VERIFIABLE CPD PAPER

IN BRIEF

- This paper shows changes in the form and size of the skull and jaws over a period of 676 years.
- Cranial vault measurements increased by 10 mm between the fourteenth and twentieth centuries.
- The face has become more retruded in relation to the forehead.

A cephalometric comparison of skulls from the fourteenth, sixteenth and twentieth centuries

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Objectives To evaluate changes in the size and shape of the skull and jaws in British populations between the thirteenth and twentieth centuries.
Method Lateral cephalometric radiograms were obtained from skulls of three groups of subjects: 30 skulls were from the remains of those who died in the London Black Death epidemic of 1348, 54 skulls were recovered from the wreck of the Mary Rose which sank in 1545 and 31 skulls were representative of modern cephalometric values.
Results Horizontal measurements in the base of the anterior cranial fossa and in the maxillary complex were greater in the modern group than in the medieval skulls. Cranial vault measurements were significantly higher (P = 0.000) in the twentieth century skulls, especially in the anterior cranial fossa.
Conclusion Results suggest that our medieval ancestors had more prominent faces and smaller cranial vaults than modern man.

INTRODUCTION

This study describes comparisons between cephalometric radiograms from three groups: two groups of medieval skulls and a representative sample from a modern population. Similar studies have been attempted before but this one has the added interest that the medieval skulls were from two groups of subjects who died together at very specific times and as a result of remarkable events in English history.

The oldest skulls were excavated in the 1980s during building works in London, adjacent to Spitalfields and at the site of the Royal Mint. During the course of these works burial pits were uncovered which contained the remains of victims of bubonic plague – the Black Death – which killed between a third and a half of the London population in 1348 and 1349.[1,2]

The second group of skulls were recovered from the wreck of the Mary Rose, the pride of Henry VIII's fleet, which capsized and sank just outside Portsmouth harbour on 19 July 1545.

The third group of radiograms were selected from amongst orthodontic records at the Birmingham Dental Hospital as representing 'normal' cephalometric values for a modern population of young adults.[3]

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Previous studies that have attempted to investigate craniofacial and dental changes over the centuries have reported a trend towards smaller jaws in modern man. A Swedish study based on 124 skulls from the 500 years preceding the seventeenth century found that the medieval skulls had somewhat smaller teeth and brain cases but larger jaws and wider dental arches than those of a modern population.[4] Other trends that have been reported include a reduction in palatal width between the Romano-British period and the nineteenth century[5,6] and reductions in bi-zygomatic and maxillary widths between the twelfth and nineteenth centuries.[7]

Mandibular dimensions appear to have reduced from medieval times to the seventeenth century.[8] The changes are particularly noticeable in areas of muscle attachments, suggesting a functional causation.[9] Lavelle in 1972[10] reported a reduction in mandibular dimensions between the first and nineteenth centuries and suggested that diet and evolution may be amongst the factors responsible.

Studies based on archaeological material consistently report a low prevalence of malocclusion. Factors that have been thought to be responsible for this include diet, attrition and muscle function.[5,8,9] The suggestion that extensive attrition produced by chewing a coarse diet could greatly reduce dental crowding was central to the theories of Begg (1954)[11] when he devised a new orthodontic appliance system and the technique that bears his name. It has been suggested that approximal attrition could reduce buccal segment length by 3.5 mm and therefore create additional space for the teeth.[12] Lack of accurate information regarding the medieval diet creates problems in relating the coarseness and abrasivity of food to dental and jaw growth effects. It is clear however that bread was the staple food of many and that the grain from which it was made varied from place to place.[13]

A possible relationship between facial growth and muscle size or activity has been suggested by several studies using human subjects[14-20] and the hypothesis that jaw size may be affected adversely by reduced mastication has been supported by the results of animal experiments.[21,22] Others have cast doubt on the muscle-exercise theory, considering that normal jaw growth would proceed over a wide range of activity and that only an altogether exceptional degree of lack of use might affect it.[23]

Head posture may also play a part in facial development, since the position of the head in relation to the cervical column is related to craniofacial morphology.[24,25] A more extended head position is related to facial retrognathism and a small nasophryngeal space.

Fig. 1 A Black Death skull

Fig. 2 Side view of Black Death skull

AIM OF THE STUDY

The aim of the investigation was to compare cephalometric measurements taken from three groups of skulls dating from the fourteenth, sixteenth and twentieth centuries respectively and to look for associations with factors that might explain any differences between them.

MATERIALS AND METHODS

The study was based upon measurements taken from 115 cephalometric radiograms. Thirty were obtained from skulls of victims of the Black Death, recovered during excavations at three sites known to be London plague pits: the Royal Mint site, Spital Square and Norton Folgate. These sites were uncovered and excavated in the 1980s.[26,27] Plague raged in the City of London during the autumn of 1348 and throughout 1349; the present skulls have been confidently dated to that time. Approximately 600 skeletons were uncovered but only the 30 skulls included here were sufficiently complete to satisfy the inclusion criteria given later.[5] Some were remarkably well preserved (Figs 1 and 2). Those excluded were damaged, with bones disarticulated and mandibles or many teeth missing. Such damage may have been partly due to the fact that many bodies, especially at the Royal Mint Site, were flung haphazardly into the pits without coffins and partly due to the haste with which they were excavated towards the end of the twentieth century to prevent delay in building works.

The Mary Rose sank in 1545 and material recovered from the wreck can be dated with absolute certainty. Based on a skull and mandible count the remains of 179 persons were recovered; from these it was possible to match 54 skulls and mandibles in a way that satisfied inclusion criteria. In general the Mary Rose skulls were in better condition than the Black Death group due to their anaerobic burial in the seabed sediment and the care with which they were recovered.

Skulls and mandibles from both archaeological groups were matched according to three criteria:

- The colour match of the skull and mandible. Adjacent Black Death bones tended to absorb pigment from the surrounding soil and colours ranged from light to dark brown or black (Figs 1 and 2). Many of the Mary Rose group were as white as anatomical display bones (Figs 3 and 4).
- Fit of the condyle heads in the glenoid fossae; at least one condyle and its respective articular fossa had to be intact.
- The articulation of the teeth. There were no hard and fast rules as to the minimum number of teeth that had to be present, although it had to be possible to place the mandible in correct occlusion.

The 31 cephalograms in the modern group were taken from records stored at The University of Birmingham, School of Dentistry as representative of a modern group of young adults according to accepted standard cephalometric values.[3]

Ageing the skulls

The dates of death were known very closely for both medieval groups but the ages of the subjects at death were not known. The ages of the modern group were known from hospital records. For the archaeological material a minimum age was set by the requirement that second molars should be fully erupted. This is in line with other studies that have compared skulls from different eras.[28,29] An attempt was then made to allocate an age at the time of death based on molar wear.[30] This method has been validated by checking tooth wear in several early British groups against closure of the pubic symphysis, showing that wear rates did not change greatly from Neolithic to Medieval times . Tooth wear is measured by the areas of dentine exposed by wear on the occlusal surfaces of the three lower molar teeth in a quadrant (Fig. 5). Before the seventeenth century it was unusual for an individual to retain teeth beyond the age of 45 years.[30]

Sexing the skulls

Although males tend to have more robust skulls than females, more accurate estimation depends upon five aspects of skull morphology:[31]

- Prominence of the nuchal crest
- The volume of the mastoid process
- Prominence of the supraorbital margin
- Prominence of the glabella in the midline between the supraorbital ridges
- Projection of the mental eminence.

Radiography of the skulls
Lateral cephalograms were taken in a portable cephalostat, with the skulls mounted upside down to facilitate articulation of the mandible. The Frankfort plane was aligned to the horizontal. A scale was incorporated to allow calculation of the magnification factor. Eleven standard cephalometric points were digitised for direct recording into the GELA Program version 1.24.[32] These were S, N, A, B, Ba, ANS, PNS, Go, Gn, Me and Cd.

Radiograms of the Modern Group lacked part of the occipital area of the cranium due to the practice of collimating the X-Ray beam on modern machines. In order to permit calculation of cranial dimensions three additional constructed points were recorded on the calvarium outline of each film. These were points on the skull intersected by lines at 45° anteriorly, vertically and 45° posteriorly to the SN plane, based on Sella.

Two fiducial points at the lower left corner of each film were used to check the accuracy of digitisation. Entries more than 0.1 mm from each fiducial point were not accepted by the GELA program.

The following angular and linear measurements were calculated by the GELA program (Figs 6 and 7):

SNA	-	The relationship of the maxilla to the anterior cranial fossa
SNB	-	The relationship of the mandible to the anterior cranial fossa
ANB	-	Maxillary – mandibular base discrepancy
N-S-Ba	-	Cranial base saddle angle
Max-MP	-	Maxillary – mandibular planes angle
S-N	-	Anterior cranial base length
S-Ba	-	Posterior cranial base length
N-Ba	-	Total cranial base length
ANS-PNS	-	Maxillary length
A-Cd	-	Midfacial length
Go-Gn	-	Mandible body length
Cd-Go	-	Mandible ramus length
Cd-Gn	-	Total mandible length
N-A	-	Upper anterior face height (UAFH)
A-Me	-	Lower anterior face height (LAFH)
N-Me	-	Total anterior face height (TAFH)
LFH%	-	Lower facial height proportion
S-CVa	-	Anterior cranial height
S-CVb	-	Middle cranial height
S-CVc	-	Posterior cranial height.

Statistical analysis
ANOVA was carried out for each cephalometric measurement with era as the model. When ANOVA suggested statistical difference for a measurement, post-hoc T-Tests were used to confirm the source of the between-group difference. A post-hoc power calculation was carried out to test whether the sample was large enough to support conclusions on the basis that a 5% increase in a skull dimension would be considered clinically relevant.

Reproducibility studies
The reliability of the ageing and sexing methods was tested by assessing 15 skulls on two occasions at an interval of one month. Digitisation accuracy was checked by measuring 20 cephalograms on two separate occasions, again one month apart. Results were cross-tabulated to allow calculation of Kappa values.

RESULTS
Sample size
The average of the three cranial vault measurements was 100.4 mm, 10% of this being 10 mm. The average standard deviation was 4.5 mm. Taking 5 mm as a clinically relevant difference produces a standardised difference of 5/4.5 = 1.1, which suggests a sample size of 26, 13 in each group, to support

Fig. 3 A Mary Rose skull

Fig. 4 Side view of Mary Rose skull

Fig. 5 A quadrant of teeth from the Mary Rose, showing occlusal wear

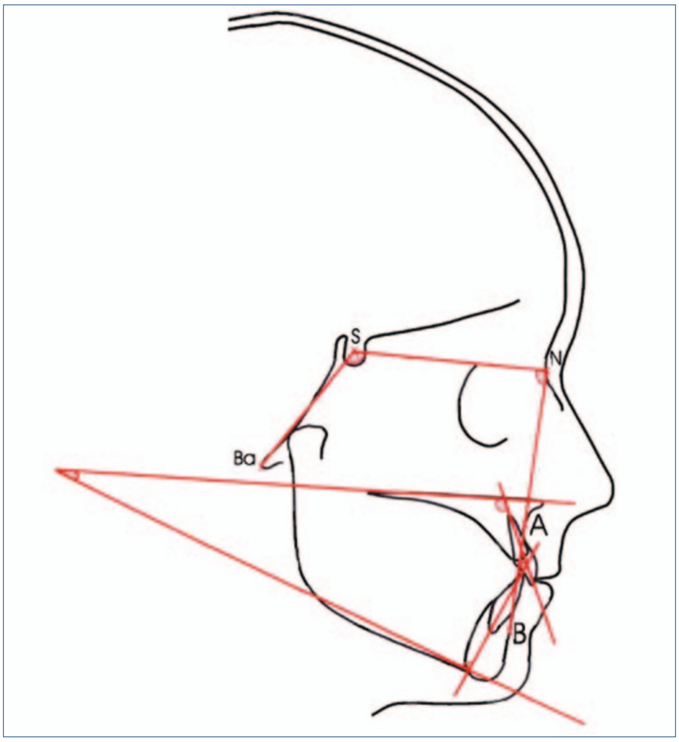

Fig. 6 Angular cephalometric measurements

Table 1 The distribution of the sample by age and sex					
Era	Number	Sex		Age	
		Male	Female	17–24	Over 24
1348	30	13	17	11	19
1545	54	53	1	29	25
1992	31	16	15	31	0

Table 2 Group means and results of inter-group ANOVA for angular cephalometric values

Value	Era	Mean	SD	ANOVA Results For Era F	P	Reasons For Era difference
SNA	1 2 3	80.92 83.79 83.42	1.89 3.55 3.83	8.03	0.001	Mod low
SNB	1 2 3	78.27 79.83 79.73	2.03 4.12 4.25	2.22	NS	NS
ANB	1 2 3	2.62 3.80 3.69	1.18 3.23 2.98	1.93	NS	NS
NSBa	1 2 3	130.80 130.56 132.57	6.72 4.83 4.20	1.50	NS	NS
MMPA	1 2 3	26.12 20.81 22.23	6.22 6.55 4.62	7.76	0.001	Mod high

Era: 1 = Modern
2 = Mary Rose
3 = Black Death

statistical significance at 95% with 80% power according to Altman's nomogram.[33]

Reproducibility studies

Crosstabulation of the first and second assessments for age and sex produced Kappa values of 0.80 and 0.73 respectively. A weighted Kappa was used to assess agreement of the first and second scoring of tooth wear, since this allows for both full and partial agreements.[34] Kappa was 0.94.

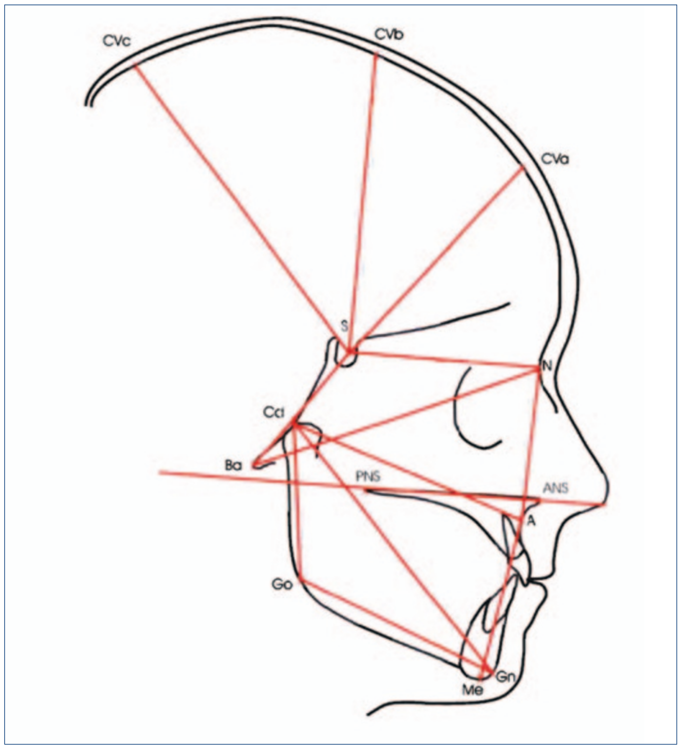

Fig. 7 Linear cephalometric measurements

MAIN STUDY

The distribution of subjects by age and sex in each of the three groups is shown in Table 1. Table 2 shows summary statistics and the results of ANOVA testing for angular cephalometric values. The confidence limits indicate the factor or factors responsible for a significant P value and these are identified in the last column. SNA was lower and MMPA was significantly higher in the modern group than in either medieval group. Angles SNB, ANB and NSBa were similar in the three groups

Five mean linear measurements relating to the anterior cranial fossa and the facial skeleton were significantly higher in the modern group than in either of the two medieval groups, these were S-N, S-Ba, ANS-PNS and A-Cd (Table 3). Cd-Go was high in the Mary Rose skulls and LFH% was low in the modern group The three measurements of calvarium height based on S were all significantly greater in the modern skulls than in the medieval ones. Especially for the vertical and anterior cranial fossa measurements the differences were considerable. Mean S-CVb was 10 mm greater in the modern group than in the other two groups. Mean S-CVa was 10.5 mm greater in the modern group than in the Mary Rose group, the mean value of which was 3.72 mm greater than for the Black Death skulls.

DISCUSSION

It is reasonable to accept that data taken from the modern group are representative of young Caucasian adults from a twentieth century British population, since the subjects were selected on that basis and published cephalometric measurements confirm this premise.[3] The provenance of the two medieval groups is less certain, however a power calculation based upon a clinically relevant difference of 5 mm for calvarium measurements has shown that numbers were large enough to support the conclusions.

What is beyond doubt is that the medieval material is truly remarkable since it represents two groups of skulls from individuals who died as a result of historically recorded disasters. The Black Death victims met their deaths in late 1348 and early 1349 and the Mary Rose sank on 15 July 1545, watched by Henry VIII. The two groups are therefore dated with great precision and represent 676 and 459 years of English history respectively. If a generation is taken as 20 years, which is probably a reasonable average between medieval times and the present day, the Black Death skulls are separated from the people of today by 33 generations and those of the Mary Rose crew by 23 generations.

Sex determinations show a reasonable balance in the Modern and Black Death groups, supporting the 'random' nature of the latter. According to the criteria used, one of those aboard the Mary Rose was a woman. Not surprisingly the other Mary Rose skulls were all identified as male and would therefore have tended to be larger than the skulls in the other groups where there were close balances between the sexes. This affects interpretation of linear measurements but not of angles.

Angle SNA was significantly lower in the modern group than in the two medieval groups, suggesting that our forefathers had rather more prominent mid faces than is the case today.

There is a clear trend for horizontal linear measurements in the base of the anterior cranial fossa and in the maxillary complex to be greater in the modern group than in the medieval groups, with mean differences ranging from 2-6 mm. However, the differences between the calvarium sizes in the modern group and in the other two groups are more striking. To allow for the fact that the occipital part of the skull outline was sometimes missing on the cephalogram, three measurements were taken, each based on S. One was vertical (S-CVb), while the others were at 45° forwards (S-CVa) and backwards (S-CVc). The mean values of both SCVa and b were around 10 mm greater in the modern group than in the medieval groups. For S-CVa, the measurement that is most representative of the anterior cranial fossa, there were significant differences between all three groups with size increasing through the ages. The anterior cranial fossa houses the frontal lobe of the brain, the great development of which is often held to be the major distinction between the human race and other primates. In particular the prefrontal areas are concerned with intellect[35] and the increased intracranial dimensions and high foreheads of the modern group are evidence that brain size has increased over the centuries.

Table 3 Group means and results of inter-group ANOVA for linear cephalometric values

Value	Era	Mean	SD	ANOVA Results For Era F	P	Reason For Era difference
S-N	1	69.05	3.88	13.11	0.000	Mod high
	2	65.31	3.13			
	3	64.69	4.44			
S-Ba	1	45.04	3.57	4.88	0.01	Mod high
	2	42.92	2.60			
	3	42.76	4.14			
N-Ba	1	104.04	5.82	9.85	0.000	Mod high
	2	98.70	4.81			
	3	98.75	6.94			
ANS-PNS	1	52.51	3.23	8.40	0.000	Mod high
	2	50.44	2.96			
	3	49.30	3.31			
A-Cd	1	88.18	5.01	5.39	0.01	Mod high
	2	85.88	4.10			
	3	84.45	4.54			
Go-Gn	1	70.55	5.45	2.89	NS	NS
	2	72.03	3.72			
	3	73.40	5.17			
Cd-Go	1	57.37	6.08	12.71	0.000	MR high
	2	61.27	4.06			
	3	56.22	4.63			
Cd-Gn	1	115.15	8.42	1.99	NS	NS
	2	113.86	5.00			
	3	111.88	6.52			
LFH%	1	53.85	2.56	7.84	0.001	Mod low
	2	55.74	2.06			
	3	56.00	2.10			
S-CVa	1	95.97	4.82	108.81	0.000	Mod>MR>BD
	2	84.51	4.11			
	3	80.79	3.94			
S-CVb	1	104.33	4.41	54.89	0.000	Mod high
	2	94.81	4.85			
	3	94.02	3.71			
S-CVc	1	120.82	5.09	19.40	0.000	Mod high
	2	115.30	4.97			
	3	112.84	5.64			

Era: 1 = Modern
2 = Mary Rose
3 = Black Death

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