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Article

Craniofacial morphology in ancient and modern Greeks through 4,000 years

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With 6 figures and 7 tables

Summary: *Background:* Multiple 20th century studies have speculated on the anthropological similarities of the modern inhabitants of Greece with their ancient predecessors. The present investigation attempts to add to this knowledge by comparing the craniofacial configuration of 141 ancient (dating around 2,000–500 BC) and 240 modern Greek skulls (the largest material among relevant national studies). *Method:* Skulls were grouped in age at death, sex, era and geographical categories; lateral cephalograms were taken and 53 variables were measured and correlated statistically. The craniofacial measurements and measurements of the basic quadrilateral and cranial polygon were compared in various groups using basic statistical methods, one-way ANOVA and assessment of the correlation matrices. *Observations:* Most of the measurements for both sexes combined followed an akin pattern in ancient and modern Greek skulls. Moreover, sketching and comparing the outline of the skull and upper face, we observed a clock-wise movement. The present study confirms that the morphological pattern of Greek skulls, as it changed during thousands of years, kept some characteristics unchanged, with others undergoing logical modifications. *Conclusion:* The analysis of our results allows us to believe that the influence upon the craniofacial complex of the various known factors, including genetic or environmental alterations, is apt to alter its form to adapt to new conditions. Even though 4,000 years seems too narrow a span to provoke evolutionary insights using conventional geometric morphometrics, the full presentation of our results makes up a useful atlas of solid data. Interpreted with caution, the craniofacial morphology in modern and ancient Greeks indicates elements of ethnic group continuation within the unavoidable multicultural mixtures.

Key words: craniofacial configuration, morphological alterations, expansion of the braincase, human evolution.

Background

One of the basic morphological alterations, occurring during the evolutionary period of mankind, was the tendency of the brain to enlarge, which had as a result the gradual expansion of the braincase (Park et al. 2007, Enlow & McNamara 1973). The craniofacial complex has been established as an anatomic characteristic of paramount importance, which underwent such decisive changes that it determined the evolution to *Homo sapiens sapiens* (Enlow 1982). The presence of a relationship between craniofacial morphology and head posture has been indicated by the comprehensive sys-

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tem of associations between variable characteristics expressing the size, shape and position of the craniofacial components on the one hand, and those expressing the postural relationships of the head and cervical column on the other (Solow & Tallgren 1976).

Hominin orthograde locomotion evolved several million years before an accelerated brain growth, documented by hominin fossils (Niemitz 2010). It seems that the formative changes of the skull are more or less concurrent, while the evolutionary change in the cranial base can be related to a differentiated development of the brain, since the occipital part is proportionally enlarged in humans (Striedter 2006). The organization of the cranial base, whose transformations have contributed decisively to evolution, is influenced by locomotion and posture (Strait 2001) within both polyphyletic phylogenetic lines with genetic isolation (Stringer 1990).

The human skull resolves into subunits, namely, the neurocranium, the basicranium and the face, each of them with a distinct function (Bacon et al. 1992). All anthropometric characteristics are usually genetically complex and also subject to environmental influence, including physical factors, such as altitude, climate (Rae et al. 2006) and mechanical forces, with the masticatory and alveolar regions contributing to discriminate better among economic strategies rather than between local populations (Kiliaridis 1995). When taking into account the total craniofacial shape, variation is more clearly patterned by structural-historical aspects of the population than by some important non-genetic differences (González-José et al. 2005).

As far as craniofacial structural changes related to ageing are concerned, the cranial base, which matures earlier than the face and maintains its stability, can be used cephalometrically as a relatively stable reference area (Ranly 2000). Despite the intensified increases in both the sagittal and vertical directions, facial characteristics remain constant in the sagittal direction (Arat et al. 2001).

Summarizing the above points, many factors in relation to craniofacial morphology have had their own contribution, slight or serious, to the alterations that have determined the morphology of modern man. Moreover, multiple 20th century studies have speculated on the causes of the striking anthropological similarities of modern inhabitants of Greece with their ancient predecessors (Coon 1939, Argyropoulos et al. 1989).

In this context, with the present investigation we aimed to present a useful atlas of data adding to the research on the craniofacial affinities between ancient and modern Greek skulls and to modestly comment on transitional patterns.

Material and methods

The material of this study consists of 141 ancient and 240 modern skulls (the largest material among relevant national studies) with the former taken from skeletal remains excavated from a number of cites in Greece, and the latter from the two biggest cemeteries of Athens. All the skulls were selected out of a big number available, and the criterion for selection was that they bore all the anatomical reference points.

Anthropologists determined the age at death and sex of the material, from the skull and the mandible (where present) (Manolis S. & Panagiaris G. 1992, personal communication). Archaeologists, who made the excavations, determined the era of their archaeological findings, which spanned from the Mesoelladic period around 2,000 BC until about 500 BC (Pentazos V. & Skorda D. 1992, personal communication).

The skulls were grouped into two categories: Group I [141 ancient Greek skulls – Group I/m for male skulls (83) and Group I/f for female (58) (Table 1)] with three subgroups: Group

Table 1. Age and sex distribution of the groups.

		$\bar{x}$	Sx	x_{min}	x_{max}	Total
Group I/m	ancient males	38.8	8.25	25	60	83
Group I/f	ancient females	36.6	8.28	25	65	58
Group II/M	modern males	51.8	7.86	25	65	134
Group II/f	modern females	53.5	9.02	30	65	106

I/1 (21 skulls from Eani), Group I/2 (22 from Fokis), and Group I/3 (98, the rest of the ancient skulls of Group I), and Group II [240 modern Greek skulls – Groups II/m for male skulls (134) and Group II/f for female (106)]. The reason for subgrouping the skulls from Fokis and Eani is that these two geographical areas have had more or less homogeneous populations because they were closed societies.

Lateral roentgen cephalograms of the skulls were taken, with the left side facing the film, using the original Bjork's principles (Bjork 1950). The distance between the X-ray focus and the median plane of the skull was 150 cm, and the distance between the median plane of the skull and the film was 9.5 cm with the Frankfort plane perpendicular to the film. The linear magnification in the median plane is 6.8 % and has not been corrected. The exposure time was 0.2 sec, with an apparatus setting of 60 kV and 5 mA, and the films used were Dupont-Cronex 4, while the metal cassette used screens for quanta fast detailed film.

Cephalometric analysis

Sixteen reference points were used as shown in Fig. 1 (Young 1917, Wilder 1920, Slomic et al. 1990) Metallic indicators were used for the two reference points Basion and Opisthion. There are two categories of variables: craniofacial measurements and measurements of the basic quadrilateral and cranial polygon (Table 2).

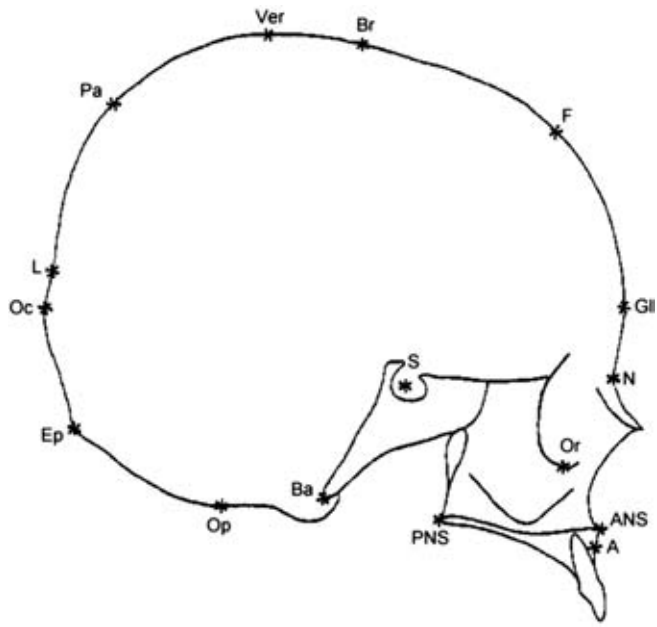

Fig. 1. The reference points.

Table 2a. Cranio and middle third of face measurements.

Sagittal angular measurements		**Sagittal linear measurements**	
1. N-S-Ba		4. N-S	8. PNS-SP
2. Ba-N-A		5. ANS-PNS	9. ANS-SP
3. Ba-S-PNS		6. Or-SP	10. A-SP
		7. Ba-SP	11. Ba-PNS
Vertical angular measurements		**Vertical linear measurements**	
12. NSL-NL	16. PNS-Ba-S	19. PNS-SN	
13. N-S-Or	17. NL-SP	20. ANS-SN	
14. S-N-Or	18. OpBa-SP	21. S-Ba	
15. S-PNS-Ba		22. S-PNS	

Abbreviations: A: Subspinale, ANS: Spina Nasalis Anterior, Ba: Basion, N: Nasion, NL: Nasal Line, NSL: Nasion-Sella Line, Op: Opisthion, Or: Orbitale, PNS: Spina Nasalis Posterior, S: Sella, SP: Sella Perpendicular Line

Table 2b. Measurements of the basic quadrilateral and cranial polygon.

Angular measurements			
23. Br-S-Ep	26. S-N-Op	29. F-Br-Pa	32. L-Ep-Ba
24. Br-S-N	27. Ba-N-F	30. Br-Pa-L	33. Ep-Ba-N
25.S-N-Br	28. N-F-Br	31. Pa-L-Ep	
Linear measurements			
34. F-NBr	39. Op-EpS	44. N-F	49. Ep-Ba
35. Br-S	40. Op-Ba	45. F-Br	50. Ba-N
36. Br-Ep	41. Op-N	46. Br-Pa	51. N-Br
37. Pa-BrEp	42. Oc-Gl	47. Pa-L	52. Br-L
38. Ep-S	43. Ver-OpN	48. L-Ep	53. L-Ba

Abbreviations: A: Subspinale, ANS: Spina Nasalis Anterior, Ba: Basion, Br: Bregma, Ep: External occipitial protuberance, F: The point of greatest curvature on the frontal arc from line Br-N, Gl: Glabella, L: Lambda, N: Nasion, NL: Nasal Line, NSL: Nasion-Sella Line, Oc: The most posterior point on the occipital bone, Op: Opisthion, Or: Orbitale, Pa: The point of greatest curvature on the parietal outline from line Br-N, PNS: Spina Nasalis Posterior, S: Sella, SP: Sella Perpendicular Line, Ver: Vertex

The coordinates of all the reference points were registered, using a Scriptel digitizer (SPA-Series graphics tablet) and stored on a computer utilizing the program Dentofacial Planner, version 5.32. With this program, 53 variables were calculated from the coordinate values of the reference points.

The 53 variables of each skull were transferred to a mainframe computer Center, University of Bergen, and the data were handled using programs from the BMDP Statistical Software.

Statistical methods

The data of 53 variables were statistically described by the mean ($\bar{x}$) and the standard deviation (Sx); x was initially tested for normal distribution. To test any differences between males and females and between ancient and modern skulls, the two-sample t-test was used. Moreover, to compare three ancient subgroups and the total modern group simultaneously, a one-way analysis of variance was utilized. If this test revealed a significant F-value, Scheffe's multiple comparison test was used to evaluate differences between pairs of means.

In the correlation analysis, the correlation coefficient value (τ) of 0.70 to 1.0 either + or – was considered strong or high (**), and τ value ranging from 0.50 to 0.69 was considered moderate to strong (*).

Thirty cephalograms were selected and digitized twice in order to check the method error of cephalometric variables. The errors, calculated according to the formula

$$\tau = \sqrt{\frac{\Sigma d^2}{2n}}$$

were all small and within acceptable limits.

Findings

Findings – Collected data and results

Descriptive statistics were computed for all 53 cephalometric variables, assessing according to group, sexes and geographical areas. Seven distinct analyses' results occurred.

Table 3 presents the comparison of the craniofacial measurements and measurements of the basic quadrilateral and cranial polygon of ancient and modern Greek skulls of both sexes.

Table 3. Comparison of both sexes measurements on ancient and modern Greek skulls.

	Group I (n = 141)		Group II (n = 240)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx		
Cranial and middle third face measurements						
Sagittal angular measurements						
1. N-S-Ba	130.2	5.08	130.9	5.02	0.1651	
2. Ba-N-A	64.1	3.41	63.0	3.33	0.0042	**
3. Ba-S-PNS	54.8	5.90	55.0	5.40	0.7179	
Sagittal linear measurements						
4. N-S	69.1	3.89	69.5	3.28	0.2551	
5. ANS-PNS	54.6	4.14	54.8	3.86	0.5267	
6. Or-SP	50.1	3.71	50.2	3.35	0.9337	
7. Ba-SP	27.8	3.44	29.1	3.33	0.0002	***
8. PNS-SP	11.8	4.62	11.5	3.96	0.5736	
9. ANS-SP	65.9	4.82	66.0	4.87	0.8809	
10. A-SP	62.4	4.82	61.4	4.81	0.0347	*
11. Ba-PNS	41.3	4.42	42.7	4.10	0.0018	**
Vertical angular measurements						
12. NSL-NL	6.8	4.16	6.3	3.15	0.2088	
13. N-S-Or	26.8	2.88	27.7	2.47	0.0017	**
14. S-N-Or	18.8	2.10	18.8	2.06	0.8959	
15. S-PNS-Ba	59.2	5.01	58.6	3.76	0.1789	
16. PNS-Ba-S	65.8	5.71	66.3	5.54	0.4671	
17. NL-SP	83.3	4.20	83.5	3.27	0.6940	
18. OpBa-SP	91.7	5.48	89.6	5.39	0.0005	***

Table 3. Continued.

	Group I (n = 141)		Group II (n = 240)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx		
Vertical linear measurements						
19. PNS-SN	44.3	3.54	46.1	3.42	0.0000	***
20. ANS-SN	50.8	3.38	52.1	3.60	0.0003	***
21. S-Ba	43.4	3.32	44.6	2.99	0.0008	***
22. S-PNS	46.1	3.69	47.7	3.60	0.0000	***
Measurements of the basic quadrilateral and cranial polygon						
Angular measurements						
23. Br-S-Ep	99.6	5.43	99.7	4.80	0.8562	
24. Br-S-N	84.1	4.57	82.8	4.18	0.0073	**
25.S-N-Br	59.2	3.33	60.6	3.24	0.0001	***
26. S-N-Op	14.3	2.35	13.7	2.38	0.0179	*
27. Ba-N-F	100.0	4.89	100.3	3.65	0.5311	
28. N-F-Br	131.2	4.22	132.0	3.88	0.0599	
29. F-Br-Pa	146.7	3.45	146.9	3.19	0.5569	
30. Br-Pa-L	131.0	4.42	129.1	4.59	0.0001	***
31. Pa-L-Ep	139.0	6.53	142.8	5.46	0.0000	***
32. L-Ep-Ba	109.1	5.00	108.1	5.10	0.0592	
33. Ep-Ba-N	142.7	4.90	140.4	5.13	0.0000	***
Linear measurements						
34. F-NBr	25.6	2.90	25.2	2.90	0.3040	
35. Br-S	99.5	4.85	101.9	4.69	0.0000	***
36. Br-Ep	157.2	7.26	158.3	7.31	0.1499	
37. Pa-BrEp	53.9	5.04	52.5	4.65	0.0043	**
38. Ep-S	106.5	5.81	105.3	5.53	0.0571	
39. Op-EpS	29.6	4.05	30.2	4.21	0.1397	
40. Op-Ba	36.5	4.41	38.4	3.12	0.0000	***
41. Op-N	137.8	6.59	141.0	5.92	0.0000	***
42. Oc-Gl	190.2	8.98	185.4	8.09	0.0000	***
43. Ver-OpN	126.1	6.23	124.3	6.63	0.0069	**
44. N-F	69.2	8.03	71.2	5.65	0.0105	*
45. F-Br	57.0	5.59	55.6	4.96	0.0130	*
46. Br-Pa	81.9	7.53	77.9	6.72	0.0000	***
47. Pa-L	54.7	7.95	58.0	6.41	0.0000	***
48. L-Ep	63.0	9.44	62.1	9.36	0.3331	
49. Ep-Ba	82.5	6.08	81.4	5.58	0.0620	
50. Ba-N	102.6	4.98	104.2	4.78	0.0013	**
51. N-Br	115.1	6.91	116.0	6.25	0.2038	
52. Br-L	124.9	7.15	123.1	6.82	0.0142	*
53. L-Ba	119.2	6.90	116.6	6.83	0.0005	***

p-value: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4a contains the comparison of the craniofacial measurements and measurements of the basic quadrilateral and cranial polygon between ancient Greek male and female skulls, with the same comparison for modern skulls presented in Table 4b.

In Table 5 the results of the attempt to focus on gender specific comparisons are presented. The comparison of the craniofacial measurements and measurements of the basic quadrilateral and cranial polygon of ancient and modern Greek male skulls is shown in Table 5a, and the respective comparison for female skulls in Table 5b.

Table 4a. Comparison of male and female measurements on ancient Greek skulls.

	Group I/m (n = 83)		Group I/f (n = 58)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx		
Cranial and middle third face measurements						
Sagittal angular measurements						
1. N-S-Ba	130.3	5.13	130.1	5.05	0.8428	
2. Ba-N-A	64.0	3.58	64.1	3.18	0.8867	
3. Ba-S-PNS	54.7	6.08	55.0	5.69	0.7161	
Sagittal linear measurements						
4. N-S	70.1	3.77	64.6	3.60	0.0001	***
5. ANS-PNS	55.6	4.00	53.2	3.95	0.0006	***
6. Or-SP	50.7	3.58	49.3	3.79	0.0348	*
7. Ba-SP	28.2	3.51	27.1	3.26	0.0445	*
8. PNS-SP	11.8	4.25	11.8	5.15	0.9970	
9. ANS-SP	66.9	4.81	64.4	4.97	0.0016	**
10. A-SP	63.4	4.80	61.1	4.55	0.0036	**
11. Ba-PNS	41.8	4.39	40.5	4.39	0.0814	
Vertical angular measurements						
12. NSL-NL	6.2	4.10	7.6	4.16	0.5200	
13. N-S-Or	26.6	2.98	27.1	2.56	0.2610	
14. S-N-Or	18.8	2.28	18.8	1.83	0.9705	
15. S-PNS-Ba	59.3	5.11	59.1	4.91	0.7510	
16. PNS-Ba-S	65.9	5.64	65.8	5.80	0.9301	
17. NL-SP	83.9	4.12	82.5	4.20	0.0438	*
18. OpBa-SP	90.7	5.35	93.0	5.42	0.0138	*

Table 4b.: Comparison of male and female measurements on modern Greek skulls.

	Group I/m (n = 83)		Group I/f (n = 58)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx		
Sagittal angular measurements						
1. N-S-Ba	130.0	5.05	132.1	4.76	0.0015	**
2. Ba-N-A	63.2	3.47	62.8	3.14	0.2957	
3. Ba-S-PNS	54.9	5.67	55.2	5.10	0.5787	
Sagittal linear measurements						
4. N-S	70.6	3.10	68.1	3.00	0.0000	***
5. ANS-PNS	55.7	4.02	53.8	3.39	0.0001	***
6. Or-SP	50.8	3.32	49.3	3.22	0.0006	***
7. Ba-SP	29.5	3.51	28.7	3.04	0.0759	
8. PNS-SP	12.3	4.21	10.5	3.37	0.0003	***
9. ANS-SP	67.6	4.81	63.9	4.13	0.0000	***
10. A-SP	62.8	4.79	59.5	4.18	0.0000	***
11. Ba-PNS	43.8	4.10	41.4	3.68	0.0000	***
Vertical angular measurements						
12. NSL-NL	6.2	3.08	6.4	3.24	0.7472	
13. N-S-Or	27.7	2.47	27.7	2.49	0.0986	
14. S-N-Or	19.2	2.10	18.2	1.86	0.0001	***
15. S-PNS-Ba	58.4	4.14	58.7	3.23	0.5150	
16. PNS-Ba-S	66.6	5.73	65.9	5.30	0.3352	
17. NL-SP	83.4	3.20	83.7	3.36	0.5055	
18. OpBa-SP	89.6	5.71	89.6	4.98	0.9858	

p-value: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Table 4a. Continued. **Group I/m (n = 83)**		**Group I/f (n = 58)**		***p*-value**		**Table 4b.**: Continued. **Group I/m (n = 83)**		**Group I/f (n = 58)**		***p*-value**	
	$\bar{x}$	**Sx**	$\bar{x}$	**Sx**			$\bar{x}$	**Sx**	$\bar{x}$	**Sx**		
Vertical linear measurements												
19. PNS-SN	44.1	3.47	43.3	3.38	0.0018	**	47.4	3.45	44.5	2.67	0.0000	***
20. ANS-SN	51.2	3.16	50.3	3.65	0.1457		53.4	3.46	50.5	3.08	0.0000	***
21. S-Ba	44.1	3.69	42.3	2.53	0.0007	***	45.7	2.88	43.1	2.41	0.0000	***
22. S-PNS	46.8	3.43	45.1	3.83	0.0073	**	49.2	3.55	45.9	2.73	0.0000	***
Measurements of the basic quadrilateral and cranial polygon												
Angular measurements												
23. Br-S-Ep	99.8	5.21	99.2	5.76	0.5557		100.4	4.50	98.8	4.94	0.0133	*
24. Br-S-N	84.0	4.37	84.3	4.88	0.7509		82.9	4.65	82.7	3.49	0.6579	
25.S-N-Br	59.2	3.18	59.2	3.58	0.9862		60.4	3.61	60.9	2.68	0.1952	
26. S-N-Op	14.1	2.40	14.7	2.25	0.1114		14.1	2.49	13.2	2.14	0.0020	**
27. Ba-N-F	99.9	4.34	100.0	5.63	0.9087		100.1	3.92	100.5	3.29	0.4364	
28. N-F-Br	131.3	4.47	131.0	3.85	0.6665		132.8	3.80	131.1	3.79	0.0009	***
29. F-Br-Pa	147.0	3.40	146.2	3.48	0.1638		146.8	3.32	147.0	3.01	0.7730	
30. Br-Pa-L	131.5	4.39	130.4	4.42	0.1284		129.1	4.80	129.2	4.34	0.8820	
31. Pa-L-Ep	138.2	6.89	140.1	5.85	0.0725		143.0	5.62	142.7	5.28	0.6429	
32. L-Ep-Ba	108.9	5.08	109.4	4.92	0.9623		107.4	5.07	109.0	5.02	0.0137	*
33. Ep-Ba-N	142.8	5.21	142.6	4.47	0.7427		140.5	5.24	140.3	5.02	0.7560	
Linear measurements												
34. F-NBr	25.8	2.93	25.2	2.83	0.1735		25.1	2.97	25.4	2.83	0.4571	
35. Br-S	100.7	4.66	97.6	4.58	0.0001	***	103.0	4.69	100.6	4.37	0.0001	***
36. Br-Ep	159.6	6.26	153.9	7.33	0.0000	***	161.5	6.44	154.4	6.39	0.0000	***
37. Pa-BrEp	54.8	5.30	52.8	4.48	0.0178	*	53.4	4.51	51.2	4.54	0.0002	***
38. Ep-S	107.9	5.86	104.4	5.36	0.0004	***	107.3	5.10	102.8	5.04	0.0000	***

p-value: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Table 4a. Continued. Group I/m (n = 83)		Group I/f (n = 58)		*p*-value		**Table 4b.**: Continued. Group I/m (n = 83)		Group I/f (n = 58)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx			$\bar{x}$	Sx	$\bar{x}$	Sx		
39. Op-EpS	29.2	4.64	30.1	2.99	0.1743		30.7	4.11	29.6	4.28	0.0507	
40. Op-Ba	37.3	4.48	35.4	4.11	0.0111	*	38.7	3.14	37.9	3.07	0.0473	*
41. Op-N	140.1	6.22	134.6	5.74	0.0000	***	143.0	5.74	138.5	5.16	0.0000	***
42. Oc-Gl	194.1	7.99	184.8	7.43	0.0000	***	188.3	7.78	181.6	6.89	0.0000	***
43. Ver-OpN	127.6	5.71	124.0	6.40	0.0009	***	126.4	6.28	121.6	6.08	0.0000	***
44. N-F	70.0	7.73	68.2	8.41	0.1915		72.2	5.84	70.0	5.19	0.0031	**
45. F-Br	57.8	5.10	55.9	6.12	0.5750		55.9	4.97	55.2	4.93	0.2397	
46. Br-Pa	82.4	7.85	81.1	7.03	0.2942		79.0	7.03	76.6	6.07	0.0048	**
47. Pa-L	55.6	8.03	53.5	7.75	0.1339		58.9	6.57	57.1	6.07	0.0182	*
48. L-Ep	65.1	9.95	60.1	7.82	0.0010	***	64.1	9.65	59.5	8.35	0.0001	***
49. Ep-Ba	83.4	6.47	81.2	5.25	0.0243	*	82.8	5.18	79.5	5.05	0.0000	***
50. Ba-N	104.2	4.74	100.2	4.35	0.0000	***	106.0	4.63	102.1	4.04	0.0000	***
51. N-Br	116.6	6.31	113.1	7.27	0.0040	**	117.5	6.49	114.1	5.38	0.0000	***
52. Br-L	126.4	6.79	122.8	7.18	0.0035	**	124.8	7.01	120.9	5.93	0.0000	***
53. L-Ba	121.5	6.76	115.9	5.75	0.0000	***	118.9	6.71	113.7	5.82	0.0000	***

p-value: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5a. Comparison of male measurements on ancient and modern Greek skulls.

	Group I/m (n = 83)		Group II/m (n = 134)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx		
Cranial and middle third face measurements						
Sagittal angular measurements						
1. N-S-Ba	130.3	5.13	130.0	5.05	0.7481	
2. Ba-N-A	64.1	3.58	63.2	3.47	0.1062	
3. Ba-S-PNS	54.7	6.08	54.9	5.67	0.8098	
Sagittal linear measurements						
4. N-S	70.1	3.77	70.6	3.10	0.2820	
5. ANS-PNS	55.6	4.00	55.7	4.02	0.8345	
6. Or-SP	50.7	3.58	50.8	3.32	0.7992	
7. Ba-SP	28.2	3.51	29.5	3.51	0.0124	*
8. PNS-SP	11.8	4.24	12.3	4.21	0.3669	
9. ANS-SP	66.9	4.81	67.6	4.81	0.3422	
10. A-SP	63.4	4.80	62.8	4.79	0.3728	
11. Ba-PNS	41.8	4.38	43.8	4.10	0.0011	**
Vertical angular measurements						
12. NSL-NL	6.2	4.10	6.2	3.10	0.9977	
13. N-S-Or	26.6	2.98	27.7	2.47	0.0045	*
14. S-N-Or	18.8	2.28	19.2	2.10	0.1683	
15. S-PNS-Ba	59.3	5.11	58.4	4.14	0.1755	
16. PNS-Ba-S	65.9	5.68	66.6	5.73	0.3765	
17. NL-SP	83.9	4.12	83.4	3.20	0.2916	
18. OpBa-SP	90.7	5.35	89.6	5.71	0.1471	

Table 5b. Comparison of female measurements on ancient and modern Greek skulls.

	Group I/m (n = 83)		Group II/m (n = 134)		*p*-value	
	$\bar{x}$	Sx	$\bar{x}$	Sx		
Sagittal angular measurements						
1. N-S-Ba	130.1	5.04	132.1	4.76	0.0153	*
2. Ba-N-A	64.1	3.18	62.8	3.14	0.0113	*
3. Ba-S-PNS	55.0	5.69	55.2	5.05	0.8061	
Sagittal linear measurements						
4. N-S	67.6	3.60	68.1	2.95	0.3608	
5. ANS-PNS	53.2	3.95	53.8	3.38	0.3058	
6. Or-SP	49.3	3.78	49.3	3.22	0.9892	
7. Ba-SP	27.1	3.25	28.7	3.03	0.0019	**
8. PNS-SP	11.8	5.15	10.5	3.37	0.0948	
9. ANS-SP	64.4	4.47	63.9	4.13	0.5182	
10. A-SP	61.1	4.54	59.5	4.18	0.0355	*
11. Ba-PNS	40.5	4.39	41.4	3.68	0.2196	
Vertical angular measurements						
12. NSL-NL	7.6	4.15	6.4	3.24	0.0496	*
13. N-S-Or	27.1	2.56	27.7	2.49	0.1535	
14. S-N-Or	18.8	1.83	18.2	1.86	0.0468	*
15. S-PNS-Ba	59.1	4.91	58.7	3.23	0.6532	
16. PNS-Ba-S	65.8	5.80	65.9	5.30	0.9117	
17. NL-SP	82.5	4.20	83.7	3.36	0.0692	
18. OpBa-SP	93.0	5.42	89.6	4.98	0.0001	***

p-value: * $p < 0.05$, ** $p < 0.01$

	Table 5a. Continude. **Group I/m (n = 83)**		**Group II/m (n = 134)**		***p*-value**		**Table 5b.** Continued. **Group I/m (n = 83)**		**Group II/m (n = 134)**		***p*-value**	
	$\bar{x}$	**Sx**	$\bar{x}$	**Sx**			$\bar{x}$	**Sx**	$\bar{x}$	**Sx**		
Vertical linear measurements												
19. PNS-SN	45.1	3.47	47.4	3.45	0.0000	***	43.2	3.38	44.5	2.67	0.0136	*
20. ANS-SN	51.2	3.16	53.4	3.46	0.0000	***	50.3	3.65	50.5	3.08	0.7041	
21. S-Ba	44.1	3.60	47.7	2.88	0.0009	***	42.3	2.53	43.1	2.41	0.0771	
22. S-PNS	46.8	3.43	49.2	3.55	0.0000	***	45.1	3.83	45.9	2.73	0.1554	
Measurements of the basic quadrilateral and cranial polygon												
Angular measurements												
23. Br-S-Ep	99.8	5.21	100.4	4.60	0.4254		99.2	5.76	98.8	4.94	0.6259	
24. Br-S-N	84.0	4.37	82.9	4.65	0.0912		84.3	4.88	82.7	3.50	0.0353	*
25.S-N-Br	59.2	3.18	60.4	3.61	0.0119	*	59.2	3.58	60.9	2.68	0.0018	**
26. S-N-Op	14.0	2.40	14.1	2.50	0.8211		14.7	2.25	13.2	2.14	0.0001	***
27. Ba-N-F	99.9	4.34	100.1	3.92	0.7597		100.0	5.62	100.5	3.29	0.5854	
28. N-F-Br	131.3	4.48	132.7	3.80	0.0169	*	131.0	3.85	131.1	3.79	0.9035	
29. F-Br-Pa	147.0	3.41	146.8	3.33	0.6984		146.2	3.48	147.0	3.01	0.1630	
30. Br-Pa-L	131.5	4.39	129.1	4.80	0.0002	***	130.4	4.42	129.2	4.34	0.1027	
31. Pa-L-Ep	138.2	6.89	143.0	5.61	0.0000	***	140.1	5.85	142.7	5.28	0.0067	**
32. L-Ep-Ba	108.9	5.08	107.4	5.07	0.0325	*	109.4	4.91	109.0	5.02	0.6263	
33. Ep-Ba-N	142.8	5.21	140.5	5.24	0.0018	**	142.6	4.47	140.3	5.02	0.0038	**
Linear measurements												
34. F-NBr	25.8	2.94	25.1	2.96	0.0830		25.2	2.83	25.4	2.83	0.6114	
35. Br-S	100.7	4.66	103.0	4.70	0.0007	***	97.6	4.58	100.6	4.37	0.0001	***
36. Br-Ep	159.6	6.25	161.5	6.44	0.0328	*	153.9	7.33	154.4	6.39	0.6545	
37. Pa-BrEp	54.8	5.29	53.4	4.51	0.0604		52.8	4.47	51.2	4.54	0.0328	
38. Ep-S	107.9	5.86	107.3	5.10	0.4247		104.4	5.35	102.8	5.04	0.0616	

p-value: * $p < 0.05$, ** $p < 0.01$

	Table 5a. Continude. **Group I/m (n = 83)**		**Group II/m (n = 134)**		***p*-value**		**Table 5b.** Continuded. **Group I/m (n = 83)**		**Group II/m (n = 134)**		***p*-value**	
	$\bar{x}$	**Sx**	$\bar{x}$	**Sx**			$\bar{x}$	**Sx**	$\bar{x}$	**Sx**		
39. Op-EpS	29.2	4.64	30.7	4.11	0.0181	*	30.1	2.99	29.6	4.28	0.4125	
40. Op-Ba	37.3	4.48	38.7	3.13	0.0129	*	35.4	4.11	37.9	3.07	0.0001	***
41. Op-N	140.1	6.22	143.0	5.73	0.0006	***	134.6	5.74	138.5	5.16	0.0000	***
42. Oc-Gl	194.1	7.99	188.3	7.77	0.0000	***	184.8	7.43	181.6	6.90	0.0089	**
43. Ver-OpN	127.6	5.71	126.4	6.28	0.1590		124.0	6.39	121.6	6.07	0.0187	*
44. N-F	70.0	7.73	72.2	5.85	0.0293	*	68.2	8.41	70.0	5.19	0.1270	
45. F-Br	57.8	5.10	55.9	4.97	0.0091	**	55.9	6.11	55.2	4.93	0.4300	
46. Br-Pa	82.4	7.85	79.0	7.02	0.0014	**	81.1	7.03	76.6	6.07	0.0001	***
47. Pa-L	55.6	8.03	58.9	6.57	0.0018	**	53.5	7.74	57.0	6.07	0.0045	**
48. L-Ep	65.1	9.95	64.1	9.64	0.4519		60.0	7.82	59.5	8.35	0.6833	
49. Ep-Ba	83.4	6.47	82.8	5.18	0.4702		81.2	5.25	79.5	5.50	0.0492	*
50. Ba-N	104.2	4.74	106.0	4.63	0.0078	**	100.2	4.35	102.1	4.04	0.0081	**
51. N-Br	116.6	6.31	117.5	6.49	0.2754		113.1	7.27	114.1	5.38	0.3381	
52. Br-L	126.4	6.79	124.8	7.01	0.0933	*	122.8	7.18	120.9	5.93	0.0933	
53. L-Ba	121.5	6.76	118.9	6.71	0.0075	**	115.9	5.75	113.7	5.82	0.0203	*

p-value: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The description of cephalometric variables and the one way analysis of variance (ANOVA) of the craniofacial measurements and measurements of the basic quadrilateral and cranial polygon of ancient and modern Greek skulls for 4 groups (Group I/1, Group I/2, Group I/3 and Group II) are presented in Tables 6 and 7 respectively.

Table 6. Description of cephalometric variables of the craniofacial measurements and measurements of the basic quadrilateral and cranial polygon of ancient and modern Greek skulls for 4 groups (Group I/1, Group I/2, Group I/3 and Group II).

	Group I/1		**Group I/2**		**Group I/3**		**Group II**		**Tail-*p***
	$\bar{x}$	**Sx**	$\bar{x}$	**Sx**	$\bar{x}$	**Sx**	$\bar{x}$	**Sx**	
Cranial and middle third face measurements									
Sagittal angular measurements									
1. N-S-Ba	127.5	4.25	131.2	5.06	130.5	5.09	130.9	5.02	0.0215
2. Ba-N-A	63.9	2.77	65.3	3.39	63.8	3.50	63.0	3.33	0.0076
3. Ba-S-PNS	52.4	4.39	55.3	5.27	55.2	6.23	55.0	5.40	0.1783
Sagittal linear measurements									
4. N-S	69.4	3.28	68.5	2.99	69.1	4.19	69.5	3.29	0.5193
5. ANS-PNS	55.5	3.07	55.6	4.30	54.2	4.25	54.8	3.86	0.2619
6. Or-SP	49.8	3.27	50.1	1.92	50.2	4.14	50.2	3.35	0.9605
7. Ba-SP	26.0	3.20	28.9	4.11	27.9	3.23	29.1	3.33	0.0000
8. PNS-SP	11.9	3.47	11.1	4.46	11.9	4.89	11.5	3.96	0.8193
9. ANS-SP	66.8	3.11	66.5	3.44	65.6	5.35	66.0	4.87	0.6695
10. A-SP	63.4	3.66	62.7	3.56	62.2	5.27	61.4	4.81	0.1344
11. Ba-PNS	39.3	3.78	42.2	3.34	41.5	4.66	42.7	4.11	0.0010
Vertical angular measurements									
12. NSL-NL	7.7	4.82	4.5	2.86	7.1	4.11	6.3	3.15	0.0039
13. N-S-Or	26.5	2.65	27.7	2.20	26.7	2.95	27.7	2.47	0.0032
14. S-N-Or	19.6	1.63	18.5	1.87	18.7	2.21	18.7	2.06	0.2800
15. S-PNS-Ba	60.7	5.60	58.4	4.43	59.1	4.98	58.6	3.76	0.1297
16. PNS-Ba-S	66.8	5.15	66.3	5.38	65.5	5.91	66.3	5.54	0.6773
17. NL-SP	82.5	4.90	85.6	3.09	83.0	4.14	83.5	3.27	0.127
18. OpBa-SP	92.5	4.70	89.7	6.12	91.9	5.44	89.6	5.39	0.0010
Vertical linear measurements									
19. PNS-SN	43.8	2.74	45.4	3.79	44.2	3.62	46.1	3.42	0.0000
20. ANS-SN	51.2	4.21	49.8	4.20	50.9	2.97	52.1	3.60	0.0019
21. S-Ba	43.1	2.72	43.8	3.47	43.4	3.42	44.6	2.99	0.0062
22. S-PNS	45.4	2.99	47.0	3.17	46.0	3.91	47.7	3.60	0.0002
Measurements of the basic quadrilateral and cranial polygon									
Angular measurements									
23. Br-S-Ep	101.1	4.65	97.4	4.87	99.7	5.60	99.7	4.80	0.1184
24. Br-S-N	83.4	4.15	85.9	3.89	83.9	4.74	82.8	4.17	0.0072
25.S-N-Br	59.1	3.08	58.7	3.32	59.3	3.41	60.6	3.24	0.0007
26. S-N-Op	14.9	1.94	13.9	2.14	14.2	2.49	13.7	2.38	0.0534
27. Ba-N-F	101.4	4.13	98.6	4.17	100.0	5.14	100.3	3.65	0.1467
28. N-F-Br	132.2	4.35	129.1	3.83	131.4	4.17	132.0	3.88	0.0106
29. F-Br-Pa	146.5	3.67	146.7	2.67	146.7	3.58	149.9	3.19	0.9322
30. Br-Pa-L	132.6	4.09	131.0	4.09	130.7	4.53	129.1	4.59	0.0004
31. Pa-L-Ep	136.7	6.33	140.3	5.32	139.1	6.76	142.9	5.46	0.0000
32. L-Ep-Ba	107.5	4.74	111.7	4.47	108.9	4.99	108.1	5.11	0.0076
33. Ep-Ba-N	142.9	4.56	142.3	6.28	142.8	4.67	140.4	5.14	0.0004

Table 6. Continued.

	Group I/1		Group I/2		Group I/3		Group II		Tail-*p*
	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	
Linear measurements									
34. F-NBr	25.0	3.09	27.2	2.71	25.3	2.80	25.2	2.90	0.0255
35. Br-S	98.0	4.34	101.0	4.57	99.4	4.95	101.9	4.70	0.0000
36. Br-Ep	158.7	5.74	155.0	6.22	157.4	7.70	158.3	7.31	0.1635
37. Pa-BrEp	53.5	4.41	54.6	5.38	53.9	5.13	52.5	4.65	0.0278
38. Ep-S	107.6	5.85	105.3	5.91	106.5	5.91	105.3	5.52	0.1328
39. Op-EpS	30.3	4.20	28.7	4.51	29.6	3.92	30.2	4.21	0.2891
40. Op-Ba	37.8	3.31	33.4	3.84	37.0	4.46	38.4	3.12	0.0000
41. Op-N	138.0	5.63	134.8	6.11	138.4	6.75	141.0	5.92	0.0000
42. Oc-Gl	191.6	8.42	190.0	6.12	190.0	9.66	185.4	8.09	0.0000
43. Ver-OpN	124.6	4.66	131.0	4.86	125.3	6.31	124.3	6.33	0.0000
44. N-F	65.2	5.31	74.8	4.62	68.9	8.48	71.2	5.66	0.0000
45. F-Br	58.9	5.23	55.4	3.79	57.0	5.92	55.6	4.96	0.0089
46. Br-Pa	79.7	7.02	85.9	6.21	81.5	7.64	77.9	6.71	0.0000
47. Pa-L	56.5	6.84	49.3	5.30	55.6	8.21	58.9	6.41	0.0000
48. L-Ep	65.7	9.54	61.6	7.66	62.8	9.76	62.1	9.36	0.3661
49. Ep-Ba	84.9	5.14	80.7	6.54	82.4	6.04	81.4	5.58	0.0219
50. Ba-N	101.6	4.48	102.9	5.28	102.7	5.02	104.2	4.78	0.0086
51. N-Br	113.4	7.18	117.9	4.63	114.9	7.16	116.0	6.25	0.0652
52. Br-L	125.1	6.19	124.0	6.31	125.1	7.55	123.1	6.82	0.0850
53. L-Ba	122.0	6.04	118.4	7.16	118.8	6.94	116.6	6.83	0.0010

Table 7. One way analysis of variance (ANOVA) of the craniofacial measurements and measurements of the basic quadrilateral and cranial polygon of ancient and modern Greek skulls for 4 groups (Group I/1, Group I/2, Group I/3 and Group II).

	F-value	Group I/1 Group 1/2	Group I/1 Group I/3	Group I/1 Group II	Group I/2 Group I/3	Group I/2 Group II	Group I/3 Group II
Cranial and middle third face measurements							
Sagittal angular measurements							
1. N-S-Ba	3.27	*	*	*			
2. Ba-N-A	4.03	*				*	
3. Ba-S-PNS	1.65						
Sagittal linear measurements							
4. N-S	0.76						
5. ANS-PNS	1.34						
6. Or-SP	0.10						
7. Ba-SP	7.80	**	*	**			**
8. PNS-SP	0.31						
9. ANS-SP	0.52						
10. A-SP	1.87						
11. Ba-PNS	5.54	**		*			

Table 7. Continued.

	F-value		Group I/1 Group 1/2	Group I/1 Group I/3	Group I/1 Group II	Group I/2 Group I/3	Group I/2 Group II	Group I/3 Group II
Vertical angular measurements								
12. NSL-NL	4.53	*	*			**		
13. N-S-Or	4.69	*						**
14. S-N-Or	1.29							
15. S-PNS-Ba	1.90							
16. PNS-Ba-S	0.51							
17. NL-SP	3.66	*	*			*	**	
18. OpBa-SP	5.55	**						
Vertical linear measurements								
19. PNS-SN	8.67	**			*			**
20. ANS-SN	5.07	*					*	*
21. S-Ba	4.19	*						**
22. S-PNS	6.76	**			*			**
Measurements of the basic quadrilateral and cranial polygon								
Angular measurements								
23. Br-S-Ep	1.97							
24. Br-S-N	4.08	*					**	
25.S-N-Br	5.84	**					*	**
26. S-N-Op	2.58							
27. Ba-N-F	1.80							
28. N-F-Br	3.79						**	
29. F-Br-Pa	0.15							
30. Br-Pa-L	6.23	**			**			*
31. Pa-L-Ep	14.41	**			**			**
32. L-Ep-Ba	4.04	*	*				**	
33. Ep-Ba-N	6.15	**						**
Linear measurements								
34. F-NBr	3.14					*	*	
35. Br-S	9.58	**						**
36. Br-Ep	1.71							
37. Pa-BrEp	3.07							
38. Ep-S	1.88							
39. Op-EpS	1.26							
40. Op-Ba	14.81	**	**			**	**	**
41. Op-N	10.11	**					**	**
42. Oc-Gl	10.11	**			**			**
43. Ver-OpN	7.78	**	**			**	**	
44. N-F	11.27	**	**		**	**		**
45. F-Br	3.92	*			**			
46. Br-Pa	12.81	**	*			*	**	**
47. Pa-L	12.33	**	**			**	**	*
48. L-Ep	1.06							
49. Ep-Ba	3.25				*			
50. Ba-N	3.94	*						*
51. N-Br	2.43							
52. Br-L	2.22							
53. L-Ba	5.56	**			**			*

p-value: * $p < 0.05$, ** $p < 0.01$

Finally, we assessed the variables used to evaluate the craniofacial morphology. After the evaluation through correlation analysis of the 53 craniofacial measurements and measurements of the basic quadrilateral and cranial polygon of the skulls, the correlation matrices were appropriately assessed and the relevant results were drawn (supplementary file). Most of the measurements for both sexes combined followed an akin pattern in ancient and modern Greek skulls.

Findings – Description and interpretation

The present study permits certain definite conclusions about the craniofacial morphology of the ancient and modern Greek skulls, as well as their similarities and differences. The most important finding is that the morphological pattern of ancient Greek skulls, as it changed during thousands of years, influenced by many factors, kept some characteristics unchanged, with others (e.g. cranial outline, bregmal position, angles of the nasopharyngeal triangle) undergoing logical modifications.

The findings from the comparison of the dimensions of the cranial base of the ancient (Table 4a, Fig. 2) and modern (Table 4b, Fig. 3) Greeks agree with the mainstream view that the anterior and posterior cranial base are bigger in males than in females (Cooke & Wei 1988, Urtane et al. 2004).

The cranial base angle is the same in male and female ancient Greeks, but is bigger in female modern Greeks, which is in agreement with Jotikasthira's study in Thai and Norwegian adults (Jotikasthira 1989). On the contrary, the angle S-N-Ba is greater in modern males than in females (Table 4b). A relatively similar conclusion has been reached in Greek and Finnish studies (Argyropoulos et al. 1989, Varella 1990).

The angles of the nasopharyngeal triangle Ba-S-PNS do not exhibit any differences between the two sexes and populations compared. The two sides S-PNS and S-

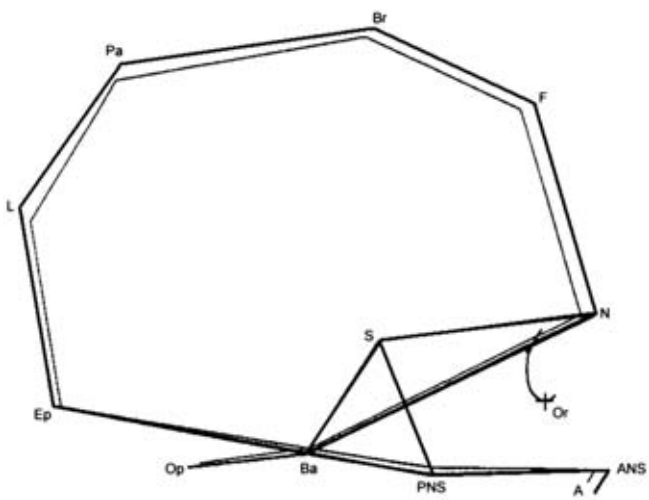

Fig. 2. Diagram showing sagittal cranial contours of mean values of ancient Greek skulls of both sexes superimposed (Nasion-Sella line as base; thick line: males, thin line: females).

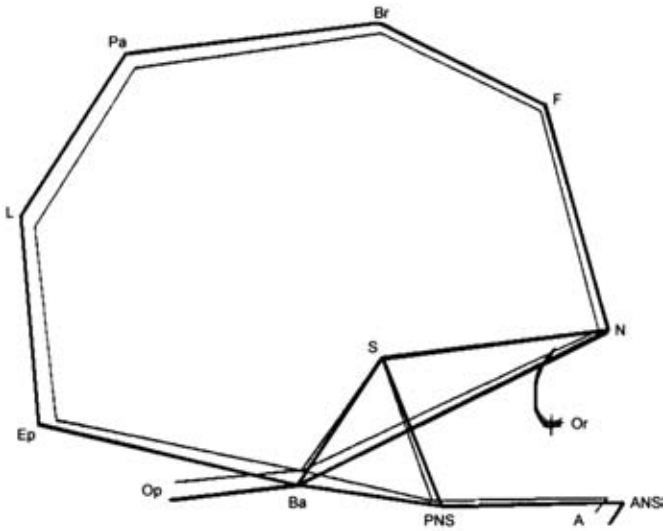

Fig. 3. Diagram showing sagittal cranial contours of mean values of modern Greek skulls of both sexes superimposed (Nasion-Sella line as base; thick line: males, thin line: females).

Ba of the triangle Ba-S-PNS are bigger in men than women, and in modern than in ancient Greeks, while the third side Ba-PNS does not exhibit any difference between the sexes in ancient Greeks, and is bigger in male than in female modern. The same distance Ba-PNS is smaller in ancient than in modern Greeks, a finding in contrast to the ascertained distance in Finns (Tables 3, 4a, 4b) (Varella 1992).

The extent of the upper jaw remains stable in ancient and modern skulls (Table 3), a finding which is in agreement with the study in Finnish, but is bigger in ancient and modern males than in females (Tables 4a, 4b) (Varela 1992). Results from a study in Chinese agree that there are sex-related differences in the maxillary base length (Cooke & Wei 1989) while for the modern Norwegian and Thai females, Jotikasthira (1989) found that modern Norwegian and Thai females have bigger upper jaw, A-PNS.

The analysis of the cranial outline, and especially the angles of the cranial polygon of the ancient Greeks, did not show any statistically significant sex differences. The angle Br-Pa-L was found to be about 130^{o}-131^{o} in modern and ancient Greeks, as the parietal curvature varies within narrow limits.

Using N-S as a reference line, we traced the outline of the skull, the distances and angles derived from the mean values of ancient Greek skulls. It was then clear that the diagram of both ancient and modern females was contained within the diagram of the males, as the statistically significant mean values of the females (Table 4a) are smaller than those of the males, except a few which do not alter the final result (Figs 2, 3). The quadrilateral N-Br-L-Ba for ancient and modern Greeks follows the same pattern.

In the diagram for modern males (Fig. 4), the cranial base angle N-S-Ba and the anterior cranial base N-S are stable, while the outline of the cranial polygon has an anti-clock-wise course in relation to ancient males, with the same observation in

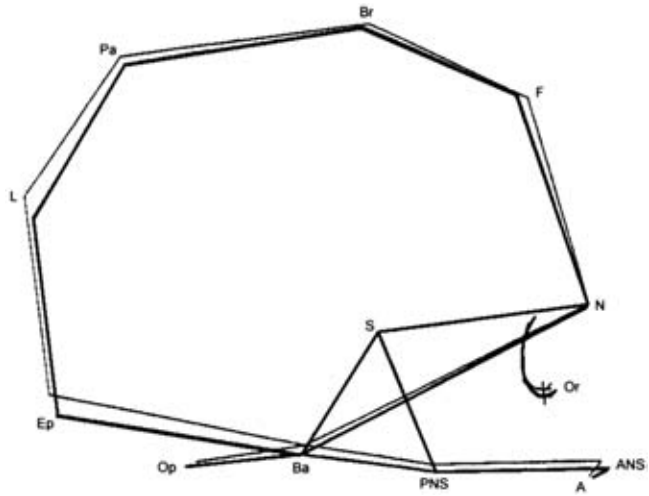

Fig. 4. Diagram showing sagittal cranial contours of mean values of ancient and modern male skulls superimposed (Nasion-Sella line as base; thick line: ancient, thin line: modern).

effect for the quadrilateral. In Fig. 5, the opposite is true between ancient and modern females, as the course and the quadrilateral are clock-wise, with only the anterior cranial base N-S stable. There was almost no difference in the upper face between ancient and modern females, despite the difference in N-S-Ba angle in modern females, while this measurement was significantly bigger in modern in comparison to ancient males (Figs 4, 5).

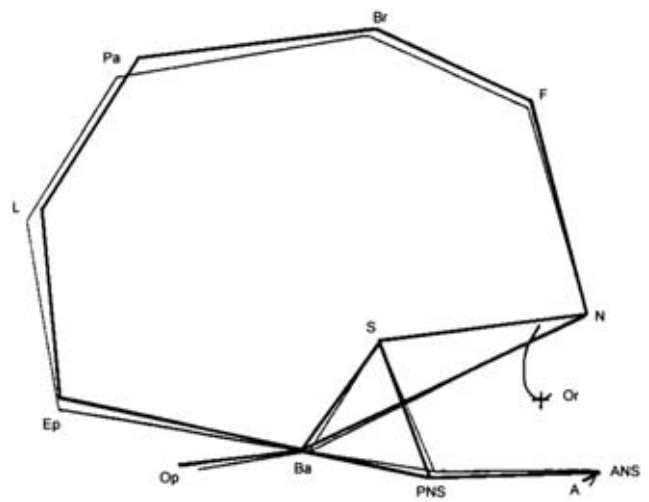

Fig. 5. Diagram showing sagittal cranial contours of mean values of ancient and modern female skulls superimposed (Nasion-Sella line as base; thick line: ancient, thin line: modern).

Finally, in Fig. 6 we observe a gradual clock-wise movement of the bregma, the parietal point and the lambda, and an upward and forward shift at the same time, in the diagrams of ancient and modern Greeks. The frontal bone, represented by the N-F-Br line, remains stable without any statistically significant difference. The parietal bone, represented by the Br-Pa-L line, alters the angular and linear measurements fluctuating the mean values significantly. The occipital bone, represented by the L-Ep-Ba line, does not alter the linear and angular mean values.

Findings – Comment

This gradual expansion of the craniofacial complex, which is accompanied by a clock-wise movement of the skull, has been identified in previous studies as a hint towards same group continuation (Papagrigorakis et al. 1988). Those bone alterations have determined the final outline of the modern skull in relation to the ancient one, with the cranial base angle N-S-Ba, the anterior cranial base N-S, and the angles of the triangle Ba-S-PNS unchanged.

An interesting finding is the bigger foramen magnum length in modern skulls. The Op has shifted upwards in modern skulls, with the Ba-SP distance and the Op-N dimension also bigger, yet with no change of their relationship to the dimension Ep-S. This remains unchanged in contrast to the external height Ver-OpN which is bigger in ancient skulls.

As has extensively been mentioned in a number of studies, the craniofacial morphology is affected by many factors, like changes in the external environment and adaptation to climatic conditions, natural selection, random genetic drift and functional factors alterations. The analysis of our results allow us to believe that, indeed,

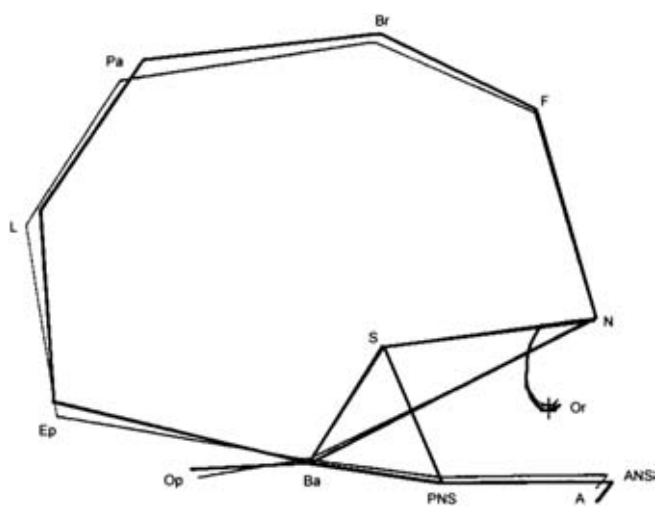

Fig. 6. Diagram showing sagittal cranial contours of mean values of ancient and modern Greek skulls superimposed (Nasion-Sella line as base; thick line: ancient, thin line: modern).

the influence upon the craniofacial complex of various factors, genetic or environmental, are apt to alter its form and adapt it to the new conditions.

Despite the fact that conventional geometric morphometrics of the upper face provide a weaker methodology in comparison to digitized techniques involving the mediolateral dimension (Jonke et al. 2008), our research work demonstrated that employment of angles and angular relationships is greatly reliable, in the way that it permits accurate comparison of patterns.

Most of the measurements for both sexes combined followed an akin pattern in ancient and modern Greek skulls. Even though the 4,000 years seems too narrow a span to provoke evolutionary insights, and of course various multicultural mixtures have taken place throughout the years, the full presentation of our results makes up a useful atlas of solid data. Interpreted with caution, the craniofacial morphology, like the paleopathological findings (Papagrigorakis et al. 2012), indicate similarity trends in modern and ancient Greeks, perhaps interpreted as elements of ethnic group continuation.

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References

Arat, M., Köklü, A., Ozdiler, E., Rübendüz, M. & Erdoğan, B. (2001): Craniofacial growth and skeletal maturation: a mixed longitudinal study. – Eur. J. Orthod. **23**, 355–361.

Argyropoulos, E., Sassouni, V. & Xeniotou, A. (1989): A comparative cephalometric investigation of the Greek craniofacial pattern through 4,000 years. – Angle Orthod. **59**, 195–204.

Bacon, W., Eiller, V., Hildwein, M. & Dubois, G. (1992): The cranial base in subjects with dental and skeletal Class II. – Eur. J. Orthod. **14**, 224–228.

Bjork, A. (1950): Some biological aspects of prognathism and occlusion of the teeth. – Acta Odontol. Scand. **9**, 1–40.

Cooke, M.S. & Wei, S.H. (1988): Cephalometric standards for the southern Chinese. – Eur. J. Orthod. **10**, 264–272.

Cooke, M.S. & Wei, S.H. (1989): A comparative study of southern Chinese and British Caucasian cephalometric standards. – Angle Orthod. **59**, 131–138.

Coon, C.S. (1939): The races of Europe. – MacMillan, New York.

Enlow, D.H. (1982): Handbook of facial growth. – W B Saunders Co, New York.

Enlow, D.H. & McNamara, J.A. Jr (1973): The neurocranial basis for facial form and pattern. – Angle Orthod **43**, 256–270.

González-José, R., Ramírez-Rozzi, F., Sardi, M., Martínez-Abadías, N., Hernández, M. & Pucciarelli, H.M. (2005): Functional-cranial approach to the influence of economic strategy on skull morphology. – Am. J. Phys. Anthropol. **128**, 757–771.

Jonke, E., Prossinger, H., Bookstein, F.L., Schaefer, K., Bernhard, M. & Freudenthaler, J.W. (2008): Secular trends in the European male facial skull from the Migration Period to the present: a cephalometric study. – Eur. J. Orthod. **30**, 614–620.

Jotikasthira, D. (1989): Variation in dentofacial morphology in Thai and Norwegian adults with ideal occlusion. – Thesis, University of Bergen.

Kiliaridis, S. (1995): Masticatory muscle influence on craniofacial growth. – Acta Odontol Scand. **53**, 196–202.

Niemitz, C. (2010): The evolution of the upright posture and gait – a review and a new synthesis. – Naturwiss. **97**, 241–263.
Papagrigorakis, M.J. & Spyropoulos, M.N. (1988): Cephalometric findings of the skull of the Petralonean man. – Anthropol. Anal. **49**, 47–53.
Papagrigorakis, M.J., Karamesinis, K.G., Daliouris, K.P., Kousoulis, A.A., Synodinos, P.N. & Hatziantoniou, M.D. (2012): Paleopathological findings in radiographs of ancient and modern Greek skulls. – Skeletal Radiol. 41, 1605–1611.
Park, M.S., Nguyen, A.D., Aryan, H.E., U, H.S., Levy, M.L. & Semendeferi, K. (2007): Evolution of the human brain: changing brain size and the fossil record. – Neurosurgery **60**, 555–562.
Rae, T.C., Vidarsdóttir, U.S., Jeffery, N. & Steegmann, A.T. (2006): Developmental response to cold stress in cranial morphology of Rattus: implications for the interpretation of climatic adaptation in fossil hominins. – Proc. Biol. Sci. **273**, 2605–2610.
Ranly, D.M. (2000): Craniofacial growth. – Dent. Clin. N. Am. **44**, 457–470.
Slomic, A.M., Bernier, J.P., Morissette, J. & Azouz, E.M. (1990): A craniometric study of the C. de Lange syndrome (CdLS). – J. Craniof. Gen. Dev. Biol. **10**, 125–133.
Solow, B. & Tallgren, A. (1976): Head posture and craniofacial morphology. – Am. J. Phys. Anthropol. **44**, 417–435.
Strait, D.S. (2001): Integration, phylogeny, and the hominid cranial base. – Am. J. Phys. Anthropol. **114**, 273–297.
Striedter, G.F. (2006): Précis of principles of brain evolution. – Behav. Brain Sci. **29**, 1–12.
Stringer, C.B. (1990): The emergence of modern humans. – Sci. Am. **263**, 98–104.
Urtane, I., Jakobsone, G. & Pugaca, J. (2004): Dentofacial Morphology of Class II Division 1. – Stomatologija **6**, 3.
Varella, J. (1990): Effects of attritive diet on craniofacial morphology: a cephalometric analysis of a Finnish skull sample. – Eur. J. Orthod. **12**, 219–223.
Varella, J. (1992): Dimensional variation of craniofacial structures in relation to changing masticatory-functional demands. – Eur. J. Orthod. **14**, 31–36.
Wilder, H.H. (1920): A laboratory manual of anthropometry. – Blakiston, Philadelphia.
Young, M. (1917): A contribution to the study of the Scottish skull. – Trans. Roy. Soc. Edinburgh **51**, 347–454.

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