 10. arms areas, PC2; 1. neck, 2. shoulder area, 7. buttocks, and 9. legs areas, PC3; the 2. shoulder, 3. chest and 4. back areas, PC4; the 4. back area, PC5; the 6. crotch area, and PC6; the 6. crotch and 7. buttocks areas. A large number of area combinations form the 3D-body curved surface shapes of males. The factor lording of 3. chest curved surface shapes in males were lower than those of the female. The significant single relationship values are mainly between the PC1 \((r = 0.26)\) or PC2 \((r = -0.03)\) or PC3 \((r = -0.27)\) value and the ages.

The 3D-body shapes of the 1,144 males were categorized into fourteen clusters by PCS1 to PCS6 of the scores. The mean age values of the fourteen clusters were separated approximately into 20s for Clusters 7, into 30s for Clusters 9, 11, and 14, into approximately younger 40s for Clusters 10, 1, and 4, into approximately elder 40s for Clusters 3, 2, and 8, into approximately 50s for Clusters 6, 5, and 12, and into approximately 60s for Cluster 13.

The 3D-body shape type of the 20s age group is shown in Cluster 7 \((N = 56, \text{ mean age values } = 28.11 \text{ years old})\) of the low and nearly plane curved surfaces of approximately all areas, except of the low and higher curved surface of the 8. sides of trunk area with the slim waistline part.

The three 3D-body shape types in the 30s group had the approximately common low or standard 3. chest, 4. back, 5. abdomen, 8. sides of trunk, and 10. arms areas, with different areas such as: for Cluster 9 \((N = 68, \text{ mean age values } = 34.07 \text{ years old})\), some higher curved shapes of the 6. crotch, 7. buttocks, and 9. legs areas; for Cluster 11 \((N = 68, \text{ mean age values } = 37.62 \text{ years old})\), some higher curved shapes of the 1. neck, 2. shoulder, 7. buttocks, and the low 8. sides of trunk curved shapes; for Cluster 14 \((N = 113, \text{ mean age values } = 38.60 \text{ years old})\), higher and low curved shapes of the 1. neck, 2. shoulder, 7. buttocks, and 9. legs areas and low curved shapes of the 6. crotch and 7. buttocks areas.

The three 3D-body shape types of the younger 40s age group were as follows: for Cluster 10 \((N = 75, \text{ mean age values } = 40.74 \text{ years old})\), higher and low curved shapes of the 2. shoulder, 3. chest, 8. sides of trunk, 9. legs, and 10. arms areas; for Cluster 1 \((N = 95, \text{ mean age values } = 42.40 \text{ years old})\), the low curved shapes of the 1. neck, 2. shoulder, and 4. back areas and the higher curved shapes of the 3. chest, 5. abdomen, 6. crotch, 8. sides of trunk, 9. legs, and 10. arms areas; for Cluster 4 \((N = 118, \text{ mean age values } = 42.40 \text{ years old})\), almost all are low curved shapes except the slightly high 6. crotch and 7. buttocks curved shapes.

The three 3D-body shape types of the era 40s age group were as follows: for Cluster 3 \((N = 85, \text{ mean age values } = 46.23 \text{ years old})\), the higher curved shapes of the lower half of 3D-body areas (5. abdomen to 10. arms included the 3. chest), the low or low and high curved shapes of the upper half of 3D-body areas (1. neck, 2. shoulder, and 4. back); for Cluster 2 \((N = 105, \text{ mean age values } = 48.96 \text{ years old})\), the low curved shapes of the 1. neck, 2. shoulder,
3. chest, and 4. back areas and the higher or highest surface shapes of the 6. crotch, 8. sides of trunk, 9. legs, and 10. arms areas; for Cluster 8 (N = 78, mean age values = 49.01 years old), the higher curved shapes of the upper half of 3D-body areas (1. neck, 2. shoulder, 3. chest and 4. back areas) and the slightly low curved shape of the 7. buttocks area.

The three 3D-body shape types of the 50s age groups and the 3D-body shape type of the 60s age group had the approximately common low or standard 4. back and 7. buttocks areas, with different areas such as: for Cluster 6 (N = 79, mean age values = 51.03 years old), the nearly standard curved shapes of all areas except of the low or slightly low curved shapes of the 9. legs and 10. arms areas; for Cluster 5 (N = 110, mean age values = 51.06 years old), the higher curved shape of the 2. shoulder area, the low 3. chest, 6. crotch, and 7. buttocks areas, and the higher and low curved shapes of the 5. abdomen and the 9. legs curved shapes; for Cluster 12 (N = 42, mean age values = 52.67 years old), the mostly higher curved shape of the all areas except the common areas in four groups; for Cluster 13 (N = 52, mean age values = 62.82 years old) the higher and low curved shapes of the 1. neck and 2. shoulder areas, the higher curved shapes of the 3. chest, 5. abdomen, 8. sides of trunk, and 10. arms areas, and the low curved shapes of the 6. crotch and 9. legs areas.

The information of the male 3D-body shape type could be determined based on the individual curved surface shapes and the changing with age by using the angle curvatures. The curvature values using the angles were able to represent the well-known visual shape of the 7. buttocks area.

Now, from the perspective of garments covering the 3D-body, we are researching the 3D-bodice forming by the 3D-body convex surface shape and their characteristics based on the 3D curvature data of the females [1] and males.

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