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Feature Examination of Curved Shapes for Tight-Fitting Patterns of Young Women by Using Concentrated Gaussian Curvature

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A new concept for clothing pattern design was created for the three-dimensional (3D) surface shape, introducing a classification for similar tight-fitting pattern (T-pattern) shapes. In this paper, for the purpose of extracting the features of T-pattern curved shapes regardless of size, we proposed a new theory of curved surface geometry by using "Concentrated Gaussian Curvature based on angle ($Kc=2\pi-\theta$)." A 3D T-pattern closed surface, the same as sewing the 5 darts and covering the holes of 3 boundary lines (neck-base line, *etc.*), was assumed. According to conservation law, the total of Kc of the 5 darts and the 3 lines is a consistent 4π (720 deg.), maintaining the theory. As a result of the theory to Total Kc of T-patterns in 203 young women, each total Kc of T-pattern of models was the same value, 720 degrees. Features of 3D curved shape of the T-pattern, regardless of size, such as the bust girth, projection of the back, tightness of the girth, shoulder slope *etc.* can be understood through the distribution of Kc of each dart and each line. It was indicated that those features were useful data for the classification of similar pattern curved shapes.

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INTRODUCTION

As we face an aging society and a trend toward individualization, the time has come for a new technique of pattern making for comfortable clothing on any figure. There are many studies focused on the understanding of figure and clothing pattern shape, including classification of clothing length for design. However, there are only a few studies which examine, in detail, how these two subjects are related to each other and how clothing patterns can be made with both figure and body size in mind. In the traditional plane drafting method, there are two organized elements (*i.e.*: "Body lengths" relating to the figure, and "Ease lengths") for physical breath and movements.[1)-6)] From our previous paper, we found that, besides "Body measurements,""Gap lengths of positive and negative values (including darts)" cover the uneven curved surface of the body by plane cloth in tight-fitting patterns[7)8)] excluding "Ease lengths." We recognized "the factor for clothing construction of the uneven body surface" is called the "Gap factor."[7)8)] It is difficult, however, to obtain the Gap factor as the actual gap length without using the draping method. In our previous papers,[7)8)] we obtained plane geometry relationship formulas for theoretically estimating gap lengths according to body lengths. We proved that it is possible to easily make tight-fitting patterns for women by using the same draping pattern with individual body lengths and estimated gap lengths.[9)]

For reference, the "Gap factor" means investigating the shape of the torso curved surface by organizing the torso plane in terms of "length." Almost all subjects had a bust dart (front waist line dart), back waist line dart, and shoulder dart with a positive gap length on a tight-fitting pattern. Their length indicated a higher value than other positive gap lengths.[7)-9)] It seems reasonable to suppose that each dart is particularly related to the torso surface curvature, since it makes a 3D curved surface of tight-fitting patterns. Regarding curvature of torso curved surface, we already investigated 110 women's 3D torso curved surfaces in terms of "angular," "Concentrated Geodesic Curvature (kc)," and "Concentrated Gaussian Curvature (Kc)."[10)] The kc is the result of deducting the angle concentrated on a circumference of one vertex upon a boundary line such as the neck-base line from π (180 deg., straight line). The result shows how the boundary line curves when the torso curved surface is developed. The Kc is the result of deducting the angle concentrated on a circumference of one vertex on the internal torso from 2π (360 deg., developable surface). Namely, it brings to light the form of the torso curved surface from the standpoint of manipulating a plane with cloth, *etc*. As far as the total of two curvatures are concerned, they hold true to the Gauss-Bonnet theorem[11)12)] which suggests that the total value of each model's two curvatures maintains a constant -4π. Based on the differences between the distributions of these curvatures on each spot, we can better understand the features of the torso curved surface regardless of size. This law is applicable to the total of two curvatures when women's clothing models have the same torso curved surface and the same Euler number.[12)] As to the basic clothing pattern for women, upon addition of the total of the two sum curvatures, one being the sum of the Kc (angles of the internal darts) the other being the sum of the kc (boundary lines of the neck-base line, the armhole line, and the waist line), the total is a consistent -4π (-720 deg.), thus maintaining the conservation law.[13)]

In this study, we first attempt to formulate a theorem for extracting the characteristics of the 3D shape of the tight-fitting pattern curved surface, regardless of size, according to the Kc. This is for the purpose of showing the wide assortment of figures concerned with clothing pattern making. Secondly, we will classify the shape of the tight-fitting pattern curved surface according to types in our next paper. Utilizing the angle like a dart, which shows the shape of the tight-fitting pattern curved surface, we extract not the size, but the shape of the tight-fitting pattern in similar figures. Next, we investigate the classification of figures according to the type of shapes that the tight-fitting pattern curved surface falls under. After we deduce this, we will take size into consideration and make a pattern by grading. In this paper, we propose a new theory that the above-mentioned total of two curvatures, with the angle located on the tight-fitting pattern,[7)] is not the negative value, -4π (-720 deg.), but the positive value, 4π (720 deg.), on the condition that only the Kc, derived from the angles of darts and lines, constitutes a closed surface[12)] of the tight-fitting pattern. In other words, we make the feature of the tight-fitting curved surface more comprehensible by using only the positive value of the Kc, regardless of size. Analyzing the tight-fittings of 203 young women, we first prove that the total of the Kc, derived from the darts and the lines of each subject, is a constant 720 degrees. Secondly, we examined the distribution of these curvatures and we explain the feature of the Kc in tight-fitting pattern making. We initially examined the feature of the tight-fitting pattern curved shape from the standpoint of angles and acquired the basic information necessary to classify tight-fitting pattern curved shapes, which will be discussed in our next paper.

THEORY

In this paper, we will investigate Concentrated Gaussian Curvature (also called "Kc: deficit angle") derived from the angle of the tight-fitting pattern (T-pattern) by using five darts (GFWD, GFAD, GBWD, GBAD, GBSD) of the internal pattern for covering the torso curved surface with a plane of cloth and Kc of three external boundary lines (GNL, GAHL, GWL) (Fig. 1, Table 1). As GFAD and GBAD extract the curved shape of the side surface, they are set up with automatic computer development in order to straighten the side of the bust line (FBL2-FBL3, BBL2-BBL3) (Fig. 1) of the T-pattern made in advance (Fig. 6 mentioned later). The details of the procedure will be mentioned in "Experimentation."

We reported that regarding the basic clothing pattern of the torso on the condition that the hole is sewn up, the total of the two curvatures (kc translated from the curvature along the line and Kc translated from the curvature of the dart), is the constant, -4π (the Euler number $-2\times2\pi$) *i.e.* negative value of -720 degrees.[13)] Here, we would like to explain the pattern's curved surface by using a kind of curvature that would make the Total Kc (sum of Kc of five darts +sum of Kc of three lines) a positive value. We assume that the surface of the 3D T-pattern is closed where the boundary lines are sewn up, for example, a sewn dart (Fig. 2). We do this so that we can describe the curvatures derived from the angles of the dart and the line respectively by using only the Kc. Based on differential geometry, the closed surface of the 3D T-pattern is theoretically similar to a non-hole spherical surface. Thus we can investigate the curvature derived from the angle by using only the Kc. As the Euler number of the spherical surface[12)] is two, the Total Kc is the constant 4π (the Euler number $2\times2\pi$) according to Gauss-Bonnet theorem,

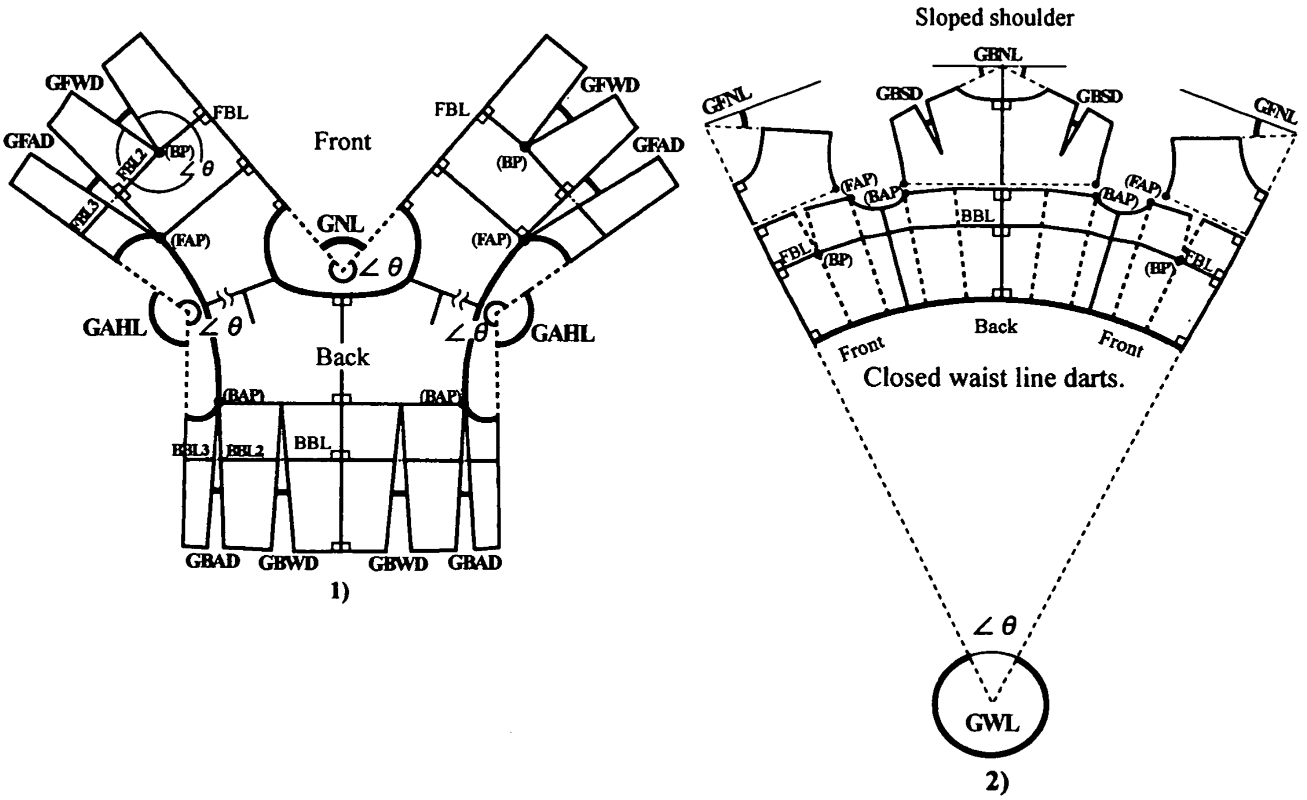


Fig. 1. Concentrated Gaussian Curvature (Kc) of darts and lines on the flat tight-fitting pattern

Kc is called the "deficit angle"; $2\pi-\theta=360°-\angle\theta$. The sloped angle of shoulder-line is represented by GNL. BP: bust point, FAP: front armpit point, BAP: back armpit point. (See Table 1.)

Table 1. Measurement items of Concentrated Gaussian curvatures Kc (deficit angles)

Deficit angles Kc	
Darts	
Front	
GFWD	Kc of front waist line dart
GFAD	Kc of front armpit line dart
Back	
GBWD	Kc of back waist line dart
GBAD	Kc of back armpit line dart
GBSD	Kc of shoulder dart
Lines	
GNL	Kc of neck-base line
GAHL	Kc of armhole line
GWL	Kc of waist line

See Fig. 1.

regardless of size. The angles (*e.g.* GFWD in Fig. 1) of the darts show an external angle to the interior angle θ of the pattern. The angle concentrated on one vertex (*e.g.* BP in Fig. 1) of the plane is 2π (360 deg.). The angle of the dart is calculated in the following equation by using the same method as the "Kc" of 3D torso curved surface.

$$\mathrm{Kc}=2\pi-\theta \quad (1)$$
$$=360°-\angle\theta \quad (2)$$

For example, GFWD (Kc of the front waist line dart), in short, evaluates the difficulty of manipulating the cloth plane on the front torso curved surface centered on the bust. The more positive the value of GFWD is, the more difficult it is for the figure to be translated into a plane on the pattern curved surface.

The curvature of an angle along the line derived from the angle on the closed surface of the T-pattern, is an external angle θ relating to the kc along the line (Fig. 1, Fig. 2). It is calculated by using the same equation, (1) and (2), in terms of the "Kc." In our previous paper, the kc of the line was calculated in the equation "$\pi-\theta$" so as to show how the line curves compared with the angle π of the segmented approximate lines.[10] After dividing the T-pattern lines into the segmented approximate lines in the same way as our previous paper (Fig. 3), the kc of an arbitrary vertex is a negative value $-$kc as it curves at an angle greater than π. The internal angle θ of the kc in Fig. 3

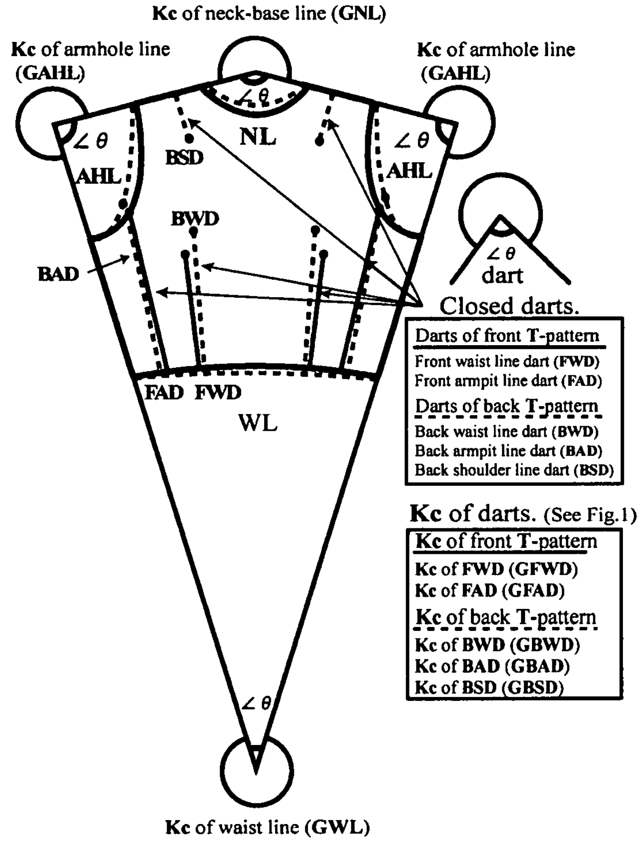


Fig. 2. Closed darts and covered linens of tight-fitting pattern

Kc is Concentrated Gaussian Curvature: $Kc = 2\pi - \theta = 360° - \angle\theta$. Kc of five darts + Kc of three lines $= 4\pi$ (720°). (See Table 1.)

is expressed by α and β. For example, kc_1 is calculated in the following equation.

$$kc_1 = \pi - (2\pi - (\beta_1 + \alpha_2)) \tag{3}$$

$$-kc_1 = \pi - (\beta_1 + \alpha_2) \tag{4}$$

Therefore the Sum of $-kc$ is as follows:

$$\begin{aligned}\sum_{i=1}^{n} -kc &= \sum_{i=1}^{n-1} (\pi - (\beta_i + \alpha_{i+1})) + (\pi - (\beta_n + \alpha_1)) \\ &= (\pi - (\beta_1 + \alpha_1)) + (\pi - (\beta_2 + \alpha_2)) + \cdots \\ &\quad + (\pi - (\beta_n + \alpha_n)) \\ &= \sum_{i=1}^{n} (\pi - (\beta_i + \alpha_i)) \end{aligned} \tag{5}$$

Then, the Sum of the internal angle θ of the Kc on the line shown in P1 of Fig. 3 is as follows:

$$\sum_{i=1}^{n} \theta = \sum_{i=1}^{n} (\pi - (\alpha_i + \beta_i)) \tag{6}$$

Therefore

$$\sum_{i=1}^{n} -kc = \sum_{i=1}^{n} \theta = \angle\theta_i \tag{7}$$

The value of $\angle\theta$ relates to the sum of $-kc$.

It should be clear that the Kc on the line of the closed surface of the T-pattern reflects the kc of the ordinary T-pattern whose lines make a hole. In light of the closed surface of the T-pattern, we can investigate the pattern curvatures only with the Kc. In theory, there must be a conservation law, described earlier in which the total of curvature is the constant positive value, 4π (720 deg.), in any model. We can extract the features of the pattern's curved shape regardless of size of the Kc based on the angle (*e.g.* the difference in "deficit angle (Kc)").

EXPERIMENTATION

Subjects

The subjects are 203 young women with an average age of 19.6 years old. Means and standard deviations (S.D.) of fundamental measurements are as follows; stature: 157.3 cm (S.D. = 5.3 cm), body weight: 50.8 kg (S.D. = 5.7 kg), posterior waist length: 37.5 cm (S.D. = 2.2 cm), sleeve length: 52.2 cm (S.D. = 2.4 cm), neck-base girth: 37.0 cm (S.D. = 1.9 cm), bust girth: 82.6 cm (S.D. = 4.6 cm), waist girth: 63.5 cm (S.D. = 3.8 cm), hip girth: 91.1 cm (S.D. = 4.4 cm), upper arm circumference: 26.4 cm (S.D. = 2.3 cm), posterior shoulder length: 38.1 cm (2.1 cm). Comparing the means of measurements of these areas to those of similar aged models reported by the Ningen Seikatsu Kougaku Kenkyu Center,[14] we found that the average neck-base girth measurement of our models was slightly less than the national average. However, all the other measurements were approximately the same. We may say that the subject group used in of our study represents a group of the standard physique.

Making of T-pattern and fitting test

For the purpose of making the T-patterns exactly representative of the figure of each model under the same conditions, we molded the right side torso (female model) of each stationary model using the same method as in our previous paper.[7)-9)] Also, we made a pattern by using the draping technique, developed previously by Masuda, immediately after undergoing the plane drafting method for T-pattern.[9)] The following describes how we made a molded torso. After marking the fundamental points of the vertical and horizontal standard lines[7)-9)] on the right side of the torso surface, we applied 2 or 3 pieces of bandage to the surface for transcribing purposes. The exterior of the mold with a mean thickness of 0.2 cm to 0.3 cm, had almost the same shape as the interior of the mold, resulting in a 5% risk rate and no intentional difference between the standard line measurements of both sides. The interior and exterior of the molded

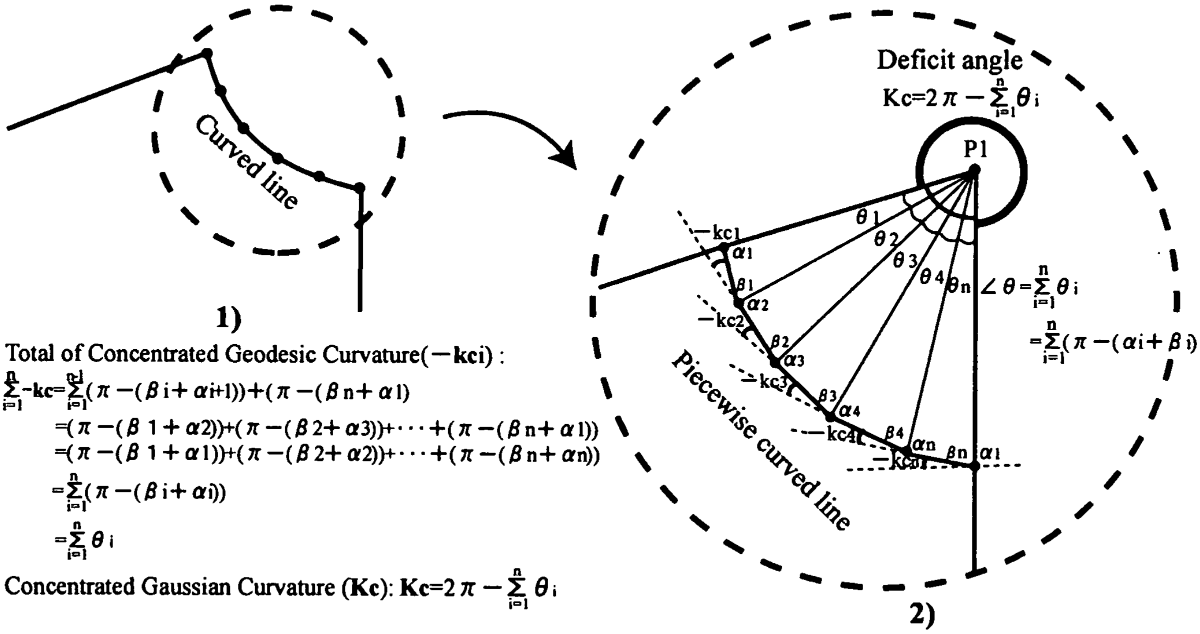
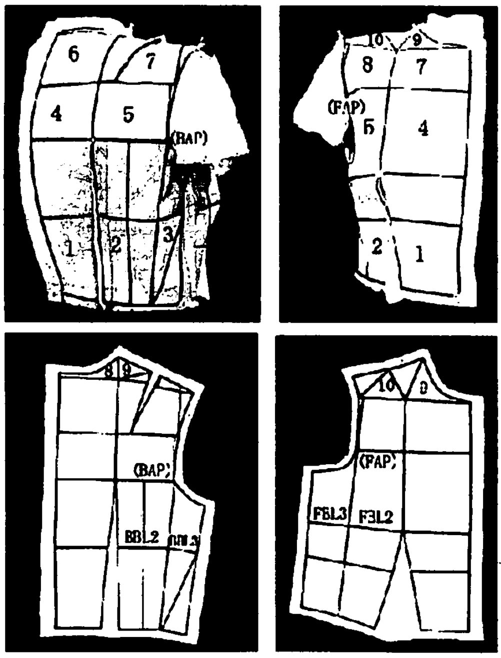


Fig. 3. Concentrated Gaussian Curvature (Kc) of curved line

Kc (deficit angle)$=2\pi-\sum_{i=1}^{n}\theta_i$. $\sum_{i=1}^{n}-kc=\sum_{i=1}^{n}\theta_i$. Concentrated Geodesic Curvature ($-kc$) of the point on piecewise curved line. $-kc=\pi-(\alpha+\beta)$.



Back **Front**

Abbreviations for standard points: (FAP) front armpit, (BAP) back armpit
Abbreviations for standard lines: FBL front bust line, BBL back bust line

Fig. 4. Tight-fitting patterns after the fitting test

1. The tight-fitting pattern was drawn automatically by computer.[10] The patterns were divided by body measurement lines into ten blocks on the front and nine blocks on the back. 2. The best fit of the cut cloth, tight-fitting pattern was determined by using the draping method on a plaster trunk.

torso (called 'torso surface' hereafter) were divided by the vertical and horizontal standard lines. The front torso was divided into 10 blocks, the back torso into 9 blocks (Fig. 4). The standard line of each block is called a "side." The draped T-patterns of 203 subjects were made automatically by a plotter (GRAPHTEC PEN PLOTTER GP2001) using the "human body measurement (21 sides of the front torso, 19 sides of the back torso)" of the torso surface and the "side and dart measurement of T-pattern including gap length." These were derived from the calculation applying human body measurement to the functional equation of plane geometry. The sheeting (100% plain weave cotton, density 22 by 23, 0.35 mm thick, specific gravity 0.01 g/m^2) was cut so as to leave a seam allowance of 1.5 cm for the centerline, the shoulder line, and the side line on the front and back pattern. A seam allowance of 1 cm was left for all other lines. In order to suit up each subject with a T-pattern, we draped the T-pattern on the molded torso and compared the fundamental points and the standard lines of T-patterns with those of the molded torso. When we found their positions were not uniform, we adjusted the T-pattern on the molded torso (Fig. 4). The experiment was performed three times by three different experimenters in order to avoid a biased judgment of conformity. Concerning the details of pattern making and fitting experimentation, please see our previous paper.[9]

Table 2. Means, standard deviations, and coefficient of variations of Concentrated Gaussian Curvatures Kc (deficit angles)

	Deficit angles Kc (°)		
	Means	S.D.	C.V.
Sum Kc of darts	96.26	21.41	22.24
Front			
GFWD (right and left)	37.18	16.73	45.01
GFAD (right and left)	7.82	7.79	99.76
Back			
GBWD (right and left)	13.05	4.96	38.01
GBAD (right and left)	18.63	7.83	42.05
GBSD (right and left)	19.58	9.21	47.03
Sum Kc of lines	623.74	21.41	3.43
GNL	84.23	14.39	17.08
GAHL (right and left)	244.16	20.66	8.46
GWL	295.35	13.71	4.64
Total Curvatures	720.00	0.00	0.00

Subject number=203. S.D.: standard deviation. C.V.: coefficient of variation=S.D./mean×100. See Table 1 and Fig. 1.

Calculation of Concentrated Gaussian Curvature (deficit angle Kc) in a T-pattern

To calculate the deficit angles Kc of five darts and the deficit angles Kc of three lines (Table 2) set out in Fig. 1, the coordinate values of the fundamental points on T-patterns were measured with a two dimensional digitizer. In almost all subjects, FBL3 and BBL3 on the bust lines of the side torso were not located on the lengthened bust lines of the central torso FBL2 and BBL2, but sloped to the side line (Fig. 4). We interpreted this result as being caused by the side torso curved shape that became narrower from the bust line to the waist line as seen from the T-pattern side. Then, as stated above, the front and back bust lines FBL3 and BBL3 were transferred to the lengthened FBL2 and BBL2, respectively, on a personal computer. The curved shape of the T-pattern side was set up accurately as a deficit angle Kc of the front and back armpit dart (GFAD and GBAD) (Fig. 1). In most cases, the deficit angle Kc of each dart was a positive angle (Fig. 1), and the opposite Kc negative. For example, for the front and back armpit dart, the angle of the waist line is a positive Kc, and the opposite Kc of the armhole line is negative. The Kc of each dart represents the dimensions of the curved shape on the bust, the back shoulder, and so on. That is, it shows how difficult it is to transform curved surfaces into a plane. Regarding the Kc of the lines, GNLD on the neck-base line represents how the shoulder inclines while GWLD on the waist line represents how narrow the waist is. The features of these two deficit angles Kc influence deficit angles Kc (GAHL) of the armhole line.

RESULTS AND DISCUSSION

Features of Total Concentrated Gaussian Curvatures (deficit angles Kc) on the T-patterns

In Fig. 5, for each model, we show the bar graphs of the sum of the Concentrated Gaussian Curvatures (Sum Kc) of five darts (black bar) and Sum Kc of three lines (white bar), as well as a black line graph of the Total Kc (Sum Kc of five darts plus Sum Kc of three lines). Each model's Total Kc was 720 degrees, consistent with the Gauss-Bonnet theorem. A conservation law based on the theorem held up for Kc on T-patterns in the same way as for torso surface.[10] The Sum Kc of darts of each subject, shown in the black bar graphs, ranged from 45.37 degrees to 165.52 degrees, while the Sum Kc of the lines of each subject, shown in the white bar graphs, ranged from 554.48 degrees to 674.63 degrees. From this we found that the T-pattern curved shape was different for each individual. As for the Total Kc of darts and lines, by contrast, the difference between the maximum and the minimum was 120.15 degrees and the S.D. was 21.41 degrees for both totals (Table 2). Accordingly, it was also proven that the Total of both deficit angles Kc maintains a constant value (720 deg.). The individual difference of distribution between deficit angles of darts and those of lines makes it possible to identify the T-patterns curved shape regardless of size.

Distribution feature of Concentrated Gaussian Curvature (deficit angle Kc) on darts and lines of T-patterns

We will consider the features of the T-pattern curved shape based on the deficit angle Kc by using the mean value (Table 2). Figure 6 shows a pattern made up of the mean values of 203 models' measurements of a T-pattern. The Kc values of lines and those of darts in Fig. 6 are derived from distributing the mean values of one side of the body to the whole body in Table 2. As for the mean Sum Kc, that of the five darts was one sixth or less than that of the three lines, and its value was very small. However, as stated above, the S.D. of both Sum Kc were the same, though the coefficient of variation

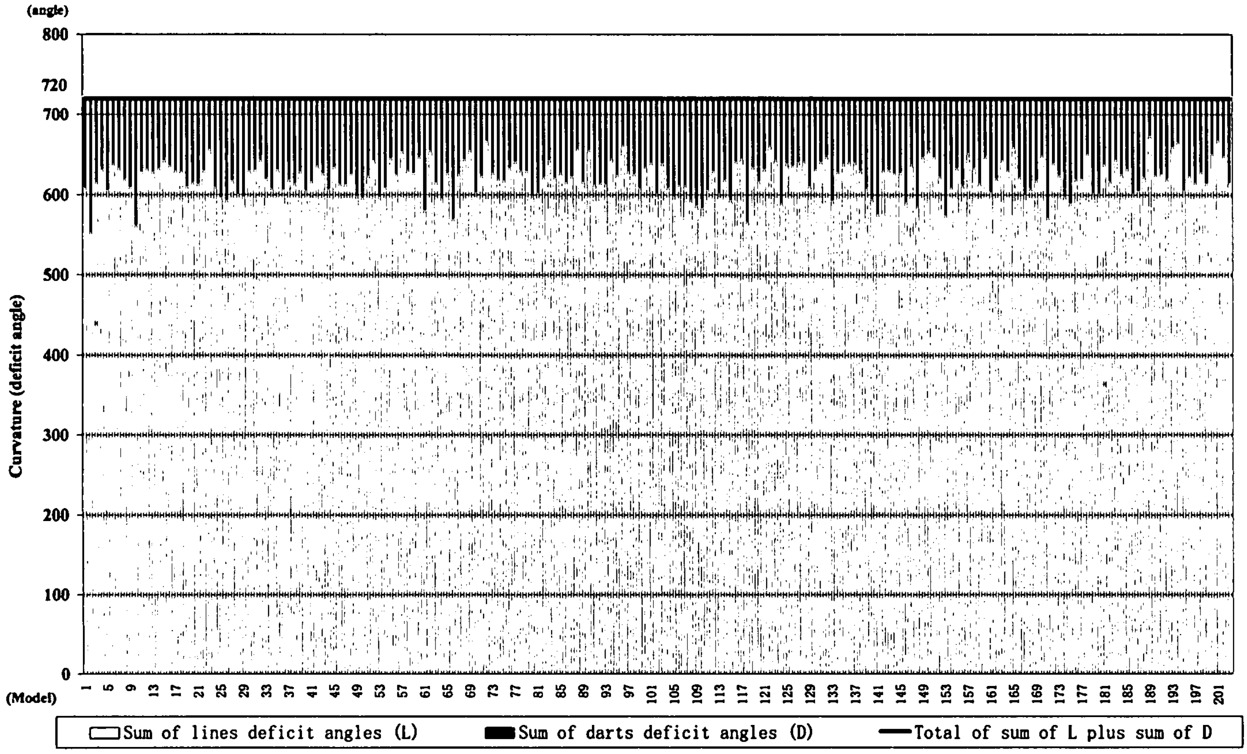


Fig. 5. Total of Concentrated Gaussian Curvatures of darts and lines for the tight-fitting pattern

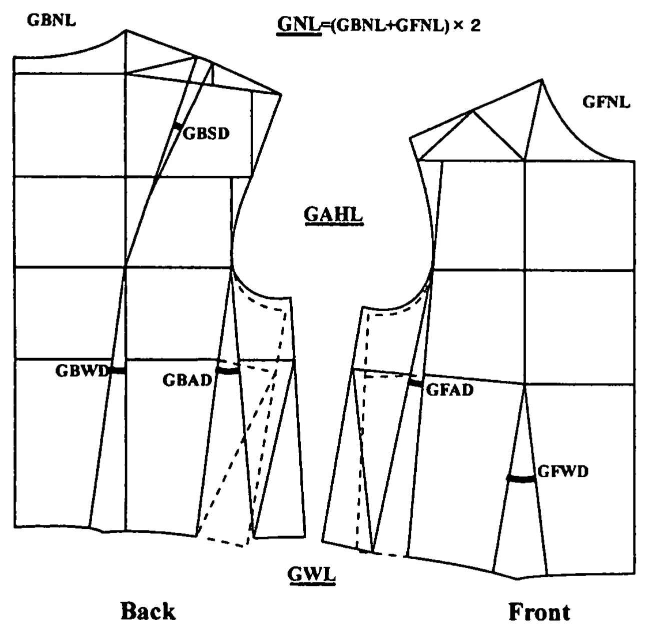


Fig. 6. The tight-fitting pattern of the right side made from the mean values of 203 models' measurements

Deficit angles of 3 lines and 5 darts are derived by distributing the mean values of one side of the body to the whole body in Table 1. See Fig.1 about deficit angles of 3 lines (GNL, GAHL, GWL).

(C.V.) in the Sum Kc of darts was large. It is reasonable to think that each Kc of five darts reflects the variation of the individual. The C.V. in each Kc of five darts shown in Table 2 is far above C.V. in each Kc of the 3 lines.

1. Features of deficit angle Kc on dart

The deficit angle Kc of the waist line dart (GFWD) was the largest. It is evident that a large value of Kc is requisite for GFWD to cover the torso curved surface from breast to waist line by a plane of cloth. In our previous paper,[10] we reported that it is very difficult to transform a bust region of the torso surface into a plane, wherein exists very positive and negative Kc (elliptical surfaces and hyperbolic surfaces). As for the T-pattern only covering a convex surface, GFWD, which made up the region centering around the bust was too large to show the difficulty of transforming. The S.D. of GFWD (right and left), the largest of the darts, ranged from 4.39 degrees to 80.76 degrees. The value of GFWD, showing 18.59 degrees as the mean of one side torso in Fig. 6, has an extensive dispersion, which means that there must be an individual variation of the closed front waist line dart curved shape (Fig. 2). It follows from this that GFWD is one of the most important factors for determining the features of the T-pattern curved shape. The mean value of Kc of the front armpit dart (GFAD) on the front side was very small, in contrast to C.V. The reason for this is that whether the GFAD is positive or negative depends on the model. The form of the dart is located on the waist line in the case of a positive value. On the other hand, it is located at the front armpit point on the armhole line in the case of a negative value. The slope of the front side bust line (FBL3 in Fig. 1) has a great influence on the T-pattern curved shape even if the GFAD is small. In other words, when GFAD is closed as a dart, the curved shape becomes narrower from the region of the front side armhole line to the waist, as in the case of a positive value shown in Fig. 6. In contrast, the opposite occurs in the case of a negative value. Consequently, the Sum Kc of the two darts on the front T-pattern (GFWD+GFAD) was about 45 degrees on average.

On the other hand, the Sum Kc of the three darts on the back T-pattern (GBWD+GBAD+GBSD) (Tabel 2) was about 51 degrees on average. The Sum Kc on the back T-pattern was larger than that on the front T-pattern. It becomes evident that, in general, the curved shape of the back T-pattern has a higher value of the Kc than that of the front T-pattern. As the Kc on the back T-pattern are distributed among three deficit angles (Fig. 6), the gently curved surface is formed by closing the deficit angles of the three darts just as one would by sewing (Fig. 1, Fig. 4). Comparing the three deficit angles, the mean value of the GBSD on the shoulder dart was the largest, while that of the GBAD on the back armpit line dart was almost the same as that of the GBSD. That of the GBWD on the back waist line dart was the smallest, representing a slight difference among individuals. To our understanding, the GBSD is a factor of determining features of the back T-pattern. As for the GFAD on the front armpit line dart of the front side T-pattern, among the deficit angles covering the side torso, a negative value was found among 30 models. A negative value of GBAD on the back side T-pattern was found only in 3 models, and the mean value of the GBAD was at least 10 degrees larger than that of the GFAD. Comparing the four darts located above the waist line, excluding the GBSD on the shoulder (Fig. 1, Table 1), the mean value of the GBAD was the second largest, behind the GFWD of the front waist line dart. The GBAD on the back armpit line dart was a key factor in identifying the features of the T-pattern curved shape. There is no correlation among the deficit angles of the five darts in Table 1.

2. Features of deficit angle Kc on line

Nearly all the Total Sum Kc of the darts and lines on the T-pattern were composed of the Sum Kc of the lines. The mean value of the Kc on the neck-base line (GNL) was much smaller than that of the Kc on the armhole line (GAHL) and the waist line (GWL). The C.V. of the GNL, however, was slightly larger, which represented the differences among individuals. We mentioned earlier that GNL shows the total angles of the front and back shoulder slope where the T-pattern is draped. As shown in Fig.1-2), the GFNL and the GBNL represent the angle of front and back shoulder inclination. The GFNL (mean value of one side: 22.5 degrees) is more distributed than the GBNL (mean value of one side: 19.62 degrees). The difference between the front and back figures appears on the pattern. It becomes necessary to make a pattern of the GNL to fit each model. The deficit angle GAHL was made up of the angle of the GNL and the inclination of the front and back side lines (Fig. 1, Fig. 2). The GAHL correlated negatively with the GNL ($r=-0.60$). The GWL, being a large deficit angle Kc of nearly 300 degrees on average, is formed by closing the four darts located above the waist line except the GBSD within all five darts. We found that the GWL correlated with the Total Kc of four darts and its coefficient was -0.72. Its correlation coefficient with the Kc of the waist line dart (GFWD) was -0.65. It turns out that the distribution of the Kc on the line between the GAHL and the GNL, and that between the GWL and the Kc of the four darts located above the waist line, all have a negative correlation. Those Kc play a part in maintaining a constant value of 720 degrees of the Total Sum Kc on the T-pattern. Between the deficit angles Kc of the darts, however, there exists no correlation as stated above. It seems that the deficit angle Kc of the darts is independent and it forms the T-pattern curved surface, which reflects individual curved shapes of the torso.

CONCLUSION

For the purpose of designing a clothing pattern to fit each unique figure, we proposed a new theory to extract the features of tight-fitting pattern (T-pattern) curved shapes, which cover 3D torso surfaces tightly regardless of size, by using "Concentrated Gaussian Curvature Kc based on angle." Concerning the T-pattern, which makes a hole along the boundary line such as an armhole line by sewing the shoulder line and the side seam line, in traditional curved surface geometry, the curvature of the internal dart is represented by using "Kc ($2\pi-\theta$)."

The curvature of the boundary line of a T-pattern is represented by using "Concentrated Geodesic Curvature kc ($\pi-\theta$)." The total of these two angular curvatures is -4π (-720 deg.), in accordance with the conservation law. In light of closing the holes formed by the boundary lines in order to make a T-pattern closed surface, it is possible to examine the T-pattern curved shape by using only the "Kc" without the "kc." We further investigated the features of T-pattern curved shapes, regardless of size, according to the theory that the total of the Kc (deficit angles) on darts and lines, such as the neck-base line, is a consistent 4π (720 deg.), in accordance with the conservation law.

Following the T-patterns of 203 young women, made by using the draping method, we cut the sheeting and adjusted the T-pattern to fit each model. The deficit angles of five darts (front waistline dart, front armpit line dart, back waistline dart, back armpit line dart, shoulder dart) and those of the three lines (neck-base line, armhole line, waist line) were accurately calculated from the coordinate values measured with a two dimensional digitizer. Each model's total deficit angle of five darts and three lines, maintained a consistent value of 720 degrees, in line with the conservation law. This was also proved on the grounds that both standard deviations, one being S.D. of the Sum deficit angles on five darts and the other being that on three lines, were equal to 21.41 degrees for all 203 subjects. The feature of the T-pattern curved shape, regardless of size, can be seen in the distribution of deficit angles of the darts and lines. The total of the deficit angles of the five darts (mean value: 96.26 deg.) was only about one sixth that of the lines (mean value: 623.74 deg.). Consequently, the mean value of the deficit angles of each dart was much smaller than that of each line, while the standard deviations were similarly small. As for the coefficient of variation, however, each deficit angle value of the five darts was much larger than that of the three lines. This suggests that darts form the internal curved surface, with differences depending on the individual. The value revealed that the T-pattern shape of the front torso formed a convex body surface which swelled through the bust, where the dart was large. In addition, the back T-pattern shape formed a gentle convex body surface throughout the shape of the shoulders and had deficit angles distributed in the upper and lower darts (*i.e.* shoulder dart and back waist line dart). The principal factor determining the T-pattern curved surface was obtained from the deficit angle of the front waist line dart on the front T-pattern, as well as that of the shoulder dart on the back T-pattern. The deficit angle of the back armpit line dart was more distributed than that of the front armpit line dart. As for the T-pattern covering the side torso, the distribution of the deficit angle of the back armpit line dart (GBAD) was extensive. Both positive and negative deficit angles were found in the front armpit line dart (GFAD). Therefore, various shapes of the curved surface were formed on the front side torso. Deficit angles of each dart, between which no correlation was found, independently formed the T-pattern curved surface. To preserve the constant value of 720 degrees, the distribution of deficit angles on each dart was related to that on each line. Regarding deficit angles of the lines, the deficit angle of the waist line was most distributed and was primarily formed from the deficit angle of the four darts located above the waist line. The deficit angle of the waist line (GWL) was correlated with that of the waist line dart (GFWD), with an extreme negative coefficient of -0.65. The large deficit angle of the armhole line (GAHL) was formed by comparing it to the distribution of the deficit angles of the neck-base line (GNL), front armpit line dart (GFAD), and the back armpit line dart (GBAD). In addition, the GAHL correlated to the GNL with a negative coefficient of -0.60. The mean value of the GNL was small, representing the angle of shoulder inclination draped with a T-pattern, while its coefficient of variation was large. In regards to the distribution of the GNL, the front T-pattern differed from the back one.

In clothing pattern design, first of all, it is necessary to grasp the size such as the length of the body surface. In addition, to design the best fit and most comfortable clothing pattern for each 3D body surface, we proposed a new method by using the angle which could extract a similar curved shape of the T-pattern regardless of size and a principle to make use of the data for pattern design. In this paper, we examined the Kc based on the angle of the T-patterns of the young women, theoretically proved the conservation law of the angle and grasped summary features of those 3D curved shapes. Consequently we were able to extract principal factors of the Kc of the darts and the lines for the classification of similar T-pattern shapes in the next paper. The merit of the new method makes it possible to compare the Kc of the same part in the clothing patterns by sex, age, and race *etc.*, enabling us to distinguish the existence of similar curved pattern shapes regardless of size. The new method can be applied to the curved body shape as a reasonable fact from the theory in the previous paper.[10)13)] This paper demonstrated a fundamental theory for new clothing pattern design based on angle and the analysis of the clothing pattern curved shape by using the Concentrated Gussian Curvature as its first step.

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点集中のガウスの曲率による青年女子の密着衣服パターン曲面形状の特徴抽出

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3 次元体表曲面を密着して覆うパターン形状の分類を明確にするため，新しい衣服パターン設計を構想した．本報ではサイズを除いた密着衣服原型(密着衣)の曲面形状の特徴を抽出するため，曲面幾何学を利用した“角度による点集中のガウスの曲率（Kc＝$2\pi-\theta$：欠損角）”による新しい理論を導いた．5 つのダーツを縫製して，3 つの境界線(ネックラインなど)の穴を覆ったような密着衣閉曲面を想定した．その 5 つのダーツの Kc の総和と 3 つの境界線の Kc の総和の合計には一種の保存則，4π(720 度)が理論的には成立する．203 名の青年女子の胴部に適合した密着衣に理論を適用した結果，それぞれのモデルの Kc の合計角度は 720 度の一定値になった．サイズに依存しない，密着衣のバストの膨らみ，背面の突出，ウエストのしまり，肩傾斜などの三次元的曲面形状の特徴を，各ダーツと各ラインの Kc の配分から把握できた．これらの特徴がパターンの相似的曲面形状分類のための有効な資料であることが示唆された．

キーワード：婦人服，青年女子，密着衣服原型，点集中のガウスの曲率，ダーツと境界線，パターン曲面の形状．