Morphotype of the human body

a clustering approach

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Context: LabCom DiTex

DiTeX is a joint research and development laboratory between the University of Technology of Troyes and the French Institute of Textiles and Clothing.

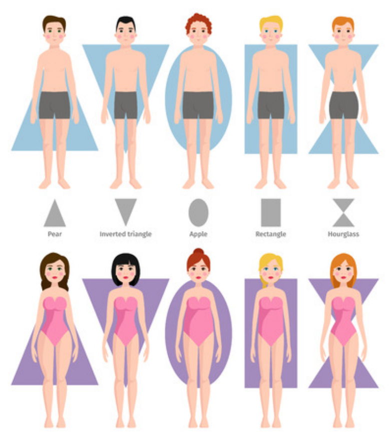
Statistical modelling and machine learning to analyse data from clothing and to respond to problems.

- The measurements of the human body:
  - What is the effect of ageing?
  - What are the types of morphologies?

Issue: Morphotypes

The **variety of human morphologies** is an important issue for the textile-apparel industry.

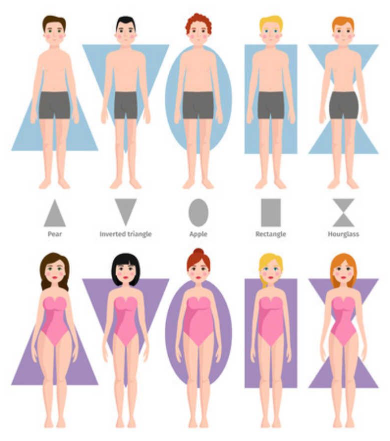
Enables proper organisation of garment sizing systems.



Issue: Morphotypes

The **variety of human morphologies** is an important issue for the textile-apparel industry.

How can these groups be defined?
How do we associate an individual with a group?



Early studies

3rd century BC

Hippocrates[1] recorded two distinct shapes of the human body:

- thin/tall
- short/thick

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1940s

W. Sheldon[2] defined the somatotype as the arrangement of three poles:

- endomorph
- mesomorph
- ectomorph

Women's measurements for garments and pattern construction

1941

O'Brien and Shelton study of women's measurements[3] :

- linear body measurement data of 14,698 women,
- statistical analysis.

Women's measurements for garments and pattern construction

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- linear body measurement data of 14,698 women,
- statistical analysis.

The analysis showed that girth measurements have little relation to vertical measurements.

20th century

1968

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August[6] categorised body shapes based on landmark identification and recognition by component.

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August[6] categorised body shapes based on landmark identification and recognition by component.

1987

Armstrong[7] described four female body shapes based on the shoulder/hip relationship.

Female Figure Identification Technique for apparel measurements

2004

Simmons, Istook, and Devarajan developed a software[8, 9] to classify 3D body scans and identify body shapes. They used a sample of 887 subjects to validate the nine identified body shapes.

Body shapes

- Hourglass
- Bottom Hourglass
- Top Hourglass
- Spoon
- Triangle
- Inverted Triangle
- Rectangle
- Diamond
- Oval

Comparison of body shape between USA and Korean women

2007

Lee, Istook, Nam, and Park[10] used a mathematical analysis and visual inspection to develop formulas based on the descriptions of the original FFIT software categories.

Formulas

BODY TYPE	MEASUREMENT
Hourglass	(bust-hip)$\leqslant$ 25), (hip-bust)$<$ 91, (bust-waist)$\geqslant$ 230 or (hip-waist)$\geqslant$ 250
Bottom hourglass	(hip-bust)$\geqslant$ 91 and (hip-bust)$<$ 250, (bust-waist)$\geqslant$ 230, (high hip/waist)$<$ 1.193
Top hourglass	(bust-hip)$>$ 25 and (bust-hip)$<$ 250, (bust-waist)$\geqslant$ 230
Spoon	(hip-bust)$>$ 51, (hip-waist)$\geqslant$ 180, (high hip/waist)$\geqslant$ 1.193
Triangle	(hip-bust)$\geqslant$ 91, (hip-waist)$<$ 230
Inverted Triangle	(bust-hip)$\geqslant$ 91, (bust-waist)$<$ 230
Rectangle	(hip-bust)$<$ 91 and (bust-hip)$<$ 91, (bust-waist)$\geqslant$ 230 and (hips-waist)$<$ 250

Modification of the FFIT Formulas to Include Plus Size Bodies

2020

Sokolowski and Bettencourt modified the FFIT mathematical formulas to be more inclusive of plus size women[11].

Formulas

BODY TYPE	MEASUREMENT
Hourglass	(bust-hip) $\leqslant 25$, (hip-bust) < 91, (bust-waist) $\geqslant 230$ or (hip-waist) $\geqslant 250$
Bottom Hourglass	(hip-bust) $\geqslant 91$ and (hip-bust) < 250, (hip-waist) $\geqslant 230$, (high hip/waist) < 1.193
Top Hourglass	(bust-hip) > 1 and (bust-hip) < 250, (bust-waist) $\geqslant 230$
Spoon	(hip-bust) > 51, (hip-waist) $\geqslant 178$, (high hip/waist) $\geqslant 1.193$
Triangle	(hip-bust) $\geqslant 91$, $0 \leqslant$ (hip-waist) < 230 or (bust-waist) < 0, (hip-waist) $\geqslant 0$
Inverted Triangle	(bust-hip) $\geqslant 91$, (bust-waist) < 9, (hip-waist) $\geqslant 0$
Rectangle	(hip-bust) < 91, and (bust-hip) < 91, $0 \leqslant$ (bust-waist) < 230 and $0 \leqslant$ (hip-waist) < 250
Diamond	(hip-waist) < 0, and (bust-waist) < 0
Oval	(hip-waist) < 0, and (bust-waist) $\geqslant 0$

Body Shape Assessment Scale

2006

Connell, Ulrich, Brannon, Alexander and Presley developed a series of scales to assess women's body shapes as seen on body scanners[12].
From 42 body scans of women aged 20 to 55, they developed nine scales based on frontal and lateral views.

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From 42 body scans of women aged 20 to 55, they developed nine scales based on frontal and lateral views.

- 3 (Body Build, Body Shape, Posture) were for whole body analysis,
- 6 (Front Torso Shape, Hip Shape, Shoulder Slope, Chest Shape, Buttock Shape, Back Curvature) for body part analysis.

Analysis and classification of 3D trunk shape

2009

Nakamura and Kurokawa used the 3D measurements of 560 Japanese women aged 19 to 63 years taken in laser metrology.

- data obtained for each subject consisted of approximately 160,000 body surface points.
- after shape data reduction, 111 representative coordinates that can cover approximately 92% of the original coordinates were chosen as the dataset for shape analysis.

Then, they applied principal component analysis with varimax rotation.

Analysis and classification of 3D trunk shape

Data analysis

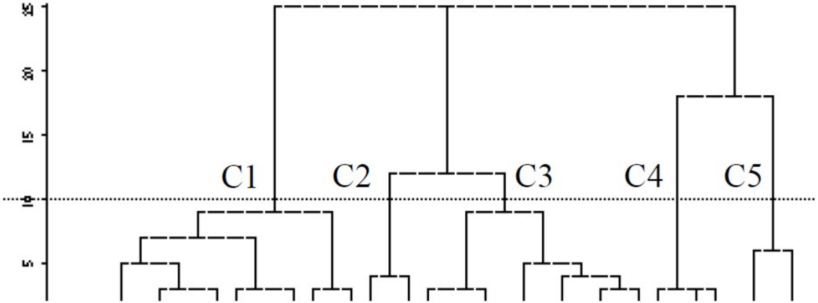
Nakamura and Kurokawa then performed cluster analysis of the scores of the six principal components.

- They adopted Ward's method[13] and used the squared Euclidean distance as the metric.
- The component scores are not normalized.
- Based on the dendrogram, they judged that 'five' is an appropriate number of classes.

Therefore, they obtained five classes: C1, C2, C3, C4 and C5.

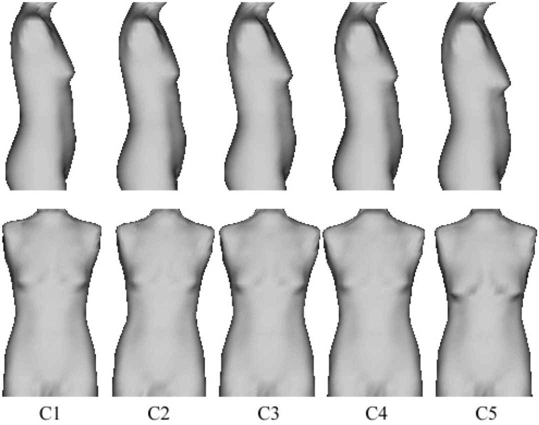
Analysis and classification of 3D trunk shape

Figure: *Dendrogram of cluster analysis and the level of the five classes*



Analysis and classification of 3D trunk shape

Figure: Average figures in the classes C1 to C5



Statistical human body form classification: Methodology development and application

2012

Cottle[14] developed a methodology to explore body shape analysis using 3D digital data generated by the body scanner.
The methodological framework is an adaptation of Costa and Cesar's framework for computational pattern analysis:

1. Form preprocessing
2. Form transformations
3. Form classification

Data analysis

- 117 body scan files were used from the Men's Mentoring Study[15].
- PCA to reduce the number of data points from 32,000 to 3,104.
- Unsupervised classification or clustering used to develop a hierarchical clustering of subjects.

Clustering of male body form

Applying the clustering technique established in the pretest to the 3 104 variables (height, weight, and 3D body scan data), seven distinct body form clusters emerged.

Cluster	number	Age (years)	Weight (kg)	Height (cm)	BMI
1	38	23.55	69.12	176.32	22.34
2	3	25.67	72.27	182.88	21.67
3	45	24.38	81.65	179.60	25.36
4	5	24.80	80.65	177.80	25.60
5	15	27.00	96.65	182.70	29.20
6	5	27.80	112.85	187.45	32.20
7	6	29.33	135.40	182.88	40.83

Body shape analyses of large persons in South Korea

2013

Park and Park studied the body shapes of large people using anthropometric data from South Korea.[16]

- A total of 1 444 males and 1 327 females were identified from the SizeKorea database.
- A total of 33 and 36 body dimensions were selected for males and females, respectively.
- For each gender, a factor analysis was conducted on the corresponding anthropometric data set. The varimax orthogonal rotation method[17] was used.
- Ward's method was performed for each gender.

Body shape analyses of large persons in South Korea

Male dataset results

Five factors were identified, which collectively accounted for 81.53% of the total variance.

Female dataset results

Three factors were identified, which collectively accounted for 74.10% of the total variance.

Figure: *Korean males.*

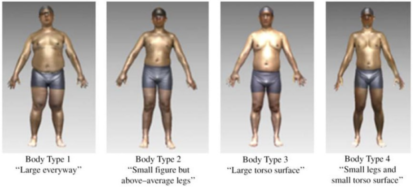


Figure: *Korean females.*

K-Medoids algorithm

PAM

A medoid is the most central representative of a class.
It minimises the distance between the points of the class and the medoid.
The PAM[18] algorithm is based on finding k medoids among the observations in the dataset.

- After finding a set of k medoids, clusters are constructed by assigning each observation to the closest medoid.
- If the sum of dissimilarities of all objects with their closest medoid can be reduced by swapping a selected object (medoid) with a non-selected object, then a swap is performed.
- This is continued until the sum of dissimilarities cannot be reduced any further.

Hierarchical clustering algorithm

Ward's Method

Ward[13]'s minimum variance criterion minimises the total variance within clusters.
At each step, the pair of clusters that results in a minimum increase in total variance within the cluster after merging must be found.
The Euclidean distance between the factor score vectors of two individuals was used as a measure of dissimilarity.

Finding the optimal number of clusters

Number of clusters

For the same dataset, there are many possible partitionings[19]. It is therefore necessary to choose the most relevant number of clusters K to highlight the interesting patterns. Unfortunately, there is no automatic procedure for this.

Finding the optimal number of clusters

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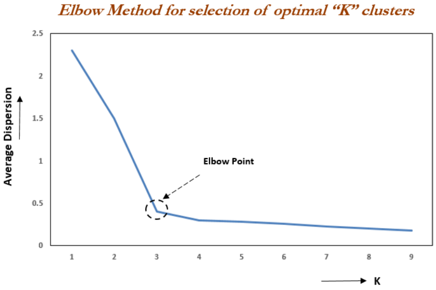
Choice of the method

Most of the indices account for both the separation and the compactness of clusters.[19]
Therefore, we will use the elbow method.

Finding the optimal number of clusters

Elbow method

Empirical method that consists of running the clustering algorithm with different K values, calculating the variance between the clusters, and then placing the different numbers of K clusters according to the variance on a graph.



[20]

Database

ANSUR II

Data from the Anthropometric Survey of U.S. Army Personnel[21]

- published internally in 2012
- made available to the public in 2017
- include 93 measurements for over 6,000 US military adults
  - 4,082 men
  - 1,986 women

Data sets preparation

Data selection

We decide to keep only 14 torso and thigh measurements.

Measurements

- bicristal breadth
- buttock circumference
- buttock depth
- chest breadth
- chest circumference
- chest depth
- hip breadth
- lower thigh circumference
- shoulder circumference
- thigh circumference
- vertical trunk circumference
- waist breadth
- waist circumference
- waist depth.

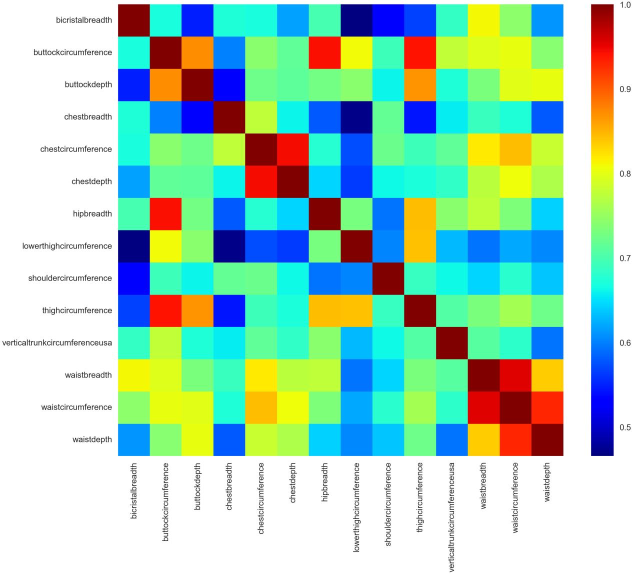
Results

We present the results we have obtained but, due to time constraints, we have not had time to discuss them.

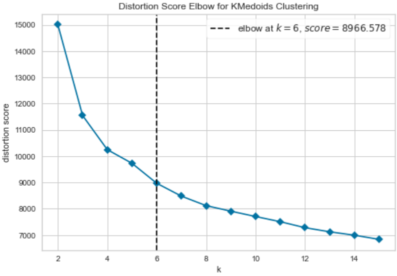
Female data set

Age	Height (cm)	Weight (kg)	BMI	*Count*
28.94	164.09	66.91	24.82	*1986*

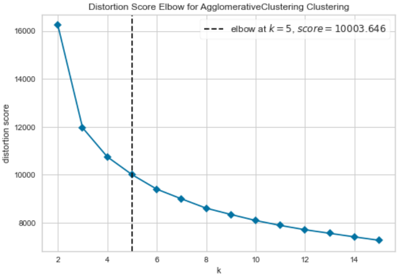
Correlation matrix



Elbow method



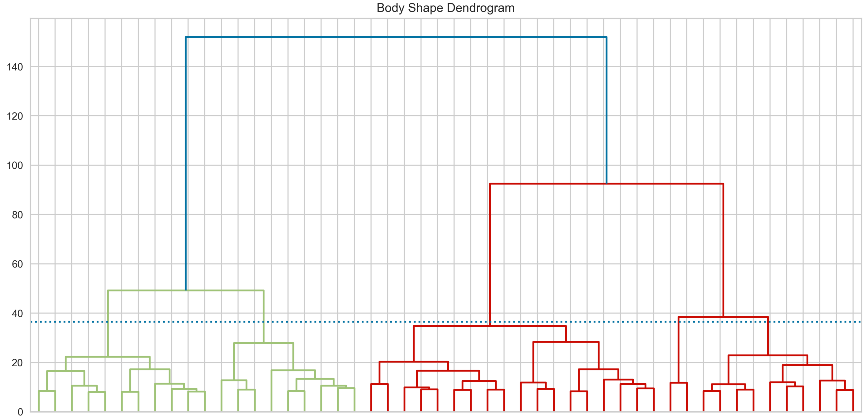
We choose a number of clusters $k = 6$ for the K-Medoids.



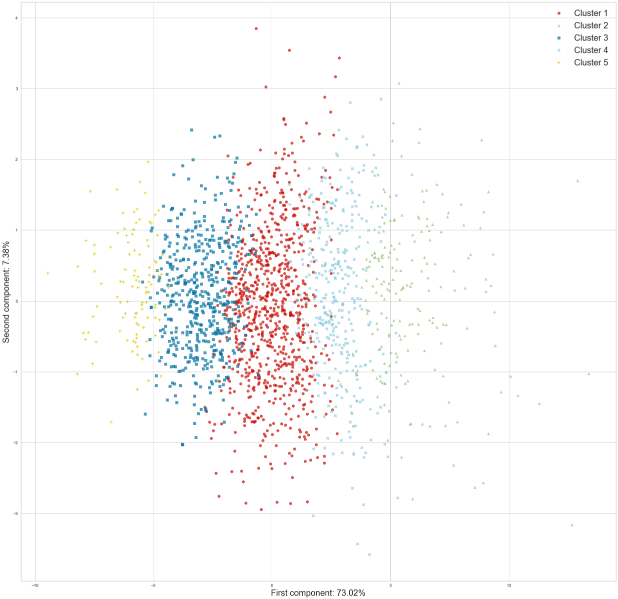
We choose a number of clusters $k = 5$ for the Ward's method.

K-Medoids Clusters

Female Ward's Method Dendrogram



Female Ward's Method Clusters



Female K-Medoids Medoids

	Cluster					
	1	**2**	**3**	**4**	**5**	**6**
Bicristal breadth	270	278	261	260	299	292
Buttock circumference	970	1016	917	1015	1136	1076
Buttock depth	216	235	193	233	280	251
Chest breadth	258	281	248	255	295	270
Chest circumference	892	962	866	906	1069	998
Chest depth	227	253	225	237	287	267
Hip breadth	340	357	322	344	387	366
Lower thigh circumference	395	402	351	398	443	534
Shoulder circumference	993	1035	965	1035	1075	1035
Thigh circumference	588	623	545	606	702	663
Vertical trunk circumference	1519	1581	1477	1553	1639	1594
Waist breadth	272	316	268	276	357	324
Waist circumference	807	886	731	824	1028	933
Waist depth	203	212	176	199	269	232
Height (cm)	160.02	167.64	160.02	170.18	165.10	162.56
Weight (kg)	63.50	65.32	56.70	70.31	81.65	73.94
BMI	24.80	23.24	22.14	24.28	29.95	27.98

Female K-Medoids Centroids

	Cluster					
	1	**2**	**3**	**4**	**5**	**6**
Bicristal breadth	264.87	279.85	250.56	257.97	304.40	285.79
Buttock circumference	971.19	1025.85	913.16	1015.66	1140.41	1086.44
Buttock depth	215.91	231.80	201.88	233.22	271.63	252.97
Chest breadth	260.40	278.94	248.44	259.82	294.71	275.44
Chest circumference	892.16	972.16	845.13	913.87	1084.39	995.67
Chest depth	229.04	254.31	215.36	239.00	290.64	263.69
Hip breadth	338.80	357.38	318.61	349.07	391.98	374.09
Lower thigh circumference	383.46	399.40	357.00	402.33	446.39	426.38
Shoulder circumference	995.66	1040.72	962.36	1027.85	1102.64	1053.20
Thigh circumference	581.25	617.04	538.02	616.74	698.05	663.93
Vertical trunk circumference	1512.24	1576.08	1469.05	1542.88	1667.78	1607.07
Waist breadth	281.69	308.71	257.91	282.77	354.14	322.38
Waist circumference	801.46	881.72	730.60	817.72	1031.28	932.32
Waist depth	194.05	215.56	177.07	202.71	265.71	234.44
Age	26.64	29.04	26.67	27.81	33.14	31.38
Height (cm)	161.81	164.86	160.23	164.78	168.53	166.29
Weight (kg)	59.84	67.86	53.18	65.50	81.79	74.39
BMI	22.90	25.02	20.75	24.20	29.82	27.30
Count	*360*	*452*	*299*	*301*	*232*	*342*

Female Hierarchical Medoids

	Cluster				
	1	**2**	**3**	**4**	**5**
Bicristal breadth	271	299	253	292	232
Buttock circumference	1011	1136	981	1076	876
Buttock depth	236	280	217	251	201
Chest breadth	274	295	251	270	241
Chest circumference	926	1069	872	998	808
Chest depth	245	287	221	267	199
Hip breadth	346	387	328	366	306
Lower thigh circumference	408	443	375	435	360
Shoulder circumference	1013	1075	990	1035	934
Thigh circumference	635	702	576	663	510
Vertical trunk circumference	1604	1639	1526	1594	1411
Waist breadth	288	357	273	324	241
Waist circumference	847	1028	751	933	694
Waist depth	213	269	180	232	168
Height (cm)	162.56	165.10	165.10	162.56	147.32
Weight (kg)	68.04	81.65	58.06	73.94	46.72
BMI	24.96	29.95	21.30	27.98	21.53

Female Hierarchical Centroids

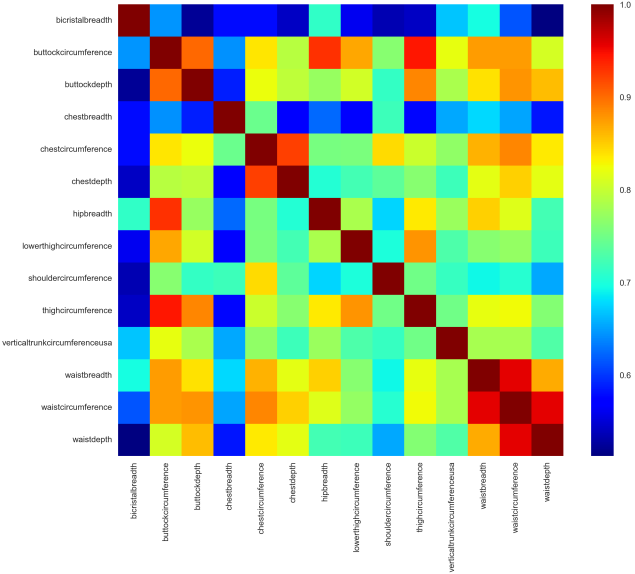
	Cluster				
	1	**2**	**3**	**4**	**5**
Bicristal breadth	272.00	304.44	258.05	290.10	241.75
Buttock circumference	1023.85	1145.92	953.31	1083.18	883.93
Buttock depth	232.58	274.36	212.08	251.15	196.41
Chest breadth	269.94	293.10	256.20	281.37	242.37
Chest circumference	943.96	1084.66	878.83	1011.03	821.18
Chest depth	246.12	292.01	226.07	267.25	209.18
Hip breadth	355.12	393.09	332.02	373.99	306.83
Lower thigh circumference	403.12	449.87	374.27	420.94	347.40
Shoulder circumference	1029.85	1107.76	989.31	1062.31	942.58
Thigh circumference	618.78	703.84	568.17	658.48	518.18
Vertical trunk circumference	1558.54	1669.85	1502.72	1615.76	1441.26
Waist breadth	298.75	355.29	272.37	327.45	244.24
Waist circumference	856.81	1036.32	773.93	945.45	696.40
Waist depth	210.79	268.05	187.36	236.94	169.92
Age	28.71	32.90	26.76	31.36	25.73
Height (cm)	164.20	168.69	162,07	166,04	157.72
Weight (kg)	66.66	85.16	58.00	75.04	49.88
BMI	24.78	30.00	22.13	27.26	20.09
Count	*831*	*200*	*503*	*347*	*105*

Male data set

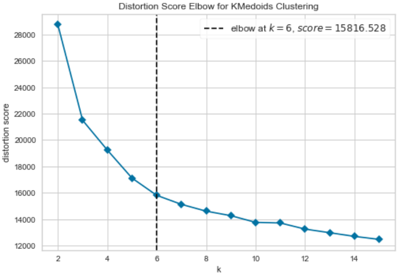
Male data set

Age	Height (cm)	Weight (kg)	BMI	*Count*
30.16	177.89	85.28	26.93	*4082*

Correlation matrix



Elbow method



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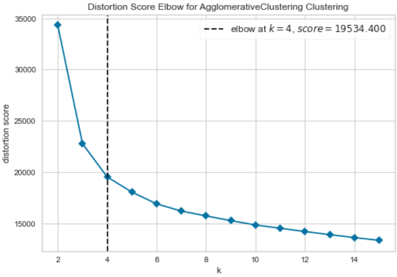
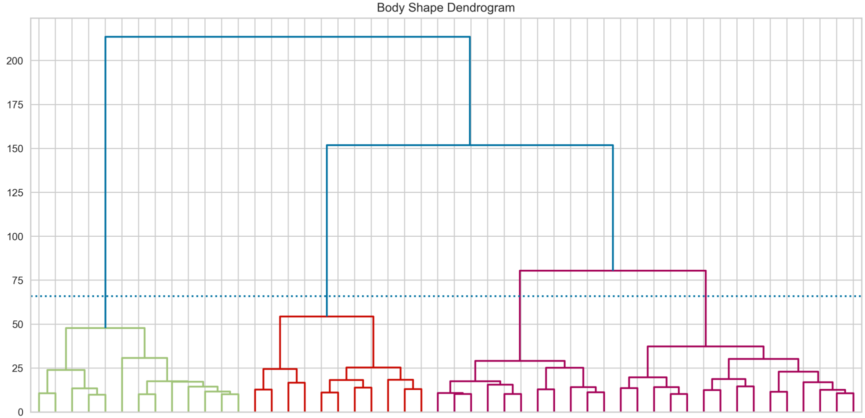


We choose a number of clusters $k = 4$ for the Ward's method.

K-Medoids Clusters

Male Ward's Method Dendrogram



Male Ward's Method Clusters

Male K-Medoids Medoids

	Cluster					
	1	**2**	**3**	**4**	**5**	**6**
Bicristal breadth	275	252	263	293	301	269
Buttock circumference	1004	1073	916	1097	1178	959
Buttock depth	242	251	214	267	293	220
Chest breadth	288	298	263	300	316	278
Chest circumference	1026	1100	940	1145	1237	996
Chest depth	241	266	224	276	304	238
Hip breadth	345	362	317	373	396	331
Lower thigh circumference	403	437	376	443	460	379
Shoulder circumference	1173	1190	1082	1245	1255	1140
Thigh circumference	613	653	553	679	730	587
Vertical trunk circumference	1657	1682	1559	1742	1813	1604
Waist breadth	322	362	285	367	402	308
Waist circumference	902	1012	784	1078	1167	860
Waist depth	220	255	199	270	306	212
Height (cm)	175.26	185.42	172.72	177.80	175.26	170.18
Weight (kg)	79.38	96.62	70.31	97.52	79.38	67.13
BMI	25.84	28.10	23.56	30.85	33.75	24.75

Male K-Medoids Centroids

	Cluster					
	1	**2**	**3**	**4**	**5**	**6**
Bicristal breadth	258.85	289.87	301.60	276.16	274.10	260.88
Buttock circumference	888.46	1097.33	1175.34	1042.16	1002.36	947.35
Buttock depth	203.21	270.81	297.09	256.19	238.10	222.51
Chest breadth	266.54	304.60	315.88	292.76	287.50	284.67
Chest circumference	916.22	1143.49	1224.53	1096.04	1033.34	977.17
Chest depth	212.10	277.48	300.32	266.28	245.60	231.38
Hip breadth	310.12	369.20	392.81	350.47	341.45	323.36
Lower thigh circumference	356.46	437.62	467.97	418.71	402.94	383.29
Shoulder circumference	1080.04	1235.39	1284.64	1196.08	1166.80	1125.71
Thigh circumference	521.68	679.03	737.53	643.89	613.09	575.66
Vertical trunk circumference	1532.31	1749.64	1821.66	1686.94	1650.50	1582.26
Waist breadth	272.79	361.23	394.14	339.52	317.06	292.08
Waist circumference	764.56	1051.71	1162.59	987.48	905.36	833.12
Waist depth	188.54	269.77	305.78	252.28	225.12	207.64
Age	30.49	32.70	25.43	32.74	31.47	26.80
Height (cm)	174.67	180.69	183.11	177.06	178.46	174.84
Weight (kg)	64.28	98.97	113.35	89.00	81.57	72.89
BMI	26.12	28.63	22.18	31.20	33.79	24.04
Count	*1366*	*902*	*593*	*528*	*218*	*475*

Male Hierarchical Medoids

	Cluster			
	1	**2**	**3**	**4**
Bicristal breadth	288	261	275	282
Buttock circumference	1134	954	1004	1073
Buttock depth	278	224	242	251
Chest breadth	304	275	288	298
Chest circumference	1118	968	1026	1100
Chest depth	289	232	241	266
Hip breadth	383	318	345	362
Lower thigh circumference	459	382	403	437
Shoulder circumference	1234	1112	1173	1190
Thigh circumference	718	579	613	653
Vertical trunk circumference	1776	1561	1657	1682
Waist breadth	376	286	322	362
Waist circumference	1110	811	902	1012
Waist depth	286	204	220	255
Height (cm)	177.8	170.18	175.26	185.42
Weight (kg)	103.87	67.13	79.39	96.62
BMI	32.86	23.18	25.84	28.10

Male Hierarchical Centroids

	Cluster			
	1	**2**	**3**	**4**
Bicristal breadth	292.70	261.52	271.98	282.87
Buttock circumference	1130.19	931.38	1003.26	1056.97
Buttock depth	282.71	217.15	239.82	258.46
Chest breadth	306.17	272.56	288.38	297.21
Chest circumference	1172.70	958.13	1045.75	1103.14
Chest depth	286.56	225.26	249.70	266.93
Hip breadth	378.40	320.13	340.47	357.01
Lower thigh circumference	450.08	375.81	403.29	424.28
Shoulder circumference	1254.00	1113.15	1173.93	1200.74
Thigh circumference	705.53	560.26	615.02	650.81
Vertical trunk circumference	1779.18	1571.25	1648.97	1704.96
Waist breadth	374.05	287.00	318.79	345.34
Waist circumference	1097.06	813.05	915.67	999.87
Waist depth	285.36	201.73	229.35	253.85
Age	32.37	26.04	30.49	32.70
Height (cm)	181.10	175.18	177.73	178.68
Weight (kg)	104.33	70.31	82.31	91.23
BMI	31.95	23.01	26.12	28.63
Count	*746*	*1068*	*1366*	*902*

Conclusion

According to the state of the art and the results we have obtained, clustering methods seem to be adapted to the classification of human morphotypes. Among them, Ward's method associated with a principal component analysis seems to me to be the best.

In the near future, we will continue this study on a database representative of the French population.

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