Int J Legal Med (2017) 131:1123–1131
DOI 10.1007/s00414-016-1483-4

ORIGINAL ARTICLE

Metric assessment of ancestry from the vertebrae in South Africans

Özge Ünlütürk[1]

Received: 23 January 2016 / Accepted: 19 October 2016 / Published online: 7 November 2016

Abstract Ancestry estimation is one of the four basic steps for developing a biological profile. Research has shown that there are a certain amount of morphological and anthropometric differences among skeletons in populations. The aim of this study was to examine the Pretoria Bone Collection to analyze the ancestral variation in the vertebrae of the South African black and white population. The sample was composed of complete vertebrae from 144 individuals (73 whites, 71 blacks). Ancestry differences were assessed using the discriminant function procedure. Regarding the results of this study, when vertebral columns were evaluated, the data indicated (with high reliability) a difference between the two ancestries. The analysis provided an accuracy rate of 98 % in males and 93.5 % in females. Compared to skeleton pieces such as the skull and the pelvis, which have been studied often with high reliability results, these rates are highly significant.

Keywords Forensic science · Forensic anthropology · Ancestry · Vertebrae · Discriminant function analysis · Anthropometric measurements

Introduction

Estimation of ancestry is one of the basic steps for identification in forensic anthropology. Forensic identification is a two-stage process. The first stage includes the developments in the biological profile of the individual; in the second stage, the positive matching attempt is in question. Ancestry estimation is one of the four basic steps for developing biological profile in addition to identification of age, stature, and sex [1]. This process also enables the list of missing individuals to be narrowed by virtue of comparing skeletal remains with dental records, medical records, and other data [2].

Research has shown that there are a certain amount of morphological and anthropological differences among skeletons in local populations. In this context, the area with the most focus has been the skull. Many studies conducted in both metric [3–5] and non-metric [6–9] have proven that there are clear, distinctive osteologic, and morphologic characteristics on the skull. In addition, the skull and teeth are also studied [10–13], and many studies involve examination of the femur and pelvis for ancestry differentiation. One of the reasons for the focus on the femur is the fact that it was discovered that the femur anterior curvature differentiates between ancestries, and studies concentrated on this point [14–17]. The pelvis is one of the bones that have interracial distinctive characteristics, and it is one of the areas that have been preferred in postcranial studies [18–21]. The vertebrae are among the least studied bones [1].

When bones are found as a whole at a crime scene, accurate detections can be made easily. In the contrary cases, the process both takes longer and grows more difficult. Because of the environmental conditions of the scene, damaged caused by animals, or careless investigation of the scene, not all of the pieces of the skeleton which is found buried are reached, and, even if they are, the bones may be seriously damaged [22–24]. In such frequent cases, identification must be made from only the deficient and damaged pieces. In these circumstances, it is thought that, due to the fact that the vertebrae are large in number and small in size, there may be some ease in identification [25]. However, the vertebrae that have distinctive features are

✉ Özge Ünlütürk
ozgeunluturk@gmail.com

[1] Council of Forensic Medicine, Yenibosna, ÇobançeşmeMah., Bahçelievler, 34196 Istanbul, Turkey

important, because they show similar morphological features regardless of the fact that they are many in number.

By their structure and number, the vertebrae may hold significant information about the deceased. For instance, certain diseases and fractures such as scoliosis and tuberculosis leave permanent marks on the vertebra [26]. In addition, these bones, which constitute the vertebral column, have the potential to provide clues as to the body structure or even the profession of the individual [26–28].

The aim of this study was to examine the Pretoria Bone Collection to analyze the ancestral variation in the vertebrae of the South African black and white population. Studies of ancestry were mostly conducted over the bone collections whose demographical characteristics were known. South Africa consists mostly of European white and African black populations who have been genetically isolated from their ancestors, and this requires a specific demographical analysis of the population [29]. The collection consists of donors and socioeconomically restricted individuals.

The materials and the methods

In this study, the cervical, thoracic, and lumbar vertebrae and sacrum of 144 people from the Pretoria Bone Collection were used in total, with 37 of these being white males, 36 white females, 35 black males, and 36 black females. The initial plan was to take measurements from the entire vertebral column except for the atlas and axis. However, since all of the bones of the vertebral column of each measured skeleton do not exist, or the trauma on the existing bones did not allow a measurement, the number of samples decreased, and this led to missing data. While all the skeletons that consist of all the vertebral column bones were included in the study, the vertebral column was divided into three groups as the cervical, thoracic, and lumbar in order to increase the number of samples, and it was regarded that the bones of the chosen samples were complete at least in one group. The ages of the individuals ranged from 22 to 65 years in blacks, and from 28 to 86 years in whites. The Pretoria Bone Collection consists of more than 1000 human skeleton remains, which were included in the collection after being used in anatomical dissection. All of the demographical data of the skeletons such as age, sex, ancestry, and cause of death were present [29, 30].

In this study, data gathered from the vertebral column and sacrum were used. On average, seven dimensions were taken from the vertebrae in between cervical 3 (C3) and lumbar 5 (L5), and six dimensions from the sacrum. Because cervical 1 (atlas) and cervical 2 (axis) are morphologically different from the other vertebrae, they were not included in the study.

The dimensions of the vertebrae used in the study:

1. Anterior height (anth) was taken from between the highest and the lowest points of the anterior surface of the corpus.
2. Posterior height (posth) was recorded in the same way as anterior height, but this dimension was taken from the inner side of the spinal canal.
3. Superior and inferior transverse breadth (suptrbr and inftrbr) were recorded from between the farthest points on the superior and inferior surfaces of the body.
4. Middle transverse breadth (midtrbr) was taken from the largest middle part of the body periphery.
5. Inferior and superior anteroposterior diameter (infap and supap) were recorded from the middle points of the anterior-posterior direction of the surface.

The dimensions of the sacrum used in the study:

- Sacrum segment count (*n* of sacrum): the number of segments in the sacrum.
- Bialare: the distance between the two wings (*ala ossis sacri*) that encompass the surfaces of the sacroiliac joint of the sacrum.
- S1 superior anterior-posterior diameter (S1 supap): the dimensions of diameter in the direction of anterior to posterior of the corpus of the vertebra, which is located in the superior surface of the sacrum.
- S1 superior transverse breadth (S1 suptrbr): the dimensions that were taken from the broadest area of the vertebral corpus, which is located on the superior surface of the sacrum.
- Sacral anterior height (sacanth): the height from the anterior facet of the vertebra, which is located on the superior surface of the sacrum, to its articulation point with the coccyx below.
- Sacral posterior height (sacposth): the height from the posterior facet of the vertebra, which is located on the superior surface of the sacrum, to its articulation point with the coccyx below.

In spite of the fact that the individuals with complete sets of bones of the vertebral column were included in the study, the bones that had undergone intense trauma and pathological bones were not included. A digital caliper with a sensitivity of 0.01 mm was used for taking dimensions. Measurements were made from the outer periphery of the annular epiphysis on the superior and inferior surfaces, and dimensions were taken in the same way from all of the vertebrae. Measurement could not be made from the synostosis vertebrae due to the presence of osteophytes. In addition, adjoined spines were discovered in three skeletons, and the dimensions of these bones were taken together with the adjoined vertebrae.

Due to the morphological structure of the vertebral corpus, the middle transverse breadth dimensions were not taken from the cervical column and the L5. At the points where osteophytes were seen, the height dimensions were moved out of the center of measurement to points where there were less osteophytes and where there would be less deviation from the real dimensions. With the bones that had osteophytes, superior and inferior dimensions were taken from inside the osteophytes but from the outmost circumference of the annular epiphysis. Due to osteophyte on the superior-anterior surface, anterior height measurement was shifted to the right of the central axis. Fractures were frequently observed at the articulation point with the coccyx, and, because anterior and posterior heights could not be taken, these bones were kept out of the study.

The data was analyzed with the use of SPSS.21 statistics software. Student's *t* test was used to define the metrical relevance between the two populations. To detect the value that provided the best inter-ancestral discrimination, the stepwise method was used, and a discriminant function analysis was performed. Discriminant function formulas were generated by determining the sectioning points with tables, and the accuracy rates for the estimations were defined as percentages.

Results

The *t* test, which evaluated the statistical relevance ($p < 0.05$) of the difference between the two groups by comparing their average, was applied to each vertebral group and sacrum. When the averages were considered for males, all of the dimensions were larger in whites compared to blacks. For females, all of the dimensions except for C3 and C4 inferior anteroposterior diameter, C3, C4, and T1 superior anteroposterior diameter, T3 anterior height, T9 middle transverse breadth, and L2 posterior height seemed to be larger in whites compared to blacks. Also, each vertebral group was investigated separately; the vertebrae that were most recognizable regarding their position on the skeleton and their morphological structures (C7, T1, T12, and L5) were evaluated one by one. From the identifiable vertebrae, it was seen that C7 inferior anteroposterior diameter and T1 superior anteroposterior diameter were smaller in size only in white females in comparison to black ones, and that all the other measurements for both sexes were bigger in whites in proportion to blacks (Table 1).

Table 2 shows the measurements for the two ancestries chosen with stepwise method and F-ratios taken as a result of two-way ANOVA statistics. In assessment, each vertebral group (the cervical, thoracic, and lumbar) was examined separately. In ancestry determination for each group, the dimensions with the highest discriminative power were chosen with the stepwise method. For instance, in cervical for males, three dimensions including C3 posterior height, C7 superior transverse breadth, and C3 superior anteroposterior diameter were chosen to determine the ancestry. When the stepwise method was applied on C7, T1, T12, and L5, which are called the recognizable vertebrae, it was seen that C7 was left out of the statistics and five dimensions from the three other vertebrae in males were counted, and, in females, at least one dimension was taken from each one of them.

Table 3 shows the unstandardized discriminant function coefficient and sectioning point for determining the ancestry with the dimensions chosen with the stepwise method. The sectioning point is located by averaging the centroid. These parameters were used to calculate the discriminant function score. If the score was larger than the sectioning point, the remnant bone would be classified as white; otherwise, it would be classified as black. The discriminant function score was calculated with the formula $Y_{(\text{ancestry})} = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n$ for ancestry determination.

For instance, if the dimensions taken from the cervical of subject 47 were used:

C3 posterior height (C3 posth): 13.96 mm with a coefficient of 1.036 mm
C3 superior anteroposterior diameter (C3 supap): 17.46 mm with a coefficient of −0.344 mm
C7 superior transverse breadth (C3 suptrbr): 30.51 mm with a coefficient of 0.316 mm
Constant: −17.269

When the dimensions and the parameters were applied to the formula:

$$Y_{(\text{ancestry})} = \text{constant} + (\text{C3 posth}) \times (\text{associated coefficient}) + (\text{C3 supap}) \times (\text{associated coefficient}) + (\text{C3 suptrbr}) \times (\text{associated coefficient})$$

$$Y_{(\text{ancestry})} = (-17.269) + (13.96 \times 1.036) + (17.46 \times -0.344) + (30.51 \times 0.316)$$

$$Y_{(\text{ancestry})} = (-17.269) + (14.470) + (-6.006) + (9.641)$$

$$\text{Discriminant function score} = 0.836$$

As the score is larger than the sectioning point, the individual is determined to be white.

Accuracy in classification and cross-validation percentages are shown in Table 4. It is clear that accuracy was higher in blacks than in whites. This difference was higher in females especially. Only the rate in the cervical vertebrae of white males was higher compared to black males. The accuracy rate was 100 % with both black males and black females when the thoracic vertebrae were used. Additionally, thoracic vertebrae gave the best results for both ancestries among other vertebral groups. The credible results were 96.8 % for males and 96.6 % for females. Evaluations from the sacrum gave out a low accuracy rate especially in whites compared to others. The best determination rates for both males (96.8 %) and females (96.6 %) were found when the thoracic vertebrae

Table 1 Descriptive statistic of recognizable vertebrae dimensions (mm) in male and female South African whites and blacks and *t* test of significant between means

	Male								Female							
	White			Black			*t* test for equality of means		White			Black			*t* test for equality of means	
	N	Mean	Std. D.	*N*	Mean	Std. D.	*t*	df	*N*	Mean	Std. D.	*N*	Mean	Std. D.	*t*	df
Cervical 7																
C7 anth	33	14.84	1.28	34	14.17	1.10	2.21	65[a]	34	13.68	1.01	36	12.91	1.03	3.17	68[c]
C7 posth	33	15.48	1.09	34	14.14	0.97	5.31	65[c]	34	14.26	0.87	36	13.21	0.95	4.79	68[c]
C7 suptrbr	33	27.75	2.36	34	24.99	1.63	5.59	65[c]	34	25.87	2.17	36	23.79	1.96	4.21	68[c]
C7 inftrbr	37	28.19	2.27	35	27.19	1.95	2.00	70[a]	34	26.27	1.93	36	25.20	1.69	2.93	68[b]
C7 infap	37	17.76	1.81	35	16.16	1.26	4.33	70[c]	34	15.17	1.42	36	15.66	1.45	−1.43	68
C7 supap	33	18.47	2.02	34	16.49	1.34	4.74	65[c]	34	16.18	1.70	36	15.94	1.63	0.59	68
Thoracic 1																
T1 anth	36	16.59	1.20	35	16.10	1.17	1.74	69	36	15.47	1.11	35	14.63	0.89	3.51	69[c]
T1 posth	36	17.93	1.17	35	16.66	0.94	5.01	69[c]	36	16.37	0.90	35	15.08	0.84	6.29	69[c]
T1 suptrbr	36	28.15	2.34	35	27.26	1.75	1.82	69	36	26.18	2.27	36	25.10	2.06	2.09	70[a]
T1 midtrbr	36	29.81	3.37	35	25.69	2.74	6.42	69[c]	36	27.25	2.73	36	24.17	1.89	5.57	70[c]
T1 inftrbr	36	31.42	2.44	35	30.01	1.82	3.54	69[c]	36	29.17	2.43	35	27.57	1.50	3.31	69[c]
T1 infap	36	18.65	2.17	35	16.64	1.21	4.80	69[c]	36	16.16	1.35	35	16.03	1.19	0.42	69
T1 supap	36	17.92	1.85	35	16.24	1.18	4.56	69[c]	36	15.26	1.39	36	15.66	1.40	1.22	70
Thoracic 12																
T12 anth	33	24.35	2.16	35	23.35	1.32	2.31	66[a]	34	24.04	1.52	35	22.52	1.52	4.06	67[c]
T12 posth	33	27.61	1.78	35	25.16	1.54	6.09	66[c]	35	25.26	1.66	35	24.44	1.62	2.34	68[a]
T12 suptrbr	33	44.56	3.37	35	40.40	2.47	5.82	66[c]	35	38.79	2.57	35	37.75	2.21	1.81	68
T12 midtrbr	34	40.30	3.38	35	36.65	2.42	5.18	67[c]	36	35.75	2.60	35	33.65	3.02	2.97	69[c]
T12 inftrbr	34	46.60	3.66	35	43.54	3.03	3.80	67[c]	36	41.98	3.04	35	40.15	2.39	2.82	69[b]
T12 infap	34	32.98	3.53	35	28.22	1.88	7.03	67[c]	35	28.84	2.69	35	25.59	2.04	5.69	68
T12 supap	33	33.57	3.84	35	27.31	1.97	8.52	66[c]	36	28.74	2.85	35	25.43	2.18	5.48	69[c]
Lumbar 5																
L5 anth	35	29.26	2.11	35	26.60	1.78	5.70	68[c]	34	28.86	2.11	36	26.28	1.29	7.50	68[c]
L5 posth	35	24.98	2.04	35	23.27	1.88	3.64	68[c]	33	23.84	2.05	35	22.95	2.21	1.73	66
L5 suptrbr	35	53.31	5.68	35	51.60	3.74	2.64	68[c]	35	49.29	4.14	36	49.03	2.77	1.06	69
L5 midtrbr	35	51.84	4.44	35	47.22	3.14	5.02	68[c]	35	48.30	3.78	35	43.95	3.51	4.99	68[c]
L5 inftrbr	35	54.77	4.72	35	50.32	3.82	4.34	68[c]	32	49.55	3.48	35	46.78	4.02	3.00	65[c]
L5 infap	35	35.44	3.15	35	33.65	2.40	2.66	68[b]	32	31.36	2.57	35	31.23	3.02	−0.30	65
L5 supap	35	36.36	3.50	35	34.03	2.58	3.16	68[c]	35	31.94	2.20	36	31.82	2.32	0.23	69

[a] Significance $p > 0.01 < 0.05$

[b] Significance $p = 0.01$

[c] Significance $p < 0.01$

were used. When the recognizable vertebrae were evaluated, highly credible results—such as 95.5 % for males and 98.5 % for females—were reached. Prediction accuracy of ancestral identification in the vertebrae without sex is shown in Table 5. In this circumstance as well, prediction accuracy for blacks was higher than whites. The highest prediction accuracy was given by the thoracic vertebrae in both ancestries. The lowest accuracy rate for both ancestries was taken by sacral predictions (77.8 % in whites, 88.2 % in blacks). The vertebrae, which are recognizable morphologically, allowed ancestral identification predictions without knowledge of sex: 91.8 % for whites and 92.8 % for blacks. Here, the difference between the sample numbers on Tables 1 and 4 remarks. In the *t* test analysis on Table 1, the measures taken from each sample are evaluated one by one. However, since the vertebrae are evaluated as groups such as the cervical,

Table 2 Stepwise discriminant function analysis of vertebral dimensions for white and black South African males and females

Males						Females					
Step	Entered/removed	Wilks'	Exact *F*	df	Sig.*	Step	Entered/removed	Wilks'	Exact *F*	df	Sig.*
Function 1 (cervical)											
1	C3 posth	0.478	54.69	1.50	0.00	1	C6 suptrbr	0.636	29.80	1.52	0.00
2	C7 suptrbr	0.397	37.20	2.49	0.00	2	C3 infap	0.556	20.35	2.51	0.00
3	C3 supap	0.362	28.25	3.48	0.00	3	C7 supap	0.452	20.24	3.50	0.00
						4	C4 supap	0.358	21.99	4.49	0.00
						5	C5 infap	3.180	20.54	5.48	0.00
Function 2 (thoracic)											
1	T2 midtrbr	0.376	84.58	1.51	0.00	1	T6 infap	0.536	40.62	1.47	0.00
2	T3 suptrbr	0.304	57.16	2.50	0.00	2	T2 supap	0.391	35.85	2.46	0.00
3	T10 supap	0.245	50.24	3.49	0.00	3	T1 midtrbr	0.326	31.00	3.45	0.00
4	T3 posth	0.204	46.86	4.48	0.00	4	T12 suptrbr	0.260	31.25	4.44	0.00
5	T5 supap	0.183	42.04	5.47	0.00	5	T4 posth	0.218	30.79	5.43	0.00
6	T12 posth	0.163	39.25	6.46	0.00	6	T10 inftrbr	0.187	30.40	6.42	0.00
7	T9 supap	0.146	37.71	7.45	0.00	7	T3 inftrbr	0.165	29.64	7.41	0.00
8	T10 supap/R**	0.149	43.66	6.46	0.00	8	T11 suptrbr	0.144	29.64	8.40	0.00
9	T10 anth	0.133	41.78	7.45	0.00	9	T5 supap	0.127	29.78	9.39	0.00
10	T5 anth	0.121	39.86	8.44	0.00	10	T5 anth	0.113	29.97	10.38	0.00
11	T5 posth	0.106	40.36	9.43	0.00						
Function 3 (lumbar)											
1	L4 anth	0.600	35.37	1.53	0.00	1	L5 anth	0.606	34.47	1.53	0.00
2	L1 supap	0.507	25.24	2.52	0.00	2	L5 midtrbr	0.530	23.09	2.52	0.00
3	L5 infap	0.424	23.08	3.51	0.00	3	L5 supap	0.433	22.23	3.51	0.00
4	L3 anth	0.383	20.14	4.50	0.00	4	L1 supap	0.306	28.31	4.50	0.00
5	L4 anth/R**	0.385	27.12	3.51	0.00	5	L4 suptrbr	0.277	25.62	5.49	0.00
6	L5 inftrbr	0.346	23.65	4.50	0.00	6	L3 supap	0.250	23.94	6.48	0.00
7	L5 anth	0.306	22.20	5.49	0.00						
Function 4 (Sacrum)											
1	Bialare	0.591	36.65	1.53	0.00	1	Bialare	0.706	17.05	1.41	0.00
2	Sacposth	0.535	22.56	2.52	0.00						
3	Sacanth	0.405	24.99	3.51	0.00						
Function 5 (recognizable vertebrae)											
1	T12 supap	0.487	60.98	1.58	0.00	1	L5 anth	0.535	52.10	1.60	0.00
2	L5 infap	0.390	44.65	2.57	0.00	2	C7 infap	0.462	34.29	2.59	0.00
3	T1 midtrbr	0.301	43.29	3.56	0.00	3	L5 midrtrbr	0.366	33.51	3.58	0.00
4	T12 infap	0.265	38.05	4.55	0.00	4	T12 infap	0.322	30.01	4.57	0.00
5	T12 inftrbr	0.241	33.92	5.54	0.00	5	L5 supap	0.322	32.87	5.56	0.00
						6	T1 infap	0.235	29.76	6.55	0.00
						7	L5 suptrbr	0.216	27.96	7.54	0.00

*All values are significant ($p = 0.00$)

** *R* removed

thoracic, lumbar, sacrum, and recognizable vertebrae, the vertebrae with missing measures have been held out of evaluation as missing data. Therefore, a difference exists the number of samples between the tables, and the number *N* looks less in Table 4 compared to Table 1.

Discussion

For ancestry estimation based on anthropometric dimensions, many studies, especially those done on the skull and the pelvis, have proven these differences [4, 31, 32].

Table 3 Canonical discriminant function coefficients for vertebral dimensions of white and black South African males and females

Males				Females			
Function & variable	Standardized coefficient	Unstandardized coefficient	Centroid	Function & variable	Standardized coefficient	Unstandardized coefficient	Centroid
Function 1 (cervical)							
C3 posth	0.910	1.036	W = 1.354	C3 infap	−1.848	−1.270	W = 1.800
C3 supap	−0.424	−0.344	B = −1.254	C4 supap	1.310	0.923	B = −1.145
C7 suptrbr	0.607	0.316		C5 infap	−0.815	−0.480	
				C6 suptrbr	0.842	0.494	
				C7 supap	1.224	0.860	
(Constant)		−17.269		(Constant)		−11.456	
Sectioning point		0.100		Sectioning point		0.328	
Function 2 (thoracic)							
T2 midtrbr	1.697	−0.447	W = 3.384	T1 midtrbr	0.533	1.040	W = 3.047
T3 posth	−0.761	0.479	B = −2.402	T2 supap	0.795	−0.731	B = −2.483
T3 suptrbr	−0.949	0.977		T3 inftrbr	0.585	−0.651	
T5 anth	0.918	−0.574		T4 posth	−0.995	0.274	
T5 posth	−0.993	−0.543		T5 anth	−0.617	−0.704	
T5 supap	−0.696	0.553		T5 supap	0.527	−0.388	
T9 supap	1.417	−0.684		T6 infap	0.864	0.450	
T10 anth	−0.740	−0.355		T10 inftrbr	2.157	0.367	
T12 posth	0.802	0.627		T11 suptrbr	−1.523	0.519	
				T12 suptrbr	−1.476	0.502	
(Constant)		−11.013		(Constant)		−8.295	
Sectioning point		0.491		Sectioning point		0.282	
Function 3 (lumbar)							
L1 supap	1.327	0.568	W = 1.743	L1 supap	0.674	0.282	W = 1.930
L3 anth	1.131	0.591	B = −1.253	L3 supap	0.575	0.342	B = −1.494
L5 anth	−0.649	−0.329		L4 suptrbr	0.835	−0.239	
L5 inftrbr	0.704	−0.615		L5 anth	−0.694	0.376	
L5 infap	−1.688	0.165		L5 midtrbr	0.855	0.223	
				L5 supap	−1.391	−0.592	
(Constant)		−11.857		(Constant)		−8.592	
Sectioning point		0.245		Sectioning point		0.218	
Function 4 (sacrum)							
Bialare	0.344	0.043	W = 1.404	bialare	1.000	0.128	W = 0.742
Sacanth	−1.925	−0.165	B = −1.009				B = −0.534
Sacposth	2.272	0.209					
(Constant)		−10.189		(Constant)		−14.008	
Sectioning point		0.198		Sectioning point		0.104	
Function 5 (recognizable vertebrae)							
T12 supap	2.646	0.897	W = 1.933	L5 anth	0.561	0.368	W = 1.998
L5 infap	−0.930	−0.321	B = −1.524	C7 infap	−1.006	−0.696	B = −1.756
T1 midtrbr	0.706	0.262		L5 midrtrbr	0.976	0.258	
T12 infap	−1.161	−0.414		T12 infap	0.937	0.386	
T12 inftrbr	−0.570	−0.166		L5 supap	−0.831	−0.357	
				T1 infap	0.630	0.499	
				L5 suptrbr	−0.507	−0.151	
(Constant)		−3.027		(Constant)		−11.018	
Sectioning point		0.205		Sectioning point		0.121	

A portion of these studies are anthropometric, and some others are morphological.

In this study, the bone collection of the University of Pretoria was used. In the 16th century, when the Afrikaans migrated from Europe, South Africa was one of the most isolated areas in the world [33]. White South Africans, who had migrated from Holland, France, Germany, the UK, and Portugal named themselves Afrikaans. Different studies show that white South Africans are osteologically different from the European and American populations [29, 34]. This study represents the whites who migrated from Europe and the local black population of South Africa, and the samples are specific

Table 4 Prediction accuracy of ancestral identification in the vertebrae

	Males					Females				
	White *n/N*[a]	%	Black *n/N*	%	% total	White *n/N*[a]	%	Black *n/N*	%	% total
Cervical										
Original	24/27	88.9	26/30	86.7	87.7	21/24	87.5	32/33	97.0	93.0
Cross-validated	22/27	81.5	26/30	86.7	84.2	21/24	87.5	31/33	93.9	91.2
Thoracic										
Original	27/29	93.1	34/34	100.0	96.8	24/26	92.3	32/32	100.0	96.6
Cross-validated	27/29	93.1	34/34	100.0	96.8	25/26	96.2	32/32	100.0	98.3
Lumbar										
Original	31/37	83.8	34/35	97.1	90.3	33/36	91.7	34/36	94.4	93.1
Cross-validated	30/37	81.1	33/35	94.3	87.5	32/36	88.9	34/36	94.4	91.7
Sacrum										
Original	27/37	73.0	32/35	91.4	81.9	24/36	66.7	33/36	91.7	79.2
Cross-validated	26/37	70.3	30/35	91.7	77.8	24/36	66.7	33/36	91.7	79.2
Recognizable vertebrae										
Original	29/31	93.5	34/35	97.1	95.5	31/32	96.9	33/33	100.0	98.5
Cross-validated	26/31	83.9	34/35	97.1	90.9	31/32	96.9	32/33	97.0	96.9

[a] *n/N*: the number of males and females, defined via the total number of males or females

to this population. Studies must make use of similar methods for different populations in order to determine the worldwide ancestry differences of anthropometric measurements, particularly those of the vertebrae.

Regarding the results of this study, when vertebral columns of blacks and whites were evaluated, there seemed to be a difference (with high reliability) between the two ancestries. It is notable that this difference was apparent especially in males. When the stepwise method was applied to the dimensions of the recognizable vertebrae, five dimensions for males, and seven dimensions for females were included in calculations. With the calculations done after the sectioning points were located and the discriminant function analysis was applied, in the thoracic vertebrae dimensions, the rates of ancestry determination were 96.8 % for males and 96.6 % for females. When the recognizable vertebrae were used, the rates were 95.5 % for males and 98.5 % for females. In recognizable vertebrae, this rate was 92.3 % average, without considering sex. Compared to skeleton parts which have been studied often and which have given out results with high reliability such as the skull and the pelvis, these rates are highly significant.

Table 5 Prediction accuracy of ancestral identification in the vertebrae without sex

	White *n/N*	%	Black *n/N*	%	% total
Cervical					
Original	41/48	85.4	56/61	91.8	89.0
Cross-validated	39/48	81.3	55/61	90.2	86.2
Thoracic					
Original	54/58	93.1	65/65	100.0	96.7
Cross-validated	53/58	91.4	63/65	100.0	94.3
Lumbar					
Original	50/56	89.3	60/65	92.3	90.9
Cross-validated	48/56	85.7	58/65	89.2	87.6
Sacrum					
Original	49/63	77.8	60/68	88.2	83.2
Cross-validated	48/63	76.2	60/68	88.2	82.4
Recognizable vertebrae					
Original	56/61	91.8	64/69	92.8	92.3
Cross-validated	53/61	86.9	64/69	92.8	90.0

When ancestral dimorphism is in question, morphological differences are quite typical, especially in the skull. Certain specific ancestral features do not fully develop in puberty. For this, sexual maturity needs to be reached. Kafatasından ancestry tayinine yönelik yapılan pek çok çalışma iki ırk arasında kafatasındaki belirgin morfolojik farkları ortaya koymuştur [31, 32, 35–37].

Ancestral differences were also seen in the mandible and teeth, though they were less salient in the postcranial skeleton. Only some of them could be seen in the femoral curvature. In studies conducted on blacks in America, it was detected that the femur anterior curvature was straighter. At the same time, studies have been conducted on cervical spinous processes in the vertebrae [1].

There have also been anthropometric studies on the pelvis, and reliable results have been reached. For instance, in the study conducted by Patriquin et al. (2002) on the South African population as to ancestry determination through studying the pelvis, when all of the 12 dimensions taken were used, it was seen that ancestry determination was possible with an accuracy rate of 88 % in males and 85 % in females [20].

Conclusion

In this study, the aim was ancestry determination by using vertebrae in different combinations. The results acquired suggest that the study has a high level of reliability. Because of the fact that it was difficult to find a complete vertebral column, the number of samples in the study was limited. Yet, studies conducted on different populations with larger sample groups should increase the level of reliability. Regarding the fact that the vertebrae were found at many in scenes, when various pieces of a skeleton were missing or damaged, they appeared to be notably useful materials for analysis. In the event that bones were dispersed or damaged, according to their morphological features, certain vertebrae could be distinguished, and their position on the column could be fixed. Under these circumstances, ancestry determination was possible only for four vertebrae. However, compared to the skull, the pelvis, and the long bones, the vertebrae are, so far, very rarely studied bones.

Acknowledgments This study was prepared by using the materials in the Pretoria Bone Collection with the permission of the Medical Faculty of the University of Pretoria. I would like to thank Prof. Maryna Steyn for providing access to the skeletal collection. I would also like to thank Prof. M. Yaşar İşcan, who provided his full support for my study to be completed.

References

1. Duray SM, Morter HB, Smith FJ (1999) Morphological variation in cervical spinous processes: potential applications in the forensic identification of race from the skeleton. J Forensic Sci 44(5):937–44
2. Sauer NJ (1992) Forensic anthropology and the concept of race: if races don't exist, why are forensic anthropologists so good at identifying them? Soc Sci Med 34(2):107–11
3. Birkby WH (1966) An evaluation of race and sex identification from cranial measurements. Am J Phys Anthropol 24(1):21–7
4. İşcan MY, Steyn M (1999) Craniometric determination of population affinity in South Africans. Int J Legal Med 112(2):91–7
5. Stull KE, Kenyhercz MW, L'Abbé EN (2014) Ancestry estimation in South Africa using craniometrics and geometric morphometrics. Forensic Sci Int 245C(206):e1-206.e7
6. Howells WW (1970) Multivariate analysis for the identification of race from the crania. In: Stewart TD (ed) Personal identification in mass disasters. National Museum of Natural History, Smithsonian Institution, Washington, pp 111–23
7. Snow CC, Hartman S, Giles E, Young FA (1979) Sex and race determination of crania by calipers and computer: a test of the Giles and Elliot discriminant functions in 52 forensic science cases. J Forensic Sci 24(2):448–60
8. Gill GW, Hughes SS, Bennett SM, Gilbert BM (1988) Racial identification from the midfacial skeleton with special reference to American Indians and whites. J Forensic Sci 33(1):92–9
9. Hefner JT (2009) Cranial nonmetric variation and estimating ancestry. J Forensic Sci 54(5):985–95
10. Hanihara K (1967) Racial characteristics in the dentition. J Dent Res 46(5):923–6
11. Haines DH (1972) Racial characteristics in forensic dentistry. Med Sci Law 12(2):131–8
12. Jacob T (1967) Racial identification of the Bronze Age human dentitions from Bali. Indonesia. J Dent Res 46(5):903–10
13. Burris BG, Harris EF (1998) Identification of race and sex from palate dimensions. J Forensic Sci 43(5):959–63
14. Stewart TD (1962) Anterior femoral curvature: its utility for race identification. Hum Biol 34:49–62
15. Walensky NA (1965) A study of anterior femoral curvature in man. Anat Rec 151:559–70
16. Gilbert BM (1976) Anterior femoral curvature: its progably basis and utility as a criterion of racial assessment. Am J Phys Anthropol 45(3 pt. 2):601–4
17. Gill GW (2001) Racial variation in the proximal and distal femur: heritability and forensic utility. J Forensic Sci 46(4):791–9
18. İşcan MY (1983) Assessment of race from the pelvis. Am J Phys Anthropol 62(2):205–8
19. İşcan MY, Steyn M (1985) Assessment of race from the pelvis. Am J Phys Anthropol 62(2):205–8
20. Patriquin ML, Steyn M, Loth SR (2002) Metric assessment of race from the pelvis in South Africans. Forensic Sci Int 127(1-2):104–13
21. Handa VL, Lockhart ME, Fielding JR, Bradley CS, Brubaker L, Cundiff GW et al (2008) Racial differences in pelvic anatomy by magnetic resonance imaging. Obstet Gynecol 111(4): 914–20
22. Krogman WM, İşcan MY (1986) The human skeleton in forensic medicine. Charles C. Thomas, Springfield
23. Steyn M, İşcan MY (2000) Bone pathology and ante-mortem trauma in forensic cases. In: Siegel J, Saukko P, Knupfer G (eds) Encyclopedia of forensic sciences. Academic, London, pp 217–27
24. İşcan MY, McCabe BQ (2000) Animal effects on human remains. In: Siegel J, Saukko P, Knupfer G (eds) Encyclopedia of forensic sciences. Academic, London, pp 198–206
25. MacLaughlin SM, Oldale KN (1992) Vertebral body diameters and sex prediction. Ann Hum Biol 19(3):285–92
26. Ortner DJ, Putschar WGJ (1981) Identification of pathological conditions in human skeletal remains. Smithsonian Institution Press, Washington
27. Brothwell DR (1981) Digging up bones: the excavation, treatment and study of human skeletal remains. Cornell University Press, Ithaca
28. Merbs CF (1989) Trauma. In: İşcan MY, Kennedy KAR (eds) Reconstruction of life from the skeleton. Wiley-Liss, New York, pp 161–89
29. Patriquin ML (2001) A comparative analysis of differences in the pelves of South African blacks and whites. University of Pretoria, Faculty of Medicine, Pretoria
30. L'Abbe EN, Loots M, Meiring JH (2005) The Pretoria Bone Collection: a modern South African skeletal sample. Homo 56(2): 197–205
31. İşcan MY, Loth SR, Steyn M (2000) Determination of racial affinity. In: Siegel J, Saukko P, Knupfer G (eds) Encyclopedia of forensic sciences. Academic, London, pp 227–35
32. Marks MK, Synstelien JA (2005) Determination of racial affinity. In: Payne-James J, Byard R, Corey T, Henderso C (eds) Encyclopedia of forensic and legal medicine. Academic, London, pp 137–42

33. Jenkins T (1986) Genetic variation and disease in southern African peoples. In: Singer R, Lundy JK (eds) Variation, culture and evolution in African populations. Witwatersrand University Press, Johannesburg, pp 143–58
34. Macho GA (1990) Is sexual dimorphism in the femur a "population specific phenomenon?". Z Morphol Anthropol 78(2):229–42
35. Hoyme S, İşcan MY (1989) Determination of sex and race: accuracy and assumptions. In: İşcan MY, Kennedy KAR (eds) Reconstruction of life from the skeleton. Wiley-Liss, Inc., New York, pp 53–94
36. Gill GW, Rhine S. (eds.) (1990) Skeletal attribution of race: Methods for forensic anthropology [xxviii, 99p.: ill., 28 cm]. In: Anthropological papers no 4. Maxwell Mueseum of Anthropology, Albuquerque, N.M.
37. Novotny V, İşcan MY, Loth SR (1993) Morphologic and osteometric assessment of age, sex, and race from the skull. In: İşcan MY, Helmer RP (eds) Forensic analysis of the skull. Wiley-Liss, Inc., New York, pp 71–88