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SOME OBSERVATIONS ON ESOPHAGEAL ATRESIAS AND TRACHEO-ESOPHAGEAL FISTULAS OF CONGENITAL ORIGIN

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THIS meeting marks the fortieth anniversary of the founding of The American Association for Thoracic Surgery. During the existence of the Association, the advancements which have been made in thoracic surgery have been truly astounding. The progress in this field which was envisioned by our founders has far exceeded their fondest hopes and most vivid dreams. Such is the fascination of the ever-changing realm of medicine. On this occasion I should like to present some observations on congenital esophageal atresias and tracheo-esophageal fistulas, a subject which has been of particular interest to me for a number of years. Since a complete presentation of all aspects of the subject would require more than a judicious amount of time, my remarks will of necessity be limited to certain selected observations which I hope will be of interest to you.

The development of a satisfactory approach to the correction of congenital atresia of the esophagus provides a stimulating example of a quest for the solution to a baffling problem. The pioneering efforts of many surgeons working in this field established the groundwork for the satisfactory correction of the anomaly. Credit for their efforts should be generously paid to a list of names too long to be given in full; I should especially like to pay tribute, however, to H. M. Richter, N. Logan Leven, W. E. Ladd; and to Thomas H. Lanman and Robert Shaw, the latter two being the first active proponents of the principle of esophageal anastomosis for the correction of atresia.

In the literature, and even more so in hospital vernacular, the term tracheo-esophageal fistula, or T.E.F., is often loosely used to cover an esophageal atresia

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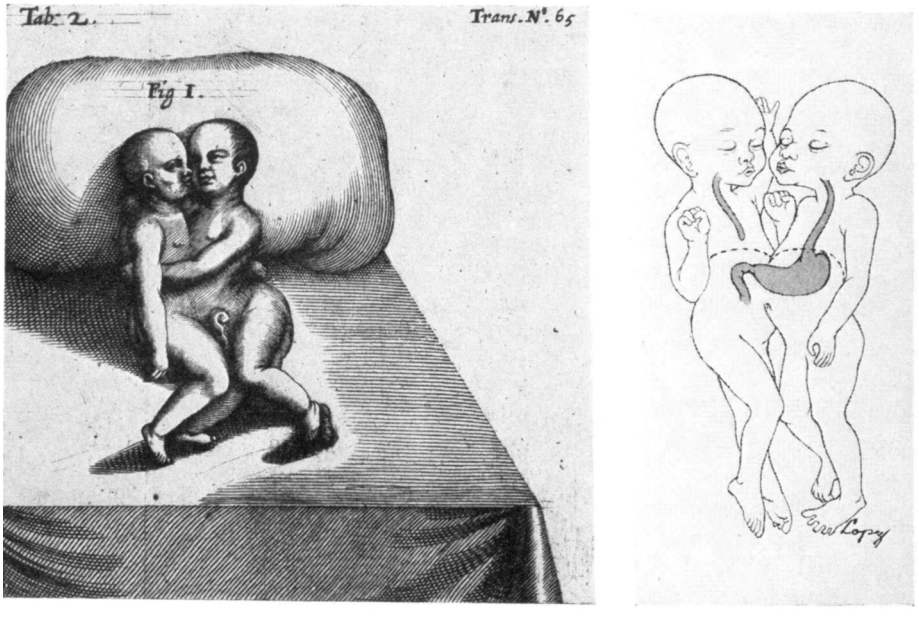
which is not accompanied by any connection with the trachea. This terminology appears to me to be inaccurate and misleading. Although a tracheoesophageal fistula is usually present along with esophageal atresia, the atresia may be present alone. Conversely, there may be a fistulous tract between the trachea and an otherwise normal esophagus. Our terminology should designate these conditions accurately. We should recognize three categories: (1) esophageal atresia accompanied by tracheoesophageal fistula, (2) esophageal atresia without tracheoesophageal fistula, and (3) tracheoesophageal fistula without esophageal atresia. In this paper the term "esophageal atresia" will be used to include atresias which may or may not be accompanied by a tracheoesophageal fistula. Conversely, the term "tracheoesophageal fistula" will be used to designate those cases where there is a fistula between the trachea and an otherwise normal esophagus.

The earliest description of esophageal atresia was presented by William Durston,[1] in 1670. In some writings, this case has been referred to erroneously as one of esophageal atresia with tracheoesophageal fistula. In this case, however, a simple atresia, in which there was no associated tracheoesophageal fistula, was found in the right component of conjoined twins. It was published in volume V of the *Philosophical Transactions of the Royal Society*, under the title of "A Narrative of a Monstrous Birth in Plymouth, Octob. 22, 1670; together with the Anatomical Observations, taken thereupon by William Durston, Doctor in Physick, and communicated to Dr. Tim. Clerk." Reference to this unusual case is often found in the literature; but since I have not found it reproduced in any writings to date, a facsimile of the twins is shown in Fig. 1, *A*. The type of anomaly is illustrated in Fig. 1, *B*.

Durston's case represents one instance in which history has not as yet repeated itself, although a somewhat similar case is to be found in the 8 mm. embryo of the monster type described by Ysander[2] slightly more than 250 years later. This embryo, of the type thoracopagus tetrabrachius, had but one stomach and one heart anlage, while the esophagus and respiratory apparatus were duplicated identically. Each "embryo" presented a typical esophageal atresia with tracheoesophageal fistula. It is believed by Rosenthal[3] to be the youngest known embryo showing such an anomaly.

The first description of a case of esophageal atresia with the typical form of tracheoesophageal fistula is the frequently cited case of Thomas Gibson,[4] Physician General to the British army, and husband of Anne, the youngest daughter of Richard Cromwell.[5] Gibson was the author of *The Anatomy of Humane Bodies Epitomized*, a work very popular in its day and published in at least seven editions. Appearing for the first time in the fifth edition, in 1697, is his classical case of esophageal atresia with tracheoesophageal fistula. It was presented not only because it represented a previously undescribed case of esophageal atresia with associated tracheoesophageal fistula, but also as evidence to support the then currently accepted opinion that the fetus receives nourishment by the mouth in the latter months of gestation. Gibson's case has been reproduced verbatim in the articles by Plass[6] and Ferguson.[7]

During the eighteenth century, no reports of congenital atresia of the esophagus were found in the comprehensive review of the literature by Plass. Only a few cases were reported in the first part of the nineteenth century. In 1861, Hirschsprung[8] collected 10 cases of the anomaly and added 4 cases which had come under his own notice. In 1880, Mackenzie[9] collected 37 cases of esophageal atresia, with a tracheoesophageal fistula in 34 cases, and a broncho-esophageal fistula in 3. By 1919, Plass had been able to verify the reports of 136 cases; he also found an additional 13 cases referred to by various authors,



A. *B.*

Fig. 1.—*A*, Durston's case in which an esophageal atresia without a tracheoesophageal fistula was found in the right component of a conjoined twin. (Courtesy of University of Michigan Library.)

B, A current diagrammatic representation of the type of anomaly described by Durston.

but he was unable to verify the references. Rosenthal,[3] in 1931, was able to collect 255 cases, including 8 in which he described the post-mortem findings. Thus, it became evident that the anomaly is not a rare one.

ETIOLOGY

The etiology of congenital atresia of the esophagus is still not completely understood. The factors that have been mentioned as possible contributing causes most frequently implicate systemic diseases of the mother, abnormalities of the placenta, and inherited tendencies. Gruenwald[10] has presented a complete review of the many causes of abnormal developments that may occur in the embryo, and Ingalls and Prindle[11] have given special attention to the epidemiologic and teratologic factors in the genesis of esophageal atresia.

Among the maternal factors are systemic disease of the mother, including virus infections and vitamin deficiencies, as well as unusual emotional situations. Local factors such as mechanical trauma and diseases of the uterus and placenta require further clarification since, conceivably, they could play a part in the causation of the anomaly. In experimental studies, Warkany, Roth, and Wilson[12] have been able to produce multiple congenital malformations in rats by means of a vitamin A deficient diet in the mothers, the most frequent anomaly being abnormal eyes. They cite the experiences of others working in this field and employing various vitamin deficient diets in different animals with the production of varying types of congenital malformations. In their study of the frequency of various anomalies in 50 offspring with abnormal eyes, Warkany, Roth, and Wilson found only one instance of tracheoesophageal fistula. They also state that nutritional deficiencies of the fetus can be caused not only by dietary deficiencies of the mother, but also by maternal or placental diseases.

By careful questioning of the parents of the patients in the series of cases observed at the University Hospital, we have not been able to discover any significant clues regarding the etiology of the anomaly. The parents of our patients reflect a wide divergence in economic and social levels, the fathers of some of the patients having been physicians and educators, and the fathers of others having been migratory laborers. Nor have we been able to elicit a history of acute infection in the mother at the presumed time of the first appearance of the anomaly in utero. In particular, we have learned of no instance of rubella in the mother during the early weeks of gestation.

EMBRYOLOGY

The embryology of esophageal atresia with or without tracheoesophageal fistula is likewise not yet fully understood. It is clear from what is known of the normal development of the region that such anomalies must originate between the end of the third week and the sixth week, fertilization age. In terms of size this would mean the defects were established in embryos between 3.5 mm. and 8 mm. Embryologists have differed in opinion regarding the exact nature of the critical disturbances involved. Those whom I have consulted, namely, Drs. Bradley M. Patten and Alexander Barry, feel that until more developmental stages are recovered and critically studied, we are in no position to be dogmatic about the precise sequence of events by which these anomalies are established.

Further complicating the explanations concerning the mode of development of the anomaly is the observation of Keith and Spicer[13] who, in 1906, described 3 cases of esophageal atresia with tracheoesophageal fistula in which the subclavian artery crossed the midline in the cleft between the upper and lower segments of the esophagus. In 2 cases the aberrant artery was the left subclavian, arising from a right aortic arch; and in one case, the right subclavian, arising from a left aortic arch. The presence of similar vascular anomalies has been observed by Saunders and Wright,[14] Fluss and Poppen,[15] and Langman.[16, 17] Langman also observed 2 cases in which a fibrous band (the thicknesses being 1 cm. and 3 mm., respectively) arose from a normal aorta below

the left subclavian artery and crossed the midline at the level of the anomaly. In another case, one with a right aortic arch and no trace of the left subclavian artery, he noted a very thick, strong muscular cord arising immediately distal to the origin of the right subclavian artery and extending behind the esophagus to the point where the left subclavian artery should have been

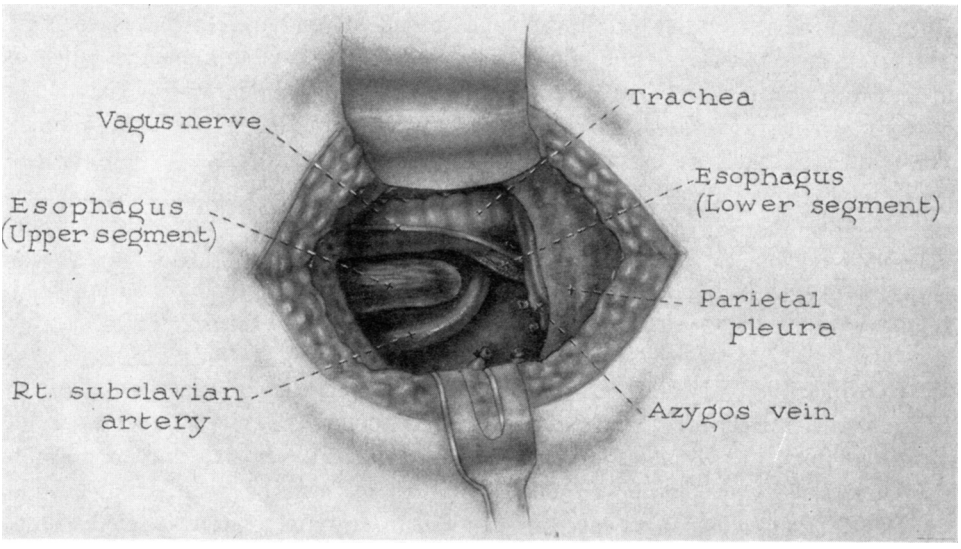


Fig. 2.—Aberrant right subclavian artery crossing the midline in the space between the upper and lower segments of the esophagus (M. B., Case 71).

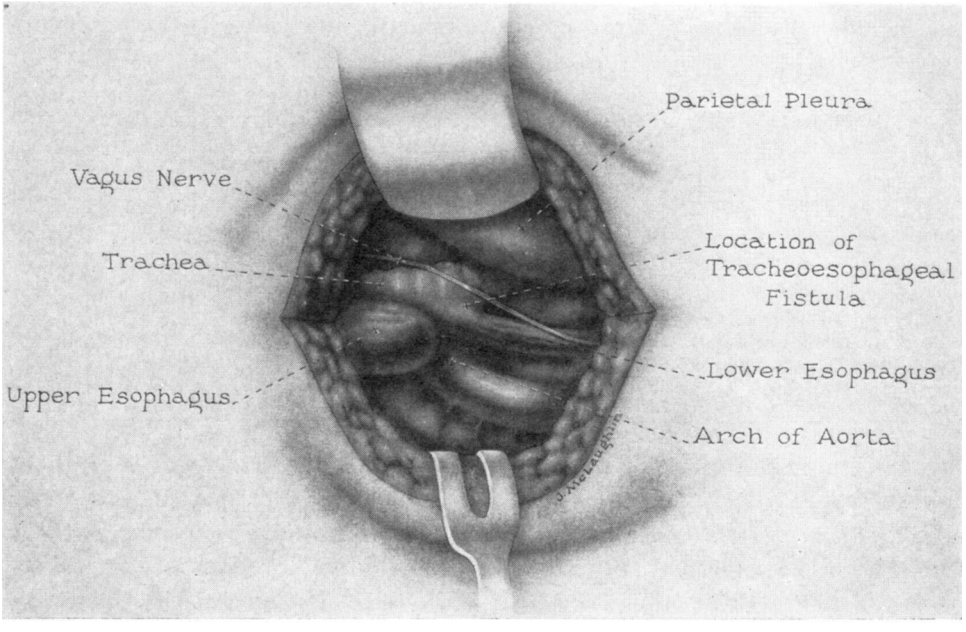


Fig 3.—Right aortic arch situated at the level of the esophageal atresia (D. G., Case 66).

found. Langman has postulated that if no trace of the primitive right aorta is found, as is often the case, this does not mean that the vessel was obliterated "in time"; but rather that it might have persisted a few weeks too long, and during that time caused the atresia and the tracheoesophageal fistula.

An anomalous right subclavian artery arising as the last branch of a left aortic arch was observed in our first operation for esophageal atresia in 1939. Since then the possibility of the presence of an anomalous vessel has been investigated in all cases. Although we have observed vascular anomalies such as an aberrant right subclavian artery (Fig. 2), a right aortic arch (Fig. 3), or a vascular ring in approximately 10 per cent of our cases, we have found a band of tissue such as has been described by Langman in only one patient. In view of the relative frequency of vascular anomalies alone, as compared with the combination of vascular anomalies and esophageal atresia, it is improbable that aberrant vessels play an important role in the formation of congenital anomalies of the esophagus.

INCIDENCE

Considerable variation in the incidence of atresia of the esophagus is to be found in articles which refer to its frequency (Table I). Comparable variations in incidence have been found in my personal observations of patients born in Washtenaw County, Michigan, in the interval between Jan. 1, 1935, and Dec. 1, 1956, when these cases are studied in any given 5-year period. Thus, the incidence varied from a high of 1-1,469 in the years 1935-1939 inclusive, to a low of 1-15,432 in the years 1945-1949 inclusive, the average incidence being 1-4,447. These observations suggest that any series of cases which does not include a sufficiently large number of births does not give a true figure of the approximate incidence of the anomaly.

TABLE I. CONGENITAL ESOPHAGEAL ATRESIA: INCIDENCE OF RECOGNIZED CASES

AUTHOR	YEAR	LOCATION	NUMBER OF CASES	INCIDENCE RATE
Hirschsprung[8]	1861	Copenhagen Lying-In Hosp.	7	1- 2,628 births
Turner[18]	1944	Brit. Post. Grad. Med. School	4	1- 2,635 births
Murphy[19]	1947	City of Philadelphia	13	1-12,804 births
Potter[20]	1947	Chicago Lying-In Hosp.	6	1- 6,000 births
Ingalls and Prindle[11]	1949	Boston Lying-In Hosp.	6	1- 5,083 births
Belsey and Donnison[21]	1950	Bristol	4	1- 800 births
Humphreys, Hogg, and Ferrer[22]	1956	Sloane Maternity Hosp.	23	1- 3,000 births
Haight	1957	Washtenaw County, Mich.	13	1- 4,447 births

Incidence in Siblings.—The incidence of esophageal atresia with or without tracheoesophageal fistula in more than one child of the same parents has rarely been described. In a series of 201 cases of atresia of the esophagus, with or without tracheoesophageal fistula, and in an additional 7 cases of tracheoesophageal fistula without other anomalies of the esophagus seen at the University Hospital, the anomaly has occurred in 2 siblings in only one family. This

finding occurred in successive births, both infants were males and each had an atresia with the typical form of tracheoesophageal fistula. In a review of this subject, Sloan and I[23] were able to find only 5 previous instances of esophageal atresia in siblings. The 2 brothers whom we reported recovered from operation and were living when the latest information regarding them was obtained. They are the only 2 patients listed among the living cases in this series whom we have been unable to locate for recent follow-up observations. Hausmann, Close, and Williams[24] have recently reported the occurrence of esophageal atresia in 3 consecutive siblings, the first 2 having had an atresia with tracheoesophageal fistula and the third, an atresia without an associated fistula.

In order to determine whether esophageal atresia has occurred more often in subsequent births than is believed to be the case, inquiry has been made of the parents of the patients in this series. The majority of the parents have replied and, to date, no other instance of esophageal atresia in siblings has been found in these families. In the past, the parents of our patients have naturally been concerned about the possibility of the anomaly occurring in subsequent births. The information which has been obtained regarding the remoteness of the anomaly in later births has furnished reassurance to parents who have desired to have additional children. The familial histories of a few of the parents of our patients have been investigated in the Heredity Clinic of the University Hospital and further studies in this field are in progress.

Incidence in One of a Pair of Twins.—The finding of an esophageal atresia with or without a tracheoesophageal fistula, or a tracheoesophageal fistula alone, in one of a pair of twins is worthy of mention. Although it is well known that twins are more likely to be afflicted with congenital anomalies than are single births, the presence of an esophageal atresia in only one of a pair of twins depreciates the factual data which suggest that this anomaly is hereditary. The possibility of an esophageal atresia occurring in one of a pair of twins has been rarely mentioned in the literature; and, to date, no case report has been published which shows the anomaly to have been observed in both of the twins. It was mentioned earlier that Ysander[2] described an esophageal atresia with tracheoesophageal fistula in both components of a monster type of embryo; and this is the only case in which any semblance of the presence of the anomaly in each of a pair of twins has been found.

The first report of an esophageal atresia in one of a pair of twins was published by Ingalls and Prindle[11] who described the finding of an esophageal atresia in one each of 4 pairs of twins in 107 births. They believed, however, that this finding, which is four times the normal expectancy, could have been caused by chance. Brown and Brown,[25] in a report of 24 cases of esophageal anomalies of which 21 were atresias, report the presence of an atresia in one each of 2 sets of twins. Leven, Varco, Lannin, and Tongen[26] describe the finding of an atresia with tracheoesophageal fistula in one each of 2 pairs of twins in 102 cases of atresia of the esophagus. The other reports, mentioned above, do not specify the type of anomaly.

In the present series, an esophageal atresia has been found in one each of 10 pairs of twins in 201 cases of atresia and in one of a pair of twins in 7 cases of tracheoesophageal fistula alone. Two pairs of twins, in whom an esophageal atresia with tracheoesophageal fistula was present in only one of each pair, are living; one pair are identical twins (Fig. 4), the other pair, fraternal. Both twins, in whom a fistula alone was found in only one, are also living. Seven of the twin brothers or sisters of the patients with atresia are living.

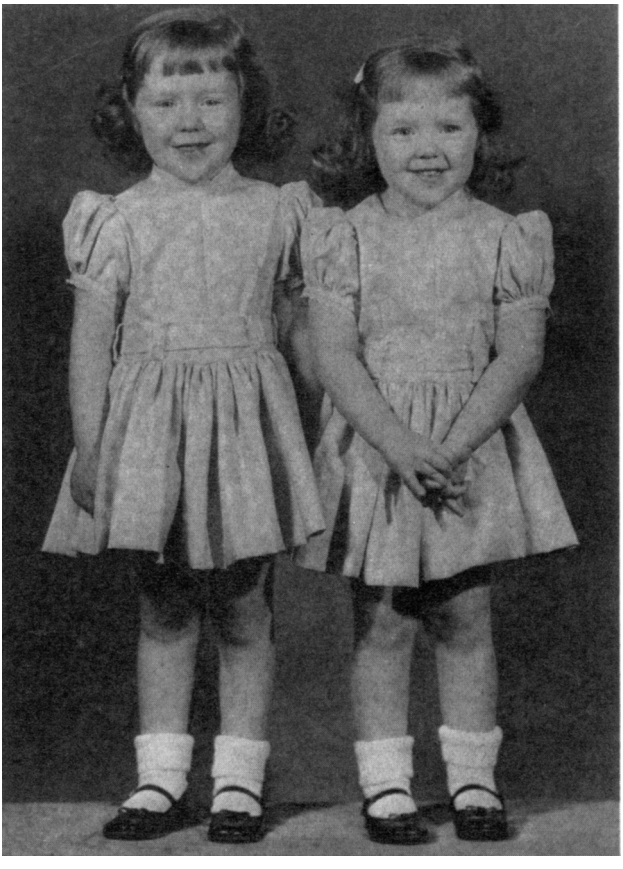


Fig. 4.—Identical twins in whom an esophageal atresia with tracheoesophageal fistula was present in one of the twins. The patient (C. S., Case 148) who had the anomaly is seen on the left; the anomaly has been corrected by a primary esophageal anastomosis.

Three of the pairs of twins were of different sexes; it is believed that at least 6 of the remaining 8 pairs of twins were identical, and it cannot be determined from the records in the remaining 2 instances whether or not they were identical twins. A question that arises is: why should the anomaly occur in one "identical" twin and not in the other? The answer is not yet clear but our observations suggest the importance of nongenetic factors in the etiology of the anomaly. Three of the twin brothers or sisters of the patients died, and their

deaths occurred at, or shortly after, birth. It is unfortunate that post-mortem examinations were not made on the 3 twins who died; in one case, however, roentgenograms of the esophagus showed it to be normal. Another of these twins was cyanotic at birth and died within an hour; the third was a still-born infant.

Of the 10 twins with esophageal atresia, it is to be noted that 6 were definitely premature babies, 2 weighing between 3 and 4 pounds at birth and 4 weighing between 4 and 5 pounds. Four of the twins can be regarded as full-term infants, in accordance with accepted standards of birth weights. Three of them weighed between 5½ and 6 pounds, and one, over 6 pounds. The anomaly in 7 of the twins with esophageal atresia consisted of an atresia with an associated tracheoesophageal fistula; whereas the remaining 3 patients had an atresia without a tracheoesophageal fistula. Data regarding the birth weights, sex, and results are shown in Table II.

TABLE II. TWINS

CASE NUMBER	BIRTH WEIGHT (LB., OZ.)	PATIENT			TWIN			SEX	
		SEX	LIVING	DIED	SEX	LIVING	DIED	SAME	OPPOSITE
				Esophageal Atresia					
21	3-12	F		*	M	*			*
32	4-6	F		*	F	*		*	
55	5-13	M		*	M	*		*	
62	5-10	M		*	M	*		*	
77	5-8	F		*	F	*		*	
78	4-10	F		*	F		*	*	
83	4-8½	M	†		F	†			*
120	3-11	F		*	F		*	*	
134	6-8	F	*		M		*		*
148	4-13	F	†		F	†		*	
				Tracheoesophageal Fistula; No Atresia					
6	5-14	M	†		M	†		*	
Totals									
11			4	7		8	3	8	3

†Twins living.

TYPES OF ANOMALY

The types of anomaly found in 200 consecutive cases of esophageal atresia are listed in the accompanying table (Table III). It is to be noted that the presence of air in the stomach, indicative of a co-existing tracheoesophageal fistula, was found in 86.5 per cent of the infants with esophageal atresia. Most of the larger series of cases reported by others have indicated a slightly higher percentage of cases in which there was an accompanying fistula. When a fistula has been present, it has been observed that the two segments of the esophagus were in approximation, or in actual partial muscular continuity, in one third of the patients in whom it was possible to ascertain the exact findings. In the case of two thirds of the patients who manifested an associated fistula, the two segments of the esophagus were separated by a distance which varied from a few millimeters to between 2 and 3 cm. In only 2 patients was a fistula found between the proximal esophagus and trachea, in addition to the fistula

between the lower esophagus and the trachea. In one of these 2 patients the proximal fistula was situated immediately above the distal fistula; in the other, the two fistulas were separated by a distance estimated to be at least 3 cm.

TABLE III. CONGENITAL ESOPHAGEAL ATRESIA: ANATOMIC VARIATIONS IN 200 CASES

	NUMBER OF CASES	PER CENT OF TOTAL
Air in Stomach—Fistula Present	173	86.5
Segments separated by variable distance	108	54.0
Segments in contact or overlapping	54	27.0
Proximal and distal tracheoesophageal fistulas	2	1.0
Exact type not known	9	4.5
No Air in Stomach	27	13.5
Small fistula between lower esophagus and trachea	3	1.5
No fistula; partial agenesis of lower esophagus	18	9.0
Atresia of lower esophagus		
Esophagus continuous	1	0.5
Segments in contact	1	0.5
Proximal fistula; no distal fistula	0	0.0
Exact type not known	4	2.0

Admission roentgenograms have failed to reveal the presence of air in the stomach or intestinal tract in 27, or 13.5 per cent, of the 200 patients with esophageal atresia. The usual finding in this group has been a partial agenesis of the lower esophagus which usually extends only 2 or 3 cm. above the diaphragm, although in occasional instances it may extend almost to the level of the bifurcation of the trachea. Partial agenesis of the lower esophagus was noted in 18 patients, or 9 per cent. Another finding in this group has been the presence of a small fistula between the lower esophagus and the trachea in 3 cases, or 1.5 per cent, but the fistula was too small to allow the passage of air into the stomach. Two patients without air in the stomach presented unusual findings. In one, the esophagus was continuous but there was an area of narrowing in the mid-third, and complete obstruction at the approximate level of the junction of the middle and lower thirds. In the other case, a small mediastinal cyst was found at the level of interruption of the two segments of the esophagus which were in contact with each other; and a complete obstruction of the lower segment of the esophagus was present where the cyst impinged upon it. Above this level, a short, 1 cm., length of lower esophagus extended up to the trachea where a small fistulous communication was present. A fistula between the upper esophagus and trachea without a fistula between the lower esophagus and trachea (type 3A of Vogt's[27] classification) was not observed in any of the cases in this series. In 4 of the patients without air in the stomach the exact nature of the lower esophagus could not be classified. Two patients died and the precise type of anomaly could not be observed because neither an operation nor a post-mortem examination was performed. Two living patients are being treated temporarily by cervical esophagostomy and gastrostomy, and the length of the lower esophagus has not as yet been investigated.

The absence of air in the stomach or intestinal tract shortly after birth is indicative of a lack of a patent channel between the pharynx and stomach. Since it is assumed that infants who do not have air in the stomach after birth

have been unable to swallow amniotic fluid during their intrauterine existence, it is not surprising to discover a history of hydramnios preceding or during birth. This may seem at first to be of academic importance only; but from a practical standpoint, the excessive amount of amniotic fluid will often cause the premature birth of the infant. It is, therefore, important to compare the birth weights of infants who have been known to have had air in the gastrointestinal tract when they were admitted with the weights of those who did not. The birth weights are known in all except 3 per cent of the patients. A comparison of the known birth weights of the two groups shows the incidence of prematurity (i.e., birth weight less than 5 pounds, 8 ounces) to be considerably greater in those infants without air in the stomach (56 per cent) than in those with air in the stomach (24.7 per cent) (Table IV). It is to be noted that the figures are actual birth weights and not admission weights, which, as a rule, are considerably lower than birth weights. The fact that infants without air in the stomach are more often premature than not is of importance with regard to selecting the preferable method of surgical treatment, inasmuch as an esophageal anastomosis cannot ordinarily be carried out in such cases without mobilization of the stomach.

TABLE IV. ESOPHAGEAL ATRESIA

	BIRTH WEIGHT	
	LESS THAN 5 LB., 8 OZ. (%)	MORE THAN 5 LB., 8 OZ. (%)
Air in stomach	24.7	75.3
No air in stomach	56.0	44.0

On some occasions in this presentation, the cases will be analyzed in two groups: the first 100 cases admitted prior to May 1, 1950, and the second 100 cases admitted between that date and March 1, 1957. The cases have been segregated into two groups because the patients in the first group obviously were not able to benefit from present methods of management. Furthermore, certain statistical observations, especially regarding the associated anomalies, become apparent when one compares a group of 100 cases with another group of similar size. Another reason for segregating the cases into two groups is that in a relatively larger number of the first 100 patients no definite attempt was made to correct the anomaly. In the first group, 4 of 11 patients were admitted prior to our first use of an operation for primary esophageal anastomosis in 1939. Seven other patients in this group were not operated upon because of their poor general condition, or because of associated anomalies; and 2 other patients were allowed to return home at the request of their parents when it was found that a primary anastomosis could not be performed. By comparison, only 2 patients in the second group of 100 cases were not operated upon.

ASSOCIATED ANOMALIES

The total number of anomalies associated with esophageal atresia, when considered collectively, is unusually high (Table V); because they are often

multiple and because slightly more than 50 per cent of the anomalies are not of life-threatening significance, they are not quite as discouraging as they might seem to be at first glance. It is advisable, I believe, to consider patients with esophageal atresia as falling into one of two groups, namely, those who show significant anomalies and those who do not. Using this differentiation, it was found that 28 per cent of the patients had significant anomalies whereas 72 per cent had none.

TABLE V. TOTAL ASSOCIATED ANOMALIES (SINGLE OR MULTIPLE) IN 200 CASES OF ESOPHAGEAL ATRESIA (Total, All Anomalies—169)

	SIGNIFICANT			NOT SIGNIFICANT		
TYPE OF ANOMALY	CASES NOS. 1-100	CASES NOS. 101-200	TOTAL	CASES NOS. 1-100	CASES NOS. 101-200	TOTAL
Cardiovascular	10	21	31	8	8	16
Gastrointestinal	4	20	24	6	7	13
Neurological	3	6	9	0	0	0
Genitourinary	3	7	10	9	10	19
Orthopedic	0	0	0	6	20	26
Others	1	1	2	4	15	19
Total	21	55	76	33	60	93

The significant anomalies include congenital heart disease and, in particular, interatrial or interventricular septal defects, tetralogy of Fallot, cor uniloculare, biloculare or triloculare, truncus arteriosus, and tricuspid atresia. Significant anomalies of the aortic arch such as coarctation of the aorta, vascular rings and patent ductus, in which the lumen of the ductus is approximately the same size as the descending aorta, are also included in this group. Gastrointestinal anomalies such as imperforate anus, with or without associated urogenital fistulas, and duodenal obstruction are of urgent significance because they require prompt treatment. Neurological anomalies such as Mongolism, hydrocephalus, encephalomalacia, cerebellar cyst and spasticity, and a few urological anomalies such as polycystic kidneys and stricture of the ureters, have likewise been included in this group because these conditions have, or could have, led to the early death of the patient.

The nonsignificant anomalies are designated as such because they do not interfere with a reasonable life expectancy. Such conditions as the frequently found Meckel's diverticulum, anomalies of the vertebrae or ribs, horseshoe kidneys, with or without a single ureter, and abnormalities of the aortic arch such as dextraposition of the aorta, or aberrant subclavian artery are included in this group.

The significant congenital anomalies, listed according to the above differentiations, have been further segregated into two groups: those which appeared in the first 100 cases and those which appeared in the second 100 cases. When multiple anomalies of several regions of the body have been encountered in a single case, as is frequently observed when, in addition to atresia, an anomaly is present, only the most imminently life-threatening anomaly has been

considered in the analysis of these cases. When this classification is used, it becomes evident that anomalies of the heart or cardiovascular system are far more important than are those which occur in other portions of the body. It is also evident that the significant anomalies encountered in the first 100 cases (18 anomalies) is greatly exceeded by the significant anomalies occurring in the second 100 (38 anomalies) (Table VI). It is also important to note that none of the 30 patients who had a congenital cardiovascular anomaly of a significant type is living, whereas 5 of 14 cases with imperforate anus or pyloric or duodenal obstruction are still alive. Of the 8 patients in whom significant neurologic anomalies were found, only one is living, and this patient has hydrocephalus which has not been improved by operation.

TABLE VI. PATIENTS WITH SIGNIFICANT ASSOCIATED ANOMALIES IN 200 CASES OF ESOPHAGEAL ATRESIA*

TYPE OF ANOMALY	CASES NOS. 1-100	CASES NOS. 101-200	TOTAL	PATIENTS LIVING
Cardiovascular	10	20	30	0
Gastrointestinal	3	11	14	5
Neurological	3	5	8	1
Genitourinary	2	1	3	0
Orthopedic	0	0	0	0
Others	0	1	1	1
Total	18	38	56	7

*When multiple anomalies have been encountered in a single patient, only the most important anomaly is listed.

DEVELOPMENT OF SURGICAL TREATMENT

Achievement of a satisfactory method for surgical correction of esophageal atresia was long in coming and will not be reviewed here in its entirety. Timothy Holmes[28] of London, the author of the text, *Surgical Management of Children's Diseases,* suggested the possibility of an esophageal anastomosis when an atresia was not accompanied by a tracheoesophageal fistula. His suggestion was vague and he gave no particulars regarding the method of approaching the esophagus. Charles Steele[29] is often cited as the first surgeon to have performed a gastrostomy for esophageal atresia. This is not the case, however, and the operation, conceived with more imagination than that required for a gastrostomy alone, was performed in the hope that a membranous obstruction of the esophagus suitable for instrumental perforation might be found. After opening the stomach, Steele passed a bougie into the lower esophagus. Simultaneously, a bougie was passed down the upper esophagus; but Steele estimated that the bougies did not meet by a distance of about an inch and a half. He then introduced into the lower esophagus a gum elastic catheter with its end removed; through the catheter he passed a long, slender, steel probe, pressing it upward as far as possible, in the hope that the lower esophagus "if twisted or narrowed might be rendered pervious." The attempt was unsuccessful, and the gastric and abdominal incisions were then closed. The infant died on the following day, and at post-mortem examination, the esophagus was found to terminate above and below in blind, rounded ends an inch and a half apart. From this

description it is evident that Steele's case was one of an esophageal atresia without a tracheoesophageal fistula. Keith,[30] in 1910, after analyzing 14 cases of esophageal atresia with tracheoesophageal fistula, suggested that operative measures to unite the two segments of the esophagus are theoretically possible, but that to his knowledge no such operation had ever been attempted.

A ray of hope was eventually focused on the anomaly when, in 1913, H. M. Richter[31] presented 2 cases in which he ligated the tracheoesophageal fistula through a transpleural approach. Richter envisioned the possibility of a direct anastomosis of the two segments of the esophagus as the ideal type of operation, and one which might prove possible in the future. Believing the procedure of anastomosis to be too hazardous at that time, Richter concluded that the imminent problem was one of closing the communication with the trachea and then of providing a gastrostomy for feeding. He further stated that the recent development of thoracic surgery justified the hope that later in the life of the patient a means of utilizing the gullet might be found. Certain details of Richter's 2 cases are significant, in that, for one thing, he employed a gastrotomy in order to intubate the lower esophagus from below by means of a pliable uterine sound immediately preceding the intrathoracic operation. Although the fistula was ligated in both of his cases, Richter was of the opinion that a more definitive closure, with the division of the lower esophagus and invagination of the open ends of the esophagus and trachea, would have been desirable. The operations were carried out through a transpleural approach which was the more remarkable because the anesthesia was administered under positive pressure and with the aid of an intratracheal tube, a method which had been developed only a few years earlier, and prior to the time when such a procedure had been generally applied to adults. In a recent communication, Richter's son, Dr. H. M. Richter, Jr., has advised me that his father used an old vacuum cleaner motor in the construction of a mechanical respirator which he built for his class in dog surgery at the Northwestern University Medical School. He had employed this machine before on 2 patients who developed respiratory arrest (one during a tonsillectomy, and the other with bulbar poliomyelitis) with dramatic effect and considerable local acclaim. It was this machine which Richter used on the 2 infants for whom he performed ligation of the tracheoesophageal fistula. Doctor Richter, Jr., has also advised me that his father had no later experience with esophageal atresias. This was unfortunate, because, had he had such experience, a satisfactory solution to a difficult problem might well have been obtained much earlier than was the case.

During the ensuing 25 years, attention regarding treatment of the anomaly was focused almost entirely on its management by gastrostomy with or without accompanying measures to prevent regurgitation of gastric contents into the trachea. In a few of the patients operated upon during the latter part of this period, efforts were also made to prevent aspiration of oral secretions by means of exteriorization of the cervical esophagus. The various procedures used during this period have been reviewed in a previous communication.[32]

In 1938, Robert Shaw,[33] in a personal communication to John Alexander, called our attention to the first case of atresia of the esophagus with tracheoesophageal fistula which he had treated on Sept. 25, 1938, by ligation and division of the fistula and primary anastomosis of the two segments of the esophagus over a catheter introduced through the nares and advanced through the esophagus into the stomach. His patient, whose case was published in December, 1939,[34] died on the twelfth postoperative day as a result of a transfusion reaction and disruption of the anastomosis. Shaw mentioned, in his article, an infant for whom a similar type of operation had been performed by Paul C. Samson.[35] The operation on Shaw's patient had been done without his knowledge of 4 similar cases operated upon by Lanman in 1936 and 1937, and subsequently reported in November, 1940,[36] more than 2 years after Shaw's first patient had been treated. A primary anastomosis was carried out by Lanman in these 4 cases and was also performed in another patient operated upon by him in March, 1939. All of these patients died following primary anastomosis done through a right extrapleural approach. The third and fourth of Lanman's 5 patients treated by primary anastomosis (Cases No. 20 and No. 22 of his report) lived 8 and 9 days, respectively. Post-mortem examination in the fourth case showed that death was caused by overhydration and not by infection, pneumonia, or mediastinitis. Shaw and Lanman should be accorded great credit for their pioneering attempts to obtain a primary anastomosis.

Approximately 5 months after Shaw had communicated with Dr. Alexander, and employing the technique which he suggested, I performed a primary repair of the anomaly for the first time on April 10, 1939. The patient died of atelectasis, presumably of the fetal type, 17 hours following the operation. During the ensuing 23 months, 4 other patients also died, 2 having been operated upon by Dr. Alexander and 2 by myself. The first of the 4 patients died immediately following operation which was carried out through a right transpleural approach, and under local anesthesia. I believe this patient, who was operated upon by Dr. Alexander, is the first one for whom an anastomosis was completed by the transpleural route. In this case, the anastomosis was performed over a T tube, as had been suggested by Shaw. Discouraged by the results of these 2 cases, I hoped in the next case to obtain a survival by ligation and division of the fistula which were done with the aid of local anesthesia in preference to an astomosis, even though the latter procedure would have been readily feasible. At that time, in August, 1940, I was unaware of the 2 survivals operated upon by Leven[37] and Ladd[38] by the multiple stage plan and whose cases were unreported as of that date. My patient died 3 days after operation as a result of overhydration, pulmonary edema, and lobular pneumonia without a cervical esophagostomy having been performed. In the case which followed, difficulty was experienced in locating the lower esophagus although the stomach contained air prior to the operation; and inadvertent injury to the aorta resulted in death during the operation. The last of these

4 patients died of sepsis subsequent to a satisfactory division and suture-ligation of the fistula and primary anastomosis of the esophageal segments over a catheter introduced into the esophagus through the wound.

With knowledge of the 10 unsuccessful attempts to obtain a primary anastomosis which have been discussed in the preceding paragraphs, we could not manifest undue encouragement when our next patient arrived on March 14, 1941, 12 days after her birth. This infant was unusually robust, weighing 8 pounds and 4 ounces upon admission. Roentgenograms obtained before admission had

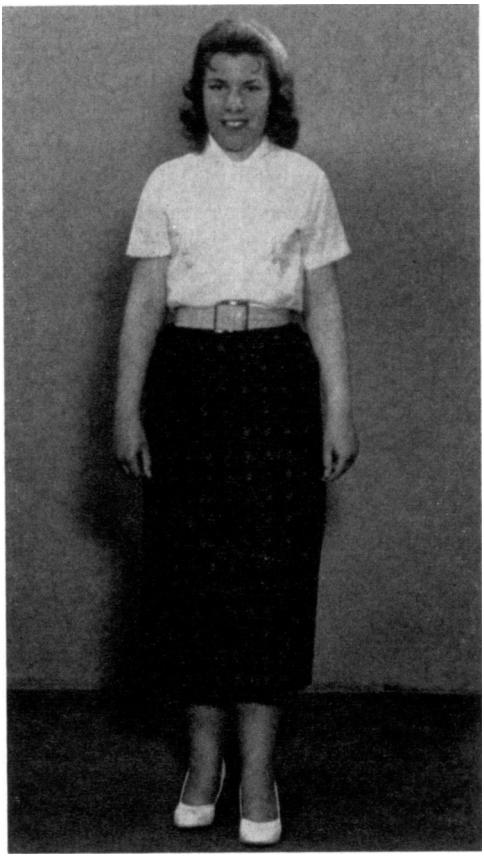


Fig. 5.—First case of recovery following primary anastomosis for esophageal atresia with tracheoesophageal fistula (J. M., Case 10).

demonstrated a blind upper esophagus. The presence of air in the stomach indicated the existence of a communication between the trachea and the lower esophagus. On the day following her admission, the patient's tracheoesophageal fistula was ligated and divided through a left extrapleural approach; and an end-to-end anastomosis was performed, employing a single layer of interrupted sutures of fine silk. Local anesthesia was administered until construction of the anastomosis was begun, when ether by the drip method was required so that

enough relaxation could be achieved to allow approximation of the esophageal segments. The wound was closed around a narrow rubber drain. Since penicillin was not then available, the only antimicrobiol agent used postoperatively was sulfathiazole, administered rectally. Fortunately, the patient survived in spite of the fact that generalized edema had appeared on the third postoperative day as a result of the excessive use of physiologic saline solution; and leakage of the anastomosis into the extrapleural wound had occurred on the seventh day after the operation. The parietal pleura had not been injured, however, at the time of operation, and the esophagocutaneous fistula remained localized and had healed by the twentieth postoperative day. In the interim, a gastrostomy to make feedings possible was performed on the tenth postoperative day. After it has become evident that the esophageal leak had closed, oral feedings were started gradually on the twenty-first postoperative day. As the oral feedings were progressively increased, the gastrostomy feedings were simultaneously reduced, and were discontinued completely on the thirty-ninth day. The gastrostomy tube was removed 3 days later. A stricture developed at the site of the anastomosis. As a result of this, accumulations of mucus in the pharynx and upper esophagus interfered greatly with the ability of the patient to swallow, and necessitated a prolonged period of convalescence in the hospital. Eventually, a single dilatation of the stricture was performed 17 months after the operation, and the patient was allowed to return to her home 20 months following the operation. She continued to improve and has developed normally. The patient is now 16 years of age (Fig. 5).

CHOICE OF OPERATION

The preferable plan for the correction of an esophageal atresia with tracheoesophageal fistula consists of a primary anastomosis of the two portions of the esophagus after the fistula has been divided and closed. A primary anastomosis is usually possible, although extensive transpleural mobilization of the lower esophagus, in addition to the usual high mobilization of the upper esophagus, may be required in order to gain enough relaxation so that the two segments of the esophagus may be brought into apposition without tension. If extensive mobilization of the lower portion of the esophagus is required, an attempt should be made first to preserve the extrinsic vascularity by not freeing the esophagus completely in the plane at which its blood supply enters. A certain amount of elevation of the lower esophagus can thereby be obtained without disrupting the intrathoracic vascularity. In other cases, the esophagus will require total mobilization. Usually the circulation of the lower esophagus will continue to be adequate through its intramural blood supply, but in our experience this has not always been true. The upper few millimeters, and at times a slightly greater length of the lower esophagus, will usually show evidence of cyanosis and this portion will require resection. Should a greater length need to be sacrificed, there may not be a sufficient remaining portion of the lower esophagus to allow an anastomosis to be performed without tension. In this event, which is remote, it becomes necessary to select one of several alternative possibilities. The most immediately appealing is mobilization of

the fundus and cardia of the stomach at the same operation. This can be accomplished readily after the esophageal hiatus has been enlarged. The stomach is then drawn partially into the thorax, thereby allowing the lower esophagus to be brought to a point higher into the right chest than would be possible if the stomach were not mobilized.

The alternative possibilities, when a primary esophageal anastomosis is not performed through the right chest, consist of the use of a left esophagogastrostomy in the immediate or distant future, or the performance of a bowel transplant at a later date in order to achieve continuity of the alimentary tract. Unless an esophagogastrostomy is carried out within a very brief period of time, a gastrostomy and cervical esophagostomy will be required as temporary measures. Should either of these plans be chosen, the lower esophagus having been transected near its junction with the trachea will of necessity need to be closed at the time of the primary operation. The decision regarding the advisability of one or the other of the alternative possibilities will be influenced not only by the preference of the surgeon but also by the general condition of the infant upon admission, and more particularly by the patient's condition at the time it is discovered that an esophageal anastomosis cannot be performed without mobilizing the stomach. Fortunately, when a tracheoesophageal fistula is present in patients with atresia, it is rarely necessary to resort to one of the alternative procedures. On the contrary, a primary and uncomplicated esophageal anastomosis is rarely possible in patients with atresia unaccompanied by tracheoesophageal fistula. The problem is particularly significant in this group of patients.

The decision regarding the choice of procedures to be employed, when an uncomplicated type of esophageal anastomosis cannot be done, should be influenced not only by the comparative risks of each of these procedures, but also by the late development of patients treated by one or another of these plans. At the present time, the number of patients treated by each of the alternative plans for restoring alimentary continuity is too small, and the period of postoperative evaluation too short, to allow valid conclusions to be reached. I believe, however, that the encroachment on pulmonary function by mobilization of the stomach into the left chest, so as to permit an anastomosis to be performed between its fundus and the upper portion of the esophagus, is greater than that resulting from mobilization of the stomach through the right chest in order to allow an esophageal anastomosis to be carried out. The additional decrease in pulmonary function when an esophagogastrostomy is performed occurs not only because a larger volume of stomach is brought into the left chest than is the case when the stomach is partially mobilized into the right hemithorax, but also because there is greater interference with the function of the left diaphragm by this operation than there is when the mobilization of the stomach into the right chest is achieved through enlargement of the diaphragmatic hiatus. It is well recognized that the sudden introduction of a large volume of the stomach into the thorax of a newborn infant is not tolerated well. Very few statistics are as yet available concerning the mortality of intrathoracic implantation of part or all of the stomach in a

newborn infant; and those that are available show the mortality to be high. Additional figures regarding the results of intrathoracic transplantation of the stomach into the right chest are urgently needed; and statistics are especially desired concerning the results of this procedure when it is employed for a premature infant who does not have air in the stomach upon admission, and in whom the presence of a rudimentary lower esophagus is to be anticipated.

The unknown factor in infants who do not have air in the stomach when admitted is the actual length of the lower esophagus. It has been shown statistically that such patients usually have a rudimentary lower esophagus which does not extend sufficiently high to communicate with the trachea. Tracheoscopy has been performed for a number of such patients in the past, and it probably should be done for patients who do not have air in the stomach, although the finding of a tracheoesophageal fistula on tracheoscopic examination can be anticipated only on rare occasions. Tracheoscopy would therefore prove to be of positive value only in the exceptional case. In the event that a fistula is not present between the trachea and lower esophagus, I believe that the initial operation should consist of a gastrostomy. It is further proposed that the actual length of the lower esophagus be determined by retrograde bouginage and roentgenograms with a portable unit at the time when gastrostomy is carried out. This plan was used on one occasion in this clinic for a patient operated upon in 1944, and is the same in principle as that employed by Steele[29] in the first reported operation for esophageal atresia in 1888. If retrograde bouginage shows the lower esophagus to extend up to, or almost up to, the level of the bifurcation of the trachea, an attempt to obtain a satisfactory primary esophageal anastomosis should undoubtedly be made. This procedure might well spare the patient the inconveniences of a prolonged need for gastrostomy and cervical esophagostomy while awaiting the delayed use of a bowel transplant.

Several questions relative to patients who have been treated by mobilization of the stomach need further clarification. One of them concerns growth and development. Is the weight gain as satisfactory in these patients as in those for whom the stomach is not brought into the chest? Another problem is one of possible regurgitation of gastric contents into the esophagus resulting from the loss of angulation normally present at the cardioesophageal junction. The only patient in this series for whom the stomach was mobilized partially, and brought into the right chest, has failed to show a satisfactory gain in weight. A delay in emptying of the infradiaphragmatic portion of the stomach is evident on roentgen studies. The roentgenograms also demonstrate reflux of gastric contents into the lower esophagus, but the patient does not vomit or regurgitate food, and esophagoscopy shows no evidence of peptic esophagitis. The fact remains that this patient has a very poor appetite and that his caloric intake is far below normal. Of interest, by way of comparison of weight gains with the use of two different procedures in this patient, is the fact that a "delayed" plan for mobilization of the stomach into the right chest was employed in his case, the patient having been fed by gastrostomy for 6½ weeks

prior to the performance of an esophageal anastomosis. During this period, secretions accumulating in the blind proximal esophagus were aspirated at frequent intervals. Likewise, during this period of 6½ weeks while the patient was receiving gastrostomy feedings, he showed a gratifying weight gain of approximately 2 pounds. During the ensuing 3 years, however, he has gained less than 9 pounds. On the contrary, the one patient in this series who was treated successfully by primary esophagogastrostomy performed through the left chest has had an excellent appetite, although her weight is likewise below normal. In her case, however, the stomach empties normally.

RESULTS

The results of treatment of esophageal atresia with or without tracheoesophageal fistula may show considerable variation from year to year and will reflect, in large measure, the general condition of the patients on admission, including the presence or absence of significant associated anomalies. They demonstrate, as well, that inexplicable something which causes a series of good results to be followed by one of poor results. Gratifying as the recoveries may be, however, the all-inclusive results leave a great deal to be desired, nor can they be regarded as final at the time a patient is discharged from the hospital. Although 108, or 54 per cent, of our patients recovered from their operations and all, except 2 with congenital heart disease, were discharged from the hospital, 22 have subsequently died. The majority, or 13, of the late deaths have resulted from causes directly attributable to the operation, or could, conceivably, have occurred because of it. A smaller number, or 9, of the late deaths resulted from associated anomalies. Because of the late deaths the survivals have been reduced in number to 86; thus only 42.7 per cent of 201 patients admitted to the University Hospital since 1935 are still living.

Improvements in the recovery rate were not significant before 1945. Since Jan. 1, 1947, the recovery rate of all patients admitted because of the anomaly has been in excess of 60 per cent each year with the exception of 1956 when an unusually high incidence (50 per cent) of serious, particularly cardiovascular, anomalies was encountered. In one year only (1954), 13, or 81.2 per cent, of 16 patients recovered after they underwent operation, and 12, or 75 per cent, are living; whereas in 1956 only 4, or 25 per cent, of 12 patients recovered and are now living.

Of the first 100 patients who were admitted between 1935 and May 1, 1950, 44 recovered from operation and 36 are living at present. Most of the early deaths were attributable to operation, to the withholding of operation because of the poor condition of the patient, to associated anomalies, or both and, finally, to an incomplete type of operation. Relatively few of the deaths, not more than 12 per cent, in the first 100 cases were caused by associated anomalies. In the first 100 cases, operation was not undertaken for 7 patients, and an additional 4 patients were admitted before the initial attempt in this clinic was made to correct the anomaly by esophageal anastomosis. During only the last 1¼ years of this period was the multiple stage plan of correcting the anomaly recommended when an anastomosis was not possible.

In the second 100 cases admitted since May 1, 1950, the recovery rate following operation has been 64 per cent. Fourteen patients have subsequently died and 50 are now living. In the second group of 100 patients, only 2 were not operated upon, one because the infant's condition was almost terminal when she was admitted, and she died within 12 hours; the other because the parents refused to grant permission for the operation because of the presence of a congenital anomaly (atresia of the vagina with hydrocolpos) which would have prevented the patient from bearing children.

In the second 100 cases, the deaths which occurred during the early postoperative period were about equally divided between those resulting from operation (22 cases), such as pneumonitis and atelectasis, leakage of the anastomosis or recurrent tracheoesophageal fistula, and those resulting from associated anomalies (26 cases). A strict differentiation between these two general causes of death has not always been possible to make, especially when operative complications have occurred in the presence of significant associated anomalies in the same patient. The cause of death, however, has been classified according to the factor which is believed to have been the most likely one.

The *late deaths* have been particularly disturbing especially when they have been attributable to the operation itself. They are also discouraging when caused by associated anomalies. Of the 22 late deaths in the combined groups, at least 11 have resulted from late complications following operation. These include 3 deaths caused by complications which appeared after the patients were readmitted for dilatation of a stricture at the anastomosis. Two of these deaths resulted from diarrhea and one from cardiac arrest which occurred while the stricture was being dilated. Two deaths have followed the surgeon's failure to recognize a recurrent fistula when it should have been detected. Two other deaths occurred suddenly while the patients were at home, and probably were caused by stricture and sudden distention of the upper esophagus with accompanying pressure against the trachea. Another death resulted from spontaneous perforation of the lower esophagus in a patient who was being treated by the multiple stage plan and was awaiting admission for a right colon transplant; one resulted from pneumonia; one followed an operation for a right colon transplant; and one was caused by a recurrence of diarrhea which originally had been contracted during early postoperative convalescence. Two late deaths occurred from causes which were not adjudged to have been the result of the operation; one as a result of tuberculous meningitis when the patient was 8 months of age; and the other at the age of 3½ months, as a result of pneumonia. The complications arising from stricture or recurrent fistula have demonstrated the need for frequent and careful evaluation of all patients after they have been discharged from the hospital.

Nine late deaths, all occurring in the second group of 100 patients, were caused by associated anomalies; 6 resulted from congenital heart disease, 2 from neurological conditions (hydrocephalus, one case, and cerebellar cyst, one case), and one from megacolon. Two of the 6 patients with congenital

heart disease had been kept in the hospital because their progress had not been satisfactory, and their deaths occurred after operation for the correction or relief of the cardiac anomaly had been undertaken.

The results of operation in the second 100 cases provide a better index to the current problem than do the results of the entire group and will therefore be analyzed according to the operative plan employed. An esophageal anastomosis was carried out for 77 patients in this group. Fifty-two, or 67.5 per cent, of these patients recovered from the operation; and 41, or 53.2 per cent, are now living. In those who died, either early or late, following esophageal anastomosis, death proved to have been the result of operative complications in 16, or 20.8 per cent, and the result of other congenital anomalies in 20, or 25.9 per cent. The multiple stage plan was started in 21 patients in the second 100 cases, 9 of whom, or 42.8 per cent, are living at the present time. Twelve, or 57.2 per cent, have died, 6, or 28.6 per cent, as a result of complications of treatment, and a similar number as a result of other congenital anomalies. Thus, in the second 100 cases, 27 deaths, including that of one patient for whom the parents refused permission for operation, were directly attributable to associated anomalies.

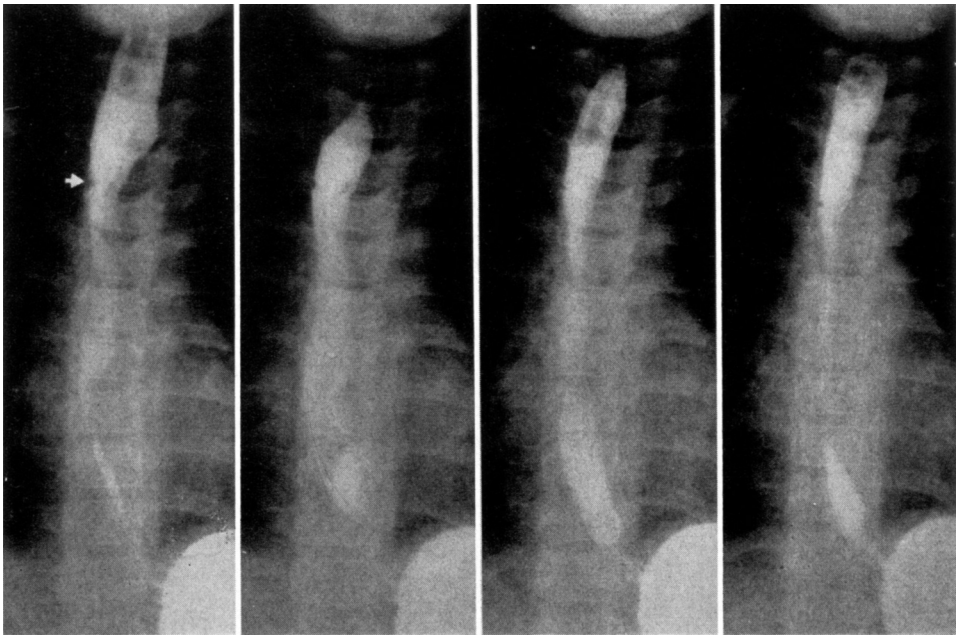
PHYSIOLOGY OF THE RECONSTRUCTED ESOPHAGUS

Particular attention to the physiologic activity of the reconstructed esophagus following esophageal anastomosis has been paid by several members of the Department of Roentgenology of the University Hospital, and especially by Dr. M. M. Figley. The level of the anastomosis has been readily apparent because of an appreciable narrowing of the lumen in some patients; and it has been barely recognizable by a slight indentation of the esophageal wall in other cases. Observations made during fluoroscopy have shown a lack of peristalsis over a distance of at least 2 or 3 cm. below the level of the anastomosis in virtually all cases. In a few cases, the absence of peristalsis has been evident at a point as low as the upper part of the lower third of the esophagus.

In 5 patients studied between 1949 and 1952, serial films were made with the rapid filming device used for angiocardiography. The ages of these patients varied from 6 to 8½ years. In these patients, films were made, as a rule, at the rate of 2 per second. In all cases, barium passed freely through the esophagus. Active peristalsis was observed in the portion of the esophagus above the level of the anastomosis. In none of the cases did the peristaltic wave pass through the level of the anastomosis; it was also absent for a variable distance of 2 or 3 to 5 cm. below the anastomosis. It then re-appeared and was present in the distal esophagus (Fig. 6). These patients, being the older ones in the series, had been operated on prior to our use of extensive mobilization of the lower esophagus when that procedure was required. It is believed, therefore, that the vagus nerve to the lower esophagus is intact except for a relatively short length of the upper portion of the lower esophagus which had been mobilized at the time of operation. The film observations, although they

are of interest from the standpoint of a permanent record for the demonstration of esophageal contractility, did not add to the information already obtained by careful fluoroscopy in the same patients. Such studies have not been continued, therefore, because of the additional radiation to which patients are subjected when roentgenograms are used extensively. Cinefluorography has not been available to us as yet, but it may be employed in the future if its advantages are found to be great enough to justify its use.

The *foreign bodies* ingested by infants and children are legion. One does not comprehend their number and variety until he has had the opportunity of observing a significant number of patients with varying degrees of narrowing of the esophagus. Objects of particular curiosity and appeal to infants are pieces of cloth, paper, and crayon. As they develop into childhood, coins



A. *B.* *C.* *D.*

Fig. 6.—Peristaltic activity of the esophagus following primary anastomosis is to be seen in this series of films made with angiocardiographic equipment at intervals of 2 second each. The illustrations have been selected from a series of films, each made at intervals of ½ second. Peristalsis was absent for a short distance below the level of the anastomosis (indicated by arrow). In *C* and *D*, the contrast material has been forced progressively higher in the esophagus than in *B*, as a result of peristalsis in the middle and lower thirds of the esophagus (G. L., Case 48).

hold a particular attraction for them. Other objects, such as beads, jingle bells, and marbles are merely reflections of the objects around which their play hours are centered. Articles of food, however, are the most frequent cause of esophageal obstruction. They are usually regurgitated readily when vomiting is induced; but on occasion they require esophagoscopic removal. The best physiologic test of the esophagus following primary anastomosis is the ability of the child to swallow a hurriedly ingested "hot dog" or a piece of steak.

PSYCHOMETRIC OBSERVATIONS

The possibility of some degree of cerebral impairment has been of concern to us in infants who have been operated upon for esophageal atresia because a number of them have experienced brief periods of profound cyanosis. The attacks of cyanosis have been present more often during the postoperative convalescence than during the brief period of preoperative preparation. Psychometric examinations have been made by R. M. Gibson, Psychologist of the Department of Pediatrics, for a number of the patients, most of whom were more than 5 years of age at the time of examination. Sixteen patients have been studied to date, and the studies are being continued. The findings show that these children are not significantly different from normal children in intellectual function and intelligence quotient. In terms of behavior, they show no abnormalities; but in terms of personality development, they demonstrate considerable fixation around oral habits. Approximately one half of the patients who have been studied thus far have shown evidence of cerebral changes which would not have been observed when neurologic, or other clinical examinations, were made. Abnormal findings were noted in their performance on the Stanford-Binet test; and were evident only because of the child's inability to perform certain visual motor tasks. Understandable overanxiety on the part of the parents is reflected in the behavior and intellectual functioning of these children; and it is particularly evident in relation to their eating habits. Increased dependency upon people in general has been observed in patients who have required repeated hospitalization and additional surgical procedures, such as esophageal dilatation, after the ages of 8 months to one year. Dependency has not been noted, however, in patients who have not needed further treatment after their initial hospitalization. The personality traits which these children demonstrate are those which might have been anticipated in children who have undergone prolonged surgical and medical treatment in infancy and early childhood. Continuing studies of personality development are expected to be of aid in minimizing unfavorable tendencies in future patients.

RIGHT COLON TRANSPLANT

The earliest attempts to restore continuity of the alimentary tract, when the multiple stage plan was employed, involved the use of antethoracic skin-lined tubes or the placement of the jejunum or stomach beneath the skin of the anterior thoracic wall. A review of the historical developments of esophagoplasty for esophageal atresia will not be presented at this time, although it should be recorded that the first patient for whom this plan was carried out was the first patient in Ladd's[38] series, the operation having been completed, in several stages, by 1944. In this case, a skin-lined tube was used to join the cervical esophagus to the stomach. It should also be noted that the antethoracic transplantation of the jejunum was employed by Swenson,[39] and by Leven and Varco,[40] who completed this procedure successfully in 8 consecutive patients.

Because the presumed viability of a segment of colon had seemed to us to be better in all probability than that of the jejunum, Fry[41] investigated the use of a segment of colon to replace the lower esophagus in our laboratory in 1951-1952. Employing the right colon and the right half of the transverse colon in dogs, Fry found that the available length would not allow it to reach higher than the level of the esophagus immediately below the aortic arch. He demonstrated, however, that the use of the right colon and the right half of the transverse colon could be successfully applied in replacing the lower esophagus in dogs. In post-mortem human studies, Fry observed that the length of the right colon in 20 patients of widely differing ages was at least equal to and usually considerably greater than the xiphoid-mastoid distance in all patients. He concluded, therefore, that the right colon was adequate for total esophagoplasty in human beings. Similar conclusions were reached by Battersby.[42] Kergin,[43] in 1953, used the right colon successfully to bridge a long segment of stenotic esophagus in a young adult. In his case the colon was interposed between the upper and lower esophagus through a left transpleural approach. It was not, however, until we had seen the encouraging reports of Mahoney and Sherman,[44] and Dale and Sherman,[45] who used the right colon substernally to bridge the defect in an infant with esophageal atresia, that we felt justified in applying this procedure to children in whom the multiple stage plan had been begun. We are greatly indebted to Sherman and Mahoney for their suggestions relative to this operation.

To date, the right colon and right half of the transverse colon have been used substernally to establish continuity of the alimentary tract in 7 patients in this series, and in another patient not included in this series because the original operations for esophageal atresia had been performed elsewhere. One of our patients who had had a right colon transplant performed in another hospital is not listed in the results which we have experienced with this procedure, although the result in this case has been excellent. The operations on our patients have been performed by a team consisting of Drs. M. S. DeWeese of the Department of Surgery, B. F. Scott of the Section of Thoracic Surgery, and myself. The intra-abdominal portion of these operations has been carried out by Dr. DeWeese.

The ages of our patients at the time the right colon transplant was undertaken have varied from 2 years and 2 months to 7 years and 4 months. In the first patient, the terminal ileum was preserved in view of the fact that the length of the transplant did not appear to be adequate had the ileum been resected. The proximal anastomosis was therefore made in this case between the cervical esophagus and terminal ileum. In the other cases, the proximal anastomosis was made between the cecum and cervical esophagus, except in the case of one patient in whom there was incomplete rotation of the colon and in whom the blood supply of the cecum and the adjacent proximal portion of the right colon appeared to be precarious after it had been drawn up to the neck. It was considered advisable to resect the proximal 4 inches of the cecum and right colon in this case, and this was done, particularly since an adequate length of the transplant was available to allow an anastomosis to be performed

between the cervical esophagus and the right colon proper. The ileocolic artery was divided in all cases, but the right colic artery was preserved whenever possible.

The colon transplant with its blood supply was brought behind the pyloric portion of the stomach in all cases, so that distention of the stomach would not exert pressure upon the vascular pedicle of the transplant. In our first 2 cases, the anastomosis between the proximal portion of the transverse colon and stomach was made rather low on the anterior wall of the stomach since it was impossible to reach a higher level because of limited exposure resulting from the presence of the gastrostomy track. In subsequent cases, the anastomosis has been made at points progressively higher on the stomach, and the gastrostomy has been taken down temporarily, when necessary, in order to provide access to the cardia and fundus of the stomach. In the last 2 cases, the left lobe of the liver has been mobilized to provide a more direct route for the colon to reach the cardia or fundus of the stomach. A short distal esophagus was mobilized in 2 cases; in one patient it was inverted into the stomach, a procedure which we do not now recommend. In the last case, the short distal esophagus and the cardioesophageal junction were resected and the anastomosis between the colon and stomach was made at the site of the resulting opening into the stomach. We believe that it is preferable to excise the distal esophagus whenever possible, in view of the fact that one of our patients, while awaiting a right colon transplant, developed a spontaneous perforation of the distal esophagus and died as a result. In order to determine whether or not resection of the lower esophagus is feasible from an abdominal approach, its length is estimated by retrograde catheterization with a cystoscope introduced into the stomach through the gastrostomy track prior to operation, or by probing the lower esophagus with a uterine sound introduced through the gastrostomy at the time of operation.

Seven of the 8 patients, for whom a right colon transplant was performed, survived operation, and each is now taking a normal diet through the reconstructed esophagus. The first patient in this group died approximately 12 hours after having been operated upon, as a result of atelectasis, cyanosis, and bloody bronchial secretions, all of which were evident clinically prior to the removal of the intratracheal tube at the conclusion of the operation. In this case, in which the proximal anastomosis was made between the cervical esophagus and the terminal ileum, post-mortem examination indicated that the blood supply of the ileum did not appear to have been adequate. Two of the patients developed temporary leakage of the cervical anastomosis. The fistula in each patient healed spontaneously without the development of a stricture. Inadequate antibiotic coverage was believed to be responsible for the leakage in the first case, as indicated by the fact that *Pseudomonas aeruginosa,* for which no antibiotic therapy had been used, was recovered when the cervical incision was reopened. In the other patient who manifested leakage of the cervical anastomosis, complete antibiotic coverage had been discontinued on the second postoperative day when the patient demonstrated evidence of renal insufficiency. Two other patients developed stricture

of the cervical anastomosis for which a plastic repair was required, 3½ and 7 months, respectively, following the right colon transplant. Another patient who developed intestinal obstruction caused by adhesions and kinking at the site of the ileotransverse colostomy was treated by releasing the obstructing adhesions 23 days after the colon transplant had been performed. One of the patients, in whom we had observed temporary leakage of the anastomosis, developed an additional complication consisting of sudden apparent obstruction within the distal portion of the colon transplant after he had returned to his home. Distention of the colon transplant was evident in the cervical region, and the patient's condition was critical. The cervical incision was reopened by his surgeon and the colon transplant, which was greatly dilated, was drained.

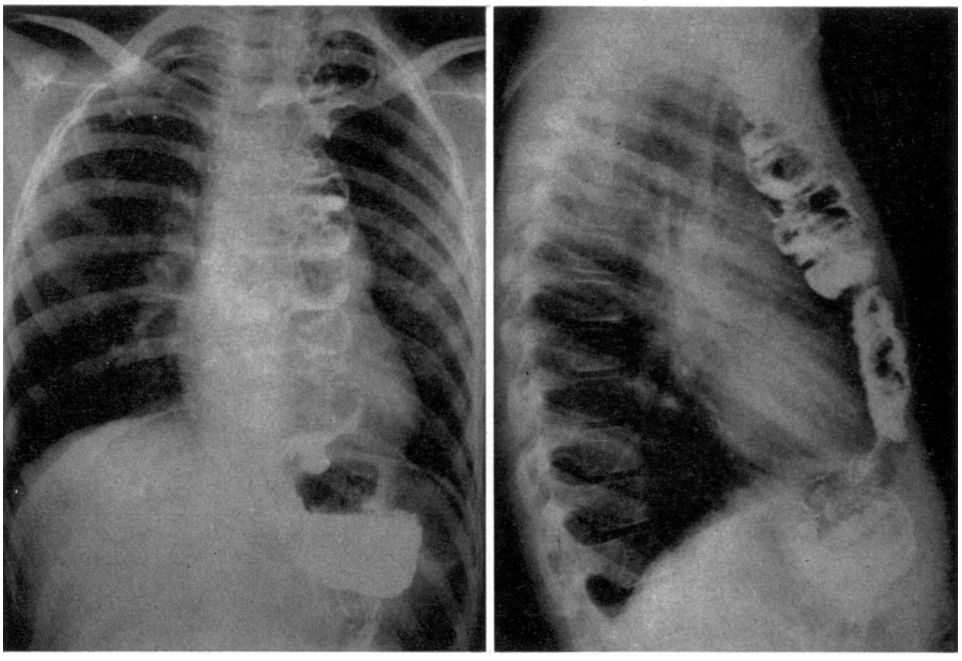


Fig. 7.—Roentgenograms of right colon transplant (R. B., Case 86). The cologastric anastomosis has been placed close to the cardioesophageal junction.

Immediate relief of the symptoms followed. The wound healed spontaneously and no subsequent symptoms have appeared. In this case, the second in our series, the cologastric anastomosis had been made close to the pylorus. Stasis within the colon transplant had been demonstrated by roentgen examination on the day preceding the apparent complete obstruction, but has not been evident during a subsequent examination. The stasis was attributed to the placement of the anastomosis too close to the pylorus. For this reason, the cologastric anastomosis has been made at a higher point on the stomach in patients for whom this operation has been done subsequently (Fig. 7), and no further complications of this type have been experienced.

Postoperative roentgen evaluation of the colon transplants has been made almost exclusively by Dr. M. M. Figley of the Department of Roentgenology. He has observed the ingested contrast material to pass freely but slowly through the transplant when the patient is in either the horizontal or upright position. Peristalsis has not been evident with the relatively small amount of barium that the children have swallowed.

Because of our concern regarding the possibility of ulceration at the site of the cologastric anastomosis, a study of postoperative fasting gastric secretions has been made in all living patients who have been treated by this procedure. Preoperative examinations of the fasting gastric secretions have also been made in the last 4 of our patients. These examinations, first performed by Dr. Basil Hirschowitz, but chiefly by Dr. Ronald C. King in more recent patients, have consisted of evaluations of gastric acidity and pepsin levels before and after histamine stimulation. The differences observed between the preoperative and postoperative examinations have not been significant; but a striking and worrisome finding has been the unusually high gastric acidity and pepsin levels in all cases both before and after histamine stimulation was applied. The preoperative gastric acidity, expressed as milliliters of tenth normal hydrochloric acid per 100 ml. of gastric juice, has varied from 39 to 104, with a mean of 71. Postoperative findings have varied between 0 and 112 ml. with a mean of 80. Following the use of histamine stimulation, these values have increased to a mean of 125 prior to the operation, as compared with a mean of 121 after the colon transplant had been effected. The pepsin levels have shown a corresponding elevation. These findings are of concern because they suggest that ulceration may develop in the stomach or in the colon transplant. Accordingly, postoperative gastroscopic examinations are being carried out by means of a cystoscope introduced through the gastrostomy track. So far, no evidence of ulceration has been observed. In one of these cases the gastrostomy tube was removed and the track was allowed to close. In the others, the gastrostomy tube is being kept in place in order to permit further studies of the stomach to be made. The high hydrochloric acid and pepsin findings in these cases suggest strongly that a concomitant vagotomy and pyloroplasty should be performed at the time when the colon transplant is made. These adjuncts, however, have not been employed thus far in any of our cases.

CONGENITAL TRACHEOESOPHAGEAL FISTULA

In comparison with atresia of the esophagus, congenital tracheoesophageal fistula which is not associated with other anomalies of the esophagus occurs infrequently, being found in about 3 per cent of a combined group of cases. It is understandable, therefore, that this anomaly was first recognized much later than was esophageal atresia. The first case of tracheoesophageal fistula unaccompanied by an atresia was described by D. S. Lamb,[46] in 1873. Lamb was Acting Assistant Surgeon of the United States Army at the time of his report. The specimen has been preserved in the Armed Forces Institute of Pathology, Washington, D. C. and a current photograph of the specimen is reproduced in Fig. 8. Later in the same year (1873), Pinard[47] and Tarnier[48]

independently presented another case which had been observed by both authors. In 1948, I was able to collect only 10 verified cases from the literature or from personal communications and, at the time of my report, 2 of my own cases were added.[49] In a review of the English literature in 1954, Ware and Cross[50] found 26 cases of this anomaly to which they added another case. At the University Hospital, 5 additional cases have been seen since my earlier report was made, making a total of 7 cases of the anomaly which have been treated in this institution.

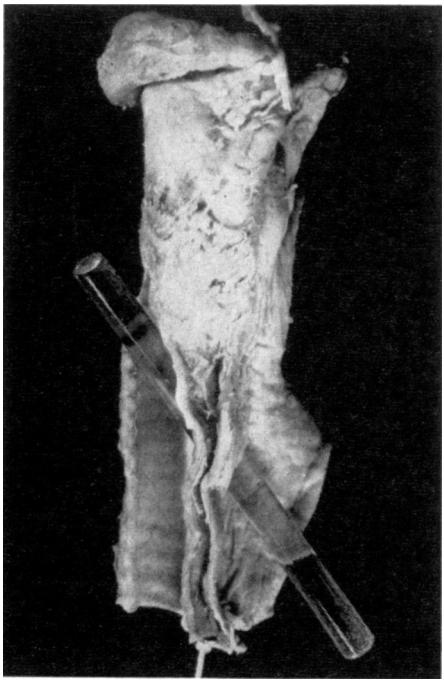


Fig. 8.—First reported case of congenital tracheoesophageal fistula without esophageal atresia, described by D. S. Lamb in 1873. Recent photograph of the specimen. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C., Col. Joe M. Blumberg, Deputy Director.)

A characteristic finding in cases of tracheoesophageal fistula, in which other anomalies of the esophagus are not involved, is the considerably higher location of the fistula in the trachea than the level at which a tracheoesophageal fistula is found when accompanied by an esophageal atresia. In our 7 cases, the fistula was located in the mid-third of the trachea in 2 cases, and at the junction of the middle and upper thirds of the trachea, or higher, in the other 5 patients. The fistulous tract between the trachea and esophagus is usually several millimeters long, although this is not always the case. If there is a short tract, the opening into the trachea is usually situated in a more cephalad position than is the opening into the esophagus. The resulting obliquity of the fistulous tract, if present, may allow its walls to be approximated temporarily during swallowing and, if so, it probably accounts for the fact that a few infants have survived for a considerable period of time before surgical closure has been

effected. A review of the literature, however, shows that the life expectancy of most untreated cases is relatively brief, being a matter of a few days or weeks.

The symptoms of tracheoesophageal fistula were severe enough to have prompted the referral of the patients for treatment prior to the third week of life in 5 of the 7 cases. They were admitted on the first, second, third, sixteenth, and eighteenth days after birth, respectively. A sixth patient was referred on the thirty-sixth day of life; while the remaining patient in the series was almost 4 years old at the time of admission.

Four patients were operated upon 6 days, 3 weeks, 7 weeks, and 4 years, respectively, after birth and the fistula was successfully divided and closed. A left cervical approach was used for 2 of the patients; the operation was done through an extrapleural thoracic approach in another patient, and an intrapleural approach was used for the fourth. In another case, not listed in this series, a tracheoesophageal fistula was suspected and an intrathoracic exploration of the trachea and esophagus was made, but no evidence of fistula was found. The patient gradually improved, although feedings by gastrostomy were required for about a year.

In this presentation I have endeavored to relate some of the observations which have come to my attention regarding certain aspects of the anomalies under consideration. My observations, in general, are far from complete and indicate the need for further study of the many facets of the problem. Our results point to the desirability of developing improved techniques for the prevention of the complications of stricture at the anastomosis and recurrence of a tracheoesophageal fistula. As yet, comparative statistics are not available concerning the relative advantages of the intrapleural and extrapleural approaches for esophageal anastomosis, especially in premature babies. I have referred to the problems that are current in the management of the infant with atresia when a partial agenesis of the lower esophagus exists. Most urgently required is an evaluation of the results of operations employing extensive mobilization of the esophagus or stomach. The late physiologic activity of the reconstructed esophagus has been described, and preliminary observations concerning the late development of patients with esophageal atresia have been made. Further studies are needed in connection with the latter, especially because one has to consider not only the treatment of the anomaly itself but also the development of the patient as a whole. Future advances in the prevention of the anomaly, as well as in its management, cannot be made by thoracic surgeons alone. Teamwork with their colleagues in the allied basic and clinical sciences should be undertaken so that the many perplexing problems which invite further investigation may be solved.

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