

AN EXPERIMENTAL EVALUATION IN THE DOG OF BRONCHIAL TRANS-PLANTATION, BRONCHIAL, TRACHEAL AND TRACHEOBRONCHIAL RESECTION WITH RECONSTRUCTION*

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RECENTLY MUCH experimental work has been done involving the local resection of portions of the bronchial and tracheobronchial tree.^{1, 2, 3, 6} Such a study was carried out in this laboratory in conjunction with studies of planes of bronchial transection and healing, function studies, and growth potentials of such procedures in young animals.

The results have been evaluated on the basis of bronchoscopy, roentgenograms, physiologic tests, spirometric studies and postmortem examinations, including gross and microscopic studies. This report concerns only the results obtained following the resection and reconstruction of various tracheal and bronchial segments.

METHODS OF STUDY

Operative Procedure. One hundred two surgical procedures were done on 71 adult mongrel dogs. Seventeen of the animals underwent two surgical procedures, and seven underwent three surgical procedures. The dogs were intravenously anesthetized with 30 mg. of nembutal per pound of body weight. All procedures were done under sterile precautions. Oxygen was supplied by a mechanical respirator. An endobronchial tube with an inflatable cuff was used in such a manner that all, or any lobar seg-

ment could be used for respiration. A right or left thoracic incision was made in the fourth intercostal space. A generous segment of the respiratory tree above and below the site of resection was dissected.

Section of the trachea or bronchus was done with a razor blade or sharp scalpel. The spillage of secretion was minimized by suction and careful sponging. Following resection and re-anastomosis, the site was repleuralized. The lungs were inflated by applying positive pressure through the endobronchial tube. Two hundred thousand units of aqueous penicillin were deposited into the chest cavity and a three-layer closure of the chest wall was done. The remaining air was aspirated by means of a catheter at the time of closure. Procaine penicillin was given intramuscularly, 150,000 units daily for three days postoperatively. Food and water were allowed upon recovery of the animal from anesthesia.

Various types of resections were done. The operative procedure will be presented in more detail with each type. The end results were evaluated by bronchoscopy, gross and microscopic studies.

TYPES OF PROCEDURES

A. Resection of the Stem Bronchi. The left stem bronchus was resected in 14 animals; the right in 15 animals. Four types of resection were done (Figs. 1 and 2A).

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The chest cavity was entered through either the right or left fourth interspace and the lung was retracted medially and ventrally. The pleura was incised ventral to the vagus nerve. The carina, stem bronchus, and its first bifurcation were dis-

sected free of vessels, nerves and adventitia. The segment to be removed was then sectioned in the desired plane. An attempt was made to resect at least a 1 cm. segment in each case. The resected segments on the right were shorter, but larger in diameter than those on the left. A direct end-to-end anastomosis was then made.

bronchi to the level of the first division were resected. Modifications in procedure were necessary in the cases undergoing resection of the carina or the carina and stem bronchi. The problem of aeration was resolved by

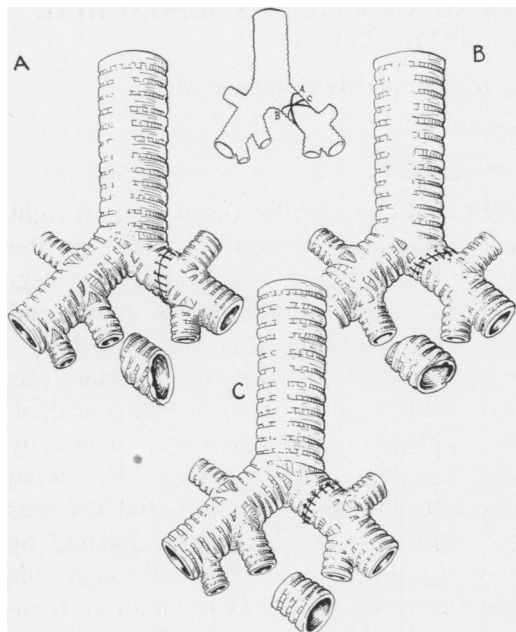


FIG. 1.—Representation of the planes of bronchial resection. A and B—two oblique, superior-inferior planes. C—A transverse plane with section between cartilages. Although this diagram has used the left main stem bronchus as an example, these procedures were carried out on both right and left sides.

sected free of vessels, nerves and adventitia. The segment to be removed was then sectioned in the desired plane. An attempt was made to resect at least a 1 cm. segment in each case. The resected segments on the right were shorter, but larger in diameter than those on the left. A direct end-to-end anastomosis was then made.

B. Resection of the Carina or the Carina with Both Stem Bronchi. The carina alone was resected in seven animals (Fig. 2B). This included a resection of the lowest two rings of the trachea and the first ring of the right and the left stem bronchi. In six other animals, the carina and both stem

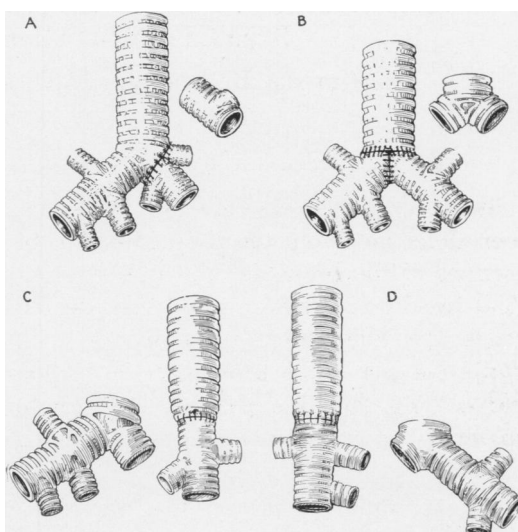


FIG. 2.—Representation of forms of bronchial and tracheal resection. A. Resection of a stem bronchus and the first bifurcation, with continuity established by direct anastomosis. This plane utilizes the breadth at the major bifurcations of the respective lung to match the larger proximal lumen. B. Resection of the carina. The carina may be resected alone or together with both stem bronchi. C. and D. Represents a carinal resection together with one stem bronchus and the entire excluded lung.

sterilizing two endobronchial tubes prior to operation. One tube was inserted into the trachea from above in the usual manner. The second sterile tube was available on a sterile instrument tray. After dissection of the lower trachea, carina, and both stem bronchi, a rapid resection was done. The second tube then was inserted by the surgeon directly into the bronchus of one lung in the operative field. This lung was used for respiration until the bronchus of the opposite lung was anastomosed into the proximal trachea. On completion of that anastomosis, the tube within the trachea was pushed downward into the lumen of

the bronchus already anastomosed. The endobronchial tube which had been inserted endobronchially in the operative field now was removed, and the anastomosis of the remaining bronchus was made.

bronchi so that each would share a proportionate amount of the tracheal lumen. This problem resolved as experience was gained.

C. *Resection of the Carina, Right or Left Stem Bronchus, and Simultaneous Pneumo-*

TABLE I.—*Bronchial Resections, Left Main Bronchus.*

Dog No.	Direction of Bronchial Section	Suture Material	Age of Anastomosis at Autopsy	Result	Comment
K-28	Vertical and diagonal (Figure 1A)	4-0 chromic	117 days	Excellent	Right main bronchus transected at 21 days with excellent results.
K-100	Vertical and diagonal	60 cotton	51 days	Excellent	Right pneumonectomy at 26 days.
M-60	Vertical and diagonal	4-0 silk	32 days	Excellent	Right pneumonectomy at 29 days. Pneumonia developed and dog sacrificed; very ill.
K-36	Diagonal and horizontal (Figure 1B)	4-0 chromic	60 days	Excellent	Right pneumonectomy at 55 days. Died 5 days after right pneumonectomy; no cause found.
M-57	Diagonal and horizontal	4-0 chromic	39 days	Excellent	Right pneumonectomy at 38 days. Dog died a. m. (O ₂ mix-up, 3 other dogs died that day).
M-63	Diagonal and horizontal	4-0 silk	77 days	Fair	Right pneumonectomy at 35 days. Ten per cent narrowing.
K-33	Transverse (Figure 1C)	4-0 chromic	76 days	Excellent	Right pneumonectomy at 58 days.
K-99	Transverse	4-0 silk	51 days	Excellent	Right pneumonectomy at 26 days.
M-59	Transverse	4-0 silk	32 days	Excellent	Right pneumonectomy at 31 days. (O ₂ mix-up, 3 other dogs died that day).
K-30	Vertical and diagonal with bifurcation (Figure 2A)	4-0 chromic	116 days	Poor	Completely strictured off. Left lung was large and spongy.
M-53	Vertical and diagonal with bifurcation	4-0 silk	24 days	Poor	Left upper lobe bronchus strictured. Right pneumonectomy at 22 days. Dog sacrificed 2 days postoperatively because of illness.
M-65	Vertical and diagonal with bifurcation	4-0 silk	35 days	Good	Slight roughness only.
B-20	Vertical and diagonal with bifurcation	60 cotton	517 days	Excellent	Cotton sutures still present.
B-21	Vertical and diagonal with bifurcation	60 cotton, anterior half; 4-0 chromic, posterior half	526 days	Excellent	Evidence of cotton present.

Oxygen was used throughout these procedures. One lung proved to be ample for oxygenation. On several occasions, the accessory median right lobe alone sufficed to provide adequate oxygenation for periods of 15 to 20 minutes duration; these instances were followed by an uncomplicated recovery of the animal.

The greatest difficulty was encountered in obtaining a smooth anastomotic line and in anastomosing the right and left stem

nectomy. Eight dogs were subjected to this procedure (Figs. 2C and 2D). Five animals underwent a simultaneous left pneumonectomy and three animals a simultaneous right pneumonectomy. The operative procedure was similar to that used in the carinal resections. However, either the right or left stem bronchus was anastomosed end-to-end with the trachea. Upon completion of the anastomosis, the excluded lung was resected.

SUPPLEMENTAL STUDIES

D. *Bronchial Transplants.* A group of 13 animals was subjected to four types of procedures (Fig. 3). The right or left stem bronchus was transected at the carina and in some cases the stem bronchus was resected. The proximal stump was closed. The stem bronchus was then anastomosed to an aperture made in the trachea on the isolateral side or to an aperture made on the medial aspect of the contralateral bronchus. The procedure did not disturb the ventilation to one lung and the anastomosis could be done leisurely.

E. *Tracheal Resections.* Tracheal resections were done in eight animals and are reported here because of incidental interest. A direct end-to-end anastomosis was done with chromic catgut in four animals. In four animals the defect produced by resection was bridged by tantalum wire gauze.*

The resections were done in a manner similar to the other resections. The endotracheal tube was withdrawn only momentarily for the resection of the desired segment, then reinserted into the distal segment. Direct end-to-end anastomosis was done, or tantalum gauze was inserted to bridge the defect. The tantalum gauze was cut into a rectangular piece long enough to be rolled around the tracheal segments containing the endotracheal tube and overlapped one centimeter. Each end of the rolled gauze was anchored to a tracheal ring in two places by a 2-0 chromic catgut suture. In two cases, a thin layer of gelfoam was wrapped over the gauze. The entire area was repleuralized. The endobronchial tube was withdrawn and the lungs re-inflated. All leaks in the pleura were closed by suture and the chest was closed in the usual manner.

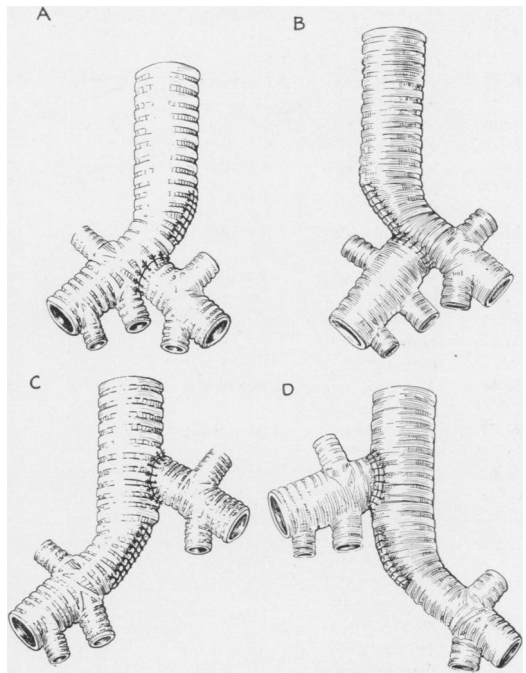


FIG. 3.—A. and B. Transplantation of a stem bronchus to the medial aspect of the contralateral stem bronchus. C. and D. Transplantation of a stem bronchus to the ipsilateral side of the trachea.

for three months, and then every two months to the time of the animal's death or to the time of termination of the experiment. The rate and manner of healing were observed.

B. *Plaster of Paris Casts.* At autopsy in certain cases the tracheobronchial tree was filled with a mixture of barium sulfate and plaster of Paris. Roentgenograms were taken and the casts were studied for general contour of the anastomotic site.

C. *Gross and Microscopic Studies.* All autopsy specimens were examined grossly and the lumina at the anastomotic site, as well as proximally and distally, were meas-

* The tantalum gauze (50 x 50) made of tantalum wire 0.003 inches in diameter, used in this experiment, was kindly supplied by Dr. H. L. Davis, Director of Experimental Research, Johnson and Johnson, New Brunswick, New Jersey.

ured. Microscopic sections were studied in representative cases.

D. *Suture*. Cotton, silk and catgut were

2. *Good*: A rough anastomotic line, completely epithelialized with no granulating areas and no stenosis.

TABLE II.—*Bronchial Resections, Right Main Bronchus.*

Dog No.	Direction of Bronchial Section	Suture Material	Age of Anastomosis at Autopsy	Result	Comment
K-32	Vertical and diagonal (Figure 1A)	4-0 chromic	76 days	Excellent	Left pneumonectomy at 58 days.
K-49	Vertical and diagonal	4-0 chromic	127 days	Excellent	Left pulmonary artery ligated at 50 days. Left pneumonectomy at 78 days.
K-66	Vertical and diagonal	4-0 chromic	113 days	Excellent	Left pulmonary artery ligated at 34 days. Left pneumonectomy at 62 days.
M-61	Vertical and diagonal	4-0 silk	30 days	Good	Rough but wide open. Left pulmonary artery ligated at 22 days. Dog died 8 days after pneumonectomy, infarction of left lung.
M-62	Vertical and diagonal	4-0 silk	76 days	Excellent	Left pulmonary artery ligated at 26 days.
M-64	Vertical and diagonal	4-0 silk	76 days	Excellent	Left pulmonary artery ligated at 26 days.
K-35	Diagonal and horizontal (Figure 1B)	4-0 chromic	75 days	Fair	Narrowed 20 per cent. Smooth. Left pneumonectomy at 56 days.
K-63	Diagonal and horizontal	4-0 chromic	70 days	Bronchus excellent	Anastomosis excellent. Distemper. Right lung abscess. Sacrificed.
K-31	Transverse (Figure 1C)	4-0 chromic	76 days	Fair	Narrowed at anastomosis 15 per cent. Smooth and well healed. Left pneumonectomy at 58 days.
K-62	Transverse	4-0 chromic	119 days	Excellent	Left pulmonary artery ligated at 42 days. Left pneumonectomy at 72 days.
K-67	Transverse	4-0 chromic	113 days	Excellent	Left pulmonary artery ligated at 34 days. Left pneumonectomy at 63 days.
K-75	Diagonal and horizontal with bifurcation (Figure 2A)	4-0 silk	113 days	Excellent	Strictered. Stricture and bifurcation resected at 34 days. Left pneumonectomy at 64 days.
K-34	Vertical and diagonal with bifurcation	4-0 chromic	110 days	Excellent	Mild pneumonia, right upper lung. Left pneumonectomy at 56 days.
K-50	Vertical and diagonal with bifurcation	4-0 chromic	118 days	Fair	Narrowing 20 per cent. Smooth. Left pulmonary artery ligated at 42 days. Left pneumonectomy at 72 days.
K-76	Vertical and diagonal with bifurcation	4-0 chromic	112 days	Excellent	Left pulmonary artery ligated at 33 days. Left pneumonectomy 63 days.

used as suture material. The effect of each suture material was evaluated from the findings on serial bronchoscopy and gross and microscopic studies.

CRITERIA

The following criteria were used in the classification of each individual anastomosis.

1. *Excellent*: A smooth anastomotic line with complete epithelialization, and no stenosis of the lumen.

3. *Fair*: A rough or smooth anastomotic line with or without granulations. Stenosis if present must not reduce the luminal diameter at the anastomotic site by more than 40 per cent when compared to the luminal diameter proximal to the anastomosis.

4. *Poor*: Any result not falling into the above three categories.

Some animals died early in the postoperative period. Therefore, insufficient time had elapsed to allow an evaluation of the

end result. However, the appearance of the suture line even at this early stage gave valuable information which allowed a reasonable estimate to be made based upon previous experience.

of observation varied from 24 to 526 days. There were 10 excellent, one good, one fair and two poor results. The two poor results both occurred in animals in which the left stem bronchus and the bifurcation of the

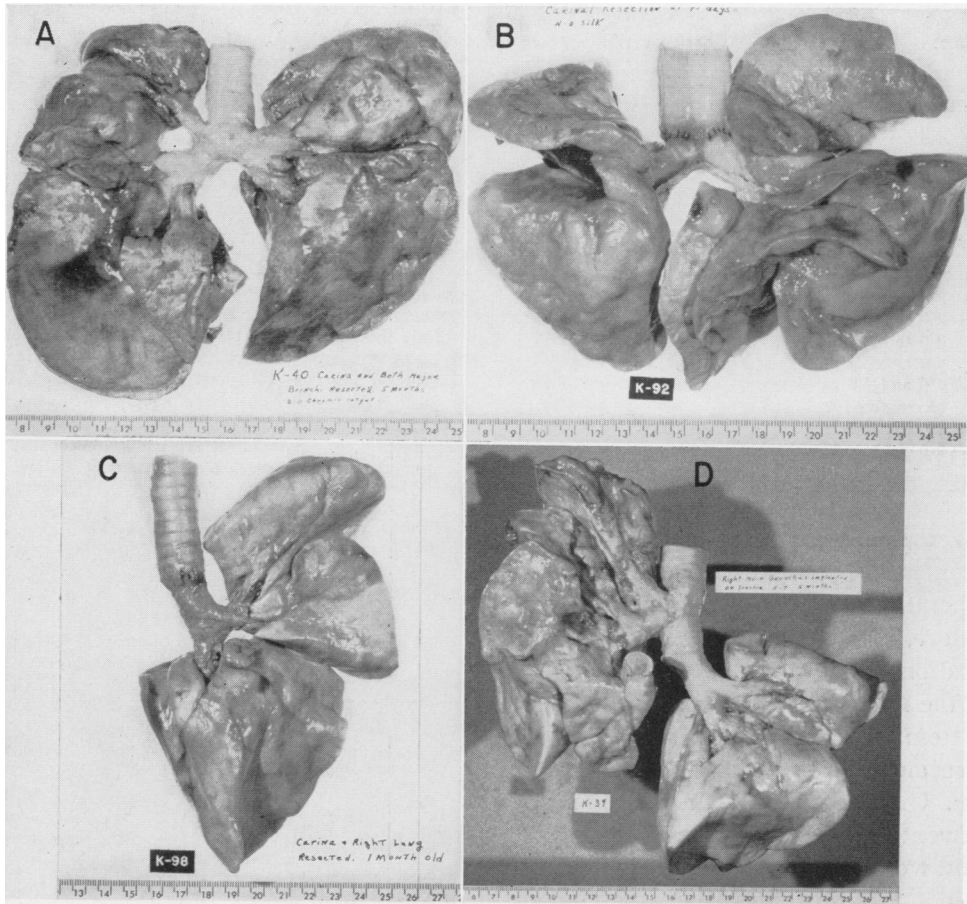


FIG. 4.—A. Gross specimen of a resection of carina and both stem bronchi at 102 days postoperative. B. Gross specimen of carinal resection, showing the suture line at 48 days. C. Gross specimen, 30 days postoperative, following the resection of the carina with simultaneous right pneumonectomy. D. Gross specimen of a transplantation of the right stem bronchus to the trachea, 102 days postoperative.

RESULTS

The results are summarized in Tables I through VII.

TYPES OF PROCEDURE

A. Resection of Stem Bronchi. The left main stem bronchus was resected in 14 animals. There were no deaths. The period

upper and lower bronchi were resected. Direct anastomosis was accomplished, but both healed with stenosis (Table I).

The right stem bronchus was resected in 15 animals. The period of observation varied from 30 to 127 days postoperatively. There were ten excellent, one good, and three fair results. There was one poor result, K-75. The right main bronchus had

TABLE III.—*Carinal Resections* (Fig. 2B).

A. <i>Carinal Resection Only</i>				
Dog No.	Suture Material	Age of Anastomosis at Autopsy	Result	Comment
K-37	4, #60 cotton; rest, 4-0 chromic.....	107 days	Poor	Left main bronchus closed off. Right main bronchus wide open. Thought poor at surgery.
K-58	2-0 chromic.....	11 days	Poor	Died. Bilateral pneumonia. Separation of mucosa at suture line.
K-71	2-0 and 4-0 alternating	66 days	Poor	Sacrificed. Left main bronchus completely off. Right main bronchus 50 per cent narrowed.
K-96	2-0 chromic.....	52 days	Excellent	Smooth.
K-78	60 cotton.....	64 days	Fair	Both narrowed but functioning well. Stricture smooth and concentric.
K-92	40 cotton.....	48 days	Excellent	Smooth. Sutures present.
M-50	4-0 silk.....	25 days	Excellent	Sacrificed due to distemper.
B. <i>Carinal Resection and Both Major Bronchi</i>				
K-40	2-0 chromic.....	102 days	Excellent	Smooth.
K-59	2-0 chromic.....	79 days	Excellent	Smooth.
K-61	2-0 and 4-0 chromic, 4-0 anteriorly	9 days	Fair	Suture lines had spread 1 cm. No narrowing. Granulations. Bilateral pneumonia.
K-72	2-0 and 4-0 chromic alternating.....	47 days	Poor	Left main bronchus completely closed off. Died. Right main bronchus narrowed 60 per cent.
K-93	40 cotton.....	49 days	Good	Left main bronchus rough and irregular.
K-94	2-0 chromic.....	29 days	Poor	Sacrificed dog, dyspneic. Right main bronchus ostium, 4 mm. Left main bronchus ostium, 2 mm.

been resected horizontally and diagonally. On bronchoscopy, approximately one month postoperatively, it was nearly closed. Therefore, the entire area, including the bifurcation, was resected and an anastomosis of the first division bronchi to the right main stem ostium at the carina was made. This second procedure produced excellent results. One month later, this same animal underwent a contralateral pneumonectomy and did well until sacrificed. All of the animals in this group, with the exception of K-63, underwent a subsequent contralateral pulmonary artery ligation or a contralateral pneumonectomy, or both procedures. Only one death resulted, M-61 (Table II).

B. *Carinal Resections.* The carina alone was resected in seven animals; the carina together with both major bronchi was resected in six animals. The results varied greatly. There were five excellent, one good, two fair, and five poor results (Figs. 4A, 4B and 6A). The end results in these cases could be predicted at the time of the immediate postoperative bronchoscopy. Unsatisfactory end results were obtained

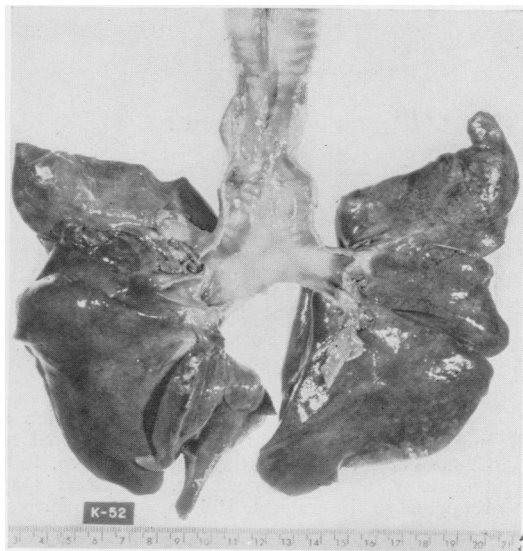


FIG. 5.—Gross specimen of a tracheal resection, bridged by tantalum gauze, 55 days postoperative. Note the firm smooth scar tissue imbedding the mesh.

when inadequate approximation or luminal disproportion was created at the time of surgery (Table III).

C. *Resection of the Carina, Right or Left Stem Bronchus and Simultaneous Pneumon-*

ectomy. Three operative deaths occurred in a group of eight animals subjected to this procedure (Table IV). An error in connections resulted in compressed air being used in place of oxygen in two of the animals. These animals had a poor immediate postoperative recovery; both expired the following day. During surgery, oxygen rather than air is essential in animals undergoing a major procedure of this nature.

anastomosis following resection of 4 to 11 rings of cartilage, measuring 1.6 to 4.5 cm. in length, all developed strictures at the site of anastomosis (Table VI). The period of observation varied from 63 to 100 days postoperatively. Three animals were sacrificed because of severe dyspnea and imminent death. At autopsy, the appearance of the specimens indicated that catgut, used in making the anastomoses, was inadequate

TABLE IV.—*Carinal Resections.*

A. *Carinal Resection with Left Main Bronchus with Simultaneous Right Pneumonectomy.* (Figure 2C)

Dog No.	Suture Material	Age of Anastomosis at Autopsy	Result	Comment
K-95	40 cotton.....	44 days	Excellent	Smooth.
K-98	60 cotton.....	30 days	Excellent	Smooth.
M-51	60 cotton.....	6 days	Good	Mucosal separation at suture line. Good otherwise. Pneumonia, left lung.

B. *Carinal Resection with Right Main Bronchus with Simultaneous Left Pneumonectomy.* (Figure 2D)

K-64	4-0 chromic.....	1 day	Poor	Mix-up on O ₂ . Developed leak in anastomosis second day. Died.
K-65	4-0 and 2-0 (6).....	1 day	Excellent	Mix-up on O ₂ . Anastomosis looked excellent.
K-69	2-0 and 4-0 alternating	69 days	Excellent	Smooth.
K-77	2-0 and 4-0 alternating	64 days	Poor	Smooth concentric stricture. Narrowed 60 per cent.
M-58	4-0 silk.....	37 days	Excellent	Smooth.

The remaining animals were observed for periods of 30 to 69 days postoperatively. Excellent results were obtained in all of the animals surviving the immediate postoperative period (Figs. 4C and 6B).

D. *Bronchial Transplantation.* The period of observation varied from 18 to 666 days postoperatively. In 13 animals operated upon there were seven excellent, two good, one fair and three poor results (Fig. 4D). There were no operative deaths. One animal was sacrificed at 22 days because of severe distemper. Two animals developed complete, or near complete, occlusion of the transplanted stem bronchus. Both of these animals did exceptionally well. Both gained weight. By observation of activity alone, there was no indication that one lung was functionless (Table V).

E. *Tracheal Resections.* The results were all poor. The animals undergoing direct

for an anastomosis made under tension. The anastomotic line in each case had separated gradually with the occurrence of a concentric narrowing at the anastomotic site.

The four animals in which the tracheal defect was bridged by means of tantalum gauze were of considerable interest. Following surgery, the animals did remarkably well and only one, K-52, was operated on within one hour of surgery because of a left pneumothorax which was uncontrolled by aspiration. A small hole in the pleura over the gauze was closed and the animal recovered completely. One animal developed a severe infection with abscess, which perforated into the right chest. This animal expired four days postoperatively. The other three animals did well postoperatively for approximately six weeks. Eventually, the results were all poor because the gauze-bridged area collapsed in each case on the

posterior aspect and in juxtaposition to the esophagus. The three remaining animals lived comfortably until the diameter of the graft was decreased by 40 to 50 per cent that of normal. With additional stenosis, the animals became dyspneic. When the diameter at the anastomotic site was re-

duced by the pressure of food boli descending the esophagus.

SUPPLEMENTAL STUDIES

A. Bronchoscopy. Bronchoscopy immediately postoperatively occasionally revealed areas of poor mucosa-to-mucosa

TABLE V.—Bronchial Transplantations.

A. Transplantation of the Left Main Bronchus to Right Main Bronchus with Resection of Left Main Bronchus. (Figure 3A)				
Dog No.	Suture Material	Age of Anastomosis at Autopsy	Result	Comment
K-42	4-0 chromic.....	22 days	Excellent	Distemper. Sacrificed.
K-85	4-0 chromic.....	18 days	Poor	Stricture and pneumonia. Left main bronchus nearly closed off. Died.
K-87	4-0 chromic.....	56 days	Good	Irregular and rough but wide total lumen.
B-23	60 cotton.....	562 days	Excellent	
B. Transplantation of the Right Main Bronchus to Left Main Bronchus with Resection of Right Main Bronchus. (Figure 3B)				
K-43	4-0 chromic.....	104 days	Excellent	Two mm. opening; emphysemic.
K-84	4-0 chromic.....	55 days	Poor	
K-88	4-0 chromic.....	48 days	Excellent	
C. Transplantation of Left Main Bronchus to Trachea. (Figure 3C)				
K-38	4-0 chromic..... (C4-5-6)*	99 days	Excellent	Slight distortion of left main bronchus. Pulled downward. Completely closed off at 4 months postoperatively. Under arch of aorta. Tension present.
K-82	4-0 chromic (C5-7)..	62 days	Good	
B-25	60 cotton.....	519 days	Poor	
B-26	40 cotton.....	666 days	Excellent	
D. Transplantation of the Right Main Bronchus to Trachea. (Figure 3D)				
K-39	2-0 chromic (C5-7)..	102 days	Excellent	Slight distortion, but wide open and smooth.
K-83	2-0 and 4-0 chromic (C6-8)	62 days	Fair	Right main bronchus narrowed and pulled down. Lung appeared excellent.

*Denotes number of cartilage rings above carina.

duced 20 to 25 per cent of normal, the animals became extremely dyspneic and clinically moribund.

The autopsy specimens of the latter three cases revealed very little tissue reaction about the gauze. The dissection of the surrounding structures was easy. In two of the animals the gauze was visible in only a small area of the internal surface. The remainder of the surface was covered by a smooth, hard, gray-pink fibrous tissue. Epithelialization was in progress from each end of the graft (Fig. 5). However, in each case the gauze was indented over its posterior aspect. It is felt that the collapse was

approximation. In some cases of carinal resection, gross disproportion was noted between the newly created ostia of the right and left stem bronchi. During serial bronchoscopies, progressive changes were noted. In most cases these changes could be attributed directly to the surgical technique. When a firm anastomosis with non-absorbable suture was made with a good mucosal approximation, satisfactory results were obtained. Non-absorbable sutures proved to be better than catgut in anastomoses made under tension.

If approximation of the mucosa was incomplete or disproportion of lumina oc-

curred, the end results were variable. When catgut was used in such situations, one could observe progressive separation of the anastomotic line over a period of weeks. The site became covered by granulation tissue. In the majority of cases, local infection was present. The infection appeared to be secondary to the anastomotic line separation.

ing at the suture lines was observed. In general, the rate and type of healing depended upon three factors: (1) initial adequate mucosa-to-mucosa approximation, (2) the presence or absence of infection, and (3) the ability of the suture to maintain approximation once the anastomosis was established.

Microscopically, the pattern of healing

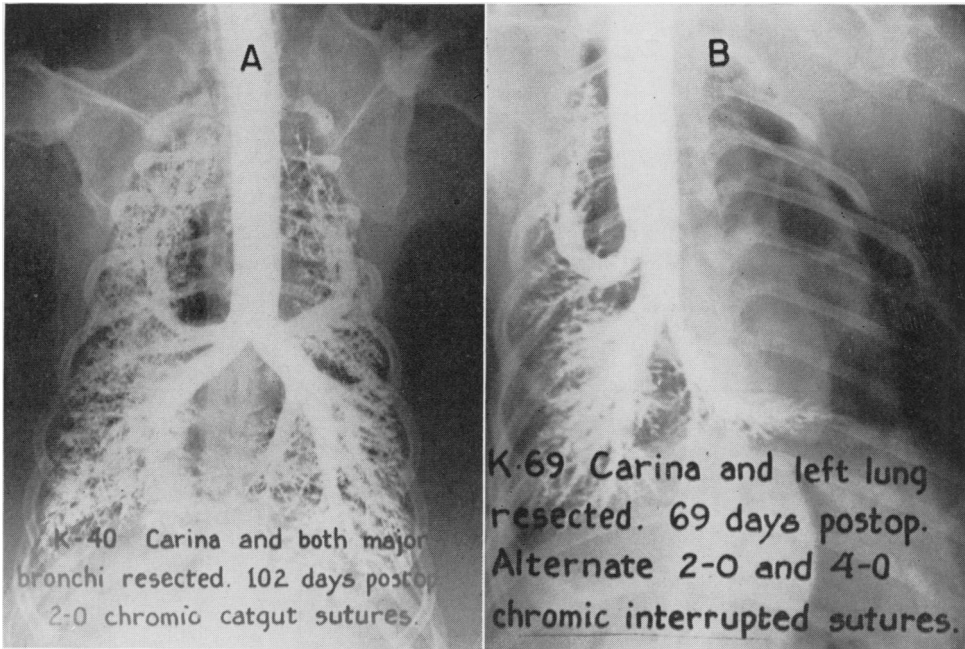


FIG. 6.—Autopsy specimens. Roentgen ray studies after the instillation of a mixture of barium sulfate and plaster of Paris into the respiratory tree.

Luminal disproportion frequently was noted in cases subjected to carinal resection. Bronchoscopic follow-up showed that if the newly formed carina was distorted, or if one or both lumina to the lungs was narrowed, the end results were usually unsatisfactory.

B. Gross and Microscopic Studies. Gross examination, in addition to bronchoscopy, included roentgenogram examinations, cast specimens, and direct inspection of the autopsy specimens. In general, once the lumen has healed, its size and configuration remains essentially unchanged.

A variation in the rate and type of heal-

was the same as that described in a previous publication.⁴ However, since tension often was present at the line of anastomosis following resections, a number of cases were found to have delayed healing, with an associated increase in the inflammatory reaction. Consequently, the nature of healing often was directly related to the type of resection and the ease with which a satisfactory anastomosis could be made. However, the majority of anastomoses resulted in a firm, smooth lumen (Fig. 7).

C. Suture Material. Cotton, silk and chromic catgut interrupted sutures were used in making the anastomoses. The re-

sults of each type of suture material are summarized in Table VII. The total number of cases is small; however, the findings confirm the general impression that the cases in which the anastomosis was made under tension, a non-absorbable suture was more satisfactory. However, the overall results do not reflect the effect of suture material alone. Additional consideration must be given to the experimental nature of the

and the complexity of the procedure. Resections of the stem bronchi with direct end-to-end anastomosis were accomplished without mortality. However, the mortality rose with the more complex procedures. In their performance, the probability of contamination is greater, as are the technical problems of aeration and reconstruction. Furthermore, the anastomosis itself is more difficult.

TABLE VI.—*Tracheal Resections.*

A. Varying Lengths					
Dog No.	Suture Material	Age of Anastomosis at Autopsy	Result	Comment	
K-46	2-0 chromic (11 rings 4.5 cm.)*	100 days	Original = 1.5 cm. interior diameter Autopsy = 0.3 " " "	Sacrificed. Very dyspneic. Progressive narrowing.	
K-47	2-0 chromic (9 rings 4.5 cm.)	99 days	Original = 1.4 cm. " " Autopsy = 0.3 " " "	Sacrificed. Very dyspneic. Progressive narrowing.	
K-53	2-0 chromic (9 rings 4.0 cm.)	97 days	Original = 1.8 cm. " " Autopsy = 1.2 " " "	Narrowed, 33 per cent.	
K-54	2-0 chromic (4 rings 1.6 cm.)	63 days	Original = 1.4 cm. " " Autopsy = 0.6 " " "	Sacrificed. Very dyspneic. Progressive narrowing.	
B. With Tantalum Gauze					
K-45	4 rings (1.7 cm.) Gel-foam used to wrap	58 days	Narrowed to 9 mm. exterior diameter. Screen covered in 80 to 90 per cent of area by scar tissue and epithelium.	Sacrificed. No dyspnea resting. Dyspnea on exercise. No reaction about screen. Narrowed to 30 to 40 per cent of original diameter.	
K-44	6 rings (3.5 cm.) Gel-foam used to wrap	4 days	Abscess about screen with perforation into right chest.	Died. Abscess about screen. Bilateral pneumonia.	
K-51	5 rings (1.9 cm.)...	48 days	Screen 8 mm. exterior diameter. Ends and one-third circumference covered by scar tissue and epithelium.	Sacrificed. Severe dyspnea. Narrowed to 20 to 25 per cent of original diameter.	
K-52	9 rings (3.5 cm.)...	55 days	Screen nearly covered by scar tissue and epithelium.	Died suddenly; suffocated. Narrowed to 20 to 25 per cent of original diameter. No reaction about screen.	

*Denotes number of rings resected and length of segment.

problem and to the technical difficulties encountered during some of the more complex resections and reconstructions.

The silk and cotton sutures eventually were sloughed or epithelialized to remain as permanent fixtures. The chromic catgut sutures usually sloughed early, but produced more cellular reaction than did the silk or cotton.

DISCUSSION

The resection and reconstruction of the tracheobronchial tree in the dog may be performed with a reasonable mortality rate. The end results vary with the extent

The problem of making anastomoses between the lumina of different sizes following carinal or bronchial resections was resolved in several ways. Ordinarily, the lumen of the proximal segment is larger than that of the distal segment. However, if the distal transection is made near the base of the first bifurcation, the resultant opening is larger than is its more proximal components. In this case, the distal orifice is slightly ovoid, but on anastomosis of the proximal segment, the semi-rigid walls of each segment "give" a little and a good anastomosis results. If disparity of the lumen size is small, one or more "pucker-

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ing” stitches can be taken in the membranous portion of the larger segment, thus equalizing the sizes of the lumina. The size of any orifice of the tracheobronchial tree can be altered by “tailoring.” A diagonal or tangential plane of transection will produce a larger orifice than will a transverse transection. Finally, the end of the distal or proximal segment can be “tailored” in two or more planes as is done when two bronchi

factor. The bronchus is too short to be anastomosed above the arch, and therefore must be placed under the arch. As a consequence, a downward and compressive force is exerted by the aortic arch. This tends to elongate and narrow the bronchial lumen.

A transplant to the medial aspect of the contralateral bronchus can be done with little or no tension. However, the anastomosis with the newly created orifice is

TABLE VII.—Comparative Results in the Use of Absorbable and Non-absorbable Suture in Bronchial Resections and Transplants.

Operation	Suture Material	No. of Cases	Results			
			Excellent	Good	Fair	Poor
A. Resection of stem bronchi....	{ Silk or Cotton.....	12	8	2	1	1
	{ Cotton and Catgut.....	1	1	.	.	.
	{ 4-0 Chromic Catgut.....	16	12	.	3	1
	{ Total.....	29	21	2	4	2
B. Resections other than stem bronchi alone, but not including trachea.....	{ Silk or Cotton.....	11	7	2	1	1
	{ Cotton and Catgut.....	1	.	.	.	1
	{ Chromic Catgut, 2-0.....	6	4	.	.	2
	{ 2-0 and 4-0 Chromic Catgut....	7	2	.	2	3
	{ 4-0 Chromic Catgut.....	9	4	2	.	3
{ Total.....	34	17	4	3	10	
C. Totals.....	{ Silk or Cotton.....	23	15	4	2	2
	{ Cotton and Catgut.....	2	1	.	.	1
	{ Chromic Catgut.....	38	22	2	5	9

are anastomosed to a larger one. The plane of transection does not appear to be important with regard to healing.

Bronchial transplantation was done in 13 cases without mortality. Bronchial transplantation is readily accomplished, but several factors must be considered. The distance that a lung segment can be moved is limited by the length of arteries and veins. With the arteries and veins intact, it was found that the greatest distance that one could transplant a bronchus to the side of the trachea was approximately seven cartilaginous rings above the carina (3.5 to 4.0 cm.). The pulmonary veins are short and constitute the main limiting factor. If a complete resection of the stem bronchus is done, then the distance is reduced to 3 to 4 cartilaginous rings above the carina. In transplanting the left stem bronchus as high as possible on the same side of the trachea, the aortic arch was an obstructing

difficult. These difficulties are related to the necessity of working deep in the mediastinum and the presence of the endotracheal tube, which is necessary for respiration in the recipient bronchus.

In spite of these handicaps, a broncho-bronchial transplantation has merit, for it results in an approximation without tension. On this basis alone, it should result in more frequent success than does a broncho-tracheal transplant, except when the broncho-tracheal transplant can be done low on the trachea and without tension.

An excellent evaluation of tracheal resections with direct anastomosis has been reported.¹ However, the four animals in which various lengths of the thoracic trachea were resected with the bridgement of the defect by tantalum gauze are of interest. Prior to performing this procedure, it was expected that the animals would develop mediastinal emphysema and pneu-

mothorax. However, if mediastinal emphysema developed, it was undetected and insufficient to embarrass the animal. The constant indentation of the gauze form posteriorly was attributed to the pressure of

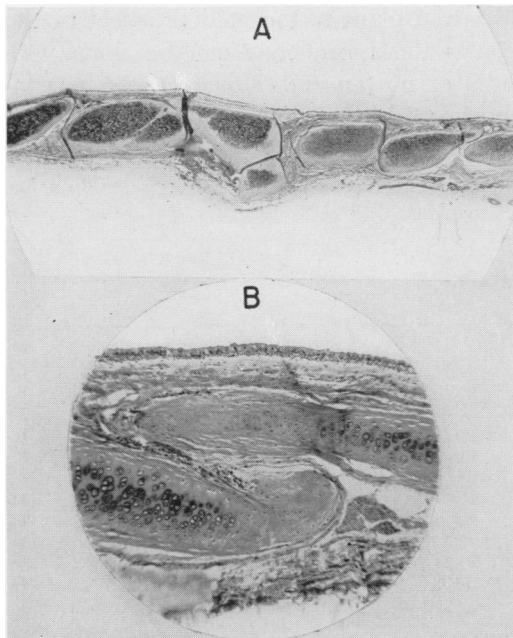


FIG. 7.—A. B-21, 526 days postoperative showing anastomosis of the left stem bronchus to the left lower lobe bronchus following resection of left stem bronchus and first bifurcation. Note the firm wall with normal epithelium. B. B-20, 517 days showing anastomosis of left stem bronchus to the left upper lobe bronchus following the resection of the left stem bronchus and the first bifurcation. (Magnification: A. 12 x, B. 40 x.)

food boli descending the esophagus. Therefore, if a more rigid tantalum gauze, ribbed gauze, or stainless steel gauze were used, this collapse probably would not occur. However, the danger of erosion would be increased. The dog frequently bolts large masses of food rapidly. It is possible that a tantalum gauze similar to that utilized here might be adequate in man.

When a solid metal, glass, or plastic prosthesis is used to bridge a defect, the granulating base must encroach upon the center from the ends. Likewise, the blood supply to the granulation and epithelial tissue must be provided from the same sites. By the

utilization of a wire mesh, granulation tissue appears rapidly at all points through the perforations. Consequently, its blood supply is derived from the immediate area. It was hoped that under these conditions, epithelialization would progress more rapidly. From the appearance of the autopsied material, early epithelialization has occurred. The advantages are apparent. However, the mesh must be sufficiently rigid to resist collapse.

It is apparent, also, that animals in whom various resections and reconstruction procedures were carried out tolerated contralateral pulmonary ligation and/or pneumonectomy without any evidence of respiratory or ventilatory embarrassment. A detailed report of these findings will be presented in a subsequent publication.⁵

CONCLUSIONS

1. In the dog bronchial stem resections with direct anastomosis can be done with safety.
2. Bronchial transplantation with or without bronchial resection can be made to a new site on the trachea or contralateral bronchus. The distance and direction of the transplantation is limited by the length of the pulmonary veins and, in addition, on the left side by the aortic arch.
3. Resection of the carina, the carina and stem bronchi, carina and one lung, followed by reconstruction can be done as a one-stage procedure. The mortality is not prohibitive.
4. Long tracheal defects can be bridged with immediate success by tantalum mesh gauze alone. A narrowed lumen eventually results due to posterior indentation of the "graft" in juxtaposition to the esophagus.
5. Respiratory and ventilatory function of pulmonic tissue distal to a resection and reconstruction is apparently normal.
6. Disproportionate bronchi to be anastomosed can be "tailored" at either or both ends to the size and shape necessary for a

satisfactory anastomosis. Healing appears to be unaffected by the plane of transection.

7. A non-absorbable suture is advised in making an anastomosis under tension.

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ANNOUNCEMENT

The National Paraplegia Foundation wishes to announce the continuation of a limited number of fellowships for research in spinal cord disease and trauma, and in the complications commonly associated with such disease or injury. These fellowships carry a minimum stipend of \$3000 per year and may be awarded to any candidate who has demonstrated a capacity for medical research and has outlined a program of meritorious study. The fellowships will be awarded by the Medical Advisory Committee and are open for award for the academic year 1953-1954. Application forms may be obtained from the Chairman of the Medical Advisory Committee, and applications should be submitted to him not later than May 1, 1953.