THE ANOMALOUS RIGHT SUBCLAVIAN ARTERY CONSIDERED IN THE LIGHT OF RECENT FINDINGS IN ARTERIAL DEVELOPMENT; WITH A NOTE ON TWO CASES OF AN UNUSUAL RELATION OF THE INNOMINATE ARTERY TO THE TRACHEA

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I. THE ANOMALOUS RIGHT SUBCLAVIAN ARTERY: REPORT OF TWO CASES, WITH REVIEW OF LITERATURE

Cases in which the right subclavian artery arises directly from the arch of the aorta are classified by Quain (1844) into four groups, according as the artery arises before the right common carotid, immediately after the right common carotid, immediately after the left common carotid, or after the left subclavian. Cases of the fourth type appear to be not uncommon. Quain himself observed four cases in the examination of nearly 1000 subjects. Bradley (1871) observed two cases in 120 subjects. The third annual report of the committee of collective investigation presented by Thomson (1893) gave the incidence of the anomaly as 5 in 500, while, according to Gould (1909), the frequency has been variously estimated as 0·4 to 0·8 per cent. Harvey (1917) observed two cases in 237 subjects; Hudson (1921), 1 in 70; Goldbloom (1922), 4 in 225; and De Garis (1923), 1 in 139. In this department, the condition has been observed twice in the examination of 203 subjects. Holzapfel, whose paper I have unfortunately not been able to consult, collected (in 1899) 196 cases of the anomaly, the earliest being recorded by Bohmer in 1741; Holzapfel himself added four further cases, and Hudson (1921) mentions that he has been able to find 25 additional cases recorded in the present century. The literature at my disposal includes six further cases, one reported by Hudson, four by Goldbloom (1922), and one by De Garis (1923), bringing the total number of published cases up to at least 231.

Smith (1891) reports the occurrence of the same anomaly in the rabbit; he found it once in the examination of about 700 specimens. In this case, the right subclavian arose from the dorsal aspect of the arch of the aorta at the point where the aorta began to descend, and passed to the right dorsal to the oesophagus.

In the human subject, the anomalous right subclavian passes dorsal to the oesophagus in the great majority of cases. Indeed, certain writers in recent years have expressed doubt as to whether there has been any definitely proved case in which such a vessel passed either between the oesophagus and the trachea or ventral to the trachea.

Particulars of cases

The essential particulars of the cases recorded in the literature to which I have access are indicated for convenience in Table I. The following are particulars of the two cases which I have seen, arranged under the same headings:

Case I

Subject.—Female, aet. 56

Branches of aortic arch: Bicarotid, left subclavian, right subclavian.

Origin of right subclavian: Dorsal aspect of arch, just beyond left subclavian.

Course of right subclavian: Behind oesophagus.

Branches of subclavian: On right side, from first part, vertebral, common trunk giving rise to thyroid axis and internal mammary; from second part, costo-cervical trunk. On left side, usual.

Origin of vertebral: Usual.

Right inferior laryngeal nerve: Turned round inferior thyroid artery.

Termination of thoracic duct: Usual.

Case II

Subject.—Male, aet. 70

Branches of aortic arch: Right common carotid, left common carotid, left subclavian, right subclavian.

Origin of right subclavian: Dorsal aspect of arch, opposite third thoracic vertebra.

Course of right subclavian: Behind oesophagus.

Branches of subclavian: On right side, from first part, vertebral, superior intercostal (not costo-cervical trunk), common trunk giving rise to inferior thyroid and suprascapular, internal mammary; from second part, deep cervical; from third part, transverse cervical. On left side, from first part, vertebral, common trunk giving rise to inferior thyroid and suprascapular, internal mammary, superior intercostal, deep cervical; from second part, transverse cervical.

Origin of vertebral: Usual.

Right inferior laryngeal nerve: Passed directly to the lower border of inferior constrictor, its course being very slightly curved with the convexity downwards.

Termination of thoracic duct: Usual.

Fig. 1 represents a drawing of a cast of the specimen in the second case.

Some facts and principles in the normal transformation of the aortic-arch system

The usual descriptions of the development of the aortic-arch system as presented in our standard text-books appear to be dominated by the influence

of Rathke and to imply a belief in a strict ontogenetic recapitulation of phylogeny. The conventional diagram shows, even if the text does not definitely describe, five or six paired arterial arches present at one and the same time, and from this pattern the definitive vessels are produced by the erasing of certain fixed segments, "as though the system were made up of hard and fast units existing of and for themselves." As a natural consequence, the theories which have hitherto been advanced in connection with the anomalous right subclavian in its various aspects have similarly involved the

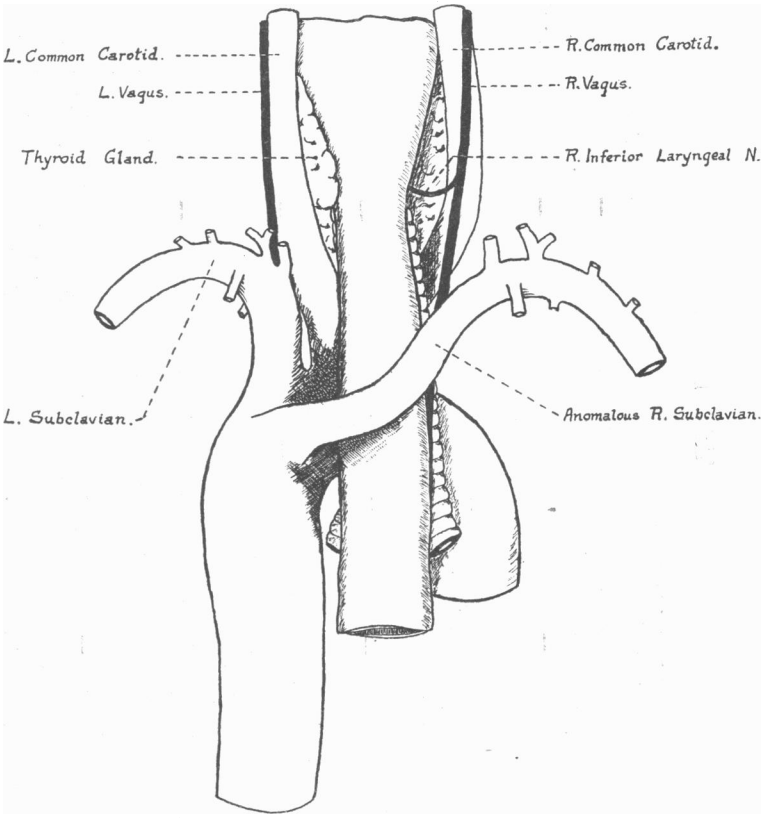

Fig. 1. Specimen in Case II, seen from behind.

assumption of an aortic-arch system composed of certain fixed segments, which, without the necessity of furnishing any adequate explanation of causes, may be obliterated or retained in any combination which suits the requirements of the case.

In a recent volume of *Contributions to Embryology*, E. D. Congdon (1922) presents the results of a detailed research in which he followed the successive changes in the aortic-arch system through a series of human embryos ranging from 1·3 mm. to 24 mm. in length, 29 stages being included in the series.

Table I

Year	Reported by	Subject	Branches of aortic arch	Origin of right subclavian	Course of right subclavian	Branches of subclavian	Origin of vertebral	R. inferior laryngeal nerve	Termination of thoracic duct
1871	Bradley	Female	—	Extreme left of transverse arch on posterior aspect	Between trachea and oesophagus	—	—	—	—
1888	Brodie	—	Bicarotid L. vertebral L. subclavian R. subclavian	—	Behind oesophagus	—	Right from R. common carotid. Left from aorta	—	—
1889	Shepherd	Female aet. 30	R. common carotid L. common carotid L. vertebral L. subclavian R. subclavian	Posterior part of aortic arch opposite 3rd thoracic vertebra	Behind oesophagus	—	Right from R. common carotid. Left from aorta	Turned round right vertebral	—
1892	Abbott	—	Bicarotid L. vertebral L. subclavian R. subclavian	—	Behind oesophagus	—	Right from R. common carotid. Left from aorta	—	—
1893	Clarkson	—	—	Posterior aspect of descending part of arch ½-inch below origin of left subclavian	—	—	—	Not recurrent	—
1897	Turner	Negro	—	Last branch of arch	Behind oesophagus	—	—	—	—
1909	Gould	Male	R. common carotid L. common carotid L. subclavian R. subclavian	Just beyond left subclavian opposite lower border of 3rd thoracic vertebra	Behind oesophagus, on bodies of upper 3rd thoracic vertebrae	From 1st part: vertebral, thyroid axis, internal mammary, superior intercostal. From 2nd part: none. From 3rd part: posterior scapular	Usual	Slight recurrency	Usual
1911	Geddes	—	—	—	Behind oesophagus	On R. side, first branch is superior intercostal proper On L. side, first branch is costocervical	—	—	—
1914	Cobey	Male negro aet. 45	R. common carotid L. common carotid L. subclavian R. subclavian	Dorsal aspect of descending limb of arch, ½-inch distal to left subclavian	Behind oesophagus, obliquely at an angle of 45 degrees	From 1st part: vertebral, transverse cervical. At junction of 1st and 2nd parts: inferior thyroid, suprascapular, internal mammary	Usual	Not recurrent	

1915	Gladstone and Wakeley	Male aet. 71	R. common carotid L. common carotid L. subclavian R. subclavian	Posterior aspect of arch at level of 4th thoracic vertebra	Behind oesophagus	On R. side:—From 1st part: vertebral, costo-cervical, inferior thyroid, common trunk of supra-scapular transverse cervical and internal mammary. From 2nd part: none. From 3rd part: Posterior scapular On L. side: vertebral, internal mammary, thyroid axis, superior intercostal, posterior scapular	Usual	Turned round inferior thyroid artery	Right angulus venosus
		Female aet. 63	Bicarotid L. subclavian R. subclavian	Posterior aspect of arch $\frac{1}{2}$-inch beyond origin of left subclavian	Behind oesophagus	On R. side: vertebral, costo-cervical, thyro-cervical, internal mammary On L. side: vertebral, superior intercostal, internal mammary, inferior thyroid, transverse cervical, suprascapular	Usual	Turned round inferior thyroid artery	Usual
1915	Bevier	Caucasian female aet. 40 or 45	—	1 cm. distal to left subclavian	Behind oesophagus Related to 2nd thoracic vertebra, on which it produced a groove on left side and a flattening on ventral surface	On R. side: vertebral, deep cervical, ascending cervical, internal mammary, transversalis colli On L. side: vertebral, superior intercostal, ascending cervical, internal mammary, deep cervical, transversalis colli	Usual	Not recurrent	—
1917	Harvey	White male aet. 60	Bicarotid L. subclavian R. subclavian	Right side of descending arch at its commencement	Behind oesophagus, across body of 3rd thoracic vertebra. Considerably dilated up to the point where it emerges behind oesophagus	—	—	Represented by 3 or 4 twigs direct to larynx	Usual
		White male old age	Similar	—	Similar but not dilated	—	—	—	—
1921	Hudson	Male middle age	Bicarotid L. subclavian R. subclavian	Right side of descending arch at level of 3rd thoracic vertebra	Behind oesophagus, across 2nd and 3rd thoracic vertebrae. Presents a slight fusiform dilatation where it lies behind oesophagus	From 1st part: vertebral, internal mammary, thyro-cervical trunk, superior intercostal and deep cervical. From 2nd part: none. From 3rd part: posterior scapular	Usual	Round upper branch of inferior thyroid artery	Usual
1923	De Garis	Male negro	R. common carotid L. common carotid L. subclavian R. subclavian	Deep left extremity of aortic arch opposite 3rd thoracic vertebra	Behind oesophagus, crossing dorsal thoracic wall at an angle of 50 degrees to the horizontal	—	Right from R. common carotid. Left from L. Subclavian	Passed to larynx beneath inferior thyroid artery	—

He points out that these vessels do not in any complete sense recapitulate their phylogenetic history, and stresses the importance of recognising the formative influence of one developing organ on another. From the study of Congdon's paper, certain facts and principles become evident and throw new light on the theories which have previously been advanced regarding the anomalous subclavian artery. It therefore seems appropriate to refer briefly to these points at the present stage.

In tracing the development of the aortic-arch system, Congdon recognises two distinct phases:—(A) the branchial phase, in which the vessels approximate to the branchial pattern of lower vertebrates; (B) the post-branchial phase, during which the branchial pattern is being replaced by the adult arterial arrangement. Though it is not intended that the points mentioned here should represent anything approaching a complete summary of Congdon's paper, it is deemed advisable, for clearness, to arrange the remarks under the headings of these two phases.

A. *The Branchial Phase*

The branchial phase is regarded as commencing with the establishment of the first arch and as terminating with the interruption of the right pulmonary arch. It thus lasts about 22 days, viz. from the 23rd day of development (estimated average length of embryo 1·3 mm.) to the 45th day of development (estimated average length 12 mm.).

Due to the caudal movement of the heart relative to the pharynx, the aortic arches develop in regular order from cephalic to caudal; as the more caudal ones become developed, the first and then the second undergo involution. Thus, during the branchial phase, the blood-stream from the heart to the dorsal aorta on each side makes use of the following channels in succession: (*a*) first arch; (*b*) first and second arches; (*c*) second and third arches (*d*) third and fourth arches; (*e*) third, fourth and pulmonary arches, with in some cases the so-called fifth arch as well. The chief cause of the disappearance of the first and second arches is to be found in the transference of the blood-stream to the more caudal arches, as a result of the "descent" of the heart.

The last nine days of the branchial phase, represented by embryos from 6 to 12 mm. in length, constitute a period of relative stability of the aortic-arch system, termed the "late branchial period," during which the blood-stream from the heart to the dorsal aorta on each side is divided between the third, fourth, and pulmonary arches. By the end of the late branchial period these arches have, in association with the "descent" of the heart, moved as far caudally as the pharyngeal pouches and other structures allow. At the commencement of the late branchial period (fig. 2), the third, fourth, and pulmonary arches on each side radiate from a saccular enlargement, flattened dorso-ventrally, and situated cephalic to the truncus arteriosus. Before the end of the late branchial period, this enlargement has become completely separated into two parts (fig. 3): (*a*) a tubular pulmonary portion, from which

the pulmonary arches arise; and (*b*) a saccular aortic portion, termed the "aortic sac," from which the third and fourth arches arise. It is worthy of note that no ventral aortae occur in the human embryo; the external carotid, we may observe in passing, is therefore not formed from a vessel known as the ventral aorta, but is first seen as an independent sprout extending cephalically from the saccular enlargement referred to above; its origin is gradually displaced laterally to such an extent, that, at the end of the branchial period, it is seen to arise from the third arch at its junction with the aortic sac.

At the commencement of the branchial phase, the dorsal aortae are separated from each other along their whole length by the neural tube, the notochord, and the alimentary canal. Gradually, however, the neural tube becomes separated from the notochord by an interval (occupied by mesenchyme), in which, in the thoracic region, the dorsal aortae approach each

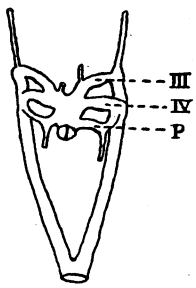

Fig. 2

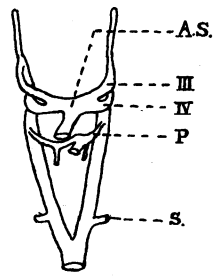

Fig. 3

Figs. 2 and 3. Aortic-arch system of the late branchial period (Congdon). III=third arch; IV=fourth arch; P.=pulmonary arch; A.S.=aortic sac; S.=primitive subclavian. Fig. 2 represents condition at the commencement, fig. 3 towards the end, of the late branchial period.

other until they lie almost in contact. Fusion of the dorsal aortae now occurs, commencing in the more caudal parts and gradually extending in a cephalic direction, actual fusion at any point being preceded by the development of transverse anastomoses. Such fusion is seen in progress in embryos of 3 to 6 mm.; the process thus comes to an end at the commencement of the late branchial period, by which time the cephalic end of the unpaired aorta, referred to as the "bifurcation," is opposite, approximately, the seventh body segment.

The primitive subclavian artery can first be recognised in embryos of 4 to 6 mm. (i.e. at the stage when the fourth arches are present but the pulmonary arches are not yet complete), when it takes the form of a slender channel lying in an intersegmental space and arising from an outpocketing of the aorta which also gives off a dorsal segmental artery. Soon this outpocketing from the aorta develops into the stem of a segmental artery, typically the seventh, of which the subclavian comes to be a branch. As the subclavian increases in size, it gradually incorporates the stem of the segmental

artery, which thus by the end of the branchial period has completely lost its identity in the subclavian; on the right side at least the subclavian is still referred to as the primitive subclavian. In Congdon's series, the primitive subclavian, or more correctly the stem of the segmental artery from which it arose, was found in all cases to arise at first from the unpaired aorta a short distance caudal to the bifurcation. As the aorta descends, however, the subclavian appears to be retained in position by its large vertebral branch, and thus its origin is gradually displaced in a cephalic direction on the aorta. In three out of four embryos of the late branchial period the origin of the subclavian was found by Congdon to be already from the paired aorta a little cephalic to the bifurcation (fig. 3).

The development of the vertebral by the formation of anastomoses between the first seven segmental arteries together with the interruption of the proximal segments of the first six is of course well recognised. Suffice it to state here that these processes commence in the latter part of the branchial period (two successive stages being shown by two 9 mm. embryos in Congdon's series), but are not complete until early in the post-branchial phase, when the vertebral is seen as a large vessel arising from the proximal part of the primitive subclavian.

B. *The Post-branchial Phase*

The post-branchial phase commences with the interruption of the right pulmonary arch (estimated average length of embryo 12 mm., 45th day of development); the essential changes of the phase are completed within two weeks, i.e. by the time the length of the embryo has reached 24 mm. It is worthy of note that a 24 mm. embryo has large arteries in the cephalic part of the body which differ only in minor details from those of the adult.

Of the various features of the post-branchial phase, only three will be mentioned here, viz.: (1) the interruption of the branchial pattern; (2) the migration of the origins of the innominate and left subclavian arteries; (3) the evolution of the right subclavian artery.

1. *The interruption of the branchial pattern.*

Early in the post-branchial phase the way is made clear for the evolution of the arch of the aorta and the great vessels arising from it by the interruption of the branchial pattern in the following situations, and in the order mentioned: (*a*) the right pulmonary arch distal to the origin of the right pulmonary artery; (*b*) the paired aorta on each side, between the third and fourth arches; (*c*) the right paired aorta caudal to the origin of the primitive subclavian. The time occupied by each of these interruptions is approximately one day; the last of them is well towards completion at the 16 mm. stage.

These interruptions are shown to have the following features in common.

(*a*) *In all cases, the primary factor in the causation of the disappearance o the particular segment is a decrease in blood-flow leading up to an absence of blood-flow.* In the case of the distal segment of the right pulmonary arch,

diminution in current is due to the fact that the left pulmonary arch represents a shorter and more direct route to the dorsal aorta than the right, and this in turn is due to the fact that the bifurcation which cuts off the pulmonary trunk is well to the left of the mid-sagittal plane (fig. 3); in this way the right pulmonary arch comes eventually to carry a supply of blood sufficient only for the right pulmonary artery, and in consequence the segment of the arch distal to the origin of the right pulmonary artery ceases to function. In the case of the dorsal aorta between the third and fourth arches, the interruption is preceded by the development of continuous curvature of the third arch with the part of the dorsal aorta cephalic to it and of the fourth arch with the part of the dorsal aorta caudal to it (fig. 4), such curves indicating that the current from the third arch is now passing cephalically while that from the fourth arch is passing caudally; as a consequence, the blood-flow in the segment of the dorsal aorta between the third and fourth arches comes to a standstill. In the case of the terminal segment of the right dorsal aorta, the diminution in blood-flow is due to the fact that the aortic trunk has now assumed an oblique direction, in accordance with which a greater proportion of blood passes viâ the left fourth arch and left paired aorta than viâ the right fourth arch and right paired aorta, which thus come eventually to retain a current adequate only for the supply of the right primitive subclavian; thus the current ceases in the segment of the right paired aorta distal to the origin of the primitive subclavian. As a result of the diminution in blood-flow, the wall of the vessel in each case becomes thickened and the lumen becomes diminished.

It would appear to be established that, when once any particular segment of the aorta-arch system ceases to function in the carrying of a portion of the blood-stream, that segment is destined to disappear; and that, on the contrary, as long as any particular segment continues to function in the carrying of a portion of the blood-stream, that segment does not undergo degeneration from any other cause. As an example of the latter principle may be mentioned the case of the left pulmonary arch, which, though exposed to pressure from the left vagus and its inferior laryngeal branch, so far from disappearing, actually increases in diameter at a time when the distal segment of the right pulmonary arch is in process of obliteration.

(*b*) *In all cases, a secondary factor exists in the form of tension thrown on the particular segment as a result of the "descent" of the aorta.* Tension appears to exert its influence only after the walls of the vessel have already become weakened; it then has the effect of stretching the weakened segment, thus leading to its interruption and favouring its disappearance.

(*c*) *In all cases, the disappearance of the interrupted segment is complete.* At a slightly later stage no trace of such segments can be found. Degeneration of a vessel into a fibrous cord, such as is seen in early extra-uterine life, does not occur at this early embryonic stage.

It is worthy of note that, in the case of the segment of the right dorsal

aorta distal to the origin of the primitive subclavian, the current descriptions and diagrams are incorrect in that they represent the obliteration as involving a long segment of the paired aorta. As a matter of fact, at a stage immediately preceding this interruption (fig. 5), the origin of the primitive subclavian is only a short distance cephalic to the bifurcation of the unpaired aorta; the portion of the right dorsal aorta which disappears is thus only an extremely small terminal segment.

2. *The migration of the origins of the innominate and left subclavian arteries.*

At the 14 mm. stage (fig. 5), the arch of the aorta and certain of the great vessels are seen to be roughly outlined. The aortic sac, lying cephalic to the aortic trunk, is seen to have differentiated into two limbs, right and left, of which the right is a more or less transverse tube, while the left is shorter and of greater diameter; from the lateral extremity of each limb arise the third

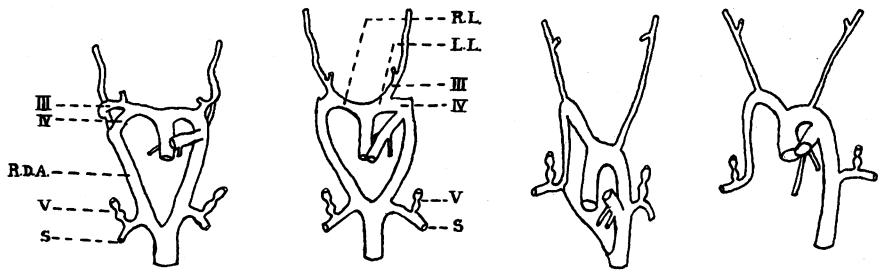

Fig. 4 Fig. 5 Fig. 6 Fig. 7

Figs. 4 to 7. Aortic-arch system of the post-branchial phase (Congdon). III = third arch; IV = fourth arch; R.D.A. = right dorsal aorta; R.L. = right limb of aortic sac; L.L. = left limb of aortic sac; V. = vertebral; S. = primitive subclavian. Fig. 4. 13 mm. embryo. Right pulmonary arch interrupted. Fig. 5. 14 mm. embryo. Dorsal aorta interrupted between third and fourth arches. Fig. 6. 16 mm. embryo. Right dorsal aorta caudal to primitive subclavian stretched to a thread. Fig. 7. 18 mm. embryo. Adult vessels recognisable.

and fourth arches. The arch of the aorta can be seen to be formed of the following parts, which are as yet distinguishable one from the other on account of irregularities and inequalities: (*a*) aortic trunk, (*b*) left limb of aortic sac, (*c*) left fourth arch, (*d*) left dorsal aorta. The innominate artery is represented by the right limb of the aortic sac. The origin of the external carotid has now moved laterally and cephalically for some distance along the third arch; thus the proximal segment of the third arch (as far as the origin of the external carotid) represents the common carotid, arising on the right side from the innominate and on the left side from the arch of the aorta. The primitive subclavian arises on each side from the dorsal aorta just cephalic to the bifurcation; the vertebral is complete and is a branch of the subclavian.

At this stage, the summit of the arch of the aorta is formed by the left fourth arch, and the left common carotid arises proximal to the summit. Due to more rapid growth of the segment of the arch of the aorta proximal to the

origin of the left common carotid relatively to the distal segment, the region of the origin of the left common carotid becomes later the summit of the arch.

Due to a totally different process, the origins of the innominate and left subclavian approach the origin of the left common carotid. This is due to a plastic rearrangement; "the substance of the wall is shifted about" to permit the movement of the origins. This process occurs while the heart is descending into the thorax, and no doubt takes place in response to tension thrown on the innominate and left subclavian. By the 24 mm. stage, the innominate has moved up alongside the left common carotid, while the origin of the left subclavian has passed the ductus arteriosus but is still separated from the origin of the left common carotid by an interval; at the 31 mm. stage, however, the left subclavian is shown lying close to the left common carotid.

A similar migration of the origin of vessels has been found in the large abdominal arteries. Evans (1912) suggests that such movements may be due to unequal growth of the ventral and dorsal walls of the main vessel. According to Congdon, the exact nature of the translocation of material appears to be at present very uncertain.

3. *The evolution of the right subclavian artery.*

When once the right dorsal aorta has become interrupted caudal to the origin of the primitive subclavian artery, any further movement of the origin of the latter vessel cephalically on the dorsal aorta becomes unnecessary. At this stage (fig. 7), the various developmental parts of the definitive subclavian can be recognised, viz.: (*a*) right fourth arch, (*b*) adjacent uninterrupted segment of right dorsal aorta, (*c*) primitive subclavian, which has already incorporated the stem of the seventh segmental artery.

By the time that the heart has sunk into the thorax and the sternal bands have fused, the curves of the right subclavian have disappeared and its developmental parts have become indistinguishable, the right fourth arch and adjacent part of the right dorsal aorta having lost their identity in the subclavian. In this way a channel of considerable tortuosity has become relatively straight at a time when the embryo as a whole has increased only about 30 per cent. in length; such a change in the subclavian must obviously have been produced by a great slowing in the rate of growth in length of its wall.

THE DEVELOPMENTAL EXPLANATION OF THE USUAL TYPE OF ANOMALOUS RIGHT SUBCLAVIAN PASSING DORSAL TO THE OESOPHAGUS

A. *The generally accepted view*

The generally accepted theory of the occurrence of the anomalous right subclavian is to the effect that it arises by a failure of the caudal segment of the right dorsal aorta to become interrupted, this segment becoming incorporated in the right subclavian as its proximal part in lieu of the right fourth arch and the segment of the right dorsal aorta adjacent to it. The position of the anomalous subclavian dorsal to the oesophagus favours the interpre-

tation that the distal part of the right dorsal aorta is included in the abnormal artery, while the uniform failure of the inferior laryngeal nerve to be recurrent round it certainly indicates that it includes no portion of the right fourth arch.

In elaborating this theory in the light of Congdon's findings, we may, for the sake of convenience, confine our attention at this stage to those cases in which the right vertebral arises in the usual manner from the subclavian. Cases in which the right vertebral arises from the right common carotid will be referred to separately in discussing the course of the right inferior laryngeal nerve.

We have already seen that the evolution of the normal subclavian is permitted by the interruption of the segment of the right dorsal aorta distal to the origin of the primitive subclavian, and that, just previous to this interruption (fig. 8 A), the primitive subclavian takes origin from the right dorsal aorta only a very short distance cephalic to the bifurcation of the unpaired aorta. The occasional occurrence of an anomalous subclavian would

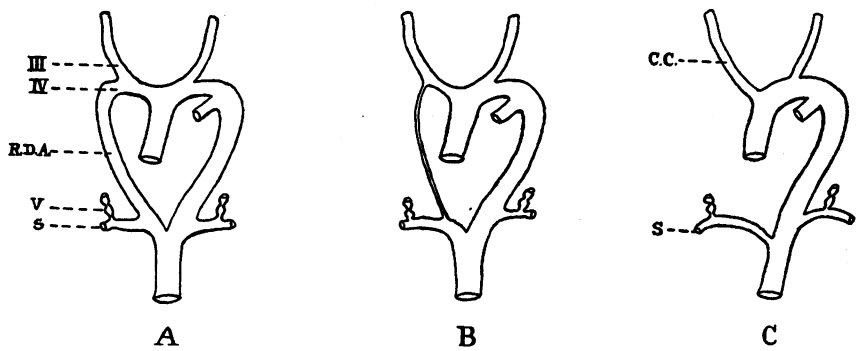

Fig. 8. To illustrate the generally accepted theory of the formation of an anomalous right subclavian artery of which the vertebral is a branch. III=third arch; IV=fourth arch; R.D.A.=right dorsal aorta; C.C.=common carotid; V.=vertebral; S.=subclavian.

appear to be due in all probability to the primitive subclavian tapping the main blood-stream in the unpaired aorta by means of the short terminal segment of the right dorsal aorta, and in this way receiving its blood-flow by the shorter route. When we consider the proximity of the origin of the primitive subclavian to the unpaired aorta, it is not surprising that this should occasionally occur. Under such circumstances, the caudal segment of the right dorsal aorta, having acquired a new function in conveying a portion of the blood-stream, is not subject to the influence of a factor which would ordinarily have caused its disappearance. For a short time, no doubt, the cephalic segment of the right dorsal aorta also continues to carry blood to the primitive subclavian; it seems likely, however, that the caudal segment, when once the blood-flow through it towards the primitive subclavian is definitely established, proves the more advantageous route. In response to the greater demand thus thrown on the blood-stream in the unpaired aorta, the proportion of the current passing to the unpaired aorta viâ the left dorsal aorta probably in-

creases, with the result that the right limb of the aortic sac comes eventually to carry a proportion only of the current adequate for the supply of the right common carotid. Thus the right fourth arch and the cephalic part of the right dorsal aorta come to be an area of diminishing blood-flow (fig. 8 B), and, ceasing to function, become interrupted (fig. 8 C) in accordance with the general principle seen in the interruption of certain portions of the branchial pattern.

This interruption, though possibly occurring a little later than the time at which the caudal segment of the right dorsal aorta usually becomes obliterated, no doubt occurs at a relatively early stage, and therefore we should expect the disappearance of the segment to be complete. The earlier interruption of the right pulmonary arch caused the inferior laryngeal branch of the right vagus to come into relation with the right fourth arch, while the disappearance of the latter leaves no structure derived from the original branchial pattern round which the nerve should pass. Contrary to the opinion expressed by Gould (1909), one would not expect to find any fibrous cord representing the degenerated fourth arch, since at this early stage degeneration of a vessel to a fibrous cord does not occur.

The anomalous subclavian, at the time of its formation (fig. 8 C), takes origin from the developing aorta at a point corresponding to the bifurcation of the unpaired aorta and therefore distal to the origin of the left subclavian. The fact that in the adult the origin of the anomalous vessel is commonly found at a considerably higher level is no doubt due to the migration of its origin in a cephalic direction during the descent of the aorta into the thorax. The anomalous subclavian is obviously exposed to the same influences as the normal innominate and left subclavian, and no doubt the movement of its origin occurs by the same process as is responsible for the movement of these vessels.

B. *Gould's theory of the vessels by which the terminal segment of the right dorsal aorta is normally represented*

Gould (1909), in affirming the generally accepted theory of the origin of the anomalous subclavian by the incorporation of the caudal segment of the right dorsal aorta, raised the question of the vessels by which, if any, the caudal segment of the right dorsal aorta is represented in the ordinary case where a normal right subclavian is present.

At this time, apparently, the view that the right superior intercostal artery represented a portion of the caudal segment of the right dorsal aorta was fairly generally accepted, and a further portion of this segment was assumed to exist in the form of either a vas aberrans from the aorta or an anastomosis between the superior intercostal and the first aortic intercostal; as a necessary adjunct to this theory, it was further assumed that the anomalous subclavian when it occurred, incorporated a portion of the right superior intercostal. It was against the view that the right superior intercostal represents any portion of the right dorsal aorta that much of Gould's

argument was directed. Whatever criticism has been and may still be brought against any part of his reasoning, it is I think generally recognised to-day that his conclusion was entirely correct. It now appears to be definitely established that the longitudinal stem of the superior intercostal artery on both sides arises by a process similar to that which occurs in the development of the vertebral, i.e. by the establishment of anastomoses between certain segmental arteries and the disappearance of their proximal segments.

Gould, however, in rejecting the theory of the superior intercostal as a portion of the right dorsal aorta, expressed his opinion in favour of another theory, to the effect that the caudal segment of the right dorsal aorta is frequently if not normally represented by a vas aberrans from the right subclavian and a second vas aberrans either from the aorta or from the first aortic intercostal; these vessels he appears to have regarded as fairly constant in their occurrence, for he deprecates the omission of the first of them from certain of the standard text-books.

This theory in its turn was criticised by Gladstone and Wakeley (1915), who found, from the examination of a series of embryos over 17 mm. in length, that in every case the terminal segment of the right dorsal aorta had completely disappeared. This observation harmonises with the more recent finding of Congdon, whose figures of reconstructions clearly show that normally the disappearance of this segment is absolute. Gladstone and Wakeley further pointed out that, in 16 subjects in which they specially looked for the aberrant branch of the subclavian, they were able to find no trace of it, from which they concluded that, whatever the frequency of this branch, it is certainly not normally present.

From the references which I have located there appears to be nothing to indicate any considerable frequency in the occurrence of this aberrant branch. The following extracts may be taken as typical of the descriptions usually given. Poirier and Nicolas (in Poirier and Charpy's *Traité d'anatomie humaine*, 1912) refer to it as follows: "Un vaisseau aberrant qui descend derrière l'artère vertébrale et l'oesophage, et se termine dans les parois de l'aorte thoracique. Ce rameau est intéressant au point de vue morphologique, car il représente la racine droite descendante de l'aorte thoracique." Thane (in Quain's *Elements of Anatomy*, 1892) describes it as "a small vessel arising from the right subclavian artery near the vertebral, and descending to the left between the oesophagus and spine to join the termination of the arch; it is a vestige of the right aortic root. A brach arising in this situation and terminating on the trachea and oesophagus is not uncommon." Shepherd (1889), in another section of the paper in which he describes his case of anomalous subclavian, mentions an instance of a branch from the first part of the right subclavian passing down behind the aortic arch to reach the bifurcation of the trachea; he further says: "I have several times seen this artery. On one occasion it reached the descending aorta, with which it communicated, and I looked upon it as a persistence of the right aortic root."

From these descriptions, there would appear to be two types of aberrant branch occasionally seen arising near the commencement of the right subclavian; the one passing to the trachea or to the trachea and oesophagus; the other passing behind the oesophagus to reach the arch of the aorta, with which it may communicate.

It is evident that the first type of vas aberrans does not represent any part of the right dorsal aorta. Whether the second type does represent the normally interrupted terminal segment of the right dorsal aorta appears to be undetermined. The position and form of such an aberrant vessel are certainly suggestive of a stretched and attenuated but unobliterated terminal segment of the right dorsal aorta. The observations of Gladstone and Wakeley and more recently of Congdon show definitely that normally in the human embryo this segment has completely disappeared after the 17 mm. stage. This however cannot be taken as proving that the segment cannot occasionally be represented in the adult by a vas aberrans, for if it be admitted that the segment may sometimes persist as a portion of the right subclavian, then it is but reasonable to admit that it might also occasionally persist in another form. From developmental considerations it does not appear to be impossible that the vas aberrans might arise in this manner, provided for some reason the blood-flow in the terminal segment of the right dorsal aorta does not cease at the usual stage. For example, it may happen that, owing to delay in the production of sufficient inclination of the arotic trunk to the left, the right dorsal aorta, at a time when its terminal segment should disappear, continues to carry a little more blood than is adequate for the supply of the primitive subclavian, the excess continuing to pass by way of the terminal segment of the right dorsal aorta to the unpaired aorta. Under such circumstances one would expect the lumen of this terminal segment to become diminished in accordance with its diminished blood-flow, while, what little current there is, is likely to prevent complete obliteration. Meanwhile the larger cephalic segment of the right dorsal aorta has begun to be incorporated in the definitive subclavian in the usual manner. It seems possible that, with the continued descent of the developing aorta, the already dwindling and possibly weakened caudal segment may become stretched without of necessity becoming obliterated throughout, and in this way giving rise to a vas aberrans occupying approximately the position of the "thread" shown in fig. 6.

On the contrary, however, the case described by Geddes (1911 *a*) shows, in addition to an anomalous right subclavian, an unusual anastomosis between the right superior intercostal and a vas aberrans which arises from the aorta by a trunk common to it and the first left aortic intercostal. In position and form this vessel closely resembles the type of vas aberrans just referred to, from which it differs mainly in the fact that it is connected with the superior intercostal instead of directly with the subclavian. It is evident that the small vessel described by Geddes cannot represent the terminal segment

of the right dorsal aorta (since the latter is incorporated in the anomalous subclavian), but must be of entirely separate origin. And if this vessel could arise quite independently of the right dorsal aorta, then it seems probable that the occasional vas aberrans previously referred to might similarly be, from a developmental point of view, a structure entirely independent of the right dorsal aorta.

To what extent, then, Gould's hypothesis is correct remains undetermined. It may or may not be that the vas aberrans passing from the subclavian to the aortic arch, in those rather rare cases when it occurs, represents the terminal segment of the right dorsal aorta. Gould's view that this aberrant branch is almost constant in its occurrence appears, however, to be clearly disproved.

C. *Geddes's theory of two types of anomalous right subclavian*

Geddes (1911 *a*), while accepting Gould's conclusion that the right superior intercostal is developmentally a structure entirely separate from the terminal part of the right dorsal aorta, reasoned from the specimen already referred to that two types of anomalous right subclavian probably occur. Type 1, in which the obliteration of the whole right dorsal aorta is complete, and the anomalous subclavian is produced by the opening up of a channel of anastomosis between the first aortic intercostal and the right superior intercostal. Type 2, in which the anomalous subclavian is produced, according to the usual theory, by incorporating the distal segment of the right dorsal aorta, while the proximal segment, which usually becomes a part of the subclavian, disappears.

Regarding the possibility of the occurrence of an anomalous subclavian of Geddes's first type, it must be admitted that, provided it be granted that in some cases the whole of the right dorsal aorta may become obliterated, then an efficient right subclavian would probably be produced in the manner suggested by Geddes. The aspect of this theory, however, which requires further scrutiny is the question of the probability of the whole of the right dorsal aorta ever becoming obliterated from any cause. Viewed from the developmental standpoint, such an obliteration certainly seems improbable. From the study of the normal changes which occur in the aortic-arch system, it is evident that no portion of the system ever becomes obliterated except in response to the primary factor of a decrease in blood-flow, and further, that, provided any portion of the system continues to function in carrying a part of the blood-stream, that portion cannot become obliterated from any other cause. It therefore seems reasonable to assume that the right dorsal aorta as a whole could not become obliterated unless some other more advantageously placed channel had already deprived it of its share of the current. Since, according to Geddes's theory, the channel which forms the proximal segment of the anomalous subclavian is the anastomosis between the first aortic intercostal and the right superior intercostal,

one is no doubt justified in concluding that this anastomosis would be the vessel concerned in diverting the blood-stream from the right dorsal aorta. It is certainly difficult to conceive any case in which such a channel would prove a more advantageous route from the unpaired aorta to the primitive subclavian than that offered by the terminal segment of the right dorsal aorta.

The only case in the literature at my disposal in which it is suggested that the anomalous subclavian may be of Geddes's first type is the case recorded by De Garis (1923), who describes the right subclavian as being "both relatively and absolutely small throughout, its size suggesting type 1 of Geddes." From the diagram one would judge the diameter of the vessel to be about two-thirds that of the common carotid and not quite two-thirds that of the left subclavian. The relatively small diameter of this vessel does not appear to be adequate proof of its formation by the opening up of a channel of anastomosis; and, in view of the objections from the developmental standpoint, one believes that it cannot be regarded as established that cases ever occur in the manner indicated by Geddes's first type.

D. *The value of adult branches as evidence of the mode of formation of the anomalous subclavian*

In the papers of Gould (1909), Geddes (1911 *a*), and Gladstone and Wakeley (1915), considerable prominence is given to the position of origin, form, and anastomotic branches of the superior intercostal artery as evidence for or against the views under discussion. Indeed Gould, in his opening remarks, refers to the records of previous cases as affording "no information on the details of the condition such as the branches which the artery gives off, on the study of which the true interpretation of the abnormality depends."

In the light of more recent investigations on the development of arteries, it seems reasonable to doubt whether arguments based on the observation of the branches in the adult are of the value which has been attributed to them. Woollard (1922), from his study of the development of the forelimb arteries in the pig, concludes that in the formation of an individual arterial tube three stages may be distinguished: (1) the stage of the capillary net; (2) the stage characterised by enlarged tubes showing island-formation, coalescence, and a tendency to fuse—the retiform stage; (3) the stage of the formation of a definite stem; each of these stages occurs in response to definite physiological demands. In the human embryo, at the relatively early stage when the terminal segment of the right dorsal aorta becomes interrupted, it is evident that the branches of the subclavian have by no means assumed their adult form. If, then, at this early stage, an abnormal subclavian should commence to be evolved in place of a normal subclavian (either in the manner suggested by the usual theory or in any other way), then it is but reasonable to suggest that the branches of the subclavian, being as yet incompletely formed and relatively "plastic," may later in response to physiological

demands assume a form which in the adult will merely conform to one of the recognised types. For example, in the case of a subclavian being formed (if that be possible) by the opening up of a channel of anastomosis according to the theory of Geddes's first type, it appears to be possible that the superior intercostal might still in the course of subsequent development assume the form which is regarded as normal in the adult, instead of giving any indication of the mode of formation of the anomalous parent trunk. Again the presence in the adult of an anastomosis between the superior intercostal and the first aortic intercostal cannot be regarded as a conclusive argument that the abnormal subclavian has not arisen at an early stage by the opening up of such a channel of anastomosis unless we are in a position definitely to assert the impossibility of a second anastomosis occurring between these two arteries.

Further, in considering the evolution of adult branches, the phenomenon of migration of branches along the trunk of the parent vessel must be borne in mind. Thus it is possible that the position of the origin of the superior intercostal relative to that of the vertebral may be different in the adult form from what it was at the stage when the subclavian first became outlined.

In view of such considerations, one believes that a reasonable degree of caution should be exercised before accepting as conclusive, arguments which, being based on the study of adult branches, imply that the form and position of such branches are already immutable at the time when the definitive parent trunk commences to be outlined.

THE COURSE OF THE RIGHT INFERIOR LARYNGEAL NERVE IN CASES OF ANOMALOUS RIGHT SUBCLAVIAN ARTERY

Reference to Table I shows that, in cases of anomalous right subclavian artery, the right inferior laryngeal nerve may present one of three courses: (1) it may be recurrent round the right vertebral artery; (2) it may turn round the inferior thyroid artery or one of its branches; or (3) it may pass to the larynx directly.

1. *Cases in which the nerve is recurrent round the right vertebral artery*

Although the table of cases given in this paper contains only one definite instance (viz. the case of Shepherd, 1889) in which the nerve turns round the vertebral artery, the perusal of the literature leads me to believe that not only have similar cases been recorded but that also in all such cases the origin of the right vertebral is from the right common carotid. Thane (Quain's *Elements of Anatomy*, 1892) states that, in all cases of anomalous right subclavian in which the right vertebral arises from the right common carotid, the inferior laryngeal nerve passes inwards to the larynx around the first part of the vertebral artery.

The occurrence of a right vertebral arising from the right common carotid and having the inferior laryngeal nerve recurrent round it has been explained on the very reasonable assumption that the vertebral in these cases has in-

corporated part or the whole of the right fourth arch together with, possibly, the adjoining part of the right dorsal aorta.

On the point, however, of how the vertebral comes to incorporate these parts of the original branchial pattern, the existing statements are far from clear. According to Shepherd (1889), the condition is explained by the disappearance of the fourth arch external to the origin of the vertebral. Thane (in Quain's *Elements of Anatomy*, 1892) offers the following explanation: "The subclavian is derived from the dorsal aorta while the vertebral is continued from the fourth arch, the connection of the latter with the dorsal aorta being obliterated." Cobey (1914), in explaining the anomalous subclavian as due to absorption of the fourth arch, states that the extent and position of the absorption appear to determine the point of origin of the vertebral; if the absorption is not complete medially, then the unabsorbed portion persists as the vertebral arising from the common carotid. Goldbloom (1922) states that obstruction medial to the origin of the vertebral at an early period results in the vertebral arising from the anomalous subclavian, while obstruction beyond the origin of the vertebral results in the vertebral arising from the common carotid. Apart from the fact that these statements all imply the dropping out of certain fixed segments of the branchial pattern from no apparent cause, they are further open to objection in that they are completely lacking in significance unless we assume the origin of the primitive vertebral to be either from the right dorsal aorta or from the right fourth arch, independent of and cephalic to the primitive subclavian. In an arterial arrangement such as depicted in fig. 5, no disappearance of any portion of the fourth arch (Shepherd), or obliteration of the connection of the fourth arch with the dorsal aorta (Thane), or failure of absorption in the medial part (Cobey), or obstruction anywhere along the fourth arch and right dorsal aorta (Goldbloom), could possibly result in the origin of the vertebral from the common carotid.

It is therefore evident that, in order to explain the occurrence of an adult right vertebral which arises from the common carotid and in which the right fourth arch is incorporated, we must assume that, prior to the interruption of the right dorsal aorta, the primitive vertebral arose from the right dorsal aorta cephalic to the origin of the primitive subclavian, as indicated in fig. 9 A.

In this connection it is interesting to note that, in three out of four cases in the table in which the right vertebral is definitely stated to arise from the right common carotid, the left vertebral is also unusual in that it arises from the arch of the aorta proximal to the origin of the left subclavian. In these cases, then, not only did the right vertebral at a relatively early stage arise from the right dorsal aorta proximal to the primitive subclavian, but also at some stage the left vertebral arose from the left dorsal aorta in a corresponding position.

In seeking an explanation as to why one or both vertebrals should arise from the paired aortae in this manner, three possible theories suggest them-

selves. At first sight it seems possible that the origin of the vertebral may have migrated medially from the subclavian on to the paired aorta. On closer inspection, however, factors to cause such a migration appear to be entirely lacking. On the contrary, in the case of a normal subclavian the much more medial position of the origin of the right vertebral in the adult as compared with its position when the right subclavian is first outlined (fig. 5) appears to be explained entirely by a relative failure of growth of the part of such a subclavian derived from the right fourth arch and the right dorsal aorta. The second theory which suggests itself is that the proximal portion of the primitive subclavian may have become absorbed into the paired aorta, a theory which has been used by Robinson (in Cunningham's *Text-book of Anatomy*, 1922) to explain the origin of the left vertebral from the arch or the aorta, and also by Harris (1922) to explain the origin of the left vertebral from the left dorsal aorta in a case of an entirely different nature. On the left side, where the paired aorta undergoes a considerable increase in diameter, such an absorption appears to be by no means impossible, but even here the theory is open to objection in that there appears to be no reason why such an absorption should occur in a few cases and not in all. In the case of the right side, where the diameter of the paired aorta is becoming diminished, the theory appears to be quite untenable. The third and simplest theory seems to be the most probable, namely that in such cases the vertebral has from its inception incorporated the stem of the sixth segmental, while the subclavian has incorporated the stem of the seventh segmental in the usual manner. In favour of this theory is the fact that independent origins of the primitive vertebral and of the primitive subclavian on the right side would confer a tendency towards the development of an abnormal rather than a normal subclavian; while the fact that in some cases the primitive vertebral may at an early stage arise from the paired aorta cephalic to the primitive subclavian is clearly demonstrated by the aortic-arch system of the 17 mm. stage described by Gladstone and Wakeley (1915). In this case the left vertebral had an independent origin from the left dorsal aorta about midway between the left common carotid and the left subclavian.

Assuming, then, a case in which, at say the 14 mm. stage, the primitive vertebral and the primitive subclavian are seen to arise independently from the right dorsal aorta (fig. 9 A), we may construct the history of the subsequent changes very briefly as follows. The right paired aorta is as yet uninterrupted at any point caudal to the fourth arch, but, owing to the inclination of the aortic trunk to the left, the right fourth arch and right paired aorta are now carrying a much smaller proportion of the blood-stream than the corresponding parts on the left side. The diminishing current in the right paired aorta is being mainly taken by the primitive vertebral, in consequence of which the primitive subclavian, deprived of a sufficient blood-flow by the usual route, comes to tap the main stream in the unpaired aorta by means of the short terminal segment of the right dorsal aorta (fig. 9 B). Thus, in

the short segment of the right dorsal aorta between the origin of the primitive vertebral and the origin of the primitive subclavian, the current becomes greatly diminished, eventually ceases, and as a result the segment itself disappears. In this way the permanent vessels come to be outlined (fig. 9 c), the vertebral now consisting of the right fourth arch, the adjacent uninterrupted part of the right dorsal aorta, and the primitive vertebral, while the subclavian consists of the short caudal segment of the right dorsal aorta together with the primitive subclavian.

Should a similar arrangement of the primitive vertebral and primitive subclavian exist on the left side (fig. 9), though a segment of paired aorta intervenes between their origins, this segment, since it continues to function

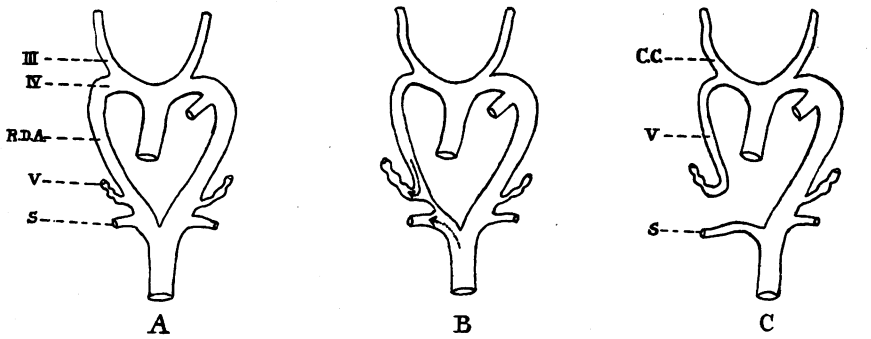

Fig. 9. To illustrate the theory of the formation of an anomalous right subclavian artery with the vertebral as a branch of the right common carotid. III=third arch; IV=fourth arch; R.D.A.=right dorsal aorta; C.C.=common carotid; V.=vertebral; S.=subclavian.

in the conveyance of the main blood-stream, shows no tendency towards interruption but develops in the usual manner into a portion of the definitive aorta. During the descent of the aorta, the origin of the vertebral no doubt migrates in a cephalic direction in the same manner as the origin of the left subclavian, so that in the adult it arises from the summit of the arch between the left common carotid and the left subclavian.

The recent case recorded by De Garis (1923) differs from those already referred to in hat, while the right vertebral arises from the right common carotid, only that portion of the inferior laryngeal nerve which is distributed to the trachea and oesophagus is recurrent round it; the rest of the nerve passes to the larynx beneath the inferior thyroid artery. In the absence of any detailed account of the early development of the inferior laryngeal nerve, one is led to assume that in this case only a portion of the nerve was ever caudal to the right fourth arch, the remaining filaments being cephalic to it from the beginning. Such a possibility is suggested by Hudson (1921) for the whole nerve; "it seems probable that here the cervical visceral branches of the vagus came off above the fourth aortic arch instead of below it, and in

consequence were not drawn down the neck in a loop during the caudal migration of the heart and great vessels."

2. *Cases in which the nerve is recurrent round the inferior thyroid artery or one of its branches*

In those cases in which the nerve does not pass round the vertebral artery it may be assumed that the disappearance of the right fourth arch and the cephalic segment of the right dorsal aorta has been complete. The varying relation of the nerve, in such cases, to the inferior thyroid artery is no doubt explainable on the basis of the normal variation of the relation of the artery to that part of the nerve which is in relation with the thyroid gland; it is a well-established fact that the artery may pass entirely behind or entirely in front of the nerve, or that some of the branches of the artery may pass in front of and some behind the nerve. Cases in which, in the presence of an anomalous subclavian, the nerve loops round the whole of the inferior thyroid artery no doubt represent cases in which, had the fourth arch persisted, the nerve would, when in the region of the thyroid gland, have passed entirely behind the artery; cases in which the nerve loops round one or more of the upper branches of the artery no doubt represent cases where the nerve would have had some of the branches of the artery in front of it and some behind it; while cases in which the nerve bears no relation to the artery no doubt represent cases where the nerve would have passed entirely in front of the artery.

3. *Cases in which the nerve passes direct to the larynx*

In those cases in which the nerve is recurrent round neither the vertebral nor the inferior thyroid artery, it is usually described as passing directly to the larynx.

Gould (1909), however, pointed out that, in his case, the nerve did not take the shortest possible course from the vagus to the lower border of the inferior constrictor, but presented a slight curve with the convexity downwards. A similar condition existed in the second of the cases which I have seen.

Gould suggested that such recurrency is a question of the point in development at which the permanent arterial pattern becomes defined, and expressed the opinion that further cases would (in the absence of any structure round which the nerve turned) show varying degrees of recurrency, being greater in cases where there is more delay in the outlining of the permanent arterial pattern. Up to the present, however, the prophecy contained in the latter part of this statement remains unfulfilled. From the consideration of the normal arterial development and the theories based upon it, it would seem that, although individual cases may show some very slight variation in the time at which the anomalous subclavian is outlined, it is improbable that there is any considerable variation in this point. It is quite possible that Gould's theory represents the correct explanation of the difference between a perfectly straight and a slightly curved course such as has been

observed, yet it appears unlikely that there is sufficient variation in the time of interruption of the right dorsal aorta to account for any marked variation in the degree of recurrency of the nerve.

THE QUESTION OF THE OCCURRENCE OF AN ANOMALOUS RIGHT SUBCLAVIAN PASSING EITHER IN FRONT OF THE TRACHEA OR BETWEEN THE TRACHEA AND THE OESOPHAGUS

In the series of approximately 200 cases collected by Holzapfel in 1899, the anomalous subclavian, though described in the majority of cases as passing behind the oesophagus, was stated to pass between the trachea and oesophagus in 20 cases, and in front of the trachea in six cases. More recently, however, Geddes (1911 *b*) has expressed doubt as to whether any definitely substantiated case exists in which the artery occupied either of the latter two positions.

With regard to the course of the artery ventral to the trachea, Geddes found, on investigating the literature, that references to such a position of the artery appeared to rest for their authority on the case recorded by Walter in 1785, which Geddes believes to be a "case of right aortic-arch with the right subclavian artery arising last and representing the left arch, and so passing in front of the trachea." It is interesting to note that the observation of Walter was also doubted by Quain (1844).

With regard to the course of the anomalous subclavian between the trachea and oesophagus, Quain (1844) appears to accept as genuine the cases of Bayford and of Meckel, while Geddes appears to regard both of these as at least doubtful. Concerning Meckel's observations, Geddes is disposed to the opinion that Meckel had not seen a case. As the quotations given by Quain and by Geddes differ, it may not be out of place to mention the passage quoted by Quain: "Dem normalen näher ist der Weg zwischen der Luft und Speiseröhre, welchen diese Arterie bisweile nimmt. Dies fand in dem dritten der von mir beobachteten Fälle" (*Handbuch der Pathol. Anatomie*, Band 2, S. 100).

In the opening paragraph of Geddes's paper, there occurs a statement to the effect that the description of the anomalous subclavian as passing either between the trachea and oesophagus or in front of the trachea appears to rest on the authority of Power. In view of the fact that Geddes's conclusions have been accepted without question by certain more recent writers, it is unfortunate that this statement, on which the remainder of his paper is based, is not entirely correct, since it leaves out of account the very definite case recorded by Bradley (1871). The anomalous artery in this case (observed in the dissecting-room of the Manchester School of Medicine and Surgery) is described as follows: "It sprang from the extreme left of the transverse arch on its posterior aspect, and passed upwards and to the right, running between the oesophagus and trachea to continue down the arm in the usual manner." The position of this vessel with relation to the trachea and oesophagus is

emphasised in a footnote, in which Bradley refers to a second case of anomalous right subclavian observed during the same session. in the second case, the artery "did not, as in the former instance, pass between the trachea and oesophagus, but behind them both."

It must therefore be admitted that at least one definite case has occurred in which the anomalous right subclavian artery passed between the trachea (ventrally) and the oesophagus (dorsally). The developmental explanation of such a position of the vessel is by no means obvious. One can but suggest that, in this case, the fusion of the paired aortae to form the unpaired aorta may have occurred, at any rate in its cephalic part, ventral to the alimentary canal instead of dorsal to it; and that subsequently the anomalous artery was developed by the incorporation of the terminal segment of the right dorsal aorta in the usual manner.

The branches of the anomalous right subclavian artery

The suggestion of Gould (already referred to) that it is on the study of the branches of the abnormal subclavian that the true interpretation of the anomaly depends appears to have resulted in the recording, by practically all the more recent writers on this subject, of the branches of one or both subclavian arteries in the cases observed by them.

Although it is not impossible that such records of branches may later prove to be of value, they do not appear, in the writer's opinion, to have thrown any particular light on the causation of the anomaly. Indeed, in consideration of the investigations recorded by Thomson (1893) and De Garis (1924) on the branching of the normal subclavian artery, it would seem that the branches of the anomalous artery, though showing considerable variation, are no more variable in their origin than the branches of the normal artery.

The termination of the thoracic duct in cases of anomalous right subclavian artery

Geddes (1911 *b*) states that "another legend which haunts this arteria variation is that the thoracic duct ends usually on the right side." According to Geddes, this statement appears to rest on the condition found in one case in the middle of the eighteenth century, and described in the Museum Anatomicum of Sandifort.

Of the cases recorded since the appearance of Geddes's paper, one of the two cases reported by Gladstone and Wakeley (1915) showed the thoracic duct terminating at the junction of the right internal jugular and subclavian veins; while in a case reported in 1916 by Poynter (quoted by Hudson) the thoracic duct divided opposite the fifth thoracic vertebra into two trunks, of which the larger opened into the right, and the smaller into the left, angulus venosus. Reference to Table I shows that, of five cases in which the termination of the thoracic duct is definitely stated, in four the duct terminates in

the usual manner on the left side; this was also the case in the two instances which I have seen. From the few cases mentioned, it appears obvious that the duct terminates usually on the left side and less frequently on the right.

That the thoracic duct is not always of the type described in the text-books is clearly shown by Davis (1915), who points out that seven distinct types of thoracic duct have been observed, while from developmental considerations two further types probably exist. Though the cases given by this observer appear to be too few to justify the use of percentages, it is evident from his paper that in the majority of cases the thoracic duct terminates on the left side as usually described, while a smaller number of cases definitely exists in which the duct either terminates on the right side or divides to terminate on both sides.

In connection with the anomalous subclavian, neither from the records of cases nor from theoretical considerations does there seem to be any indication that the termination of the thoracic duct on the right side is more frequent in such cases than would be expected from the normal variations of the duct itself.

Clinical significance of the anomalous right subclavian artery

From the frequency with which the anomalous right subclavian has been observed in dissecting-room subjects, it must I think be obvious that the majority of such cases occur without the production of any symptoms during life. From the clinical point of view, various possibilities have been suggested by some of the writers on this subject; of such suggestions, a few appear to be substantiated by definite cases, while many appear to be merely in the nature of surmise.

The possibility of unequal radial pulses is mentioned by Harvey (1917) and Goldbloom (1922). The same writers also mention that, in at least one recorded case, the unusual position of the artery caused difficulty in the operation for ligation of the subclavian. Harvey further suggests that in surgical conditions involving the oesophagus and in operations on the thorax the presence of the anomalous artery may be of considerable importance, while Goldbloom directs attention to the unusual position of the inferior laryngeal nerve in connection with operations on the front of the neck. Cobey (1914) suggests the possibility of symptoms similar to those of cervical rib. Goldbloom (1922) mentions the possibility of pressure on the thoracic duct, in which connection it is interesting to note that, in the case recorded by De Garis (1923), the thoracic duct was more than usually varicose, and in addition presented a definite dilatation for about 4 cm. just before passing beneath the anomalous subclavian.

The possibility of dysphagia being caused by an anomalous subclavian has been referred to by a number of writers dating back at least to Bayford, whose case was described in 1794. The earliest reference to this question in the literature at my disposal appears in the writings of Quain (1844) who gives

some particulars of Bayford's case. A female who died at the age of nearly 62 had occasional difficulty in swallowing from childhood; the condition became worse at puberty, and thereafter was aggravated once or twice a month throughout life; for three weeks before death the patient was scarcely able to swallow; post-mortem, nothing could be found to which the difficulty in swallowing could be assigned except the presence of the right subclavian between the trachea and the oesophagus, from which it was "reasonably concluded that the vessel was the source of the symptoms." Quain refers to this case as "an isolated observation which has not been confirmed"; he points out that in the majority of cases there is no dysphagia, and cites the case of Otto, in which a young man who was observed for some time before death had not had the slightest difficulty in swallowing, but was found post-mortem to have an anomalous subclavian artery between the oesophagus and the vertebral column. More recently it has been suggested by Holzapfel (quoted by Harvey) that only by an aneurismal enlargement of the abnormal subclavian may dysphagia be produced. In the cases recorded in the present century, dilatation of the part of the vessel related to the oesophagus is stated by Harvey to have been observed in one of the cases collected by Bean in 1904, and in the table of cases in this paper is shown to have occurred in one of the two cases recorded by Harvey (1917) and in the case recorded by Hudson (1921).

Summary and Conclusions

1. The anomalous right subclavian artery arising from the arch of the aorta distal to the origin of the left subclavian appears to be not uncommon. At least 231 cases have been recorded, and two further cases are presented here. The frequency with which the condition has been observed by different writers varies from 4 in 1000 to 4 in 225.

2. Reference is made to the recent research of Congdon on the developmental changes in the aortic-arch system in the human embryo, from the study of which it appears evident that the classical descriptions of this portion of embryology as they appear in most of our standard text-books require revision. In view of certain facts and principles brought out by Congdon, it has appeared advisable to review the existing theories and discussion on the anomalous subclavian artery, since such statements have hitherto been based on the incomplete and in some respects inaccurate data provided by the description and diagrams of Rathke.

3. The occasional occurrence of an anomalous right subclavian artery appears to be adequately explained on the assumption that the primitive subclavian in such cases taps the main blood-stream in the unpaired aorta by means of the short terminal segment of the right dorsal aorta; this segment thus escapes its usual fate of disappearance consequent upon an absence of function, and becomes incorporated in the definitive subclavian. The suggestion of Geddes that in some instances the anomalous subclavian arises by

the opening up of a channel of anastomosis between the first aortic intercostal and the right superior intercostal appears to be very improbable from developmental considerations and is not substantiated by actual cases.

4. Congdon's work, as well as the earlier observations of Gladstone and Wakeley, shows that as a general rule in normal cases the short segment of the right dorsal aorta distal to the origin of the primitive subclavian disappears altogether. That no portion of this segment is represented in the normal right superior intercostal is definitely proved, but whether the segment may occasionally be represented by an aberrant branch from the right subclavian appears uncertain.

5. In view of the fact that the branches of the subclavian are, at the time when the anomalous parent vessel is no doubt outlined, as yet incompletely formed and later may be modified considerably in response to physiological demands, it is suggested that reasonable caution should be exercised in the examination of arguments which are based entirely on the position of origin, form, and anastomoses of the branches as seen in the adult.

6. The right inferior laryngeal nerve in cases of anomalous subclavian is found, by reference to the literature, to take one of three courses to the larynx. Firstly, it may be recurrent round the right vertebral artery, which in such cases arises from the right common carotid; in these cases it appears evident that the vertebral has incorporated the right fourth arch and an adjacent portion of the dorsal aorta. It is suggested that the factor which is mainly responsible for the development of such an arterial pattern consists probably in the primitive vertebral having incorporated the stem of the sixth segmental artery and having failed to establish the usual anastomosis with the seventh segmental artery. Secondly, the nerve may turn round the inferior thyroid artery or one of its branches; or, thirdly, the nerve may pass direct to the larynx. In all such cases the right fourth arch has no doubt disappeared completely (degeneration of a vessel into a fibrous cord does not occur at this early stage). The varying relation of the nerve to the inferior thyroid artery appears to be nothing more than the expression in such cases of the normal variation of the relation of the nerve to the artery (and its branches) in the region of the thyroid gland.

7. That the anomalous subclavian artery passes in the great majority of cases dorsal to the oesophagus is of course established. Whether such a vessel ever passes ventral to the trachea or between the trachea and oesophagus has been doubted. The observations of Quain and more recently of Geddes indicate that there is no reliable case in which the artery is shown to pass in front of the trachea. In the matter of the passage of the artery between the trachea and the oesophagus, the case of Bayford may be open to doubt, but the case of Bradley constitutes one definitely recorded instance of an extremely rare condition.

8. The branches of the anomalous right subclavian appear to be no more variable than the branches of the normal subclavian, and the thoracic duct

in such cases appears to show only its normal variation in form and termination.

9. Undoubtedly the great majority of cases of anomalous subclavian artery produce no symptoms and pass unrecognised throughout life. In the matter of clinical significance, different writers have suggested various possibilities, a number of which appear as yet to be purely hypothetical.

II. TWO CASES OF AN UNUSUAL RELATION OF THE INNOMINATE ARTERY TO THE TRACHEA

Cases in which the innominate artery lies ventral to the cervical portion of the trachea consist as a rule of the condition known as "high bifurcation" of the innominate; in such instances the vessel ascends in front of the trachea, with a gradual inclination to the right, and terminates at a higher level than usual.

Two cases of a rather different nature from this well-recognised type have recently come under my notice, having been observed in the dissecting-room

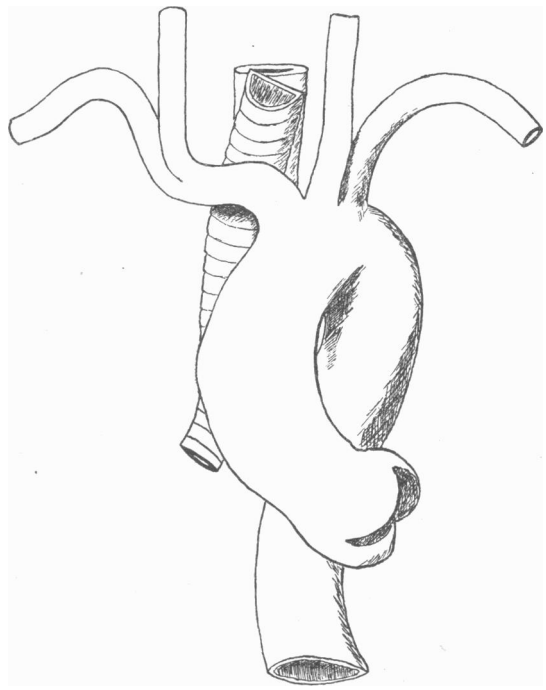

Fig. 10. Specimen from first case, seen from front.

on successive days. In both cases the innominate artery was seen in the dissection of the neck to pass transversely in front of the trachea at about the level of the suprasternal notch, and on further investigation I found the main features of the condition to be as follows.

In the first case (fig. 10), the summit of the arch of the aorta was at the level of the suprasternal notch, and from it the innominate artery arose at what appeared to be the usual point. From its origin the innominate artery passed to the right, being at first inclined slightly upwards but for the most part lying horizontally. It lay ventral to the trachea, on which it produced a definite impression, and terminated in the usual position behind the right sterno-clavicular joint. The length of the vessel was about 1¼ inches.

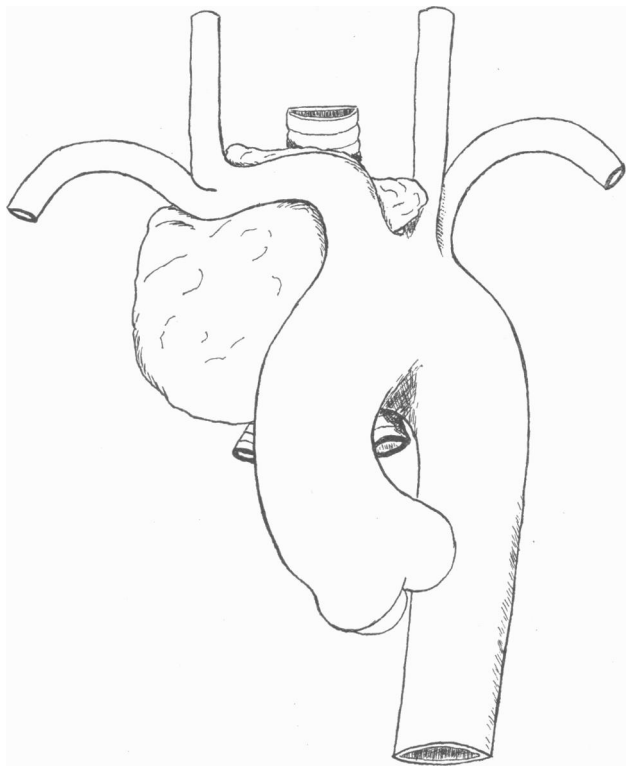

Fig. 11. Specimen from second case, seen from front.

Only the upper part of it was visible above the suprasternal notch, and here it was partly overlapped by the thyroid gland, which was enlarged. The thoracic portion of the vertebral column showed definite scoliosis, the convexity being directed towards the right. Apparently as a result of this condition, the trachea, at the point where the innominate artery crossed it, was disposed to the right of its normal position. The heart was normal in size and in its position relative to the ventral thoracic wall. The aortic orifice occupied its usual position behind the lower border of the third left costal cartilage at its junction with the sternum; the aortic arch was not atheromatous or dilated. The subject was a male aged 81, and the cause of death was certified as cerebral haemorrhage.

In the second case (fig. 11), the summit of the arch of the aorta was again at the level of the suprasternal notch. The innominate artery, arising at apparently the usual point on the arch, first ascended for about ¾ inch, and then passed transversely to the right to terminate a short distance above and lateral to the right sterno-clavicular joint. Its total length was about 2 inches. In its ascending portion and at the commencement of its transverse portion it lay ventral to the trachea, from which it was separated by a part of the mass of tissue shown in the figure. This mass lay in the superior mediastinum mainly to the right of the trachea, but was partly placed between the trachea behind and the transverse part of the arch of the aorta and the innominate artery in front. A small portion extended to the left between the origins of the innominate and left common carotid arteries. The innominate artery occupied a groove in it, being separated by less than ¼ inch from the trachea. The mass was definitely encapsulated, and on histological examination was found to consist entirely of fat. Practically the whole width of the transverse portion of the innominate artery was visible above the suprasternal notch, and was separated by an interval from the thyroid gland, which was small and atrophic. The heart was enlarged and hypertrophied, the arch of the aorta was atheromatous and dilated, and the innominate artery was also dilated near its origin. The subject was a male negro aged 72, and death was certified as due to myocarditis and heart failure.

The only instances of a similar condition which I have been able to find mentioned in the literature consist in two cases recorded by Koster and described in English by Moore (1867). In one of these cases the innominate artery, arising "just under the jugular notch of the sternum," ran for nearly 3 cm. above the sternum directly in front of the trachea and then turned to the right before dividing into its two branches. The subject was a female aged 75. "The arch of the aorta lay high, was atheromatous and ossified, dilated about one-half more than in the normal state." In the other case the course of the innominate was similar, but the portion of the vessel which ascended ventral to the trachea and above the sternum was only 1¾ cm. in length; the subject was a male aged 40. Koster points out that the condition does not appear to have been previously described; he regards it as a "congenital abnormal position of the arteries."

In the two cases which I have seen, it is not impossible that the position of the innominate artery may be explained as resulting from the pathological changes shown to be present. In the first case, it is obvious that the occurrence of scoliosis has caused the supero-inferior extent of the left half of the thorax to become diminished. As a consequence of this, the arch of the aorta may have become raised relatively to the skeleton of the thorax, while the innominate artery, subjected to pressure from above by the enlarged thyroid gland, may have been caused to assume a more or less transverse position. In the second case it is possible that the obvious dilatation of the arch of the aorta is the factor which accounts for the high position of the

summit of the arch, while the course of the innominate artery may be accounted for by the height of the arch, and the dilatation of the commencement of the innominate itself, together. The presence of the fatty mass (in which the artery was embedded) was a possible factor which prevented the vessel from becoming still further elevated into the neck.

In the first case at least I am disposed to doubt the accuracy of such a theory. Examination of the specimen shows that the aorta appears to have accommodated itself to the diminished vertical extent of the left half of the thorax by the development of a marked curve in its descending thoracic portion following the abnormal curve of the vertebral column, rather than by elevation of the arch. The aortic valves occupied their usual position relative to the ventral thoracic wall, the ascending portion of the arch appeared to be normal in its course and direction, while the innominate artery with the other two large vessels arose in the usual manner from the region of the summit of the arch. It thus appeared that the relatively high position of the summit of the arch was accompanied by an increase in the length of that segment of the arch which extends from the aortic valves to the origin of the innominate, a condition which could not have been caused by pathological changes in the skeleton of the thorax.

It may therefore be permissible to point out as an alternative theory that the practically transverse position of the innominate artery may conceivably be due to arrest of the descent of the arch of the aorta at the stage when it reached the inlet of the thorax. At this stage, as has been shown by Congdon (1922), the innominate artery still takes the form of a transverse tube, and in the course of normal development only later becomes longitudinal in response to the caudal movement of the arch.

In conclusion, I desire to express my thanks to Prof. W. P. Gowland for permission to publish the cases which have occurred in the dissecting-room of this department.

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