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Categorization of lower body shapes of abdominal obese men using a script-based 3D body measurement software

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Abstract

The objectives of this study are to identify the principal components that represent distinctive shapes from the silhouette and profile views of the lower body shapes of abdominal obese Korean men and to categorize their body types. Using 3D scans of 625 men aged 35–64 in the 6th SizeKorea dataset, 173 scans (27.7%) of men in 'abdominal obese' category (BMI value of 25, waist girth to height ratio of 0.53, and waist girth to hip girth ratio of 0.9 or higher) were utilized. We developed a script to measure 38 items such as front/back crotch length and front/back depths and angles using the SNU-BM program, which is a script-based automated 3D body scan measurement software. The measurements used for principal component (PC) analysis were 31 drops, 2 heights, 2 lengths and 4 angles. Ten PCs representing distinctive silhouettes and profiles of lower body shapes were extracted. The PCs were interpreted as follows: abdomen prominence, thigh to knee profile, upper buttocks prominence, waist to hip drop, thigh to knee silhouette, lower body tilt angle, waist to crotch length, vertical height, abdomen to crotch height, and lower buttocks slope. The three body shape groups were categorized using a K means cluster analysis with ten PC scores. Group 1 had a flat abdomen but prominent buttocks. Group 2 had a developed abdomen and buttocks with vertical thighs. Group 3 had drooped buttocks with tilted thighs.

Keywords: Obese men, Lower body shape, 3D scan data, Script-based measurement software

Introduction

Clothing fit is an important element that enhances wearing satisfaction. To improve clothing fit, it is important to understand the characteristics of consumers' body shapes and develop patterns suitable for diverse types. In the field of apparel studies, although studies related to body shape analysis have been actively conducted, male body shape studies are insufficient as compared to female body shape studies and are limited to average body shapes. Most ready-to-wear companies design clothing for consumers of average body shape and weight (Faust and Carrier 2010). However, sizes other than those representing average shape and weight represent a significant percentage of the population (O'Connell 2019).

According to a 2017 report by the Organization for Economic Co-operation and Development (OECD), obesity rates are projected to further increase by 2030, and Korea is the country where the obesity rate is projected to increase the most rapidly (OECD 2017). Although the ratio of obese men was only 28.5% among those aged below 19 years, it increased to 36.7% among those in their 20 s. Thereafter, the foregoing ratio increased greatly to 47.2% among those in their 30 s, indicating that almost half of the male population in their 30 s were obese. It was found that 43.5% of men in their forties and 39.8% of men in their 50 s were obese and the rate of obesity is increasing yearly. When the abdominal size of the men aged 35 to 64 increases, their muscle mass at the hips and thighs decreases Ministry of Health and Welfare (2018). Therefore, it is necessary to identify the principal components (PCs) necessary to represent the shape of each lower body region and to categorize the body types of men ages 35 to 64.

Previous studies regarding obese men's lower body shapes generally defined obese men as those with a BMI of 25, waist girth of 90 cm, or a waist girth to hip girth ratio of 0.90 or higher (Lee and Shu 2011; Lim 2011; Sung and Ha 2012). They conducted principal component analysis and cluster analysis to classify the body shapes using girths, heights, and lengths, which were included in the SizeKorea dataset. This analysis tended to collect most vertical measurements (heights and lengths) under one principal component (PC), and most horizontal measurements (girths and widths) under the other PC, which resulted in specific body shape characteristics such as waist and hip relationships not being distinguished from one another. Therefore, it is necessary to extract principal components that can represent distinctive shapes from the silhouette and profile views of specific body parts using values such as the drop (difference) values of front depths, back depths or angles. Since the SizeKorea dataset did not include these types of measurements, it was necessary to collect them using a new measuring technology. We used a script-based versatile 3D body measurement system, the SNU-BM (Kim and Kim 2018), as the tool to obtain these new types of measurements, which was developed based on the C++ compiler system. The advantages of this software are that it is able to define custom landmarks and customize measurement paths easily by writing appropriate scripts, and to generate measurements of a number of scans in a short time. Using these types of measurement values taken from a script-based automated 3D body scan measurement software, this study developed a reliable and objective categorization method for the lower body shapes of abdominal obese men aged 35–64.

Literature review

The BMI, which is a representative measure of obesity, estimates the amount of fat by dividing body weight (kg) by height (m) squared. The Asia–Pacific WHO (2000) classifies persons with a BMI exceeding 23 as 'overweight,' those with a BMI of 25 and over as 'obese,' and those with a BMI higher than 30 as 'extremely obese.' In addition, the criteria for obesity according to waist girth defines abdominal obesity in adult men as having a waist girth exceeding 90 cm. However, since the BMI is intended to judge obesity based on body weight and height and cannot reflect the dimensions of various body parts, it can be said that reflecting this index in the clothing industry has limitations.

Therefore, previous studies on obese men have been using the BMI, waist girth, waist girth to hip girth ratio (WHR), waist girth to chest girth ratio (WCR), and waist girth to height ratio (W/Ht) as criteria for obesity. In a study conducted by Nam et al. (2007), males from age 10–60 were judged to be obese when they satisfied one or more of the criteria (BMI over 25 and WHR exceeding 1). In a principal component analysis (PCA) to derive the PCs that can show the characteristics of obesity, body height and weight were excluded because these were judged to be inappropriate to represent body shape, so a total of 17 anthropometric values such as girth, depth, width, and length were used. Through a cluster analysis, obese body shapes were categorized into four groups: super-size obesity, triangle obesity (lower body obesity), reverse triangle obesity (upper body obesity), and log obesity. The ratios of obese body shapes by age group were examined and the results indicated that the ratio of triangle obesity was the highest among teenagers, the ratio of log obesity was the highest among adults in their 20–30 s, and the ratio of reverse triangle obesity was the highest among older adults; that is, the ratios of upper body and abdominal obesity increased with age.

Choi et al. (2009) studied subjects with a BMI over 25 and categorized the body shapes according to age groups, divided as children (7–12 years old), youth (13–18 years old), and adults (19–39 years old). To compare their physical proportions, PCA was conducted and the flatness ratios were obtained by dividing the width by the depth of various parts, and the proportional values were obtained by dividing the girths of various parts by the waist girth. The body shapes were classified as three types: lower body obesity, abdominal obesity, and upper body obesity. The distribution of obesity types by age group was examined, and it was discovered that the ratios of those with lower body obesity and abdominal obesity were higher in children and youth, while the ratio of upper body obesity was higher in the adult group, indicating that obesity type varied according to age.

In a study conducted by Sung and Ha (2012), obese men ages 35–55 were divided into three types; small log obesity, upper body obesity, and large and robust log obesity types based on the index values of girth, width, height, and length. The men ages 35–45 were mostly categorized in the large and robust log obesity type. But the men ages 46–55 years were mainly distributed into the small log obesity type and the large and robust log obesity type.

Lim (2011) categorized the lower body into two shapes, obesity and abdominal obesity types, using data on middle-aged men in their 40 s or 50 s who satisfied all criteria for obesity (BMI over 25, waist girth over 90 cm, and WHR over 0.90). In the analysis, the height, length, width, girth, and depth values measured in various parts of the lower body along with waist and hip flatness ratios were used. Lee and Shu (2011) categorized middle-aged men in their 30 s, 40 s, and 50 s with a BMI over 25 and a waist girth at the level of the navel over 85.68 cm (34 in) as obese. They used measurements taken from 31 parts of the lower body and two drop values: hip girth-waist girth and hip girth-waist girth at the level of the navel. The subjects were classified according to the following characteristics: prominent abdomen, a body shape that is straight from waist to the ankle, and prominent hips. Lee (2013) extracted data from men ages 20–39 who met the following criteria for obesity: WCR over 0.87, W/Ht over 0.53, and WHR over 0.90. A PCA was conducted using chest girth index values for various parts of the upper body to classify trunk region obesity into three types: chest obesity, abdomen and hip obesity, and entire body extreme obesity.

According to a literature review of studies that categorized obese men's body shapes, the studies primarily concentrated on the upper body and defined the characteristics of obesity using only abdominal obesity. They conducted both PCA and cluster analysis to classify the body shapes using girth, height, and length values which were included in the SizeKorea dataset. This analysis revealed that the studies tended to collect most of their vertical measurements (height and length) under one PC, and most of the horizontal measurements (girth and width) under the other PC. These PCs only represented body size rather than body shape. In order to identify the PCs needed to represent the shape of each lower body region such as the abdomen and buttocks, specified values such as the drop (difference) values of front depths, back depths, or angles needed to be extracted. Since the SizeKorea dataset did not include these types of measurements, it was necessary to collect them using a new measuring technology.

In order to obtain these new types of measurements, we focused on a script-based versatile 3D body measurement system, SNU-BM (Kim and Kim 2018), which was developed based on a script language C++ compiler system. The advantages of this software are that it is able to define custom landmarks and customize measurement paths easily by writing appropriate scripts, and to generate measurements of a large number of scans in a short time.

We selected the target age for this study because most previous studies divided the ages of subjects into 10-year units, or categorized ages as adolescence for below 35 years, middle age for 35–59 years, and senescence for ages 60 or older. However, according to Welfare of the Aged Act, those ages 65 and over are defined as the "aged group" (Korea Ministry of Government Legislation 2019). Accordingly, we determined that to consider obesity characteristics and human body changes, this study should be expanded to include those in their 30–60 s, who are in age groups in which obesity rates prominently fluctuate.

Objectives

The objectives of this study were to identify the principal components (PCs) that represent distinctive shapes from the silhouette and profile views of the lower body shapes of Korean abdominal obese men ages 35–64 and to classify their body types. The detailed objectives for this study were as follows:

1. To determine appropriate criteria to define male abdominal obesity and select a sample from the 6th SizeKorea dataset.
2. To develop a script to automatically generate 38 measurements from the front/back depth, front/back crotch length, and angles.
3. To extract PCs that can represent a distinctive shape from the silhouette and profile views of abdominal obese men's lower bodies.
4. To classify abdominal obese men's lower body types and identify their characteristics.

Methods

Sample selection

The 3D scan data from the 6th SizeKorea (Korean Agency for Technology and Standards 2010) was used to analyze obese men's lower body shapes. The number of 3D scan data from men ages 35–64 years was 625 in total. The criteria selected from previous studies was that subjects must have a BMI over 25, WHR over 0.90, and W/Ht over 0.53. The number of 3D scan data with a BMI over 25 was 220, the number of 3D scan data with a WHR over 0.90 was 397, and the number of 3D scan data with W/Ht over 0.53 was 245. The number of 3D scan data that satisfied at least one of the obesity conditions was 411 in total, which was a sufficient number for analysis. However, since the BMI, which is a method for indirectly measuring body fat, can be overestimated in the case of those with large muscle mass or those who are very short in stature (Lee 2013), classifying those that satisfy only one condition as obese was judged to be inappropriate. After these subjects were removed, 181 data satisfied all three obesity conditions and a total of 173 (27.7%) scanned data excluding 8 with poor scan conditions were used in the analysis.

Measurement items

A total of 38 items related to lower body shapes were measured for the analysis: 5 heights, 6 girths, 6 widths, 6 front depths, 6 back depths, 2 lengths, and 4 angles. Measurements related to lower body shape analysis were selected on the basis of two considerations: (a) width, front/back depth, and angles should be included for more specific categorization of both the silhouette and profile of the lower body, unlike previous body shape analysis methods based on ratios or drops of girth measurements only, (b) measurements should be useful for producing men's pants patterns. The side seam lines (Fig. 1), which were criteria for dividing front and back depths, were defined as the vertical lines that bisect the distance between the abdomen prominence point and the hip prominence point (Song and Ashdown 2011). If the lower body is tilted toward the back, it becomes difficult to accurately measure the front/back depths below the knee. As a corrective measure, a vertical plane was offset one meter backward from the side seam line to generate a virtual plane labelled "X" in the 3D measurement program. The distances from X to the front/back reference points by part were then able to be measured (Front X, Back X) (Fig. 1). Then, the waist, abdomen, thigh, mid-thigh, and front depth was calculated by the distance from X to the front reference point (Front X) minus 1 m, and back depth was calculated by 1 m minus the distance from X to the back reference point (Back X). However, at the knee and ankle, 'Front X' and 'Back X' were utilized as they were.

Among the angle items, the lower body tilt angle is the angle formed by the vertical line coming down from the waist depth bisecting point and the straight line that connects the waist depth bisecting point to the ankle depth bisecting point (Fig. 2). The crotch point was defined as the intersection point of the midsagittal plane and the side seam plane passing from the mid-point of waist depth and the mid-point of ankle depth (Fig. 2). The front crotch length and back crotch length are the body surface lengths from the crotch point to the front waist point and back waist point, respectively. The upper buttocks angle was measured as the angle formed by the straight line that connects the back waist point to the hip prominence point and the vertical line coming down from

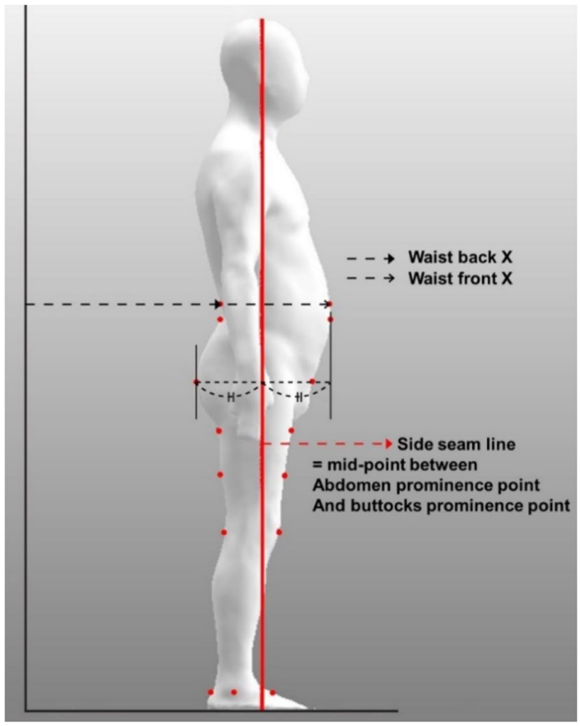

Fig. 1 Definition of side seam and front/back X

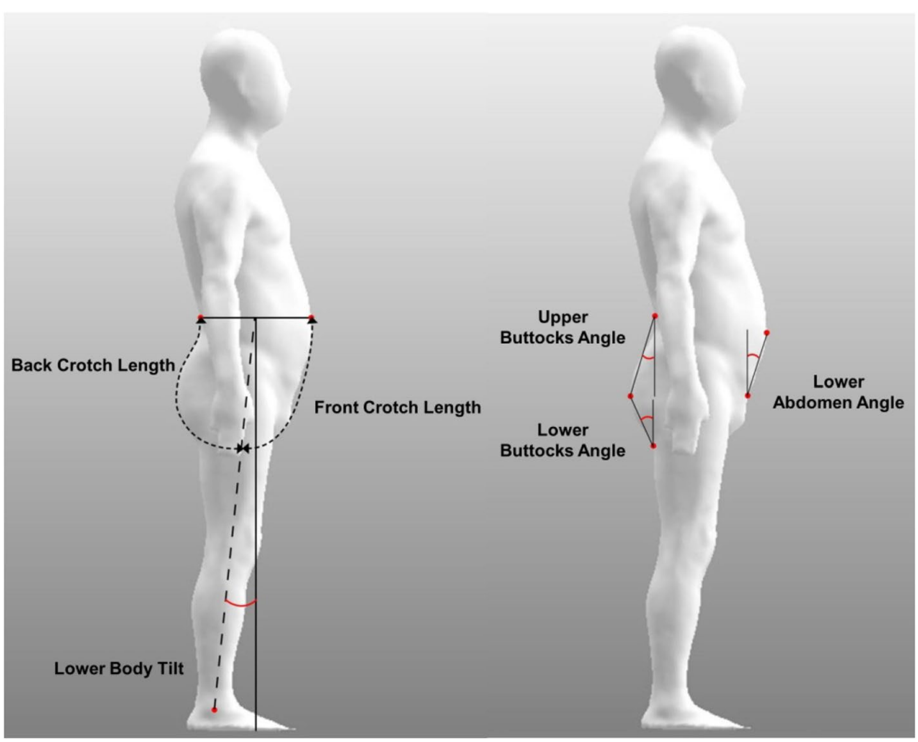

Fig. 2 Measurement methods of lengths and angles

the back waist point, and the lower buttocks angle was measured as the angle formed by the straight line that connects the gluteal furrow point to the hip prominence point and the vertical line coming down from the gluteal furrow point. The lower abdomen angle was measured as the angle formed by the straight line that connects the front hip point to the abdominal prominence point and the vertical line coming down from the front hip point (Fig. 2).

Measurement collection

Among those measurement items, the 6th SizeKorea dataset did not include front/back depths, front/back crotch lengths, or angles, so it was necessary to measure these using the 3D body measurement software SNU-BM (Kim and Kim 2018). SNU-BM was developed based on a script language compiler system, so it was easy for the researchers to customize measurement paths by writing appropriate scripts (Fig. 3). In order to detect landmarks accurately, the researchers utilized the 6 height measurements provided by the original SizeKorea dataset: waist height, abdomen height, hip height, crotch height, mid-knee height, and ankle height. The script was developed to import csv files including the heights and to find the anterior point with the largest value of z coordinates, a posterior point with the smallest value of z coordinates, a left point with the smallest value of x coordinates, and a right point with the largest value of x coordinates for waist height, abdomen height and hip height. For the thigh, mid-knee, and ankle, landmarks were detected only on the right leg. Next we customized the script to generate the measurements and save them in csv format.

Lower body shape categorization method

This study focused on analyzing body shape rather than body size, so the *drop*, or the difference between the two dimensions was calculated to represent a specific body proportion as shown in Table 1. A total of 37 variables (31 drops, 4 angles, and 2 heights) were utilized.

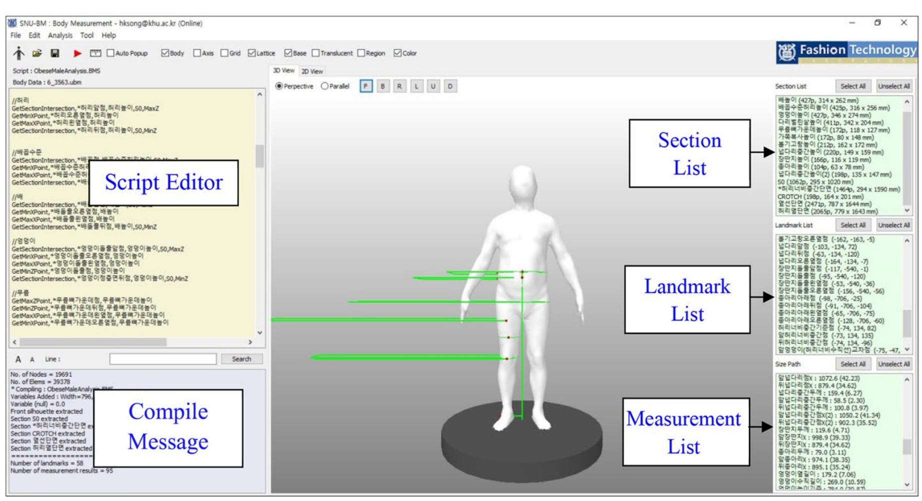

Fig. 3 Script-based automated 3D body scan measurements generated from SNU-BM software

Table 1 Variables used for statistical analysis

Two locations where the drop was calculated	Item					
	Girth	Width	Front depth	Back depth	Angle	Height
Abdomen—waist	O	O	O	O	Lower body tilt, lower abdomen angle, upper buttocks angle, lower buttocks angle	O
Hip–waist	O	O	O	O		O
Abdomen–hip	O	O	O	O		O
Abdomen–thigh			O			O
Hip–thigh				O		
Thigh–knee	O	O	O	O		O
Mid-thigh–knee	O	O	O	O		
Knee–ankle			O (Front X)	O (Back X)		Crotch height, Knee height
Waist–ankle			O (Front X)	O (Back X)		

O represents 'calculated.' For example, if the two locations where the drop was calculated is 'Abdomen–Waist' and the item is 'Girth,' this means abdomen girth minus waist girth

Statistical methods for body classification consisted of a PCA and a cluster analysis using SPSS 24 software. For the PCA, the Varimax rotation method was used and PCs which had eigenvalues greater than 1.0 were extracted. A K-means cluster analysis was conducted using the PC scores as independent variables to categorize body shapes. Each body measurement was compared through Duncan's multiple range test with ANOVA post-hoc analysis.

Results and discussion

Principal component analysis

The decisions on the number of principal components (PCs) to be retained was made in consideration of two aspects: (a) eigenvalues that corresponded to the sum of the squared loadings for a PC and (b) rotated component loadings (Warner 2012). With respect to eigenvalues, PCs should have eigenvalues greater than 1.0 and they should also be large enough to be distinguished from the rest of the PCs. The next consideration was that each measurement should have high component loadings (correlations) with one PC. If a measurement was highly correlated with more than two components, the analysis was re-conducted with this measurement removed.

Finally, a PCA was conducted using 35 variables and yielded 87.55% of the variations explained by ten PCs with eigenvalues 1.0 and greater (Table 2). When compared to past studies, the number of PCs was relatively high, but the researchers in this study considered ten PCs as appropriate, since each PC had three or four variables with high loadings for only their PC, and each PC clearly represented a distinctive shape from either the silhouette or profile view of the body.

PC1 was composed of the drop of the front abdomen to thigh depth, the drop of the front hip to abdomen depth, the drop of the front hip to waist depth, and the lower abdomen angle. Since these are items related to the shapes of the areas below the front waist, PC1 can be interpreted as 'abdomen prominence.' The eigenvalue for abdomen prominence was shown to be 4.31 and the explanatory variable was shown to be 12.32%. PC2 was composed of the drop of the back mid-thigh to knee depth, the drop of the back

Table 2 Varimax-rotated PCA loading values

PC	Variable	1	2	3	4	5	6	7	8	9	10
Abdomen prominence	Front depth: abdomen–thigh	*0.849*	−0.005	0.177	−0.102	0.035	0.080	0.013	0.002	0.055	−0.211
	Front depth: abdomen–hip	*0.839*	−0.200	0.241	−0.185	0.021	0.029	0.172	0.012	0.090	0.042
	Front depth: waist–hip	*0.823*	−.180	0.263	−0.179	0.022	0.037	0.159	−0.023	0.153	0.047
	Lower abdomen angle	*0.726*	−0.120	0.230	−0.216	−0.033	0.013	0.192	0.006	−0.474	−0.015
Thigh to knee profile	Back depth: mid-thigh–knee	0.015	*−0.878*	0.238	−0.257	0.114	0.044	0.118	0.010	0.017	0.112
	Back depth: thigh–knee	0.004	*−0.876*	0.242	−0.270	0.139	0.063	0.130	−0.022	0.034	0.068
	Front depth: thigh–knee	−0.219	*0.872*	−0.024	−0.066	0.267	−0.068	0.102	0.112	−0.056	−0.130
	Front depth: mid-thigh–knee	−0.308	*0.816*	0.011	−0.082	0.298	−0.054	0.080	0.095	−0.031	−0.093
Upper buttocks prominence	Upper buttocks angle	0.204	−0.094	*0.933*	−0.166	−0.001	−0.013	0.034	−0.084	−0.001	−0.072
	Back depth: hip–waist	0.188	−0.100	*0.924*	−0.064	0.027	−0.007	0.180	−0.030	−0.027	−0.033
	Back depth: hip–abdomen	0.151	−0.104	*0.868*	−0.050	0.040	0.037	0.160	−0.027	0.081	−0.002
Waist to hip drop	Width: hip–waist	−0.143	0.102	−0.257	*0.872*	0.000	−0.003	0.023	0.051	−0.103	0.007
	Width: hip–abdomen	−0.162	0.105	−0.214	*0.823*	0.015	0.008	−0.083	0.009	0.212	0.057
	Girth: hip–abdomen	−0.565	0.114	0.181	*0.677*	0.155	0.037	−0.033	−0.018	−0.008	0.035
	Girth: hip–waist	−0.571	0.100	0.201	*0.669*	0.133	0.006	0.030	0.013	−0.175	−0.009
Thigh to knee silhouette	Width: mid-thigh–knee	0.105	0.059	−0.090	0.094	*0.837*	0.110	−0.141	0.098	0.013	−0.197
	Girth: mid-thigh–knee	−0.176	−0.037	0.084	−0.173	*0.824*	0.035	0.021	0.262	−0.021	−0.124
	Girth: thigh–knee	−0.061	0.044	0.102	0.070	*0.785*	−0.063	−0.052	0.202	−0.052	0.170
	Width: thigh–knee	0.381	0.215	−0.050	0.360	*0.655*	−0.064	−0.051	0.054	0.017	−0.103
Lower body tilt angle	Front X: knee–ankle	−0.084	−0.291	−0.069	−0.048	−0.007	*0.864*	−0.058	0.099	−0.002	0.238
	Back X: knee–ankle	−0.061	−0.359	−0.126	0.049	−0.028	*0.832*	−0.163	0.076	−0.013	0.222
	Lower body tilt	0.375	0.468	0.176	0.022	0.063	*0.721*	−0.117	−0.073	−0.025	−0.227
	Front X: waist–ankle	0.538	0.334	0.097	−0.145	0.169	*0.660*	0.040	0.114	0.052	−0.104
	Back X: waist–ankle	0.065	0.539	0.242	0.250	−0.073	*0.608*	−0.146	0.016	−0.099	−0.298
Waist to crotch length	Height: waist–crotch	−0.159	0.026	−0.127	−0.007	0.185	0.033	*−0.887*	−0.039	−0.123	0.093
	Length: back crotch	0.044	−0.140	0.268	−0.177	−0.128	−0.072	*0.828*	0.173	0.044	0.101
	Length: front crotch	0.176	0.068	0.138	−0.017	0.026	−0.148	*0.716*	−0.024	−0.020	−0.002
	Height: waist–hip	−0.122	−0.035	−0.301	0.388	0.095	0.011	*0.563*	0.245	−0.064	0.079

Table 2 (continued)

PC	Variable	1	2	3	4	5	6	7	8	9	10
Vertical height	Height: crotch	0.011	0.067	− 0.057	0.037	0.226	0.065	0.112	*0.956*	− 0.005	0.061
	Height: crotch–knee	− 0.034	0.127	− 0.049	0.167	0.282	0.117	− 0.177	*0.843*	− 0.066	0.127
	Height: knee	0.056	− 0.014	− 0.051	− 0.108	0.109	− 0.006	0.386	*0.828*	0.061	− 0.024
Abdomen to crotch height	Height: abdomen–hip	0.022	− 0.066	− 0.031	0.051	0.029	-.005	− 0.037	0.027	*0.968*	0.088
	Height: abdomen–crotch	0.132	− 0.059	0.129	− 0.081	− 0.088	− 0.023	0.175	− 0.040	*0.946*	0.011
Lower buttocks angle	Lower buttocks angle	− 0.133	− 0.113	− 0.171	0.073	− 0.034	0.059	0.003	0.033	0.027	*0.917*
	Back depth: hip–thigh	0.008	− 0.244	0.093	− 0.005	− 0.135	0.093	0.015	0.109	0.085	*0.898*
Eigen values		4.31	4.14	3.40	3.15	2.93	2.87	2.83	2.61	2.25	2.16
Variance explained (%)		12.32	11.83	9.71	9.00	8.38	8.20	8.08	7.46	6.41	6.16
Cumulative variance explained (%)		12.32	24.15	33.86	42.86	51.24	59.44	67.52	74.98	81.39	87.55

Italic values indicate high loading values thigh to knee depth, the drop of the front thigh to knee depth, and the drop of the front mid-thigh to knee depth and was named 'thigh to knee profile' since it was interpreted as a PC that represented the shape of the thigh region. The eigenvalue for this area was shown to be 4.14, the explanatory variable was shown to be 11.83%, and the cumulative explanatory variable was shown to be 24.15%. PC3 was interpreted as 'upper buttocks prominence' because it was composed of items that represent the degree of prominence of the upper buttocks. Concrete items were the upper buttocks angle, the drop of the back hip to waist depth, and the drop of the back hip to abdomen depth. The eigenvalue of this angle was shown to be 3.40 and the cumulative explanatory variable was 33.86%.

PC4 was composed of those variables at the drop of the hip to waist width, the drop of the hip to abdomen width, the drop of the hip to abdomen girth, and the drop of the hip to waist girth, and represented the difference in size between the abdomen and the hip. This PC was named 'waist to hip drop,' the eigenvalue of which was shown to be 3.15, and the explanatory variable was 9.00%. PC5 was composed of the drop of the mid-thigh to knee width, the drop of the mid-thigh to knee girth, the drop of the thigh to knee girth, and the drop of the thigh to knee width and represented the size of the thigh region. The eigenvalue of this region was 2.93 and the cumulative explanatory variable was 51.24%. PC 5 was interpreted as the 'thigh to knee silhouette.'

PC6 was composed of five variables which were the drop values of the depth measurement items from plane X to the reference points. Since PC 6 was composed of the variables that represented tilts, which were the front knee point to the X depth-front ankle point to the X depth, the back knee point to the X depth-back ankle point to the X depth, the lower body tilt angle, the front waist point to the X depth-front ankle point to the X depth, and the back waist point to the X depth-back ankle point to the X depth, PC6 was named as the 'lower body tilt angle.' The eigenvalue of this angle was 2.87 and explained 8.20% of the entire variables. PC7 was composed of variables related to the waist to crotch length, which represented the difference between the waist height and the crotch height, the back crotch length, the front crotch length, and the drop of the waist to hip height. The eigenvalue of PC 7 was shown to be 2.83, and the cumulative explanatory variable was 67.52%. PC7 was thus named as 'waist to crotch length.'

PC8 was named as 'vertical height' because it represented the height of the lower limb parts: crotch height, crotch height-knee height, and knee height. The eigenvalue for PC8 was 2.61 and the explanatory variable was 7.46%. PC9 was related to abdomen height and was composed of the abdomen height-hip height and the abdomen height-crotch height, and thus was named 'abdomen to crotch height.' The eigenvalue for PC9 was 2.25 and the explanatory variable was 6.41%. Finally, PC10 represented the degree of sagging of the region below the point of hip prominence because it was composed of the lower buttocks angle and the back hip depth-back thigh depth. The eigenvalue was shown to be 2.16, and the explanatory variable was 6.16%. PC 10 was interpreted as 'lower buttocks slope.'

Cluster analysis

A K-means cluster analysis was performed using ten PC scores. To classify lower body shapes, the researchers experimented with different numbers of clusters, dividing the 173 men into two, three, and four clusters. The final number of clusters was decided by considering a similar number of people in each cluster, the significant differences among clusters, and a reasonable number of clusters for further study such as block pattern development.

The population distribution rates of 2–4 clusters were examined and according to the results, two clusters were evenly divided with distribution rates of 49.1% and 50.9%. However, these clusters were excluded because two clusters were not enough to represent complex obese lower body shapes. In the case of three clusters, the population tended to be somewhat concentrated in cluster 3 as the population distribution rates of clusters 1, 2, and 3 were 29.5%, 27.7%, and 42.7%, respectively. In the case of four clusters, generally even distribution rates were shown, as the population distribution rates of clusters 1, 2, 3, and 4 were 19.1%, 22.0%, 27.7%, and 31.2%, respectively.

Significant differences in PCs among clusters were examined when there were 3 or 4 clusters and the results indicated that there were significant differences in eight PCs excluding two out of the ten PCs among all clusters. Duncan tests were conducted to verify significant differences among the clusters. When the number of clusters was 4, two or three clusters were shown not to be significantly different from each other in all PCs. As a result, we concluded that four clusters was an inappropriate number for categorization by analysis of differences between clusters, and that the 3-cluster model was more appropriate to represent abdominal obese men's lower body shapes.

Characteristics of the three shape groups

Table 3 shows the results of the ANOVA analysis and Duncan tests for the three lower body shape groups. The overall *F* for the one-way ANOVA was statistically different among the eight PCs. Group 1 was shown to have the smallest values for PC1 (abdomen prominence), composed of the drop of the front abdomen to thigh depth, the drop of the front hip to abdomen depth, the drop of the front hip to waist depth, and the lower abdomen angle. The largest values of PC9 (abdomen to crotch height) were composed of the abdomen height-hip height and the abdomen height-crotch height, showing this type as having the least prominent abdomen and the largest length between the abdomen and the crotch. In addition, since group 1 was shown to have the largest values for PC3 (upper buttocks prominence), consisting of the upper buttocks angle, back hip depth-back waist depth and back hip depth-back abdomen depth, group 1 was named the 'flat abdomen but buttocks-developed obesity type.'

Group 2 showed the largest value for PC1 (abdominal prominence) but the smallest value for PC9 (abdomen to crotch height) among the three groups, so this group had the most prominent abdomen. In addition, group 2 had the largest value for PC3 (upper buttocks prominence) even though the mean value was slightly lower than that of group 1. Group 2 showed the smallest values for PC2 (drops of front/back mid-thigh to knee depths) indicating that the lower limb region was vertical. This group was labelled the 'abdomen and buttocks-developed obesity type with vertical thighs.'

Group 3 was shown to have the smallest value for PC3 (upper buttocks prominence) while having the largest value for the lower buttocks angle in PC10 and thus was characterized as having flat and sagging buttocks. In addition, group 3 had the largest values for PC2, consisting of the drops of the front/back mid-thigh to knee depths, indicating that the lower body is tilted. Group 3 was thus named the 'buttocks-drooped obesity type

Table 3 Mean values of the three body shape groups and results of ANOVA for the 10 PCs and 35 variables

PC	Variable	Group 1 (n = 51, 29.5%)		Group 2 (n = 48, 27.7%)		Group 3 (n = 74, 42.7%)		*F*
		Mean	SD	Mean	SD	Mean	SD	
PC 1	Abdomen prominence	− 512 C	0.881	0.599 A	1.044	− 0.035 B	0.838	18.455 ***
	Front depth: abdomen–thigh	6.670 B	2.510	7.953 A	2.106	6.706 B	1.622	6.560**
	Front depth: abdomen–hip	3.151 B	1.352	4.586 A	1.409	3.051 B	1.222	22.488***
	Front depth: waist–hip	3.077 B	1.345	4.466 A	1.544	2.885 B	1.379	19.773***
	Lower abdomen angle	1.091 B	0.464	1.720 A	0.451	1.095 B	0.442	33.404***
PC 2	Thigh to knee profile	0.067 B	0.833	− 790 C	0.962	0.467 A	0.807	31.298 ***
	Back depth: mid-thigh–knee	0.138 B	1.060	1.185 A	1.292	− 0.746 C	1.032	43.620***
	Back depth: thigh–knee	0.982 B	1.389	2.239 A	1.857	− 0.207 C	1.397	37.295***
	Front depth: thigh–knee	5.798 B	1.507	4.499 C	1.619	6.374 A	1.360	23.626***
	Front depth: mid-thigh–knee	4.505 A	1.238	3.473 B	1.249	4.888 A	1.065	21.681***
PC3	Upper buttocks prominence	0.571 A	0.704	0.305 A	0.885	− 0.591 B	0.933	31.863 ***
	Upper buttocks angle	1.638 A	0.314	1.603 A	0.325	1.108 B	0.361	48.916***
	Back depth: hip–waist	5.117 A	0.892	5.301 A	1.068	3.643 B	1.192	44.963***
	Back depth: hip–abdomen	4.755 A	1.156	4.731 A	1.149	3.561 B	1.146	22.383***
PC4	Waist to hip drop	− 355 B	0.967	.078 A	0.979	0.194 A	0.984	4.975 **
	Width: hip–waist	1.605 B	1.266	2.043 B	1.233	2.613 A	1.164	10.694***
	Width: hip–abdomen	1.839 B	1.377	1.923 B	1.146	2.777 A	1.219	10.989***
	Girth: hip–abdomen	2.936 A	3.730	1.280 B	3.886	3.455 A	3.674	5.043**
	Girth: hip–waist	3.298	3.724	1.918	3.879	3.239	3.786	2.184
PC5	Thigh to knee silhouette	− 477 B	1.063	0.147 A	0.970	0.233 A	.865	9.110 ***
	Width: mid-thigh–knee	2.041 B	1.035	2.528 A	0.993	2.690 A	0.767	7.762*
	Girth: mid-thigh–knee	9.282 B	2.484	10.387 A	2.692	10.217 AB	2.384	2.951*
	Girth: thigh–knee	19.269 B	4.010	21.444 A	2.768	21.956 A	3.430	9.654***
	Width: thigh–knee	4.434 B	1.299	5.527 A	1.238	5.678 A	1.286	15.677***
PC6	Lower body tilt angle	0.016	0.920	− 0.028	0.899	0.007	1.121	0.027
	Front X: knee–ankle	1.873	1.701	2.504	2.099	2.189	2.209	1.182
	Back X: knee–ankle	1.092	1.379	1.790	1.891	1.396	1.762	2.097
	Lower body tilt	0.487	0.140	0.462	0.113	0.488	0.123	0.718
	Front X: waist–ankle	14.378	3.204	14.915	2.447	15.218	2.491	1.458
	Back X: waist–ankle	1.338	1.816	.428	1.914	0.932	2.114	2.630*
PC7	Waist to crotch length	− 0.023	0.848	0.127	1.069	− 0.066	1.055	0.558
	Height: waist–crotch	− 28.424	1.812	− 28.566	2.063	− 27.597	2.075	4.314*
	Length: back crotch	37.327	2.426	37.578	2.484	36.432	2.098	4.250*
	Length: front crotch	39.437	1.956	39.881	2.278	39.298	4.635	.432
	Height: waist–hip	17.471	1.342	18.509	1.676	18.632	1.348	10.786***
PC8	Vertical height	− 0.394 B	0.892	0.226 A	0.997	0.125 A	1.006	6.108 **
	Height: crotch	69.795 B	3.462	73.065 A	4.142	73.301 A	4.241	13.150***
	Height: crotch–knee	26.381 B	1.829	28.108 A	2.260	28.744 A	2.603	16.243***
	Height: knee	43.414 B	2.185	44.957 A	2.456	44.557 A	2.319	6.084**
PC9	Abdomen to crotch height	0.383 A	1.032	− 0.419 C	0.870	0.008 B	0.960	8.668 ***
	Height: abdomen–hip	17.290 A	4.345	15.033 B	3.538	16.390 AB	4.077	3.951*
	Height: abdomen–crotch	28.243 A	4.680	25.090 B	3.826	25.355 B	4.466	8.504***
PC10	Lower buttocks angle	− 0.530 B	0.868	0.077 A	1.027	0.315 A	0.928	12.427***
	Lower buttocks angle	1.969 B	0.291	2.185 A	0.351	2.276 A	0.330	13.652***
	Back depth: hip–thigh	3.889 B	0.782	4.424 A	0.954	4.315 A	0.880	5.407**

*** $p < 0.001$, ** $p < 0.01$, A > B > C with tilted thighs.' Front silhouettes and profile views of each lower body shape group are also shown in Table 4 for comparison.

Conclusions

In the field of apparel studies, although studies related to body shape analysis have been actively conducted, male body shape studies are insufficient as compared to female body shape studies and are limited to average body shapes. It was found that 43.5% of men in their forties and 39.8% of men in their 50 s were obese and the rate of obesity is increasing yearly. When the abdominal size of the men aged 35 to 64 increases, their muscle mass at the hips and thighs decreases Ministry of Health and Welfare (2018). Therefore, this study identified PCs that can represent distinctive shapes from the silhouette and profile views of the lower body shapes of abdominal obese men ages 35–64 and classified their body types.

Since the variables in the SizeKorea dataset are insufficient to represent the morphological characteristics of obesity such as the prominence or sagging of the abdomen and buttocks, we developed a script to measure 38 items including front/back depths and angles using the SNU-BM program, which is a script-based automated 3D body scanning and measuring software. The advantages of this software are that it can define landmarks and customize measurement paths easily by writing appropriate scripts, and it can also generate measurements from a number of scans in a short time. We were thus able to define custom landmarks and customize measurement items by revising the scripts, and generate measurements of a number of scans in a short time. This new approach to collecting new types of measurements could help analyze body shapes more specifically and accurately.

Past studies analyzing obese men's body shapes conducted PCA using girths, heights, and lengths, but this analysis collected most of the vertical measurements (heights and lengths) under one PC, and most of the horizontal measurements (girths and widths) under the other PC, which did not allow specific body shape characteristics to be distinguished from one another. We utilized 31 drops, 2 heights, 2 lengths and 4 angles for the PCA to represent the distinctive silhouettes and profiles of lower body shapes. Ten PCs representing distinctive silhouettes and profiles of lower body shapes were extracted. The PCs were interpreted as follows: abdomen prominence, thigh to knee profile, upper buttocks prominence, waist to hip drop, thigh to knee silhouette, lower body tilt angle, waist to crotch length, vertical height, abdomen to crotch height, and lower buttocks slope.

Three body shape groups were categorized through a K-means cluster analysis using ten PC scores. A representative system identifying three lower body shape groups was developed, and the three groups from the cluster analysis were shown to be significantly different from one another in eight PCs. Group 1 was named the 'flat abdomen but buttocks-developed obesity type,' group 2 as the 'abdomen and buttocks-developed obesity type with vertical thighs,' and group 3 as the 'buttocks-drooped obesity type with tilted thighs.' Three clusters may not be sufficient to fully represent the complexity of abdominal obese men's body shapes. However, three clusters were the most efficient number for our study when compared to using two or four clusters.

Table 4 Front and side silhouettes of the three body shape groups

	Body shape group		Names of body types and their characteristics
1			Flat abdomen/ developed buttocks The least prominent abdomen The most prominent upper buttocks Thick thighs considering buttocks prominence The shortest lower body
2			Developed abdomen/ buttocks with vertical thighs The most prominent abdomen Prominent upper buttocks The most vertical lower body (from thigh to knee) The thinnest thighs
3			Drooped buttocks with tilted thighs The flattest upper buttocks The most tilted lower body (from thigh to knee) Thin thighs considering buttocks prominence

Body type analysis is a fundamental technique used to provide good clothing sizing, patterns, and fit. It has long been recognized that successful sizing systems and mass customization systems must be based on complex variations in body shapes and postures as well as sizes. Difficulties with fit could decrease if the body type categorization method that this study developed was used to develop different sizing systems and pants block patterns. Further research can be conducted using the script-based measurement software and these types of measurements to develop body shape categories for the upper bodies of men, for larger men, older men, and for men of different ethnicities.

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Authors' contributions
HKS originated the research idea. HKS and KSL carried out the research and draft the manuscript. SK guided the methods to define the landmarks and collet the measurements using SNU-BM program. All authors read and approved the final manuscript.

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