VARIATIONS PERTAINING TO THE AORTIC ARCHES AND THEIR BRANCHES[1]

With Comments on Surgically Important Types

JOHN D. LIECHTY, M.D., THOMAS W. SHIELDS, M.D.
and BARRY J. ANSON, Ph.D. (MED.SC.)

Introduction

PROGRESSIVELY increasing activity in the fields of cardiac and vascular surgery has served to revive interest in the developmental and adult anatomy of the aortic arches and the great vessels derived therefrom. Special interest, naturally, centers around the relation which anomalous arch, or arches, may bear to viscera in the neck and the thorax.

In the course of examination of specimens in the laboratory of gross anatomy, it became abundantly and strikingly evident that the "standard" type of branching from the aortic arch not only obtained in the preponderant number of cases (approximately in 2 of 3), but, also, when placed with a rather ordinary variation thereof gave a combined total which represented over 90 per cent of cases in a large series (1000 specimens).

In comparison with the profound variations presented forty years ago in the classical paper by Dr. Poynter, the departures from the anatomic norm encountered in the present authors' series seem relatively undramatic. Of course, in drawing from an extensive literature, Dr. Poynter is enabled to give the reader an imposing bibliographic history of such arterial anomalies, to include references to Vesalius' *Fabrica* (1543), the report by Casserius (1609), Eustachius (1714), that of Sandifort (1772), that of Valentin (1791)— together with numerous reports in the nineteenth century, to make a total of almost 1100 references.

As a third phase of the present study, consideration was given to variations of surgical significance; here the number was further reduced.

Of the 24 types pictured by Dr. Poynter (figs. 26 to 29 of his Plate V and Plate VI), 7 were identical with those in the present authors' series and are like those variations recorded in the pediatric surgical literature.[2]

Material and Methods

As has been recorded hereinbefore, the material, upon which this report is based, comes from three sources: original observations on 1000 adult cadavers in a laboratory of gross anatomy (at Northwestern University Medical School); collected records (by C. W. M. Pounter) from the imposing literature on "arterial anomalies pertaining to the aortic arches and the branches arising from them"; clinically important variations (as summarized by Dr. J. E. Edwards), of the type which are associated with compression of the trachea or oesophagus. Variations associated with either transposition of the great vessels or coarctation of the adult and infantile types are not included.

In order to provide graphic basis for making convenient comparisons among examples in the three categories, illustrations in the articles by Dr. Poynter and Dr. Edwards have been redrawn (figs. 3 and 4) to accompany the pictorial records

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The study of the specimens illustrated in Figure 1 served as a basis for a paper, by J. D. Liechty and B. J. Anson read at the Midwest Regional Meeting of the American Association of Anatomists, Loyola University, Chicago, November 10, 1956.

[2]It is recognized that the physiologically deforming variations, being in some instances incompatible with life, would be infrequent in the adult "population" of a labratory of anatomy.

prepared from the laboratory specimens (figs. 1 and 2).

Observations and Discussion

Authors' Cases (figs. 1 and 2).

In the 1000 specimens only two types of variation are arresting, namely, that in which the right subclavian artery is the last branch of the aortic arch (fig. 1, VI to VIII) and (of entirely different embryological origin) in which all regular branches arise from paired innominate arteries (fig. 1, IX) or from a common stem (fig. 1, XIII).

These two "anomalies," and all of the other variations encountered, will now be described.

Type I—The arrangement regarded as "normal" for man is actually encountered more frequently than all other types combined. In specimens of this variety, three branches leave the arch, in the following succession from the specimen's right to left: innominate (with right common carotid and right subclavian derivatives); left common carotid; left subclavian.

Type II.—An arrangement distinguished by reduction in the number of stems to two, both common carotid arteries arising from the innominate.

Type III—Here the distinguishing feature is increase, not reduction, in the number of derived branches. The left vertebral artery (usually arising from the subclavian) is the additional vessel.

Type IV—Differing from the preceding variety, the feature is replacement, the left vertebral artery (not the left common carotid, as in Type I) being the second stem in right-to-left succession. Both common carotid arteries arise from a common stem, as they do in examples of Type II.

Type V—In this departure from the anatomic norm, the left vertebral artery arises from the innominate, and the order of the left common carotid and left subclavian arteries is reversed.

Types VI to VIII—Three patterns similar in respect to the position of origin of the right subclavian artery; the latter vessel arises as the last branch of the aortic arch, reaching the right upper extremity by passing dorsal to the oesophagus (see also Figure 2). In respect to the origin of the other branches, the types differ.

Type IX—A bi-innominate sequence, in which paired vessels (in turn having matching main branches)are the only derivatives of the aortic arch.

Types X and XI—In both of these varieties the left vertebral artery arises from an aortic trunk from which the left subclavian is also derived. However, in Type X a regular innominate artery is present (as in Type I), whereas in Type XI the "innominate" (with regular branches) arises from an aortic trunk shared with the left common carotid.

Type XII—Here, as in Type III, an extra vessel arises from the arch between the innominate and the left subclavian; however, the added derivative in the *thyreoidea, ima*, not the *vertebralis.*

Type XIII—Unification is the distinguishing feature of this departure from the typical scheme of branching; the usual branches (see Type I) take origin from the aortic arch through a single trunk as an intermediary vessel.

Type XIV—A very infrequent variety with all branches derived from a common stem (as in Type XIII) with the exception of the left vertebral, which arises from the arch to the right of the common stem.

Type XV—In this rare variety, in which the arch passes in a reversed direction from heart to thoracic aorta, the branches maintain a normal succession in relation to the body itself; however, their position on the aortic arch itself is as a mirror-image of the "standard" scheme of derivation (see Type I).

Collected Examples (fig. 3).

In Poynter's monographic collection of irregular patterns of branching of the aortic arch, many *schemae* of derivation are presented which were not encountered in the present authors' series from 1000 cadavers.

Dr. Poynter's specimens will be reviewed, then discussed in comparison to the types already pictured (fig. 1, I to XV).

Spec. a—True double aortic arch with three major trunks arising from each side

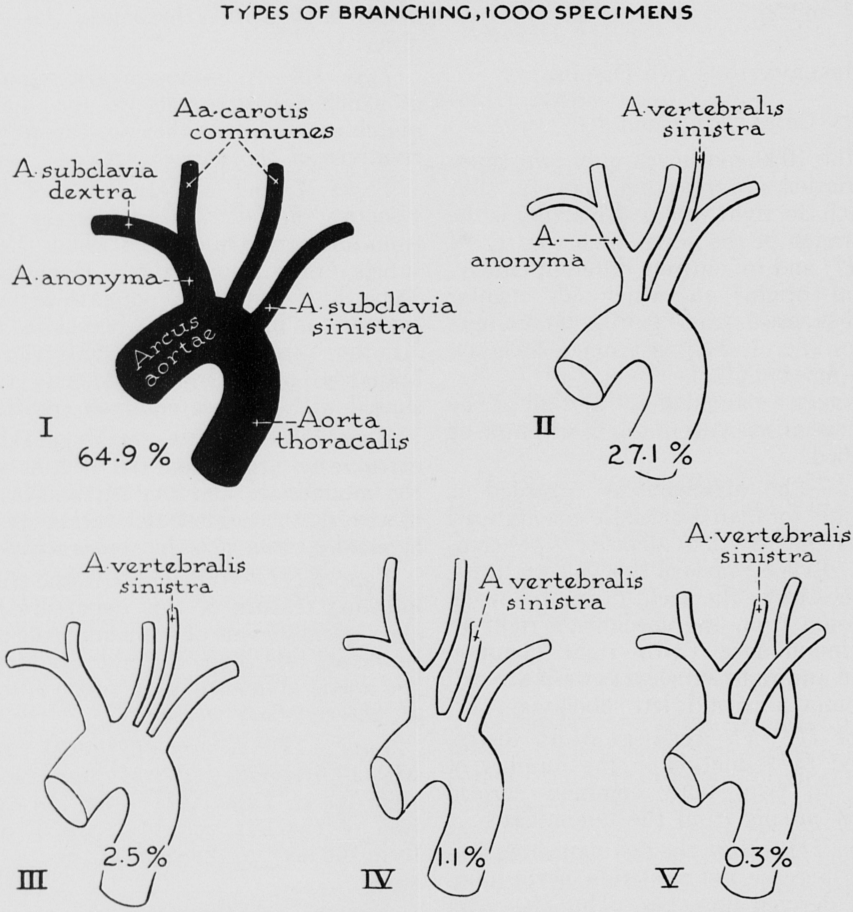

Fig. 1. Variations in branching of the aortic arch encountered in 1000 adult cadavers.

of the arch (subclavian, internal carotid, and external carotid). The aorta descendens arises at the confluence of the two arches.

Spec. b—An example of division of the aortic arch, the two segments enveloping the trachea. The anterior division gives origin to the left common carotid and the left cubclavian arteries and to a patent ductus arteriosus.[3]

Spec. c—A right aortic arch from which the left common carotid artery arises as the first branch, the left subclavian artery as the last. The latter artery shares a common short trunk with a patent ductus arteriosus.

Spec. d—An aortic arch with branches as in Type I (of Figure 1) but with persistence of both right and left arterial ducts, the former terminating in the right subclavian artery and the latter in the descending aorta.

Spec. e—An arrangement generally similar to that in Type I, but in which the left common carotid artery takes origin from the innominate trunk instead of from the aorta.

Spec. f—A right aortic arch with the branches arising in the following order: right common carotid; right vertebral; common trunk for the left common carotid

[3]In the study of 150 specimens (148 adults and 2 infants) records were taken on the anatomical features of the ductus arteriosus and the ligamentum arteriosum (Greig, Anson, McAfee and Kurth, 1954). No instance of complete aortopulmonary communication was found. In a single specimen in the adult series a minute opening, of pinpoint size, remained at the pulmonary extremity of the ligament. In each of the infants the ductus, although open at both aortic and pulmonary ends, was occluded mid-length for a distance of 1 mm.

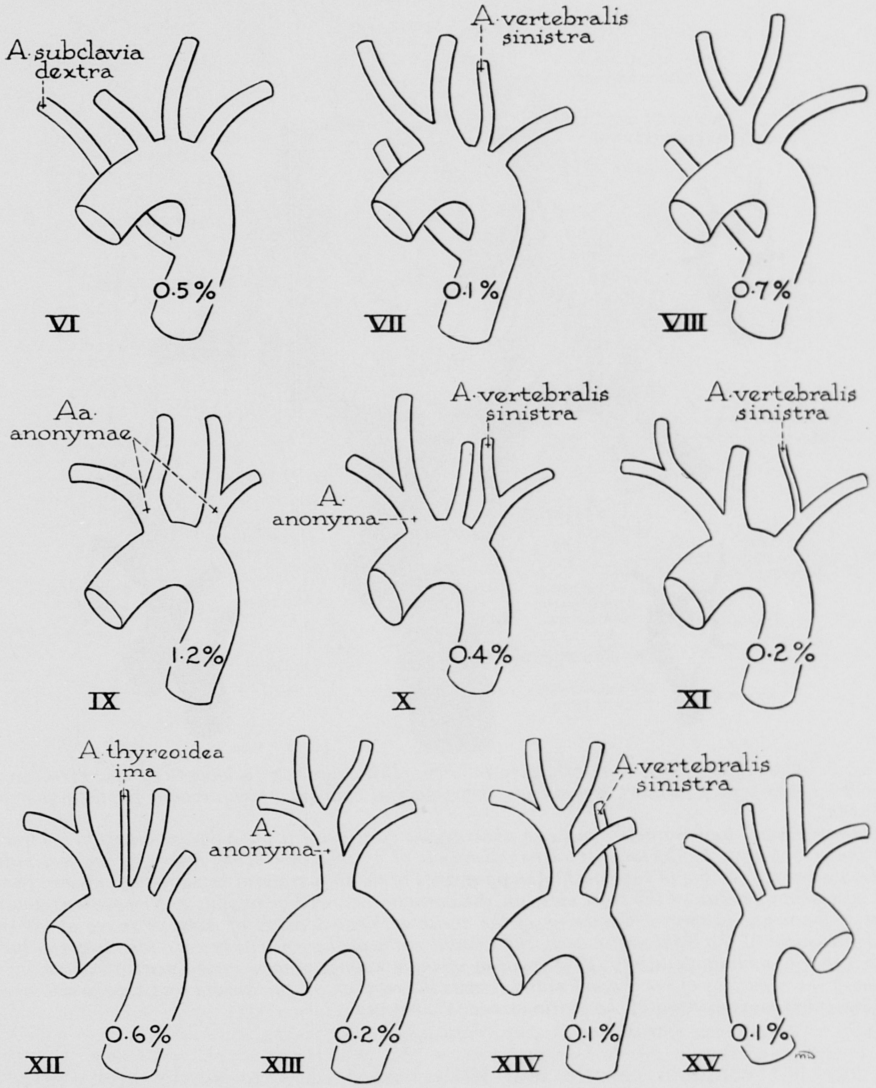

Fig. 1 (continued)

and the right subclavian, and the left subclavian. The latter also provides origin for the left vertebral artery and receives a patent ductus arteriosus.

Spec. g—An arch in which the right subclavian artery arises as the last branch in the succession. This configuration is associated with atresia of the pulmonary artery, which, although leaving the heart as a fibrous cord, rapidly enlarges to normal calibre and is supplied by a patent ductus arteriosus.

Spec. h—A case in which a single branch arises from the aortic arch, all other branches taking origin from it directly or indirectly.

Spec. i—A specimen in which the right subclavian artery, of low origin, crosses posterior to the ascending aorta. The right vertebral arises from the right common carotid artery, the left vertebral from the aortic arch.

Spec. j—An arch which gives rise to a single trunk for both common carotid arteries and a subclavian artery on each side of the median stem.

Spec. k—Low origin of the right subclavian artery differing from Spec. i in

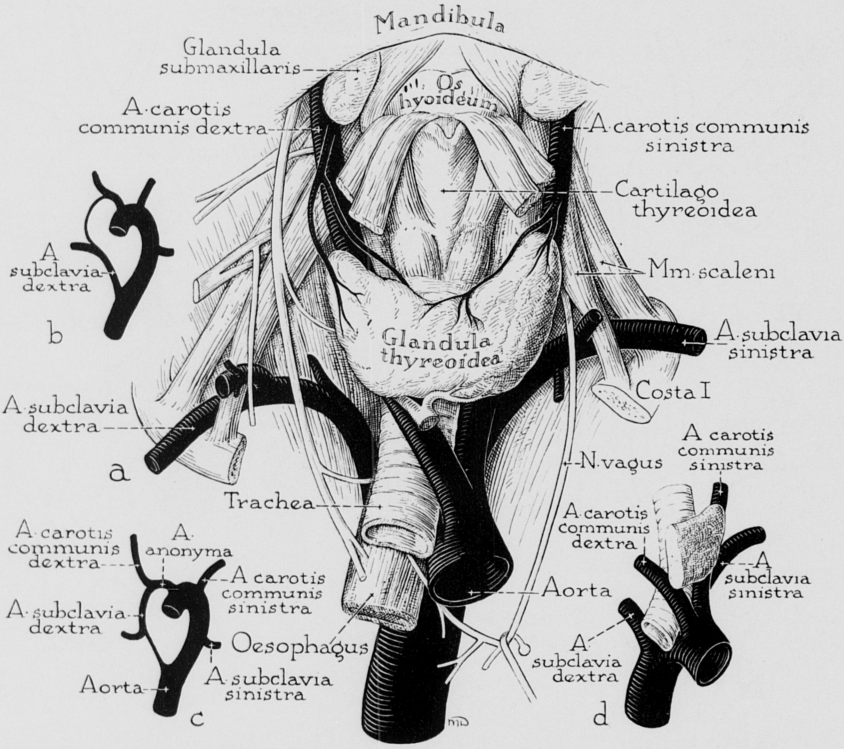

Fig. 2. Retro-oesophageal right subclavian artery. Drawings from a laboratory specimen, accompanied by schematic figures to demonstrate embryological changes which account for the anomalous branching.

a, Deep cervical and thoracic structures, showing the relation of the anomalous artery to the trachea and the oesophagus; b, Developmental establishment of a right subclavian artery as the last branch of the aortic arch; owing to subsequent disappearance of the thin segment between the common carotid and subclavian arteries of the right side, an innominate stem will be absent; c, Embryonic establishment of the usual pattern of branching of the aortic arch, as a result of disappearance of the short caudal segment of the right aortic arch, the cranial segment thereof will become the right subclavian branch of an innominate artery; d, A portion of the specimen shown in the main illustration; excision of the right lobe of the thyroid gland reveals the relation of the carotid and subclavian arteries and the intervening portion of the aortic arch to the trachea.

that the left common carotid and left subclavian arteries take origin from a common stem.

Spec. l—Specimen with independent origin of each of the common carotid and subclavian arteries from the aortic arch.

Spec. m—A configuration differing from that in Specimen 1 in that the right subclavian arises as the second branch of the aortic arch.

Spec. n—An arch similar to the "standard," except for the addition of a left vertebral which arises as the last branch.

Spec. o—A case in which the right subclavian arises as the third branch of the arch not, as is commonly the case, from an innominate artery.

Spec. p—An aortic arch with five branches, the vertebral arteries arising as the second and fourth members in the sequence.

Spec. q—An arch with six branches, the subclavian, common carotid and vertebral artery of each side being an independent aortic branch.

Clinical Selections (fig. 4).

Some of the types of variation in the aortic arch and its branches, encountered as surgical problems, did not occur among the dissection-room specimens. This is an expected circumstance, since these atypical patterns are likely to be associated with compression of the oesophagus or trachea or with the Tetralogy of Fallot.

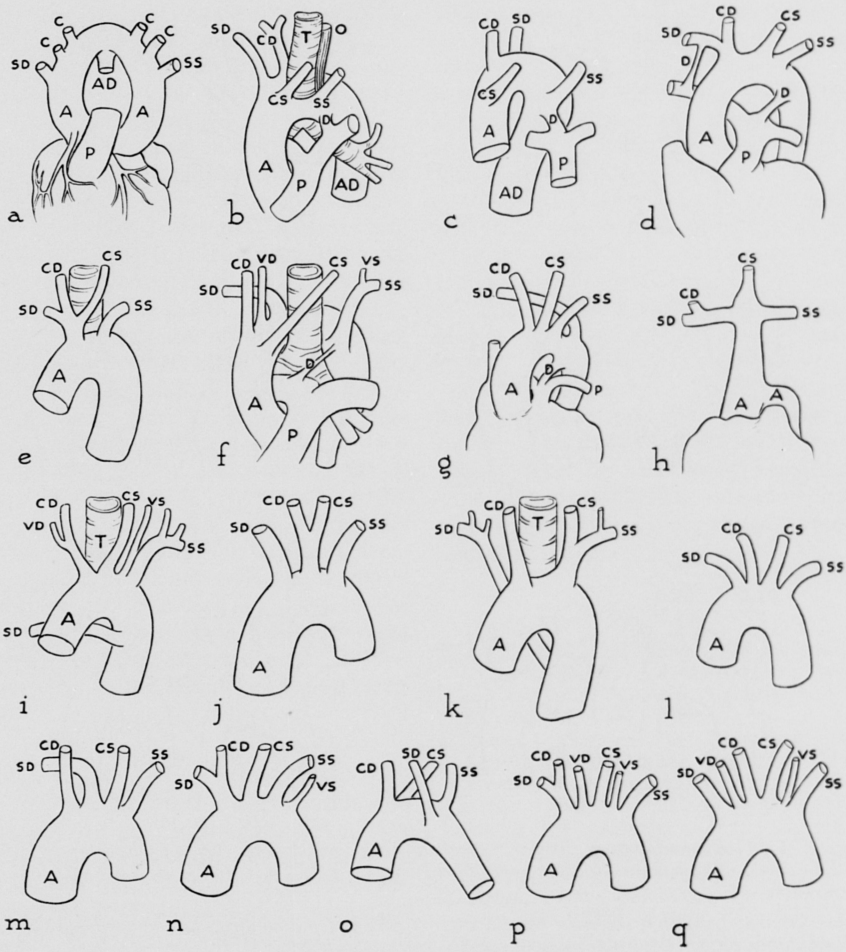

Fig. 3. Arterial anomalies pertaining to the aortic arches and the branches derived therefrom (redrawn from Poynter).

Abbreviations: A, aorta; AD, aorta descendens; C, arteria carotis; CD, a. carotis communis dextra; CS, a. carotis communis sinistra; D, ductus arteriosus; EC, a. carotis externa; IC, a. carotis interna; O, oesophagus; P, a. pulmonalis; SD, a. subclavia dextra; SS, a. subclavia sinistra; T, trachea; VD, a. vertebralis dextra; VS, a. vertebralis sinistra.

The former condition, if left untreated, often results in an early death, owing to respiratory complications. Similarly, life expectancy in untreated cases of the latter sort is poor, indeed.

Edwards (1948) has classified these anomalies on the basis of the source of the ductus arteriosus.

GROUP I—In this category belong those cases in which the arterial duct arises from the left pulmonary artery (fig. 4, *a*, *b*, *c*, *e*, *g*, and *i*).

GROUP II—The second group includes the cases in which the ductus arteriosus arises from the pulmonary artery of the right side (fig. 4, *d*, *f*, *h*, and *j*). Each of these patterns is the mirror image of one in Group I (in Figure 4 arranged in pairs, *c* and *d*, etc.)

The functioning double aortic arch may show considerable difference in calibre of its two portions. The right arch is often the larger (fig. 4*a*); in some instances the left is so small as to become obliterated in some part of its course (fig. 4*b*). Ekstrom and Sandblom (1951), in a review of 85 cases of doubling, found compression (by the vascular ring) of the trachea or the oesophagus, or of both

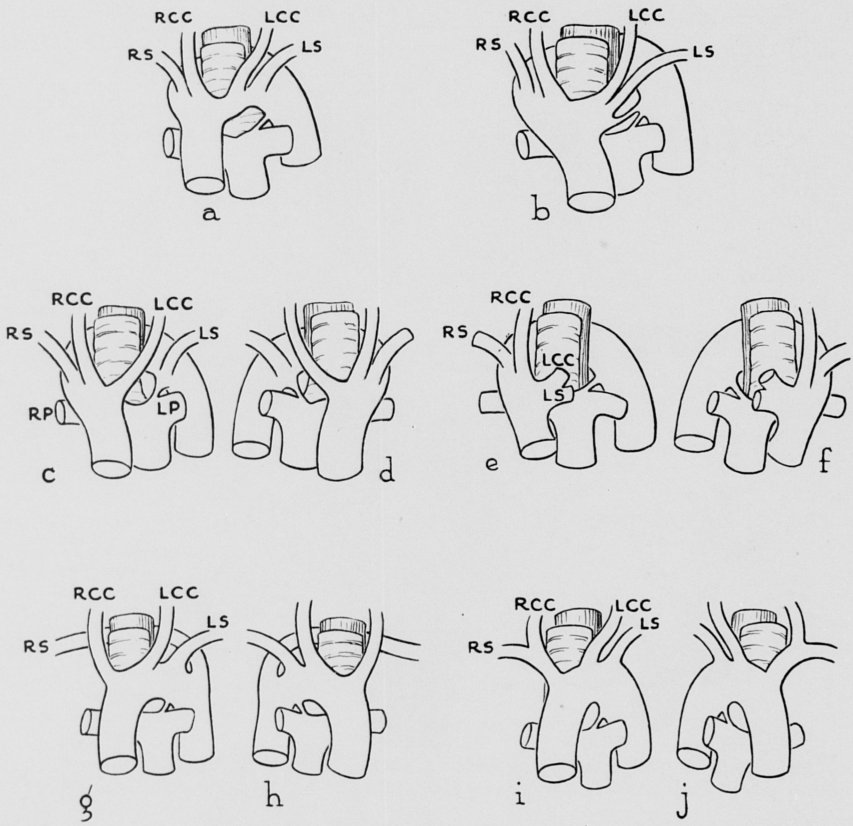

Fig. 4. Arterial anomalies of the aortic arch and its branches of clinical importance (redrawn from Edwards). The figures which are arranged in pairs (c and d, e and f, etc.) are mirror images of each other.

Abbreviations: LCC, left common carotid artery; LP, left pulmonary; LS, left subclavian; RCC, right common carotid; RP, right pulmonary; RS, right subclavian.

visceral tubes in 47 of the total number.

A vascular ring is formed by a right-sided arch associated with a left subclavian artery which is derived from an aortic diverticulum with a left-sided ductus arteriosus (fig. 4*c*). The mirror image of this pattern is rare (fig. 4*d*). However, both conditions have been reported as causing tracheal or oesophageal obstruction.

A variant of the above-described anomaly is represented by those cases in which subclavian artery originates from the innominate artery (figs. 4*e* and 4*f*). Again a ring is formed, in this *schema* by the connection between the ductus arteriosus and the pulmonary artery.

As established by the examination of laboratory specimens, the aberrant right subclavian artery (fig. 4, g) occurs with relative frequency among anomalies effecting the aortic arch (fig. 1, VI to VIII). This anomalous condition often occurs in individuals with the Tetralogy of Fallot—as does a variant of this vascular pattern, namely, one in which the arrangement is its mirror image. Bahnson and Blalock (1950) reported 36 such cases in a total of 841. The examples were equally divided between aberrant right (fig. 4, g) and aberrant left (fig. 4, h). Clinically, the presence of the anomaly gives rise to the condition known as dysphagia lusoria. Of additional importance is the fact that the right laryngeal nerve is not recurrent; with no vessel arising in such a manner as to draw the nerve downward in looping course, the nerve of the right side destined for the

larynx passes directly to its area of supply (fig. 2). In thyroidectomy or in tracheostomy the unusual (and, therefore, unexpected) position of the nerve constitutes a surgical hazard.

Even in those cases in which the succession of branches of the aortic arch is "normal" (fig. 4, i) the position of origin of the innominate artery may assume surgical significance; tracheal pressure may be the result of origin of the artery farther to the left on the aortic arch or, comparably, by the left common carotid when the latter vessel arises farther to the right than it does in normal cases (Gross, 1955).

The right-sided aortic arch with a system of branching which is the mirror image of the typical pattern (fig. 4, j) was encountered in 0.1 per cent of the present series (fig. 1, XV). However, the incidence in individuals with the Tetralogy of Fallot is 20 per cent, as reported by Blalock (1948). Self evident is the importance of this arterial departure from the anatomic norm in selecting a site for thoracotomy in the Blalock-Taussig operation.

Conclusions

The variations of the aortic arch and its branches in an "adult population" are not as striking as those encountered in the pediatric population. None-the-less, the knowledge of the common anomalies and their relative incidence may be of value in the interpretation of vascular compression of the oesophagus, the interpretation of aortagrams of the arch and, lastly, in the surgical excisions of aneurysms of the arch and of other masses in relationship to it and its branches. The "normal" pattern and its minor variants are by far the most common (90 per cent). The anomaly represented by the aberrant subclavian was seen in 1.3 per cent of the 1000 specimens and assumes some importance in the adult as well as in the child as a cause of oesophageal compression. The abnormal course of the "recurrent" laryngeal nerve, when this anomaly is present, has been commented upon. The vascular ring, as produced by a persistent double arch and those variants in which the ring is completed by the ductus, that may result in compression of the trachea and oesophagus, were not observed, though these have been reported in the adult as well as in the pediatric group. A right aortic arch was found only once, in contrast to the high incidence reported associated with the Tetralogy of Fallot. The statistical status of the latter groups thus appears relatively insignificant but none-the-less assumes importance when viewed from the standpoint of pediatric surgery.

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