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Dissection study and mensuration of the human aortic arch

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INTRODUCTION

In pursuance of other research concerning the haemodynamics of the human aortic arch, it became necessary to know accurately certain dimensions of the arch. Such dimensions are not available in standard anatomical texts; descriptions, and the few dimensions that may be quoted, seem to refer to specimens examined after treatment with preservatives. A detailed dissection study of fresh material has therefore been undertaken; measurements of the aortic arch, and observations on its general configuration and the disposition of the great vessels arising from it, are documented as being of possible value to future work.

MATERIAL

One hundred fresh cadaver specimens of the proximal aorta, obtained from the post-mortem room of a large general hospital, have been examined. As far as possible, dissection was made within 24 h of death; in many cases the time interval was considerably less. Two techniques have been employed:

(1) Fifty specimens were dissected, and direct measurements of the lumen of the aorta made at several levels; measurements were also made of the ostia and of the lumina of the main branches of the aorta. The circumference ($2\pi r$ or πd) was measured at each site, and assuming that the lumen was approximately circular, simple calculation gave an 'estimated' diameter. Thus, two values were obtained for each point of measurement, and from these a mean value.

(2) A cast was made of fifty specimens by filling the aortic segment and its branches with a quick-setting paraffin wax. The cast was then sectioned and measurements taken at selected points.

The two techniques were used in an attempt to ensure that the measurements were accurate, as might be assumed if the values obtained from the two series of specimens were in agreement. Such agreement existed, and the values given below are based on the total of 100 examinations.

RESULTS

The sites at which measurements were made are shown in Fig. 1 and the corresponding values are given in Table 1. Possible differences in dimensions due to sex or age were considered, and analyses were made to account for these two factors, which are discussed in greater detail later.

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Sex. The specimens examined were obtained from 56 male and 44 female corpses; a *t* test was applied to the data, and the results are given in Table 2. On the whole, dimensions in male subjects were greater than in female subjects, but the differences between those in the two sexes were not statistically significant (except in the case of R_2, the diameter of the innominate artery measured at 15 mm from its origin).

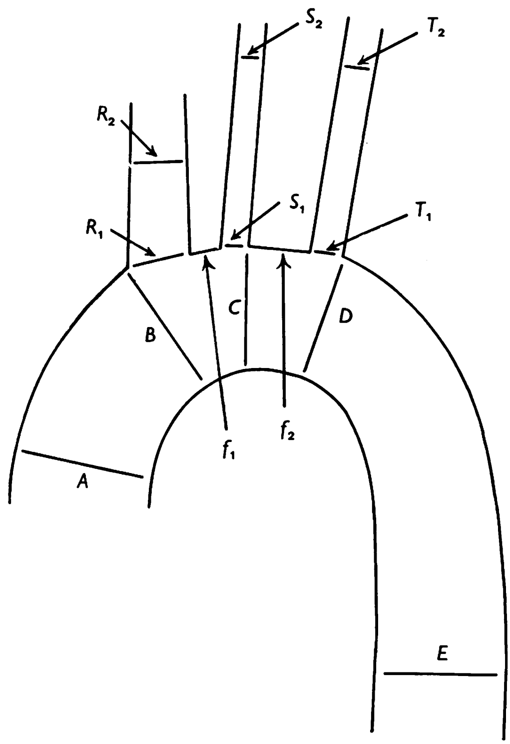


Fig. 1. Diagram of the aortic arch and main branches, showing sites at which measurements were made (see also Table 1).

Age. Subjects up to the age of 54 years were designated as 'young' and those of 55 years and over as 'old'. Thus, there were twenty-six specimens from 'young' subjects (mean age = 37·5 years) and seventy-four from 'old' subjects (mean age = 69·5 years). A *t* test was applied to the data, and the results are given in Table 3. The dimensions of the aortic arch and of its main branches were less in the younger age group, the differences between the two age groups being greater in the case of the aorta than in the case of its branch vessels.

Other findings

Apart from the actual measurements given in Table 1, certain other features were noted in the course of the dissections.

Table 1. *The measurements of diameters of the human aortic arch and its branches at multiple sites*

Site of measurement	A	B	C	D	E	R_1	R_2
Mean S* ± s.d.	24·5 ±0·76	23·0 ±1·37	20·5 ±4·06	19·5 ±2·53	19·0 ±1·14	12·5 ±1·25	9·5 ±0·76
Site of measurement	S_1	S_2	T_1	T_2	f_1	f_2	
Mean S* ±s.d.	7·5 ±2·09	5·5 ±1·30	10·0 ±2·15	7·5 ±1·05	3·0 ±1·40	7·0 ±4·12	

* Mean $S \pm$s.d. = mean value in millimetres (corrected to the nearest 0·5 mm) ± one standard deviation.

A = Ascending aorta *c.* 25 mm proximal to the origin of the innominate artery.
B = Proximal to the origin of the innominate artery.
C = Distal to the origin of the left common carotid artery.
D = Distal to the origin of the left subclavian artery.
E = Descending aorta *c.* 60 mm distal to the origin of the left subclavian artery.
R_1 = Origin of the innominate artery.
R_2 = *c.* 15 mm distal to R_1: this distance was slightly variable; the innominate artery is usually quoted as being 40–50 mm in length, but it was found frequently to be shorter and sometimes slightly dilated proximal to its bifurcation; 15 mm distance from origin was selected as a point representative of its average lumen.
S_1 = Origin of the left common carotid artery.
S_2 = 30 mm distal to S_1.
T_1 = Origin of the left subclavian artery.
T_2 = 30 mm distal to T_1.
f_1 = Distance between the adjacent margins of R_1 and S_1.
f_2 = Distance between the adjacent margins of S_1 and T_1.

Table 2. *The measurements of diameters of the human aortic arch and its branches in the two sexes*

	Male subjects			Female subjects				
Site of measurement	Mean S	(±s.d.)*	(Total)†	Mean S	(±s.d.)	(Total)	t	P‡
A	24·0	±4·87	42	24·5	±5·57	31	0·209	> 0·500
B	23·0	±3·33	51	22·0	±4·17	41	0·168	> 0·500
C	20·0	±6·84	56	20·5	±4·90	42	0·458	> 0·500
D	19·5	±2·46	56	18·5	±4·59	44	2·201	< 0·050, > 0·025
E	19·0	±3·88	54	18·5	±4·02	42	1·289	< 0·400, > 0·200
R_1	12·5	±3·99	56	12·0	±4·16	42	0·854	< 0·400, > 0·200
R_2	10·0	±1·17	50	9·0	±1·94	44	2·923	< 0·005, > 0·001
S_1	7·5	±2·20	55	7·5	±1·96	44	0·354	> 0·500
S_2	5·0	±1·73	51	5·5	±0·36	43	0·797	< 0·500, > 0·400
T_1	10·0	±2·49	55	9·5	±1·65	43	0·419	> 0·500
T_2	7·5	±0·84	50	7·0	±1·19	43	2·543	< 0·025, > 0·010
f_1	3·0	±1·20	46	3·0	±1·65	36	0·306	> 0·500
f_2	6·0	±3·97	48	7·0	±4·31	37	0·987	< 0·400, > 0·200

* Mean $S \pm$s.d. = mean value in millimetres (corrected to the nearest 0·5 mm.) ± one standard deviation.
† Total number of observations in each group.
‡ P = probability value; P equal to, or less than, 0·010 considered to be significant.

Common origin of innominate and left common carotid arteries

In seven cases in this series (i.e. 7 %) a common origin of these major vessels was noted. Piersol (1906) and Gray (1962) both state that this is the commonest variation found in the origins of the large branches of the arch, but they do not state incidence or dimensions. The arrangement resembles that found normally in the dog (Bradley, 1948) and other mammals. In this study, the diameter of the common ostium measured 14·5 mm (mean $S \pm$ S.D. = 2·97). The distance from the origin to the

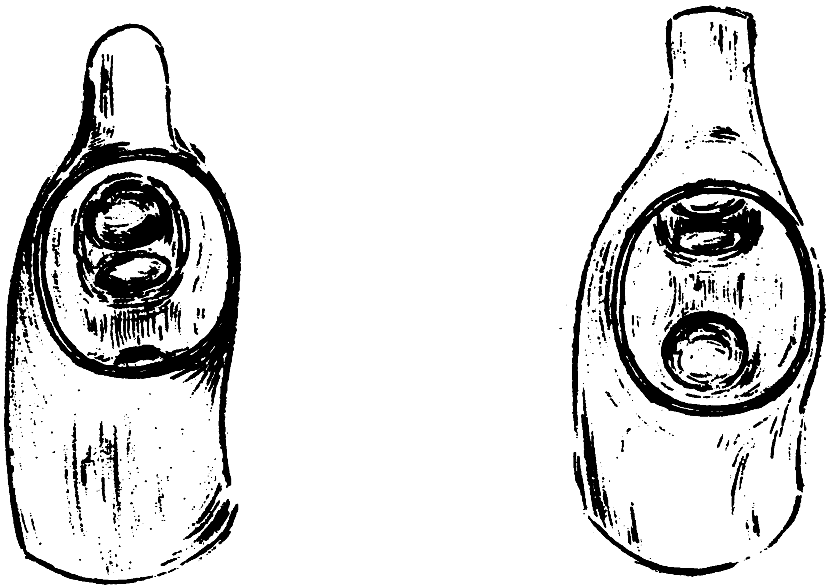
Table 3. *The measurements of diameters of the human aortic arch and its branches for different age groups*

Site of measurement	Young subjects			Old subjects				
	Mean S	($\pm$S.D.)*	(Total)†	Mean S	($\pm$S.D.)	(Total)	t	P‡
A	20·5	±3·64	20	25·5	±3·17	53	5·351	< 0·001
B	19·0	±1·28	25	23·5	±3·59	67	6·037	< 0·001
C	17·0	±3·29	26	20·5	±3·84	72	4·146	< 0·001
D	17·0	±2·72	26	20·0	±1·39	74	9·635	< 0·001
E	16·0	±2·42	26	20·0	±1·25	70	6·957	< 0·001
R_1	11·0	±2·71	26	12·5	±2·28	72	2·448	< 0·025, > 0·010
R_2	8·5	±3·83	26	9·5	±0·58	68	2·831	< 0·010, > 0·005
S_1	7·0	±0·49	26	8·0	±2·41	73	1·092	< 0·400, > 0·200
S_2	5·0	±0·86	26	5·5	±1·42	68	1·189	< 0·400, > 0·200
T_1	8·5	±1·36	26	10·0	±2·26	72	3·033	< 0·005, > 0·001
T_2	6·5	±1·18	25	7·5	±0·86	68	4·478	< 0·001
f_1	3·0	±1·26	20	3·0	±1·45	62	0·798	< 0·500, > 0·400
f_2	7·0	±4·04	21	7·0	±4·17	64	0·493	> 0·500

* Mean $S \pm$S.D. = mean value in millimetres (corrected to the nearest 0·5 mm) ± one standard deviation.
† Total number of observations in each group.
‡ P = probability value; P equal to, or less than, 0·010 considered to be significant.

division into the two main arteries measured 10·0 mm (mean $S \pm$ S.D. = 1·07); this division viewed from the interior presented a sharp carina-like edge, measuring approximately 1·5 mm, representing about the least width possible considering the thickness of the walls of the vessels.

Where an ostium and parent trunk existed, the ostium was more or less circular; ordinarily, however, with separate innominate and left common carotid arteries and separate ostia, these two vessels still tended to merge together (again showing similarity to the dog) into a common elliptical origin, the innominate artery forming the proximal and more nearly circular ostium and the left common carotid a crescentic, elliptical, or sometimes slit-like opening (Fig. 2). Whether these openings have their configuration in the living is uncertain, and further work may be directed to elucidate this point; it is possible that with each ventricular ejection they conform more nearly to a circular shape, although this would not necessarily facilitate filling. (For the sake of uniformity, in making the measurements recorded here, each branch ostium or luminal section was deformed, when necessary, to a circular outline, and this point should be borne in mind in interpreting these results.)



A B

Fig. 2. Drawings made during dissections to show the interior of the aortic arch viewed from the cardiac (proximal) end. A, Tilted to show the ostia of the innominate and left common carotid arteries. Note: the elliptical orifice common to both vessels with a narrow carina between them; the ostium of the left common carotid is, in this case, also elliptical. B, Tilted slightly, in opposite direction, to show mainly the ostium of the left subclavian artery. Note: the wide 'bridge' between the left common carotid and left subclavian; the ostium of the latter is usually rounded as shown in this case.

Distances between the ostia of the major branches of the arch

Gray (1962) states that the distances between the major branches may be increased or diminished, the most frequent change in this respect being an approximation of the left common carotid artery to the innominate artery. This fact has been borne out in the present study, in which the mean value for the distance between the innominate and left common carotid arteries (f_1) was 3·0 mm (mean $S \pm$ S.D. = 1·40), and for the distance between the left common carotid and left subclavian (f_2) 7·0 mm (mean $S \pm$ S.D. = 4·12). (In 83 cases in which measurements were made, f_2 was greater than f_1 in 69 cases (83·13 %); f_2 was equal to f_1 in 7 cases (8·43 %); f_1 was greater than f_2 in 7 cases (8·43 %). A common finding on inspection within the aorta is shown in Fig. 2; the space between the innominate and left common carotid arteries (f_1) is small, sometimes extremely narrow, and usually presenting as a carina to the bloodstream. The space between the left common carotid and left subclavian arteries (f_2) presents more like a 'bridge', although frequently slightly tilted so that the proximal edge (formed with the distal margin of the ostium of the left common carotid) also resembles a carina towards the bloodstream, the tilt of the 'bridge' sloping gently away to the ostium proper of the left subclavian (Fig. 3). This arrangement should facilitate filling of these major vessels from the fast-flowing main stream of arterial blood passing their ostia.

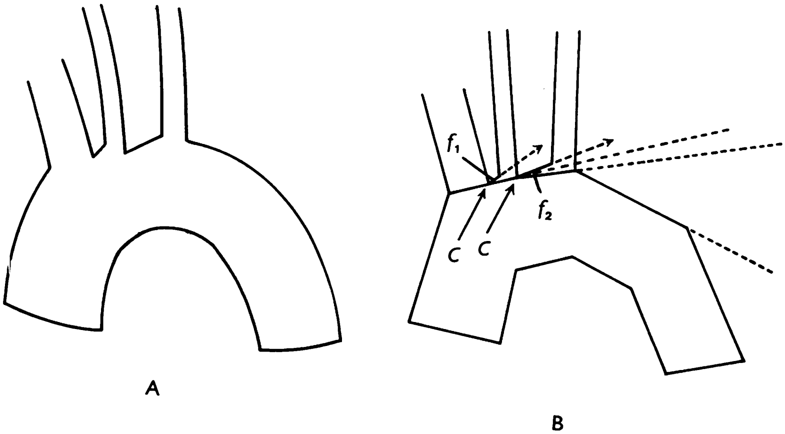


Fig. 3. A, Line drawing made directly from a specimen during a dissection. B, Diagram constructed from A to emphasize: (1) The tendency to the formation of carinae at C, C, due to (2) the tilt of f_1 and f_2; (3) the gradual reduction in diameter of the aorta proximo-distally, progressively 'stepping down'.

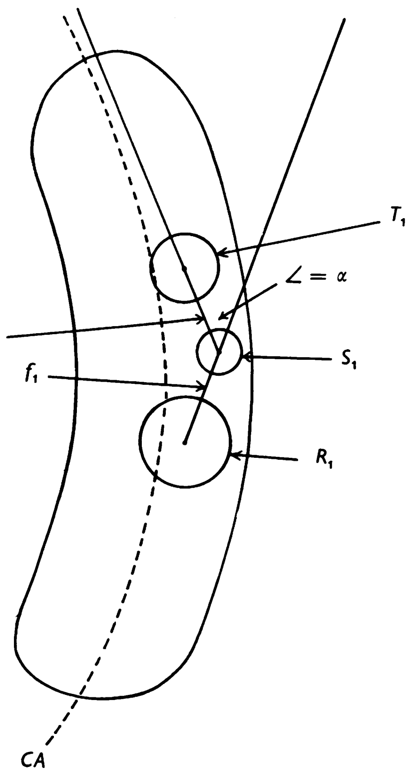


Fig. 4. Diagram of the 'secondary' curvature (i.e. convex anteriorly) of the aortic arch viewed from above. The broken line CA represents the central axis of the curve. The ostia of the three major branches, R_1, S_1 and T_1, and the angle α formed between S_1 and T_1, as described in the text, are shown.

Origins of the three major branches

Figure 4 shows a common finding which may be of haemodynamic significance. The three major ostia are situated on the apical segment of the aortic arch, but it should also be noted that these positions tend to lie anterior to the central axis of the curve. In addition, if a line is projected through the centre points of the origins of the innominate (R_1) and the left common carotid (S_1) arteries (which appear often to have a common axis), and a second line is projected through the centre points of the origins of the left common carotid (S_1) and left subclavian (T_1) arteries, the second line is found to be angled to the first. This angle (α) is greater in most cases than might be expected if the relative locations of the ostia conformed with the natural 'secondary' (i.e. convex anteriorly) curvature of the arch. The phenomenon was noted in forty-seven of fifty-three specimens specifically examined. Measurements were made in twenty-six specimens. The value of angle α was 39° (mean $S \pm$ S.D. = 11·85).

An additional branch artery

In eight cases in this series (i.e. 8 %) a small artery was noted having its origin from the arch between the left common carotid and left subclavian. Presumably this vessel was the thyroidea ima artery, although circumstances did not permit dissection of its course and precise determination of its distribution. This vessel could also have represented an atypical inferior thyroid artery (ordinarily a branch of the thyro-cervical trunk) or an aberrant bronchial or internal thoracic (mammary) artery, although the latter two possibilities were unlikely considering the direction of the proximal segment available to dissection.

The dimensions of this additional vessel were : ostium = 2·5 mm (mean $S \pm$ S.D. = 1·00); luminal diameter = 1·5 mm (mean $S \pm$ S.D. = 0·22), measured at 30 mm from its origin. In all cases in which this artery was present, the 'bridge' (f_2) between the left common carotid and left subclavian arteries was greater (mean S = 12·5 mm ± S.D. = 3·39) than the mean for the series (mean S = 7·0 mm ± S.D. = 4·12). The origin of the additional vessel was usually closer to the left subclavian than to the left common carotid, and sometimes the origin was actually from the root of the left subclavian, or almost so.

Sizes of the common carotid and left subclavian arteries

The left subclavian is an appreciably larger vessel than the left common carotid, as is evident from the measurements of the diameters of their ostia, and of their lumina at 30 mm from their origins. At first sight this might seem contradictory in view of the vital distribution of the common carotid, but not if one considers the large number of major branches which the left subclavian is required to feed.

DISCUSSION

In interpretation of the results given above, or in applying them to physiological problems, certain points should be borne in mind:

(1) The aorta is not a static organ; it is in fact a dynamic structure, its inherent distensibility being responsible, at least in part, for the pulse-wave pattern produced

by left ventricular ejection (Remington, 1963). Furthermore, it has also been shown that changes in circumference and diameter may correlate quite closely with intra-aortic pressure changes (Greenfield & Patel, 1962). The data presented here do not account for this distensibility; values given refer to measurements on cadaver material, although it is emphasized that this material was examined while in a fresh state.

(2) Sex: It seemed unlikely, in a group of cases such as provided the material for this study, that appreciable differences in the dimensions of the aortic arch and its branches would be noted between the two sexes. This has been borne out by the results (Table 2). Measurements in male subjects tended to be slightly greater than in female subjects, but the differences between the two groups were not statistically significant, except in the case of R_2 (the diameter of the innominate artery measured 15 mm beyond its origin). Since the differences between the two groups were non-significant at all other points of measurement, it seems probable that this apparently significant result for R_2 was due to other factors apart from sex.

(3) Age: it is well known that, apart from atherosclerosis, there are changes in the size and configuration of the aortic arch with increasing age. An attempt has been made to interpret these changes significantly in relation to altered physiology. Hallock & Benson (1937) studied the elastic properties of the human aorta, and presented pressure–volume curves derived experimentally from aortic segments taken from subjects in five different age groups. Differences between the curves for the first four groups, representative of ages from 20 to 52 years, were not great, but the curve for the 71 to 78-year age group was appreciably altered. The anatomical data have been further analysed in view of this finding, and to keep the age grouping roughly comparable with the above, subjects up to the age of 54 years were designated as 'young' and those of 55 years and over as 'old'. It appears, as might be predicted, that values for the younger age group were less, and significantly so, for points of measurement on the aortic arch itself; the values for the branch vessels were also consistently less, the differences between the two groups being statistically significant in the case of the two larger branches of the aortic arch (R_1 [borderline] and R_2, the innominate artery; T_1 and T_2, the left subclavian artery) but not in the case of the smallest of the main branches (S_1 and S_2, the left common carotid artery) nor in the case of the distances between the ostia of the three major branches (f_1 and f_2).

(4) Pathology. Apart from age and atherosclerosis, other disease processes and the mode of death might affect the results given here. The pathology represented in the cadavers from which specimens were obtained for this study was extremely varied, but no case of gross aortic disease (aortic valvular disease, syphilis, coarctation, dissection or aneurysm formation) has been included.

(5) Finally, it was assumed that each luminal section or branch ostium was circular; this was not true in each instance, and as already pointed out, deformity to a circular outline was made, where necessary, to facilitate mensuration.

SUMMARY

1. A study has been conducted on 100 dissections of fresh cadaver specimens of the human aortic arch. Values are given for measurements of diameters of the arch and of its branches, at certain important sites. Other values in relation to sex and age are also given.

2. A common origin to the innominate and left common carotid arteries was found in seven specimens but, even where separate ostia exist, the two major vessels still tend to merge together into a common elliptical origin.

3. The distance between the innominate and left common carotid arteries is usually considerably less than the distance between the left common carotid and left subclavian arteries. The space between the ostia of the innominate and left common carotid arteries is narrow: that between the left common carotid and the left subclavian arteries broader, but usually slightly tilted, so that, in effect, two carinae tend to form, which are directed towards the blood-flow in the arch, and may facilitate filling of the major branch vessels.

4. The three major branch ostia lie anterior to the central axis of the aortic arch. Furthermore, projection of two lines through the centre points of the ostia indicate angulation between the ostia, which is greater than might be expected if their relative locations conformed with the natural 'secondary' (i.e. convex anteriorly) curvature of the arch.

5. A small artery, probably the thyroidea ima, arising from the aortic arch between the left common carotid and the left subclavian arteries, was noted in eight cases.

6. The left subclavian artery is usually a larger vessel than the left common carotid artery.

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