Thorax (1973), **28**, 667.

Reconstruction of the trachea

Experience in 100 consecutive cases[1]

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Grillo, H. C. (1973). *Thorax*, **28**, 667–679. **Reconstruction of the trachea. Experience in 100 consecutive cases.** Anatomic mobilization of the trachea permits resection of one-half or more with primary anastomosis. An anterior approach by a cervical or cervicomediastinal route utilizes cervical flexion to devolve the larynx and tracheal mobilization with preservation of the lateral blood supply. The transthoracic route is employed for lower tracheal lesions.

Over 100 tracheal resections have been done using these methods of direct reconstruction. Eighty-four patients suffered from benign strictures, 79 resulting from intubation injuries. Eleven primary tracheal tumours and five secondary tumours are included. The majority of lesions following intubation occurred at the level of the cuff. It was possible to repair 78 of the 84 stenotic lesions through a cervical or cervicomediastinal approach. Seventy-three of the 84 patients with inflammatory lesions obtained an excellent or good functional and anatomic result. Nine of 11 patients with primary neoplasms who underwent reconstruction are alive and without known disease. There were five early postoperative deaths in these 100 consecutive patients who underwent tracheal reconstruction.

PROBLEMS OF RECONSTRUCTION

Until a decade ago reconstruction of the trachea was inhibited by the belief that no more than 2 cm of trachea—approximately four cartilaginous rings—could be circumferentially resected and the tracheal ends predictably reapproximated (Belsey, 1950). Faced with a more extensive lesion the surgeon felt, therefore, that he must abandon the ideal of end-to-end anastomosis of the trachea in favour of endoscopic removal of the lesion, lateral resection with patching of the defect by one of a variety of means, or insertion of a tubular prosthesis. Endoscopic removal was obviously only a temporizing manoeuvre to provide an airway in the case either of a neoplastic lesion or of most benign strictures. Lateral resection, performed with concern for maintaining a good isthmus of normal tracheal wall, all too often compromised resection margins and led to a recurrence of tumour. Problems with the integrity of lateral patches also arose, depending on the material used. A number of case reports of at least initial success with prostheses have been recorded. No prosthesis has yet been developed, however, which may be inserted as a replacement for long segments of trachea with a high predictability of success (Grillo, 1970). Although early leakage with resultant mediastinal sepsis may be reduced by sealing with homologous tissues, the problems of late stenosis at either end of the prosthesis and erosion of major mediastinal vessels have continued to plague the tracheal prosthesis. Placement of a foreign material, however inert, in a bed of connective tissue contiguous with potentially infected respiratory mucosa remains a biologically unstable situation. Indeed there are no examples of uniform success of other non-tracheal prostheses in analogous situations. The presently useful prostheses—cardiac, vascular, orthopaedic—are all seated entirely in potentially sterile mesenchymal tissues. The somewhat lesser obstacles of anaesthetic management of patients during airway replacement also seemed to pose dilemmas a decade ago.

ANATOMIC MOBILIZATION

In view of the then and as yet unsolved problems of providing a suitable biological basis for the use of prostheses, I began to reinvestigate systematically the problem of anatomically mobilizing the

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human trachea to permit end-to-end reconstruction following the resection of greater segments of trachea. This work was prompted by the observation in cases of traumatic severance of the trachea that the distal end of the divided cervical trachea dropped into the mediastinum. These anatomic studies (Grillo, Dignan, and Miura, 1964) were done in the pathology laboratory, since no close parallel existed in gross relationships between human and other animal tracheas. Since my viewpoint was that of a thoracic surgeon, my initial attempts were to mobilize the thoracic trachea. Our first observations demonstrated that division of the inferior pulmonary ligament and mobilization of the right hilus with loosening of carinal attachments permitted resection of an average of 3 cm of trachea or six rings. Reconstruction was possible at tensions well under 1,000 g. Pericardial dissection of the pulmonary vessels allowed the additional removal of 0·9 cm.

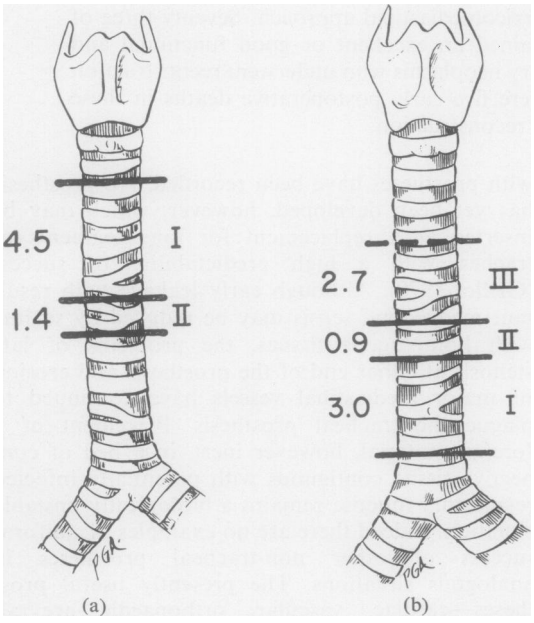

FIG. 1. *Diagram of lengths of trachea which may be resected and yet permit primary anastomosis.* (a) 4.5 *cm can be removed through an anterior approach and approximation done with* 1,000 *g of tension, utilizing cervical flexion. Intrathoracic dissection allowed further removal of* 1·4 *cm.* (b) *With the cervical spine in a neutral position, transthoracic hilar dissection and division of the pulmonary ligament allowed* 3 *cm to be removed and anastomosis done. Intrapericardial dissection added* 0·9 *cm and division of the left main bronchus with reimplantation of the bronchus intermedius permitted an additional* 2·7 *cm to be removed. If cervical flexion is utilized, a significantly greater amount than* 3 *cm may be removed.*

A large increment (2·7 cm) could be gained by dividing the left main bronchus and reimplanting it into the bronchus intermedius. Thus, removal of approximately one-half of the trachea and its reconstruction appeared to be possible (Fig. 1a). Initial studies were done with the patient's neck in a neutral position and so later proved to be a conservative statement. As our anatomical studies progressed it became clear that cervical flexion alone would permit devolvement of cervical trachea into the mediastinum so that extensive segments could be removed without having to resort to the additional hazard of reimplantation of the left main bronchus. This last manoeuvre has been reserved by me in clinical practice for carinal reconstruction (Grillo, Bendixen, and Gephart, 1963). The technique was first used clinically by Barclay, McSwan, and Welsh (1957). Experimental measurements of the tensions developed following reanastomosis after removal of successive centimetres of trachea indicated that these tensions would lie within what appeared to be experimentally safe levels. Cantrell and Folse (1961) observed that tracheal separation did not occur when the stress was under 1,700 g. In biological measurements such as this, there is every reason to accept observations from animal work as applicable to man.

In our early experiments we also proposed the possibility of devolving a segment of cervical trachea directly into the mediastinum, reconstruction to be done later in the neck. We (Grillo, Dignan, and Miura, 1966) then developed a method for construction of a full thickness skin tube supported by totally buried prosthetic material for either this eventuality or for the replacement of cervical trachea. However, after its use in a few clinical cases (Grillo, 1965) further anatomical investigation made the procedure obsolete for most situations. In further anatomical studies (Mulliken and Grillo, 1968) we sought to determine how much of the cervical and upper mediastinal trachea could be removed by an anterior approach and reconstruction effected. We utilized cervical flexion to a 'comfortable' position of not more than 35°, placed tension of 1,000 g on the trachea, and found that 4·5 cm might be removed. The addition of intrathoracic dissection added another 1·4 cm of potential length (Fig. 1b). In practice, we have been able to remove one-half or more of the trachea in a number of patients through the upper approach, utilizing only cervical flexion and such mobilization of the distal trachea as may be obtained from the anterior approach. Dedo and Fishman (1970) have described a technique for laryngeal devolvement

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which adds a further 1·5 cm of anterior mobility. This technique, in conjunction with anatomical methods described, usually obviates the need for intrathoracic entry in most lesions. It should not be used as a primary manoeuvre.

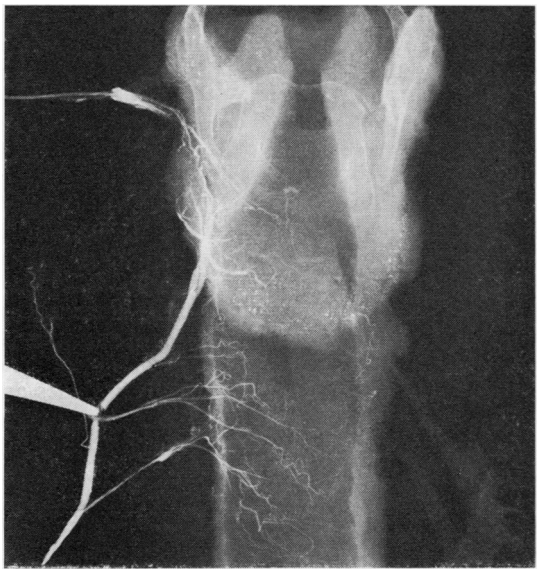

FIG. 2. *The blood supply of the upper trachea is principally from fine branches of the inferior thyroid artery. This barium sulphate arterial injection demonstrates the most common pattern.*

A critical factor in such mobilization techniques is preservation of the relatively tenuous tracheal blood supply. The lower trachea shares its supply with the oesophagus from the bronchial arteries. Precise information was not available regarding the supply of the upper trachea, and additional studies were necessary (Miura and Grillo, 1966). In general, the upper trachea is supplied by three branches from the inferior thyroid artery, and there is only the finest of collateral pathways between these branches (Fig. 2). Each branch supplies the trachea anteriorly and sends a division posteriorly to the oesophagus. The vessels are of small diameter. In mobilization of the trachea care is therefore taken to free the trachea anteriorly and posteriorly, leaving the lateral pedicles intact except for a short distance which is to be used in the anastomosis. The absence of a pedicled blood supply may be of considerable negative importance in the future if transplantation of organs becomes more widely practicable.

TABLE I

TRACHEAL RECONSTRUCTION (SINCE 1962)

	Cases	Deaths
Inflammatory		
Post-intubation	79	3
Post-traumatic	4	0
Idiopathic	1	0
Neoplastic		
Primary	11	1
Secondary	5	1
Total	100	5

CLINICAL APPLICATIONS

These anatomic methods of tracheal mobilization for reconstruction have been applied in the last decade to over 100 patients (Table I). Eighty-four of these patients suffered from benign inflammatory lesions. Of these, 79 were the consequence of intubation, usually for ventilatory support, four followed direct tracheal trauma, and one was of idiopathic origin. Eleven primary tracheal tumours and five secondary tumours were managed by excision and direct reconstruction. There were five deaths in this series of reconstructions. Two of these fatalities may have been preventable in the light of the experience gained over 10 years. This report is based on the lessons learned in the accomplishment of these 100 reconstructions. During the same period a marked number of patients with tracheal diseases were seen who did not undergo surgical treatment, either because their basic medical disease precluded surgical correction of the tracheal lesion or, in a small number, because of the extent of the tracheal disease itself. In addition, a number of patients underwent tracheal surgery other than end-to-end reconstruction. These include patients who required resection of the larynx as well as the trachea for neoplasm or underwent corrective procedures such as plastic closure of persistent tracheal stomas or surgical splinting for tracheomalacia.

My initial interest in extending the range of feasibility in surgery of the trachea was to improve the management of those rare primary tumours of the trachea which presented. A retrospective view of the Massachusetts General Hospital's experience with tracheal tumours suggested that many were of low malignancy. This was indicated by the long course of symptoms prior to their diagnosis and the fact that the tumours often appeared to be localized even at the time of the patient's death. Since death was so often due to airway obstruction, potential curability or at least lengthy palliation was suggested by these observations. Most primary tumours of the trachea, excluding carcinoma of the larynx extending into

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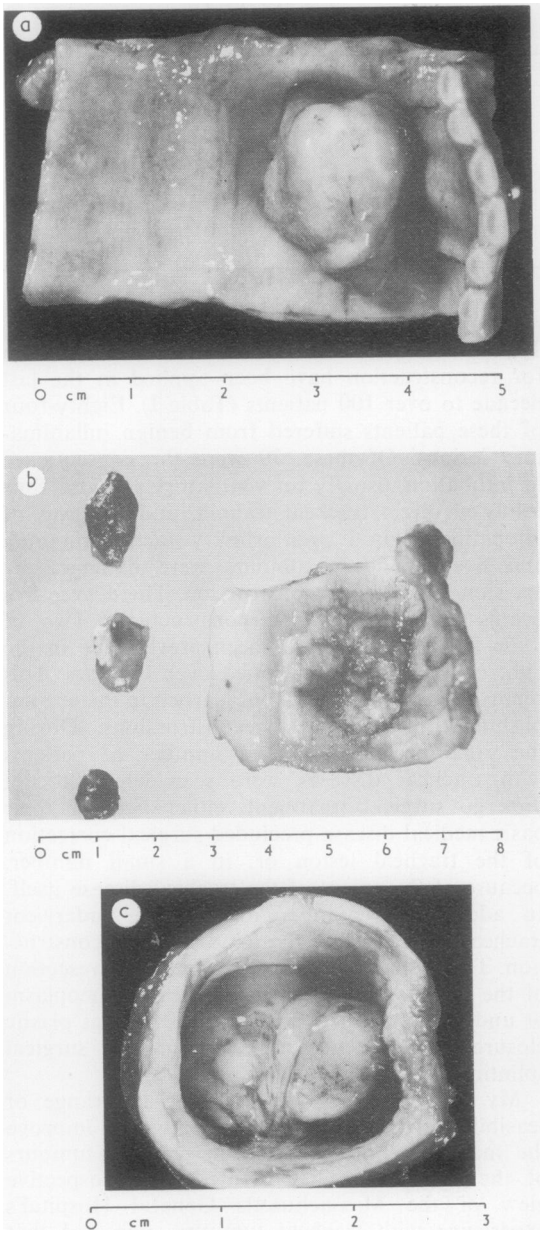

FIG. 3. *Primary tracheal neoplasms.* (a) *Squamous-cell carcinoma of trachea removed segmentally in* 1964 *by transthoracic route. Patient remains free of disease.* (b) *Squamous-cell carcinoma of upper trachea removed by an anterior approach. One node was positive and there was a paratracheal recurrence three years later.* (c) *Carcinoid adenoma obstructing lowermost trachea just above the carina.*

the trachea and those of the lung or oesophagus invading the trachea, are nonetheless epidermoid in type (Fig. 3). In approximately 30 years, 55 patients with tracheal tumours were seen at the Massachusetts General Hospital (Grillo, 1972b). Thirty of these were epidermoid carcinoma, 19 adenoid cystic carcinoma (formerly called cylindroma), and seven were of varied histology. It is interesting to note that in a similar period of time two other major institutions had a very similar experience. The Mayo Clinic (Houston, Payne, Harrison, and Olsen, 1969) reported 53 cases, of which 24 were epidermoid, 19 adenoid cystic, and 10 of mixed variety. Memorial Hospital for Cancer and Allied Diseases (Hajdu *et al.,* 1970) counted 41 tumours, of which 30 were epidermoid and seven adenoid cystic. Secondary tumours, which most frequently involve the trachea, in addition to the larynx, lung, and oesophagus, are those of the thyroid, other head and neck lesions, breast, and lymphoma. I believe that involvement of the trachea by secondary tumour usually indicates an advanced stage of an aggressive lesion which contraindicates extension of surgical procedures to include segments of trachea. On the other hand, there are a number of thyroid lesions which are better treated by concomitant or even late tracheal resection, if only to provide long-term palliation. I have included tracheal resection in some resections for carcinoma of the oesophagus where combined radiation therapy followed by surgery have been employed and where the only point of

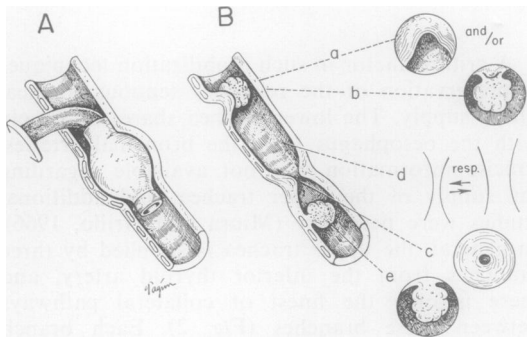

FIG. 4. *Diagram of principal lesions resulting from the use of cuffed tracheostomy tubes.* (A) *Conventional tracheostomy tube and high-pressure cuff* in situ. (B) *Lesions occur at several levels. At the stoma* (a) *anterolateral stenosis may occur, a granuloma* (b) *or a combination of both. At the cuff level* (c) *circumferential stenosis results. Varying degrees of malacia* (d) *may occur in the segment between the stomal and cuff levels. In children, particularly, granulomas may occur anteriorly where a tip of an uncuffed tube has caused ulceration of the tracheal wall* (e).

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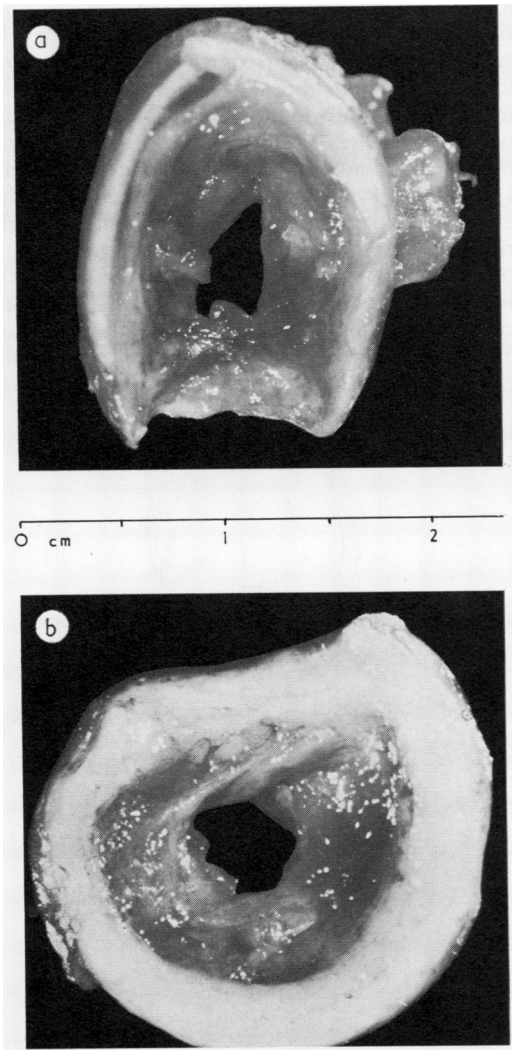

FIG. 5. *Stenotic lesions resulting from tracheostomy tubes.* (a) *Stomal stenosis. Anterolateral stricture results in a triangular shaped lumen with the apex anteriorly. In this patient the back wall of the trachea has sustained some damage and shows granulation tissue. Often the back wall is uninjured.* (b) *Cuff stenosis. The original damage was circumferential and the subsequent stenosis is therefore circumferential.*

apparent non-resectability of the lesion has been fixation to the trachea.

Coincident with our initial development of an anatomical approach to tracheal reconstruction, inflammatory lesions of the trachea secondary to successful ventilator therapy began to appear in increasing numbers. Lesions in this category confused the clinician. However, following intensive study of pathological specimens of the tracheas of patients who failed to survive ventilator therapy (Cooper and Grillo, 1969a; Florange, Muller, and Forster, 1965) and growing experience of surgical removal of these lesions (Grillo, 1969a) and, finally, after prospective analysis of tracheal damage by various types of intubation equipment (Andrews and Pearson, 1971) necrosis became indicted as the primary cause of a variety of lesions. The two principal areas of stenosis were those at the level of the stoma and at the level of the cuff (Fig. 4). Lesions at stomal level were anterolateral because the original damage had been anterolateral, and those at cuff level were circumferential consequent upon the presence of the circular cuff (Fig. 5). In addition, a variety of other lesions was noted, including tracheomalacia both at the cuff level and in the intervening segment between the stoma and the cuff, granulomas at stomal level and at the level of the tube tip, and full-thickness tracheal erosions creating tracheo-innominate fistulas and tracheo-oesophageal fistulas. These syndromes have now been precisely described (Geffin, Grillo, Cooper, and Pontoppidan, 1971; Grillo, 1970; Harley, 1971) and the diagnostic studies necessary for preoperative delineation have also been detailed (Macmillan, James, Stitik, and Grillo, 1971). In recent work we have reproduced these lesions experimentally (Cooper and Grillo, 1969b) and have devised low pressure cuffs which have the potential to eliminate cuff stenosis (Grillo, Cooper, Geffin, and Pontoppidan, 1971). The incidence of stomal strictures has also been reduced markedly by the use of light-weight connectors to avoid erosive leverage at the stomal level.

This report is not primarily concerned with this broad field of iatrogenic disease but the information is necessary background for the consideration of resectional treatment of these lesions. In our surgical patients treated by resection and anastomosis 81 had post-intubation stenoses of the trachea (Table II). Fifty-three of these lesions were at cuff level and 22 at stomal level. In five patients both lesions were present and in one it was not possible to tell what the origin had been. In addition, four patients with post-traumatic stenosis of the trachea and one with an idiopathic inflammatory stricture have been corrected surgically. Twenty-one of the patients had their original ventilatory treatment at the Massachusetts General Hospital. Sixty of these were referred from other institutions. Five patients had undergone previous resection elsewhere prior to referral but had suffered prompt recurrence of the stricture.

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TABLE II

TRACHEAL STENOSIS (SURGICAL CASES)

Post-intubation		81[1]
Stoma	22	
Cuff	53	
Both	5	
Uncertain	1	
Post-traumatic		4
Idiopathic		1

[1]MGH 21
Referred from other hospitals 60.

OPERATIVE APPROACH

The clinical common denominator of 'surgical' lesions of the trachea is most often airway obstruction whether from neoplasm or inflammation. The surgical problem is largely that of relief from obstruction and anatomical reconstruction of the airway so that it will provide normal function. Approach must obviously vary with the type and extent of pathology (Grillo, 1969b; 1972a). Detailed radiographs are obtained, except in emergency circumstances, to define the exact level of the lesion, its extent, and severity, as well as to obtain information about laryngeal function and the presence or absence of attendant malacia. We have not found contrast media to be particularly helpful. Any tracheostomy tube present is removed during these examinations to obtain maximum information about the lesion. A physician must always be present to reinsert such a tube since many patients will close their airways down rapidly and alarmingly during the course of the radiological examination. Bronchoscopy is usually deferred until the time of surgery to avoid the possibility of precipitating acute obstruction following endoscopy. Anaesthesia will not be described in detail here (Geffin *et al.*, 1969). It is designed to provide a slow, gentle induction without precipitating obstruction, to allow the patient to breathe spontaneously throughout the case, with assistance where necessary, so that he may be extubated promptly at the conclusion of the procedure and the airway evaluated prior to his leaving the operating room. If the degree of obstruction is not very great, an endotracheal tube is placed above the lesion, and through this adequate ventilation is obtained. In cases of severe stenosis (airway less than 4 mm in diameter), dilatation is performed just prior to exploration, using serial paediatric ventilating bronchoscopes, and a small endotracheal tube is passed through the stenosis.

Benign lesions of the upper trachea are approached initially through a collar incision with the addition of a vertical limb to divide the upper half of the sternum, if necessary (Fig. 6a). In particularly extensive lesions the patient is positioned on the table so that the incision may be continued into the right fourth interspace to provide access to the thoracic trachea. This type of incision is the only one which provides access to the entire trachea from cricoid to carina. Such positioning is advisable with a neoplastic lesion of the upper trachea. An existing stoma is handled variably. It is either included or not with the original collar incision. The incision, however, is always placed low and, if the stoma is not in the line of incision, it is separately excised if necessary. Occasionally, if a stricture lies far enough below an existing stoma, the opening may be left undisturbed. If, however, with the shift in position

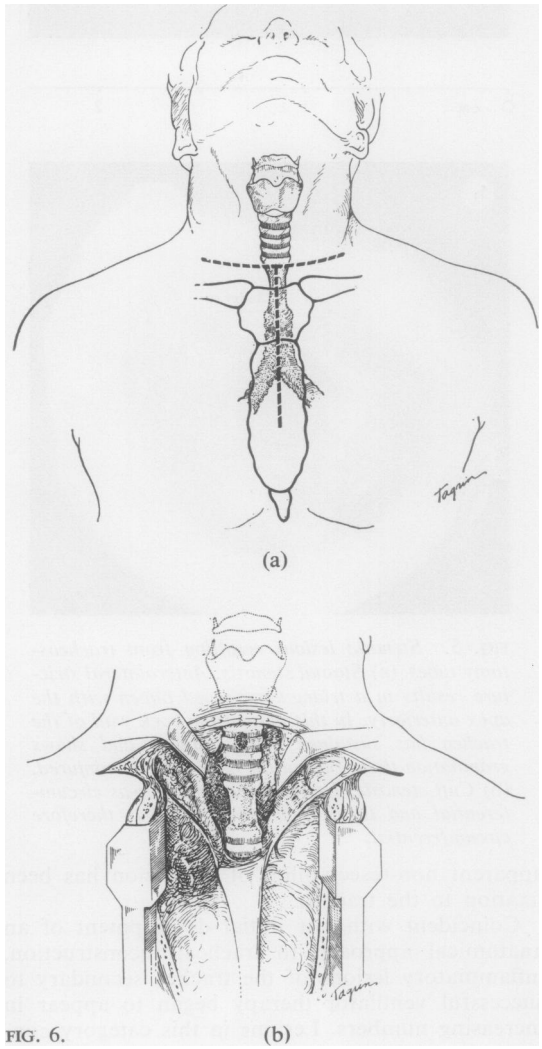

FIG. 6.

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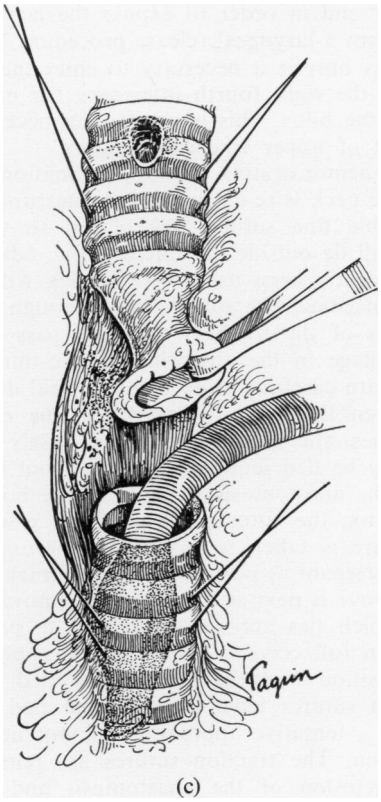

of the larynx and trachea the skin pulls too tightly on its stomal tether, the skin is detached and the stoma is exteriorized at an appropriate level. On rare occasions when such a stoma is devolved below the sternum in the course of reconstruction, it must be closed with a muscle flap. If, however, the stoma and its margins are too close to a circumferential cuff lesion, the resection must include both lesions so that the suture line will not lie in inflamed tissue. Dissection initially exposes the entire anterior surface of the trachea, in most cases, from cricoid cartilage to carina. When there is dense adherence of inflammatory tissue in benign strictures, dissection is kept hard on the trachea to avoid injury to the recurrent nerves. In particular, when dealing with a high subcricoid stenosis it is necessary to expose the inferior margin of the cricoid circumferentially without, however, dissecting up laterally far enough to injure the entry point of the recurrent nerves into the cricothyroid membrane. The approach for neoplasm is quite different, in that the operator attempts to take as much tracheal tissue in the region of the lesion as is possible and carefully dissects the nerves, isolating them initially at a distance from the lesion. Unfortunately, extensive dissection of all paratracheal tissue on both sides cannot be done for the full length of the trachea without running into the danger of devitalizing the proximal end of the distal segment of trachea which is to be left in place.

If there is insufficient space in which to work or in which to isolate the lesion because of the patient's particular anatomy, the upper sternum is divided and exposure is obtained to a point below the angle of Louis with a small chest

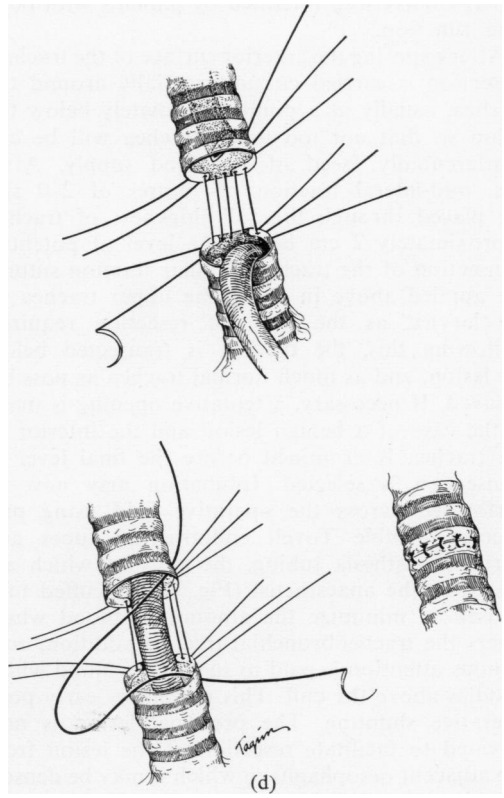

FIG. 6. *Upper tracheal reconstruction:* (a) *The collar incision permits exploration and, in many cases, reconstruction. Upper sternal division allows access to the mediastinum posterior to the great vessels.* (b) *The innominate vein is retracted since its division will not permit greater exposure. The pleura remains intact.* (c) *Following division of the trachea below the lesion, intubation is carried out across the operative field. The adherent inflammatory lesion is dissected from the oesophagus.* (d) *Details of suture technique. After the posterior two-thirds of the sutures have been placed, the tube above may be advanced distally or all sutures may be placed prior to removing the tube across the field.*

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retractor (Fig. 6b). It is not necessary to divide across the sternum into an interspace nor is it necessary to carry the incision down to the bottom of the sternum. The trachea quickly becomes a posterior mediastinal organ and the principal contribution of the sternal division is to allow working space at the thoracic inlet. Similarly, division of the innominate vein contributes nothing since the innominate artery very shortly presents itself lying anterior to the trachea. Care is taken not to enter the pleura, but if this occurs a chest tube should be placed or at least the pleura evacuated completely before closure. The anterior approach is particularly well tolerated by patients with poor lung function.

After exposing the anterior surface of the trachea, dissection is carried circumferentially around the trachea, usually at a point immediately below the lesion so that not too much trachea will be circumferentially freed of its blood supply. After this, mid-lateral traction of sutures of 2–0 silk are placed through the full thickness of trachea approximately 2 cm below the level of potential transection of the trachea. Similar traction sutures are applied above in either the upper trachea or the larynx, as the level of resection requires. Following this, the trachea is transected below the lesion, and as much normal trachea as possible is saved. If necessary, a tentative opening is made in the case of a benign lesion and the interior of the trachea is examined before the final level of transection is selected. Intubation may now be performed across the operative field using preselected flexible Tovell endotracheal tubes and sterile anaesthesia tubing, the ends of which are passed to the anaesthetist (Fig. 6c). A cuffed tube is used to minimize the amount of blood which enters the tracheobronchial tree. In addition, continuous attention is paid to suctioning blood which puddles above the cuff. This minimizes early postoperative shunting. The proximal lesion is now elevated to facilitate resection of the lesion from the adjacent oesophagus to which it may be densely adherent if inflammatory, or which it may have invaded if neoplastic. The proximal and distal trachea are also partially freed from the oesophagus posteriorly so that lateral pedicles are developed. The neck is then tentatively flexed and traction is made on either side on the upper and lower traction sutures to see if approximation may be easily obtained. If there appears to be an unsatisfactory amount of tension, additional blunt dissection at the carinal level may be accomplished. A second option, if the tension appears to be too great, is to raise the upper skin flap higher by extending and curving the collar incision upward at either end in order to expose the larynx, and to perform a laryngeal release procedure. On rare occasions only is it necessary to enter the thorax through the right fourth interspace for mobilization of the hilus. This is most often necessary in the case of upper tracheal tumours.

After demonstrating that approximation is possible, the neck is re-extended and interrupted nonabsorbable fine sutures are placed so that the knots will lie outside the trachea (Fig. 6d). I have most recently been using 4–0 Tevdek with small cutting needles. The sutures pass through the full thickness of the tracheal wall and pass through the cartilage in the anterolateral two-thirds. The sutures are carefully clipped to the field drapes so that when the neck is flexed and the exposure diminishes, the sutures will be precisely located and may be tied sequentially from front to back. When the anastomosis is made to the bottom of the larynx, the sutures are similarly placed and great care is taken to make the anastomosis as little discrepant as possible. The endotracheal tube from above is next advanced after removal of the tube which lies across the field. The patient is placed in full cervical flexion and propped up in that position and the sutures are tied serially. Traction sutures have usually been tied first to provide a tentative approximation but not intussusception. The traction sutures are removed at the conclusion of the anastomosis and its airtightness is determined under saline. There should be no leak. Postoperative tracheostomy tubes are avoided completely either above or below the anastomosis, and especially through it. On the rare occasion when ventilatory support was unexpectedly required after reconstruction, a small endotracheal tube has been left in place past the anastomotic line. Pressure of even a low pressure cuff against the anastomosis is highly undesirable and may lead to dehiscence and death. After wiring the sternum together and closing the incisions, with suction catheter wound drainage, a guardian stitch is placed just underneath the chin to the presternal skin to remind the patient that he must keep his neck flexed. After a week the suture is removed, but the patient is encouraged to keep his head in that position for at least another week to allow healing without tension on the forming anastomotic scar.

Approach to a lesion of the lower third of the trachea is usually made through a high posterolateral thoracotomy through the fourth interspace or bed of a resected fourth rib (Fig. 7a–c). I use this approach for tumours of the lower half of the trachea and carina. Only rarely should a benign stricture be approached through this route.

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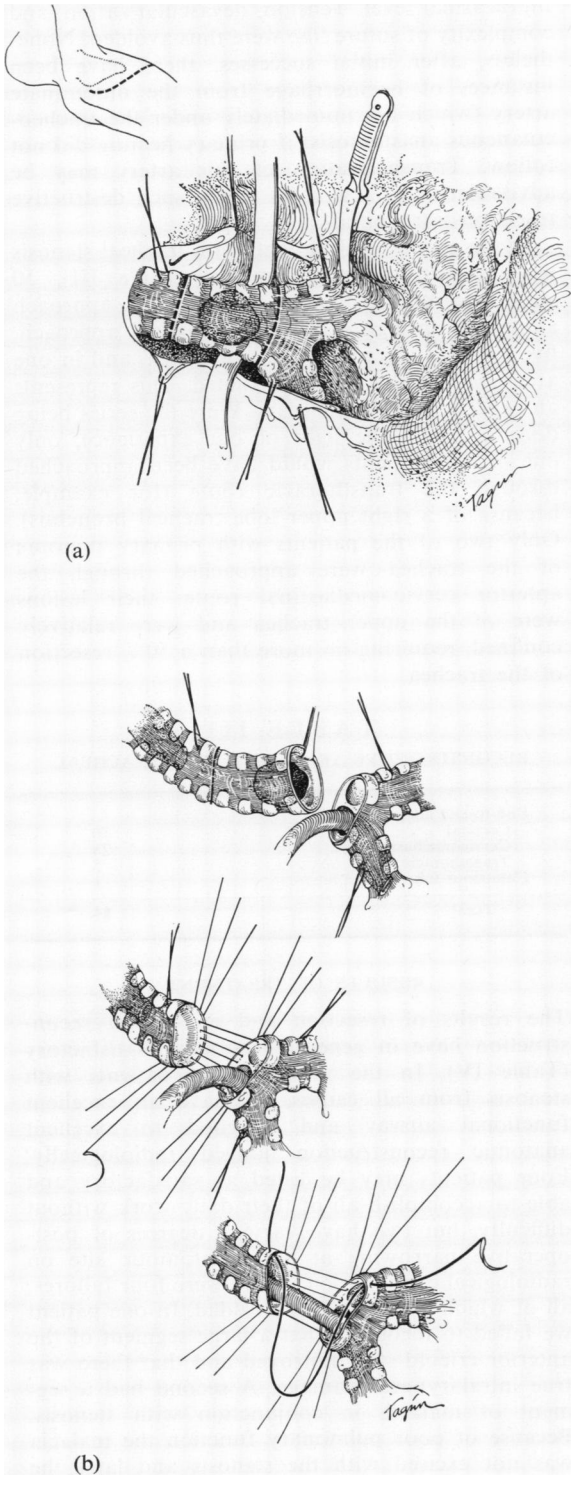

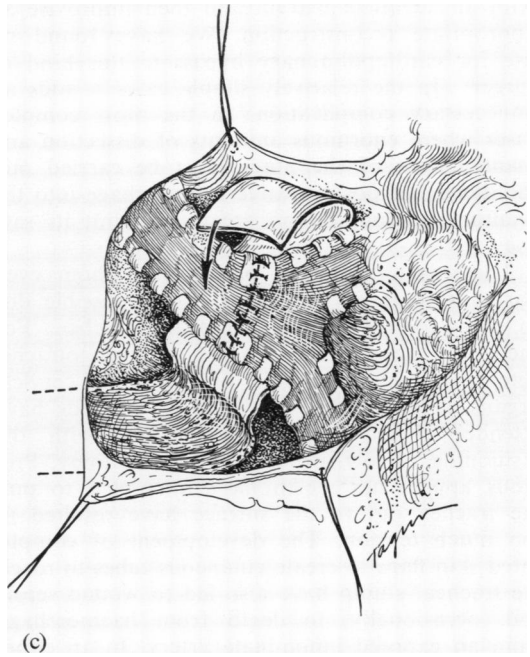

FIG. 7. *Reconstruction of the lower trachea:* (a) *Exposure is through a fourth interspace incision or the bed of the fourth rib. Full mobilization is accomplished as necessary. In the case of tumour, paratracheal nodal tissue is taken with the specimen. If the patient's arterial oxygen falls significantly, the pulmonary artery may temporarily be gently clamped while only the left lung is ventilated as in b.* (b) *The details of suturing are similar to that in the upper tracheal approach. The lateral traction sutures are useful in initial approximation but are later removed.* (c) *A pleural flap is placed over the anastomosis. Cervical flexion is utilized for approximation of the trachea in the transthoracic approach also.*

Although it may seem more attractive to the thoracic surgeon not versed in the anterior approach, it is much more traumatic to the patient and does not provide much advantage technically. Indeed it may make a simple resection difficult. The mobilization which is anticipated to be necessary is accomplished, if possible, before the division of the trachea. It is important for the anaesthetist to flex the neck in anatomic relation to the sternum to devolve as much cervical trachea as possible into the mediastinum to minimize the amount of dissection. In cases of unusually extensive tumour I also prepare the cervical region and anterior chest for upward extension or for approach into the neck for tracheal devolvement if necessary. Carinal reconstructions vary depending on the exact location of the tumour. In general, our approach has been to remove the tumour

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with an adequate margin and then improvise an appropriate reconstruction. We have found no use for cardiopulmonary bypass in this kind of surgery. In the relatively simple cases it adds an unnecessary complication. In the most complex cases where enormous amounts of dissection and manipulation of the lungs must be carried out, the danger of postoperative haemorrhage into the manipulated lung is too great to permit its safe use.

There is a group of patients in whom even partial salvage of the larynx is not possible due to extension of tumour from the trachea. For these we have done extirpative laryngotracheectomy, removing thyroid or additional cervical organs as required (Fig. 8). Many hazards have attended these destructive resections with the fashioning of low mediastinal tracheostomy. Previous approaches which have attempted to pull the trachea out to the surface have resulted in too much tension. The development of complicated skin flaps to create cutaneous tubes to reach the tracheal stump have also led to wound sepsis and, occasionally, to death from haemorrhage from an exposed innominate artery. In an effort to avoid these problems I proposed dropping an uncomplicated bipedicled anterior skin flap down to the stump of trachea after removing the anterior plaque of sternum, heads of clavicles, and the two upper rib cartilages (Grillo, 1966). In this flap with excellent blood supply a circular stoma was fashioned which could be sutured in the simplest possible line to the stump of trachea even at the supracarinal level. Tension, devascularization, and complexity of suture line were thus avoided. Nonetheless, after initial successes, there have been instances of haemorrhage from the innominate artery (which lies immediately under the tracheocutaneous anastomosis) if primary healing did not follow. Transplantation of this artery may be advisable in the few cases where such destructive resection is required.

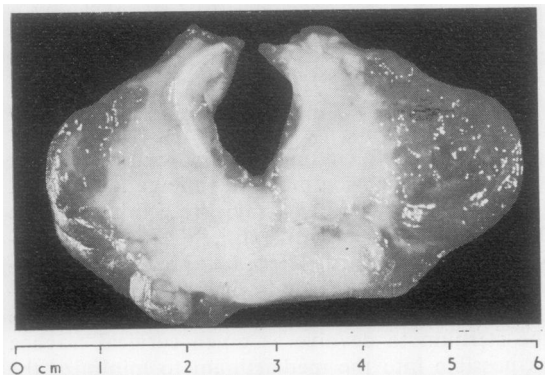

FIG. 8. *Adenoid cystic carcinoma invading trachea and thyroid gland. The larynx was also involved proximally. Laryngotracheectomy with removal of the overlying strap muscles and the anterior wall of the oesophagus was required. Despite a mediastinal tracheostomy the patient is functionally the same as the patient who has undergone laryngectomy alone.*

In the group of 84 patients with tracheal stenosis who underwent reconstruction (Table III), 50 were accomplished with the cervical approach alone, 28 through a cervicomediastinal approach, five through a transthoracic approach, and in one a cutaneous tube was constructed. This represents an experience of eight years. Were the series being done again in the light of our experience, only one or two patients would have been approached through the transthoracic route (for example, because of a right upper lobe tracheal bronchus). Only two of the patients with primary tumours of the trachea were approached through the anterior cervicomediastinal route; their lesions were of the upper trachea and were relatively confined, requiring no more than a 50% resection of the trachea.

TABLE III

RECONSTRUCTIVE TREATMENT FOR TRACHEAL STENOSIS

End-to-end anastomosis	
Cervical	50
Cervicomediastinal	28
Transthoracic	5
Cutaneous tube	1
Total	84

RESULTS OF TREATMENT

The results of resection and end-to-end reconstruction have in general been quite satisfactory (Table IV). In the group of 84 patients with stenosis from all causes, 73 have an excellent functional airway and a good to excellent anatomic reconstruction judged radiologically. Four patients may be listed as satisfactory and able to accomplish all of their daily work without difficulty, but two have varying degrees of postoperative narrowing at the anastomotic site on radiological examination. There were four failures, all of which could now be avoided. In one patient we failed to recognize that a large segment of the anterior cricoid was destroyed and that there was true intralaryngeal damage. A second had a segment of malacia in conjunction with stenosis. Because of poor pulmonary function the malacia was not excised with the stenosis and later the

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TABLE IV

TRACHEAL STENOSIS: RESULTS OF RESECTION

Good, excellent	73
Satisfactory	4
Poor, failures	4
Deaths	3
Total	84

patient required re-operation. A third patient had severe neurological damage and continued to have aspiration problems thereafter which probably were related more to the neurological problems than to the reconstruction which had been forced by the anatomic situation. Three deaths occurred in the operative series. One desperately ill intubated patient had a recurrent double stenosis following resection and insertion of a Marlex patch elsewhere. The tracheal lesion was too close to the carina to be managed by the endotracheal tube alone and reconstruction was attempted as the only alternative. She required postoperative ventilation with the then available high-pressure cuff and this led to separation of the anastomosis in four days. A later patient developed bilateral pneumonia, had to be ventilated for two weeks postoperatively, and then also suffered separation. A third patient was salvaged from an acute tracheo-innominate artery fistula, had his innominate artery resected, and underwent tracheal reconstruction. Unfortunately, cardiac arrest during the acute incident led to irreversible neurological damage.

In a group of 29 patients with primary tracheal tumours who were seen during the period of this study (1962–72) (Table V), approximately one-

TABLE V

PRIMARY NEOPLASMS OF TRACHEA: MANAGEMENT (1962-72)

	Cases	Living	Without Disease
Irradiation	10	2	0
Complex resection	8	3	1
Reconstruction	11	9	9
Total	29		

third (10 patients) had disease which was too extensive for resection to be considered at the time they were first seen. They received radiation or no treatment. At the present time only two are living and both have known metastatic disease in their lungs. Eight patients underwent varying types of complex resection. Three of these patients are living and only one is without disease. If we focus on the 11 patients who underwent resection with intent to cure and with primary reconstruction, nine patients are living and have been without disease for periods from six months to 10 years. These include both squamous-cell carcinoma and adenoid cystic carcinoma as well as other types of lesions. One patient died of recurrent disease two and one-half years following resection. There was one postoperative death which would now be avoidable. Postoperative irradiation has been added in one patient with a high adenoid cystic carcinoma of the trachea who required bevelling of the lower part of the larynx. Although frozen sections taken of the retained tissue at the time of resection showed no residual tumour, the margins were small enough so that irradiation was added. Many of these lesions are radiosensitive.

TABLE VI

TRACHEAL STENOSIS: COMPLICATIONS OF RESECTION (17 PATIENTS)

Suture line separation	2
Suture line granulations	8
Partial restenosis	5
Wound infection	3
Sternal separation	1
Innominate haemorrhage	1
Obstruction: adjacent malacia	1
cricoidal defect	1
Aspiration, persistent	1
Vocal cord dysfunction	2

In this series, 17 patients have had complications of varying severity (Table VI). Suture line separation occurred in two patients. In one it was minor posterior partial separation which eventually healed well. In the second it followed haemorrhage from the innominate artery, probably due to intraoperative injury three days following the original operation. This led to sepsis in the wound, exposure of the anastomosis, and tracheal leakage after one week. Ultimately this healed with a partial stricture which was functionally acceptable. Granulations have appeared at the site of the suture line in eight patients, and most of these have been managed by bronchoscopic removal of granulations and sutures. In five of these patients there was partial restricturing which was often difficult to separate from the formation of granulations. In each of these patients conservative management of the granulations with or without direct intra-anastomotic injection of triamcinolone has led to resolution and a satisfactory functional airway.

Specific pre-, intra-, and short-term postoperative antibiotics have been used dependent upon the specific sensitivity studies of sputum and stomal cultures. Wound sepsis, despite the presence of open stomas and bacteriologically resistant

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Staphylococcus aureus or *Pseudomonas aeruginosa* has been infrequent. In one young patient with normal tracheal flora antibiotics were not used and staphylococcal superficial wound infection occurred. In one patient with abdominal wound sepsis resected as an emergency the sternum became infected but not the trachea. In a third patient sternal separation seemed to precede local infection. Obstruction due to the failure to resect an adjacent malacia or to correct a cricoid defect has been mentioned. One patient who had persistent neurological difficulty following aspiration has been described. In two patients there was evidence of unilateral vocal cord dysfunction which may or may not have been present in one patient before the operation.

CONCLUSION

This experience demonstrates that we now have methods for the effective surgical treatment of the majority of tracheal lesions whether neoplastic or inflammatory. Lesions involving up to and more than 50% of the trachea may be effectively removed and in almost every case primary reconstruction may successfully be done. With this potential for treatment it is hoped that primary tumours, although rare, will be recognized more promptly and treated more adequately in the initial operation. We have seen no patient where reoperation on a tracheal carcinoma has led to a permanent cure. The evolution of our knowledge about iatrogenic lesions which follow respiratory therapy and the development of methods of prevention should reduce the incidence of these lesions. On the other hand, with the extension of effective respiratory care and increasing survival rates, stenoses will remain a problem.

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