한국의류산업학회지
제18권 제1호, 2016
<연구논문>

pISSN 1229-2060
eISSN 2287-5743
Fashion & Text. Res. J.
Vol. 18, No. 1, pp.91-102(2016)
http://dx.doi.org/10.5805/SFTI.2016.18.1.91

Classification of Lower Body Types of Female Adults aged 18 to 69 based on 3D Body Scan Data

- Focusing on the Front Type, Lateral-Front Type, and Lateral-Back Type -

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Abstract : This study classified the lower body types of female adults aged 18 to 69. The lower body was divided into front, lateral front, and lateral back. In order to understand the shape and somatotype of each segment, 592 people were analyzed based on girth, height, length, depth, width, angle and cross section distance for each segment. For data analysis, SPSS 18.0 was performed for descriptive statics, principal component analysis, K-means cluster analysis, ANOVA, and Duncan's test (as verification). Factor analysis was performed based on index values, calculation values, angles, and cross section distances. The measured items resulted in a.) 16 items were extracted to 5 factors in the case of the front factor (FF) of the lower body, and b.) 24 items were extracted to 6 factors in the case of lateral front factor (LFF) and lateral back factor (LBF). Each factor was put through K-means cluster analysis, classifying the lower bodies into one of four types of based on the front type (FT), the lateral front type (LFT), and the lateral back type (LBT) respectively. This study proposed an understanding of various lower body shapes by segmenting and classifying the lower body shapes for each type.

Key words : lower body type, front type, lateral front type, lateral back type

1. Introduction

Recently, the fashion industries have automated design, planning, and production processes of their work in addition to the manufacturing process. This shift has occurred as a result of highlighting ‘Mass Customization’ and the ‘MTM production method’ which have become the paradigm shift in the creation of a wide variety of product profiles and in the optimization of customer satisfaction. Even though mass customization had such advantages, there were reasons that Korean fashion industry manufactures hesitate to adopt it. The major reason was the increase in cost that results when companies producing ready-made clothing shift over to customization that requires producing clothing patterns that match customer specifications. There was also a lack of preparation for mass customization. At the current stage, a process for adjusting ready-made patterns to the figures of individual customers is necessary. However, figure property standards for ready-made patterns and standards that could be continuously applied even in the case of design or style alterations were not provided(Choi, 2008). In addition, current KS size standards reflect a limited range of body measurements, which may leave customers with figures that meet those measurements dissatisfied. As one of solutions to these problems, measurement standards for each shape were required through scientific research on figures, including the form elements of each part of the human body. Successful mass customization that meets the needs of individual customers and leads steady market growth in the fashion industry necessitates the preparation of a standard for pattern design that reflects the shape properties of each human body part. Although there has been research on how to systematize production of men's clothing over the past few years(Jang & Chang, 2008; Kim et al., 2011a; Kim et al., 2013; Kim et al., 2015), research into the process of systematizing women’s clothing remains lacking. This was because women’s clothing lacked the standardization of men’s clothing in order to give customers a larger range of choices. However, developing this larger range also took a longer period of time to develop styles that meet customer demands. For this reason, tight skirts, which requires accurate fitting, are not too complex, and come in standardized styles, have been evaluated as suitable items for mass customization production for the lower body. It is known that if transmutable standards for

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This study is a part of a doctoral dissertation.

ready-made clothing patterns for the lower body are provided, it may be possible to auto-design clothing patterns suitable for mass customization production. As such, these methods for production are employed to improve the 'Fit' of ready-made clothes(Park & Nam, 2001). Rather than only looking at size as a single measurement, these new methods took into consideration several body characteristics for each part of the item, enabling designers to make patterns that properly reflect the body types of their consumers(Hahm & Chung, 1999; Kim & Lee, 2011; Lee & Hong, 1999).

Previous body type studies, the study for on the lower body of female adults included both a factor analysis and a cluster analysis to review direct and indirect measurements including the circumference, depth, width, length, height, and angle. It then categorized the lower body shapes based on 3-6 characteristics(Kim & Lim, 1999; Lee et al., 2008; Moon, 2001). Current pattern design methods based on definite categorization are limited in their ability to in reflect all unique features. Lim(2003), who has conducted several more segmented studies, thus divided the lower body shape into the 'frontal body shape' and 'lateral body shape' for the purpose of more accurately categorizing the characteristics of various body shapes. Lim(2003) then selected a representative body shape with the highest appearance rate based on contingency rate analysis. Most advanced research separated the human body into front, back and side, and summarized and integrated the human body into several categories. However, it is necessary to classify each lower body part in more details to understand the diversity of individual figures and design appropriate basic patterns for the lower body(Rasband, 1994). Therefore, this study was conducted on female adults aged 18-69 to measure their lower bodies, angles, and cross section distances for each of the three segments, to classify the lower body types based on each of the somatotype, FT(front type), LFT(lateral front type), and LBT(lateral back type), which influenced the 'Fit' of clothes. By standardizing the lower body through the classifications of FT, LFT and LBT, alternation standards for ready-made clothing patterns could be provided together with an analysis of the differences in the surface pattern of each body part. In short, this study is designed to propose reference data to improve the 'Fit' of lower body apparels by categorizing the lower body into three somatotypes.

Table 1. Number by age groups (Unit:*N*)

Age	18~29	30~39	40~49	50~59	60~69	Total
Number	178	155	149	73	37	592

2. Methods

2.1. Subjects

The 3D data of 592 adult women aged 18-69 were reviewed.

Table 2. Items of anthropometric data

Items	Measurement items	
Girth	Waist Girth, Waist Girth(Omphalion), Abdomen Girth, Mid-Hip Girth, Hip Girth, Thigh Girth, Maximum-Thigh Girth, Mid-Thigh Girth, Knee Girth	
	Half Waist Girth(front), Half Waist Girth(front)(Omphalion), Half Abdomen Girth(front), Half Mid-Hip Girth(front), Half Hip Girth(front)	
	Half Waist Girth(back), Half Waist Girth(back)(Omphalion), Half Abdomen Girth(back), Half Mid-Hip Girth(back), Half Hip Girth(back)	
Height	Stature, Waist Height, Aabdomen Height, Hip Height, Crotch Height, Thigh Height, Knee Height	
Length	Hip Length, Waist Length, Waist Length(Omphalion), Abdomen Length, Side Hip Length	
Width	Waist Width, Waist Width(Omphalion), Abdomen Width, Mid-Hip Width, Hip Width, Crotch Width, Max-Thigh Width	
Depth	Full Depth	Waist Depth, Waist Depth(Omphalion), Abdomen Depth, Hip depth, Thigh Depth, Crotch Depth
	Front Depth	Waist Depth, Waist Depth(Omphalion), Abdomen Depth, Hip Depth, Thigh Depth
	Back Depth	Waist Depth, Waist Depth(Omphalion), Abdomen Depth, Hip Depth, Thigh Depth
Calculation	Flatness Ratio(width/depth)	Waist, Abdomen, Hip
	Girth Drop	Hip - Waist, Back Hip - Back Waist, Back Mid-Hip - Back Waist, Back Hip - Back Mid-Hip
	Width Drop	Hip - Waist, Mid-Hip - Waist
	Depth Drop	Back Hip - Back Waist, Front Abdomen - Front Waist, Back Mid-Hip - Back Waist, Front Hip - Front Waist, Front Hip - Front Abdomen
	Waist Circumference/Hip Circumference, BMI	
Angle	Upper Buttocks Angle, Lower Buttocks Angle, Upper Abdomen Angle, Lower Abdomen Angle, Lateral Abdomen Angle, Lateral Buttocks Angle, Lateral Crotch Angle, Lateral Thigh Angle, (Ang)Midpoint of Waist Depth to Midpoint of Ankle Depth	

Drop: Difference value in the comparison of the circumference(width, depth)

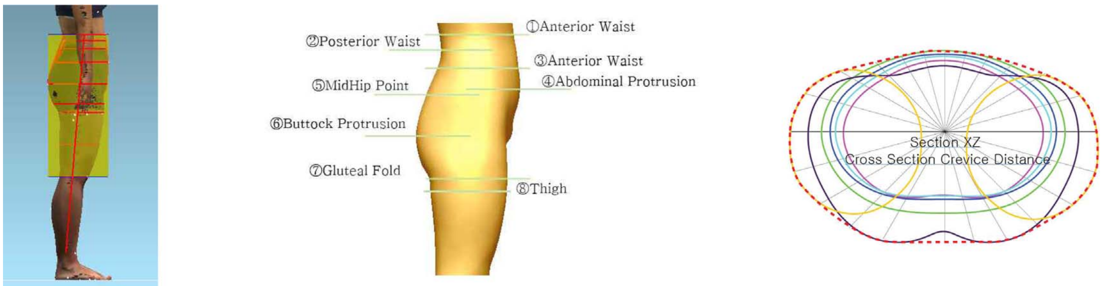

Fig. 1. Overlap map of each area cross section crevice distance.

The data was retrieved from the 'The 5th Size Korea(Korean Agency for Technology and Standards, 2004)' database. Efforts were made to have balanced representation of different age groups. However, because the 5th Size Korea database had a lower ratio of people in their fifties and sixties, this study also had lower representation from these demographics(Table 1).

2.2. Analysis items of anthropometric data

To analyze the lower body, several items utilized to design lower body apparel were chosen for measurement. 63 items were measured for anthropometric data using the 3D scan data. Data of cross sections for 216 items were used to measure the distance of each angle. To analyze the front and back features of the lateral sides and the front of the lower body, front-back depth and front-back girth were divided for measurement. There are two data points to distinguish the front and back: the midpoint of the waist depth and the midpoint of the thickest depth. The midpoint of thickest depth is the central mark which divides the horizontal distance between the hip point and the maximum abdomen point. As shown in Table 2, there are 79 measured and calculated items. Overlapping cross sections of the 3D body scans were used to analyze distances(Kim et al., 2011b). Likewise, stacked cross sections of each lower body part and each cross section distance were equally divided at the 15° intervals to measure the distances for 216 items(Fig. 1).

2.3. Data analysis

For the typology of the lower body, SPSS 18.0 was used to analyze the anthropometric data by excluding the lower body size factor and by instead focusing on shape-related factors. The measured values for height, girth, depth, width, and cross section distance were converted into index values. Principle component analysis were then used to summarize the information derived from the measurements and angles. To establish the criteria for determining the number of factors, the Scree-Test was applied. The factor shall be chosen under the condition that the explanatory power did not change and eigenvalue is over 1.0. Advanced research studies determined the number of groups to be 3 to 5 by reviewing the distribution conditions of each category. However, this research originally relied on a hieratical cluster analysis to decide the number of groups. A hieratical cluster analysis applied in line with the minimum variation of ward, and then the number of clusters were decided, classifying the lower body shapes of the female adults using K-means cluster analysis. To best reflect the shape differences and distribution rate of each segment, FT, LFT and LBT, this study chose a set number of factors. To explore the shape differences of each body part as categorized by the factor scores, ANOVA(analysis of variance) and Duncun's test were performed to check the average of the index values for shape-related items, and the absolute values for size items.

3. Results and discussion

3.1. Shape-related characteristics of the front lower body

3.1.1. Analysis of shape factors in the front lower body

To explore the shape factors comprising the front lower body of female adults, 16 index items, 4 angle items, and 8 calculated items were used in the factor analysis. To ensure the quality of the factors, analysis were repeatedly conducted to eventually narrow the items down to 16 and the analysis extracted 5 factors. Table 3 shows the factor analysis findings.

Table 3 shows that 83.54% of the variation of the 16 variables was explained by five factors with eigenvalues of 1.0 and more. Factor 1 referred to the lateral line from the waist to hip, and had an eigenvalue of 3.74 and an explanatory power of 23.34%. Factor 2 was the height of the lower body, with an eigenvalue of 3.68 and an explanatory power of 22.99%. Factor 3 formed a silhouette below the maximum hip point, with an eigenvalue of 2.57 and an explanatory power of 16.06%. Factor 4 decided the shape over the hip girth line, and had an eigenvalue of 2.19 and an explanatory power of 13.69%. Factor 5 had similar characteristics to Factor 3, representing the shape from hip to crotch of the lower front body. Factor 5 had an eigenvalue of 1.19 and an explanatory power of 7.46%.

3.1.2. Classification of front lower body shape

Table 3. Factor analysis of front body measurement

	Factor characteristic	Item	Factor				
			1	2	3	4	5
1	Waist to hip lateral silhouette	Lateral Buttocks Angle	0.92	0.09	-0.03	0.20	-0.09
		Lateral Crotch Angle	0.91	0.15	-0.04	0.28	-0.14
		Lateral Thigh Angle	0.91	0.15	-0.04	0.28	-0.13
		Lateral Abdomen Angle	0.79	0.04	-0.02	-0.12	0.04
		Width Drop : Hip to Waist	0.63	0.01	0.06	0.56	0.08
2	Lower body height	Crotch Height	0.21	0.88	-0.16	0.04	0.05
		Thigh Height	0.05	0.87	-0.11	0.05	-0.14
		Hip Height	-0.04	0.85	-0.13	-0.13	-0.19
		Waist Height	0.24	0.81	-0.15	0.05	0.09
		Abdomen Height	0.01	0.76	-0.12	0.20	0.04
3	Width below Hip	Crotch Width	0.06	-0.18	0.91	0.06	-0.29
		Hip Width	-0.03	-0.25	0.91	-0.01	0.25
		Thigh Width	-0.10	-0.16	0.88	-0.10	-0.13
4	CSD drop upper hip	Cross Section Distance Drop (CSDD): Hip - mid hip	0.10	0.08	0.00	0.90	-0.13
		Cross Section Distance Drop (CSDD): Hip - Waist	0.31	0.06	-0.08	0.88	-0.03
5	Hip to crotch silhouette	Width Drop : Hip - Crotch	-0.15	-0.09	-0.14	-0.12	0.94
		Eigenvalue	3.74	3.68	2.57	2.19	1.19
		% of variance	23.34	22.99	16.06	13.69	7.46
		Cumulative %	23.34	46.34	62.39	76.08	83.54

The scores for five factors drawn via factor analysis underwent an additional cluster analysis. The number of categories was chosen by referencing the point of the dendrogram of a hieratical cluster analysis and a vertical icicle plot where there is a rise in the dendrogram and a sudden decline in the vertical icicle plot. The analysis classified the FT(Front Type) of the lower body into 4 types. Aggregating the factor scores of each type and the average of the index values, this study considered the differences between each type of the front lower body, leading to the following classifications(Table 4, Table 5).

To sum up characteristics of each body type, FT1 had the largest waist width and a relatively small hip width when measurements were taken on the axis of the waist width and hip width. FT2 was wide below the hip girth line. The waist girth was also large, though smaller than that of FT1. FT2 had the largest hip girth and thigh girth from among the four types. The value of factor 1 was the highest for FT3, and the waist width was smaller than FT2 in Table 6. FT3 had the smallest waist width because the value of factor 1 in this type was analyzed as the largest. FT4 had the highest value in factor 4 but the absolute value was the lowest. Thus FT4 had the thinnest shape of the four.

To analyze the individual features based on the size of each front lower body type, the measured values were measured for each classification and were compared in multiple ways(Table 6). In the case of height, FT1 was the highest while FT2 was the lowest. In terms of waist girth, FT3 and FT4 were the smallest while FT1 was the

Table 4. Difference verification of factor score by front type

Factor	Type	FT1 (n=138)	FT2 (n=129)	FT3 (n=139)	FT4 (n=186)	F
1	Waist to hip lateral silhouette	-0.63d	0.16b	1.02a	-0.37c	150.96^{***}
2	Lower body height	0.78a	-0.24b	-0.19b	-0.31b	62.99^{***}
3	Width below hip	0.16b	1.03a	-0.34c	-0.69c	185.12^{***}
4	CSD drop upper hip	-0.63c	0.42b	-0.65c	0.69a	154.12^{***}
5	Hip to crotch silhouette	-0.25c	0.40a	0.07b	-0.11c	20.76^{***}

$^{***}p \leq .001$ According to Duncan-test result mean were marked with different letters which had significant difference at level $p \leq 0.5$(a>b>c>d)

Table 5. Difference verification of index values and angles by front type

Item	Type	FT1	FT2	FT3	FT4	*F*
Waist to hip lateral silhouette	Lateral Buttocks Angle	9.22d	10.90b	11.21a	10.48c	83.05***
	Lateral Crotch Angle	9.22d	10.89b	11.20a	10.48c	63.15***
	Lateral Thigh Angle	4.79d	5.14b	5.20a	4.95c	63.00***
	Lateral Abdomen Angle	10.29c	12.33b	12.80a	11.68c	95.99***
	Width Drop : Hip to Waist	0.25b	0.34a	0.35a	0.34a	67.33***
Lower body height	Crotch Height	0.45a	0.44c	0.44b	0.44c	25.43***
	Thigh Height	0.43a	0.42c	0.42b	0.42bc	41.72***
	Hip Height	0.50a	0.48c	0.48b	0.48bc	34.30***
	Waist Height	0.62a	0.62c	0.62b	0.62c	19.59***
	Abdomen Height	0.55a	0.55c	0.54c	0.55b	16.32***
Width below hip	Crotch Width	1.31b	1.40a	1.42a	1.41a	120.44***
	Hip Width	1.25b	1.34a	1.35a	1.34a	168.05***
	Thigh Width	0.63b	0.67a	0.67a	0.66a	103.19***
CSD drop upper hip	Cross Section Distance Drop (CSDD): Hip - mid hip	0.07c	0.10a	0.88b	0.11a	80.74***
	Cross Section Distance Drop (CSDD): Hip - Waist	0.25c	0.32a	0.28b	0.32a	81.03***
Hip to crotch silhouette	Width Drop : Hip - Crotch	-0.07c	-0.06a	-0.06ab	-0.06bc	4.27**

$^{**}p \leq .01$, $^{***}p \leq .001$ Duncan test: a>b>c>d

Table 6. Difference verification of measured values by front type (Unit:mm)

Item \ Type	FT1	FT2	FT3	FT4	*F*
Waist Height	988.39a	969.35b	989.05a	989.24a	14.54***
Abdomen Height	878.70a	858.93c	869.23b	880.33a	14.83***
Hip Height	787.50a	756.04c	772.74b	773.45 b	33.66***
Crotch Height	707.01a	684.94c	701.84ab	699.92b	15.81***
Thigh Height	681.85a	656.57c	671.73b	672.69	21.59***
Waist Width	275.14a	265.64b	253.05c	252.81c	61.79***
Abdomen Width	317.41b	320.79a	312.42c	301.28d	53.98***
Mid-hip Width	323.57b	328.41a	319.34c	310.75d	74.63***
Hip Width	341.61b	355.61a	341.13b	338.44c	103.78***
Crotch Width	358.70b	370.07a	356.83bc	354.80c	54.51***
Thigh Width	172.07b	176.29a	167.76c	166.64c	62.59***
Waist Girth	755.13a	735.16b	690.78c	697.63c	68.58***
Waist Girth(Omphalion)	787.93a	766.33b	736.95c	722.44d	57.34***
Abdomen Girth	870.37a	869.18a	841.52b	821.55c	39.92***
Mid-hip Girth	885.03a	889.39a	859.35b	844.39c	60.13***
Hip Girth	928.14b	952.98a	914.11c	916.77c	63.21***
Thigh Girth	539.17b	547.97a	522.24d	528.55c	27.17***
Maximum Thigh Girth	912.49b	936.85a	905.97b	908.12b	33.37***

Maximum thigh girth : The horizontal thigh circumference from side to side
$^{***}p \leq .001$, Duncan test: a>b>c>d

largest. Regarding the girth and width below the hip, FT2 was the biggest while FT3 and FT4 were smaller than FT1. These resulted resonate with those in the Jung(1994) study which argued that the shape of each type was highly correlated to the size of the human body even when the body shapes were classified in line with components constructing the human bodies. However, the index values and type differences of the measured values were not completing identical, thus revealing the difference in size sequence. In addition, when the average measured values of each type were analyzed, it was found that some items had high values of standard deviations. Thus, measured value-based shape analysis had some limitations(Choi, 1997).

3.2. Shape-related characteristics of the lower lateral body

3.2.1. Factor analysis on the lower lateral body

To extract the factors constructing lateral of lower body of female adults, 25 items for the front-back depth of the lateral side based on the reference line, 6 items for the height index values, 4 items for the angles, 10 items for the cross section distance, and 10 items for the calculation values were analyzed. To prevent redundancy, items with high correlations with various factors were excluded and then a factor analysis was again taken. This eventually led to the definition of 24 items and 6 factors as shown by Table 7.

Table 7 showed that 89.00% of the variation of the variables was explained by six factors. Factor 1 was the back depth difference between the waist and the hip girth line, and has an eigenvalue of 4.73 and an explanatory power of 19.69%. Factor 2 indicated the prominence of the abdomen between the waist and the hip girth

Table 7. Factor analysis of lateral body measurement

Factor characteristic		Items	Factor 1	2	3	4	5	6
1	Buttocks prominence	Hip - Abdomen(BDD)	0.98	0.00	-0.11	0.01	0.03	-0.08
		Hip - Waist(omphalion)(BDD)	0.97	-0.04	-0.14	-0.01	0.01	-0.03
		Hip(BD)	0.95	0.05	0.28	-0.06	0.01	-0.02
		Hip - Waist(Natural Identation)(BDD)	0.93	0.04	-0.24	0.02	-0.14	0.08
2	Abdomen prominence	Hip - Abdomen(FDD)	0.32	0.92	-0.02	0.11	-0.02	0.07
		Hip - Waist(omphalion)(FDD)	-0.42	0.87	0.07	0.05	0.05	0.06
		Upper abdomen angle(Ang)	-0.05	0.81	0.35	-0.11	0.04	0.03
		Hip - Waist(Natural Identation)(FDD)	-0.08	0.74	0.20	0.02	0.58	0.08
		Waist(omphalion)(FD)	0.48	0.64	0.36	-0.10	-0.29	0.01
		Abdomen(FD)	-0.28	0.64	0.51	-0.17	-0.25	0.00
		Waist Back(FD)	0.12	0.64	0.32	-0.12	-0.53	-0.05
3	Back side silhouette of waist to abdomen	Waist Back(BD)	-0.12	0.08	0.92	-0.15	0.12	-0.14
		Waist(omphalion)(BD)	-0.10	0.20	0.91	-0.09	0.00	0.01
		Abdomen(BD)	-0.10	0.12	0.90	-0.16	-0.06	0.13
		Waist(Natural Identation)(BD)	0.16	0.04	0.88	-0.13	0.23	-0.17
4	Lower body height	Crotch Height	-0.04	-0.08	-0.17	0.89	0.08	0.02
		Thigh Height	-0.01	-0.17	-0.08	0.86	-0.06	0.08
		Hip Height	-0.03	-0.26	0.16	0.86	-0.12	0.10
		Waist Height	-0.04	-0.03	-0.19	0.83	0.18	-0.03
		Abdomen Height	0.09	0.17	-0.34	0.75	-0.12	-0.16
5	Waist prominence	Waist(omphalion) - Waist(Natural Identation)(FDD)	0.44	0.03	0.21	-0.03	0.81	0.04
		Waist(Natural Identation)(FD)	0.12	0.54	0.17	-0.06	-0.80	-0.02
		Abdomen - Waist(Natural Identation)(FDD)	-0.43	-0.06	0.29	-0.09	0.80	0.03
6	Abdomen angle	Lower Abdomen Angle	-0.03	-0.08	-0.10	0.03	0.07	0.96
		Eigenvalue	4.73	4.54	4.48	3.70	2.87	1.06
		% of variance	19.69	18.90	18.68	15.40	11.94	4.40
		Cumulative %	19.69	38.59	57.26	72.66	84.60	89.00

BDD: Back Depth Drop, BD: Back Depth, FDD: Front Depth Drop line. This factor indicated that abdomen depth positively correlated with the angle from the waist to the maximum abdomen point. Factor 2 had an eigenvalue of 4.54 and an explanatory power of 18.90%. Factor 3 was the back depth from the waist to the abdomen girth, representing the features from the back waist to the mid-hip of lower body. Factor 3 had an eigenvalue of 4.48 and an explanatory power of 18.68%. Factor 4 was a height-related factor, including the height of the lower body. Factor 4 had an eigenvalue of 3.70 and an explanatory power of 15.40%. Factor 5 indicated the shape between the waist and the maximum abdomen point. It implied the importance of the waist depth in deciding the shape. Factor 5 had an eigenvalue of 2.87 and an explanatory power of 11.94%. Factor 6 was the angle between the tangent on the front-hip point and the maximum-abdomen point and the vertical line, which represented the angle of the prominent abdomen. Factor 6 had an eigenvalue of 1.06 and an explanatory power of 4.40%.

3.2.2. Classification of lower lateral body shape

3.2.2.1. Lateral-front type through cluster analysis

The lateral lower body factors were put through cluster analysis. Among the analysis findings on lateral of lower body, the lateral front factor to explain the frontal shape(waist and abdomen profile) was used for cluster analysis, enabling the classification of the LFT of the lower body into 4 types. Aggregating the factor scores and the averages of the index values and measured values, this study found the following results on the LFT of the lower body(Table 8, Table 9, Table 10).

LFT1 did not have a clear curve, and was the most common body type of people in their 20s(Table 11). LFT2 has a relatively prominent abdomen when the waist depth and hip depth are set as axes. The thinness of the front depth of the waist and hip lead to the prominence of the abdomen. It had largest difference between the abdomen depth and waist depth, which means that LFT2 has the largest bulge. However, when measured values were considered, the front waist girth of LFT2 was the smallest, meaning that it indicates a thin type with a large bulge. LFT2 occurred most in thirties and second most in forties. LFT3 shows the largest front girth of the waist point, and has the thickest waist in terms of lateral silhouette. This is the common body type for people in their 50s and above. This is due to the concentration of fat in the upper abdomen. LFT4 has the most prominent abdomen as it is thicker in the waist and the values related to abdomen prominence are high. The LFT4 bulge is the second largest, but the values related to girths are the largest according to measured value. The analysis on the measured

Table 8. Difference verification of factor score by lateral front type

Factor \ Type	LFT 1 (n=219)	LFT 2 (n=207)	LFT 3 (n=88)	LFT4 (n=78)	F
Abdomen prominence	-0.77c	0.13b	0.22b	1.28a	219.78***
Lower body height	0.007a	0.05a	0.01a	-0.13a	0.80
Waist prominence	-0.41c	0.86a	-1.07 d	0.23b	269.69***
Abdomen angle	-0.32c	-0.36c	0.92a	0.56b	102.13***

LFT: Lateral-Front Type, $^{***}p\leq.001$, Duncan test: a>b>c>d

Table 9. Difference verification of index values and angles by lateral front type

Item	Type	LFT 1	LFT 2	LFT 3	LFT 4	F
Abdomen prominence	Hip - Abdomen(FDD)	-0.01a	-0.02b	-0.02b	-0.02c	184.96***
	Hip - Waist(omphalion)(FDD)	-0.05a	-0.10b	-0.10b	-0.15c	156.62***
	Upper abdomen angle(Ang)	9.19c	13.33b	13.71b	17.82a	145.07***
	Hip - Waist(Natural Identation)(FDD)	-0.02a	-0.02a	-0.09b	-0.10b	90.34***
	Waist(omphalion)(FD)	0.61c	0.62b	0.64a	0.64a	85.09***
	Abdomen(FD)	0.64b	0.66a	0.66a	0.66a	62.01***
	Waist Back(FD)	0.59c	0.60c	0.63a	0.61b	70.47***
Waist prominence	Waist(omphalion) - Waist(Natural Identation)(FDD)	0.003c	0.009a	0.001d	0.007b	169.77***
	Waist(Natural Identation)(FD)	0.58c	0.55d	0.63a	0.58b	130.74***
	Abdomen - Waist(Natural Identation)(FDD)	0.06c	0.11a	0.03d	0.08b	141.07***
Abdomen angle	Lower abdomen Angle	14.30c	14.09c	18.27a	16.94b	58.92***

FDD: Front-Depth Drop, FD:Front Depth, $^{***}p\leq.001$, Duncan test: a>b>c>d

Table 10. Difference verification of measured values by lateral front type (Unit:mm)

Item \ Type	LFT 1	LFT 2	LFT 3	LFT 4	*F*
Waist Height	986.76a	991.17a	976.09b	972.83b	10.22^{***}
Abdomen Height	876.32a	874.94ab	867.87bc	863.12d	4.63^{**}
Hip Height	779.72a	772.69b	771.85b	757.26c	13.84^{***}
Crotch Height	701.52a	702.73a	694.46b	687.20c	7.42^{***}
Waist Girth	715.89bc	708.27d	724.78b	743.53a	11.09^{***}
Waist Girth(Omphalion)	778.75d	787.71bc	798.97b	830.61a	25.00^{***}
Abdomen Girth	839.82c	840.87c	858.26b	878.74a	16.29^{***}
Mid-hip Girth	856.98c	865.99b	869.97b	897.17a	25.15^{***}
Waist Girth(FG)	375.37c	359.01d	397.43a	389.99b	86.11^{***}
Waist Girth(Omphalion)(FG)	415.69c	418.64c	432.07b	443.19a	50.83^{***}
Abdomen Girth(FG)	442.57c	441.99c	452.84b	458.35a	30.66^{***}
Mid-hip Girth(FG)	446.54c	447.59c	453.48b	459.71a	21.59^{***}
Abdomen - Waist(FDD)	11.47c	20.97a	4.90d	14.97b	144.89^{***}
Waist(Omphalion) - Waist(FDD)	5.22c	14.59a	1.30d	11.66b	170.96^{***}
Abdomen - Waist(omphalion)(FDD)	6.25a	6.39a	3.60b	3.31b	15.81^{***}
Hip - Waist(FDD)	-3.91a	-3.23a	-18.09b	-18.94b	88.67^{***}
Hip - Abdomen(FDD)	-15.38a	-24.20b	-22.99b	-33.91c	185.32^{***}
Hip - Waist(Omphalion) (FDD)	-9.13a	-17.82b	-19.39b	-30.60c	153.34^{***}

FG: Front-Girth, FDD: Front-Depth Drop, $^{***}p\leq.001$, Duncan test: a>b>c>d

Table 11. Cross-tabulation of age group and LFT (Unit : *N*, %)

Type		Age Group					Total
		20s	30s	40s	50s	60s	
LFT1	*N*	123	47	36	12	1	219
	% of Age	69.1	30.3	24.2	16.4	2.7	37.0
	% of Type	56.2	21.5	16.4	5.5	0.5	100.0
	% of Total	20.8	7.9	6.1	2.0	0.2	37.0
LFT2	*N*	44	70	61	22	10	207
	% of Age	24.7	45.2	40.9	30.1	27.0	35.0
	% of Type	21.3	33.8	29.5	10.6	4.8	100.0
	% of Total	7.4	11.8	10.3	3.7	1.7	35.0
LFT3	*N*	9	25	21	20	13	88
	% of Age	5.1	16.1	14.1	27.4	35.1	14.9
	% of Type	10.2	28.4	23.9	22.7	14.8	100.0
	% of Total	1.5	4.2	3.5	3.4	2.2	14.9
LFT4	*N*	2	13	31	19	13	78
	% of Age	2	13	31	19	13	78
	% of Age	1.1	8.4	20.8	26.0	35.1	13.2
	% of Type	2.6	16.7	39.7	24.4	16.7	100.0
	% of Total	0.3	2.2	5.2	3.2	2.2	13.2
Total	*N*	178	155	149	73	37	592
	% of Age	178	155	149	73	37	592
	% of Age	100.0	100.0	100.0	100.0	100.0	100.0
	% of Type	30.1	26.2	25.2	12.3	6.3	100.0
	% of Total	30.1	26.2	25.2	12.3	6.3	100.0
$\chi^2=172.11^{***}$							

values of the size items from the LFT shows that differences between each type do not necessarily reflect the index values and measured values. This is because the lateral factors which form the shape differ significantly compared to the factors of the front shape. Therefore, the value in describing the shape exactly by comparing the measured values of the size items is limited(Table 10).

Results of cross tabulation for LFT and age group showed that there are types with a high prevalence for each age group. Those in their forties showed 4 types of LFT with a 15~30% prevalence, showing that this age range has a variety of body types. For people in their thirties, types other than LFT4 showed a prevalence of 20% or higher. For people in their twenties, LFT1 and LFT2 had a combined prevalence of 90%. For people in their fifties and sixties, types other than LFT1 showed a 20% or higher prevalence. As shown, body types for each age group differed slightly from one another, so we expected that future research would examine side body types classified according to age in greater detail.

3.2.2.2. Lateral-back type through cluster analysis

Cluster analysis on the somatotype of the lateral back side of the lower body resulted in four classifications for expressing buttocks prominence of the lower body. Among the analysis findings on lateral back of lower body, the lateral back factor to explain the shape of hip protrusion was used for cluster analysis, enabling the clas-

Table 12. Difference verification of factor score by lateral back type

Factor \ Type	LBT 1 (*n*=85)	LBT 2 (*n*=209)	LBT 3 (*n*=269)	LBT 4 (*n*=29)	*F*
Buttocks prominence	-0.18b	0.08a	-0.10b	-0.17b	46.46***
Back side silhouette of waist to abdomen	1.23b	-0.87d	0.27c	2.54a	1,265.86***
Lower body height	0.00a	0.03a	-0.04a	0.05a	0.26

*** $p \leq .001$, Duncan test: a>b>c>d

Table 13. Difference verification of index values and angles by lateral back type

Item \ Type		LBT1	LBT2	LBT3	LBT4	*F*
Buttocks prominence	Hip - Abdomen(BDD)	0.10c	0.20a	0.13b	0.05d	149.70***
	Hip - Waist(omphalion)(BDD)	0.15c	0.28a	0.20b	0.09d	173.73***
	Hip(BD)	0.61c	0.68a	0.64b	0.58d	118.76***
	Hip - Waist(Natural Identation)(BDD)	0.13c	0.30a	0.20b	0.10d	152.79***
Back side silhouette of waist to abdomen	Waist Back(BD)	0.48a	0.38c	0.44b	0.49a	648.75***
	Waist(omphalion)(BD)	0.46b	0.40d	0.45c	0.49a	630.69***
	Abdomen(BD)	0.51b	0.48c	0.52b	0.53a	574.92***
	Waist(Natural Identation)(BD)	0.44b	0.35d	0.41c	0.46a	498.12***

BDD: Back-Depth Drop, BD:Back Depth. *** $p \leq .001$, Duncan test: a>b>c>d

sification of the LBT of the lower body into 4 types. Aggregating the factor scores and the averages of the index values and measured values, this study found the following results on the LBT of the lower body(Table 12, Table 13, Table 14). The results of cross tabulation analysis of LBT and age group were shown in Table 15. Table 15 showed that there was also a difference in LBT according to age group.

LBT1 had a small depth difference between the back waist and the hip. Fat was accumulated in the back waist, creating a gentle curving silhouette from the waist to the hip. The LBT1 type occurred most often among people in their forties, but when it comes to ratio, different distributions were shown depending on age standard and LBT. For LBT1 prevalence rate at each age group, fifties age group had the highest value, 41.1%. When we analysed the age distribution of subjects who fell into the category of LBT1, we saw that forty people in their forties fit into this cat-

Table 14. Difference verification of measured values by lateral back type (Unit:mm)

Item \ Type	LBT1	LBT2	LBT3	LBT4	*F*
Waist Height	961.96c	996.77a	982.81b	941.52d	51.19***
Abdomen Height	850.15c	889.53a	865.59b	827.47d	73.32***
Hip Height	760.25c	778.33a	771.87ab	762.83bc	10.63***
Crotch Height	682.10c	709.05a	696.16b	664.80d	35.64***
Waist Depth	213.65b	177.97d	192.82c	231.77a	295.29***
Waist Back Depth	212.94b	176.66dd	192.08c	229.95a	331.28***
Waist Depth(omphalion)	219.64b	187.65 d	204.06c	241.20a	246.29***
Abdomen Depth	239.29b	205.20d	223.36c	258.59a	367.67***
Hip Depth	234.32b	219.22d	226.08c	250.40a	109.07***
Waist Girth(omphalion)(BG)	413.72b	338.57d	379.82c	452.74a	404.32***
Abdomen Girth(BG)	445.44b	373.31d	414.50c	479.31a	385.10***
Mid-hip Girth(BG)	453.52b	397.02d	423.04c	479.34a	301.14***
Hip Girth(BG)	480.94b	461.60d	468.50c	493.93a	40.40***

BG:Back Girth, *** $p \leq .001$, Duncan test: a>b>c>d egory, at a prevalence of 47.1%. With respect to waist to hip silhouette, LBT2 had the curviest silhouette and the most protrusive buttocks in the waist and hip despite its thinness. For people in their twenties, LBT2 had a 55.1% prevalence. For LBT2 prevalence rate, twenties age group had the highest value, 46.9%. LBT2 was the most common body type of people in their 20s. LBT3 had a similar lateral shape with LBT1, but its silhouette in the back waist was more slender. The LBT3 values related to buttocks prominence were larger than LBT1 according to index value. For the degree of protrusion from back waist to hip prominence, LBT3 silhouette had more clearly than LBT1. When measured values were considered, LBT1 was larger than LBT3 in the depth and girth values. LBT4 had the smallest depth difference between the back waist and hip, and features larger, sagging buttocks. The most items other than height were the largest according to measured value and LBT4 occurred most in sixties.

The results for the LFT and LBT cross tabulation for the classified LT(lateral type) was the same as Table 16. The chi-square value for LT combination was 64.97 and showed a significant relation, with a significance level of 0.001. When the prevalence of each cell is compared, LT13(LFT1 & LBT3) had highest prevalence, at 17.6% of the total, and LT23(LFT2 & LBT3) had second highest at 16.2%. The prevalence of LBT for each LFT was different; LFT1 and LFT2 occurred a lot with types LBT3 and LBT2. The combination of LBT4 with LFT2 or LFT4 did not exist. It was found that the total number of combinations of LFT and LBT with 5% or higher prevalence rate was 8. Through these results, limiting the numbers of lateral types as existing advanced research does would cause difficulties in designing patterns for customers with varying lower body types. Therefore, detailed classifications of body types were required to create a standard that reflected this variety, rather than integrating them into a single type. For example, applying current lower body type research to mass customization would improve ready-made pattern fitting for customers with 3-5 types of standardized lower bodies. Or fitting would be improved for only 3-5 types of front lower bodies and 3-5 types of sides. However, customers had a variety of bodily features, so classifying each part of the lower body would allow for ready-made pattern design and pattern alternation standards for these various types. If we combine the results of this paper, we have 64 com-

Table 15. Cross-tabulation of age group and LBT (Unit:*N*, %)

Type		Age group					Total
		20s	30s	40s	50s	60s	
LBT1	*N*	3	8	40	30	4	85
	% of Age	1.7	5.2	26.8	41.1	10.8	14.4
	% of Type	3.5	9.4	47.1	35.3	4.7	100.0
	% of Total	0.5	1.4	6.8	5.1	0.7	14.4
LBT2	*N*	98	63	34	14	0	209
	% of Age	55.1	40.6	22.8	19.2	0.0	35.3
	% of Type	46.9	30.1	16.3	6.7	0.0	100.0
	% of Total	16.6	10.6	5.7	2.4	0.0	35.3
LBT13	*N*	77	84	74	26	8	269
	% of Age	43.3	54.2	49.7	35.6	21.6	45.4
	% of Type	28.6	31.2	27.5	9.7	3.0	100.0
	% of Total	13.0	14.2	12.5	4.4	1.4	45.4
LBT4	*N*	0	0	1	3	25	29
	% of Age	0	0	1	3	25	29
	% of Age	0.0	0.0	0.7	4.1	67.6	4.9
	% of Type	0.0	0.0	3.4	10.3	86.2	100.0
	% of Total	0.0	0.0	0.2	0.5	4.2	4.9
Total	*N*	178	155	149	73	37	592
	% of Age	178	155	149	73	37	592
	% of Age	100.0	100.0	100.0	100.0	100.0	100.0
	% of Type	30.1	26.2	25.2	12.3	6.3	100.0
	% of Total	30.1	26.2	25.2	12.3	6.3	100.0
χ^2=455.90***							

Table 16. Cross-tabulation of LFT and LBT (Unit:*N*)

	LFT1		LFT2		LFT3		LFT4		Total	
	(*N*)	(%)	(*N*)	(%)	(*N*)	(%)	(*N*)	(%)	(*N*)	(%)
LBT1	36	6.1	31	5.2	3	0.5	15	2.5	85	14.4
LBT2	66	11.1	80	13.5	40	6.8	23	3.9	209	35.3
LBT3	104	17.6	96	16.2	29	4.9	40	6.8	269	45.4
LBT4	13	2.2	0	0.0	16	2.7	0	0.0	29	4.9
Total	219	37.0	207	35.0	88	14.9	78	13.2	592	100
χ^2=64.97***										

binations of lower body types that provide a wider variety of lower body types than existing advanced research does.

4. Conclusions

This study was done to classify the lower body types into 4 classifications of FT, 4 classifications of LFT, and 4 classifications of LBT. 3D body scan data of female adults aged 18-69 was utilized to measure the human bodies based on reference lines. The cross section distances of the major segments of the lower body were then measured. The resulting information was summarized via factor analysis applied to the front and lateral sides of the lower body. Cluster analysis was then performed. To analyze the shape characteristics of the classified lower body types, ANOVA and Duncan's test were used to compare the index values, absolute values, and angles of each type.

From the results of principal component analysis for the FT, five factors were produced to explain 83.54% of all variables. Those five factors to compose front body shapes were waist to hip lateral silhouette, lower body height, width below hip, cross section distance drop upper hip, hip to crotch silhouette. A cluster analysis was applied to the five factors comprising the front shapes, classifying FT into 4 types. FT1 had the largest waist width and circumference and had a relatively small hip width. FT2 had a clear silhouette for the hip and the pelvis width was larger than waist width, indicating a larger girth of the lower body. FT3 had the highest angle between the waist and buttock. The people who belong to this type were considered as those who had the ordinary size. FT4 had the largest difference between the waist width and hip width. It was considered a thin body type.

From factor analysis for the lateral factor, six factors with the cumulative % of 89.00 were buttocks prominence, abdomen prominence, back side silhouette of waist to abdomen, lower body height, waist prominence, abdomen angle. There were 6 factors comprising the lateral shapes that were segmented into LFT and LBT, which in turn were classified into 4 types each. LFT1 had a flat front silhouette when viewed from the lateral side. LFT2 had a large difference between waist and abdomen prominence because of the projected abdomen. It represented a thin body which had a prominent abdomen. LFT3 had a prominent upper abdomen with the largest front depth of the waist point. LFT4 showed the biggest waist and abdomen depths. It overall represented a thicker abdomen. In terms of the LBT of lower body, LBT1 had the second-smallest difference between back depth of abdomen girth point and back depth of the hip girth point. LBT2 had a prominent buttocks because the silhouette of the back waist and hip was the most clear. LBT3 was most representative of the standard somatotype. LBT4 had the smallest difference between the back depth of the waist and the back depth of the hip, showing a sagging buttock.

Although existing research categorizes lower body types by front, back and side, one notable feature is the lumping of the front and back sides together. Hence it limited application of understanding variety of body types of customers for mass customization production. However, this research divided and categorized the lower body and proposed a shape classification standard for each part. A pattern alternation algorithm would be proposed by analyzing body surface patterns according to the standard, and comparing them with standard body type. By combining such an algorithm with an auto-designing pattern program, it would be possible to design patterns that reflect the variety of body types. For instance, specific process are as follows:

1) The classification of lower body types based on each segment
2) Development of regression model for lower body type prediction with multinomial logistic regression
3) The analysis of surface pattern comparison among lower body types
4) Development of pattern alteration algorithm
5) Development of automatic pattern drafting program
6) Virtual garment fitting system

Through the process above, pattern alternations can be computed according to lower body features so that patterns may be customized according to type. Lastly, it may contribute to the spread of mass customization production by proposing a lower body part classification and method of altering ready-made patterns according to FT and LT. The characteristics of each individual shape must be reflected in the design patterns to ensure successful mass customization. This study reflected the lower body shape features of each consumer, enabling us to provide the best Fit for consumers. Follow-up studies are required to understand the difference in shapes with respect to age, and to gather greater insight in the lower back shapes from the rear.

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(Received 4 January 2016; 1st Revised 19 January 2016; 2nd Revised 5 February 2016; 3rd Revised 15 February 2016; Accepted 20 February 2016)