Paparella: Volume III: Head and Neck

Section 2: Disorders of the Head and Neck

Part 5: The Larynx, Trachea, and Esophagus

Chapter 35: Disease of the Trachea and Bronchi

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Disorders of the trachea are relatively uncommon problems that rarely present in the routine practice of medicine. The subtle presentation of wheezing and a normal chest x-ray film may lead to patients being treated for many months or years for presumed adult-onset asthma before the diagnosis of an organic problem is made. It requires a high index of suspicion to diagnose tracheal disorders. Physicians need to be aware of the diagnostic radiologic procedures available and their limitations. Bronchoscopy plays a vital role in the diagnosis and management of tracheal disorders but may provoke life-threatening airway obstruction. Physicians treating patients with airway disorders must be aware of the indications and limitations of flexible bronchoscopy and rigid bronchoscopy to avoid potentially dangerous situations. Surgical management requires a firm understanding of the anatomy of the trachea and its surrounding structures and basic principles of tracheal surgery. Successful outcome requires judgement in selecting suitable patients and proper timing of surgery, determining the extent of surgery required, and knowing when additional procedures are needed to relieve excessive anastomotic tension. Postoperative care can be demanding because of the inability to raise secretions and postoperative edema in compromised airways. However, with successful management of tracheal disorders, the patient can expect a normal voice and airway, thereby avoiding life-long tracheostomy.

Surgical Anatomy of the Trachea

The trachea begins at the lower border of the cricoid cartilage at which point the uppermost tracheal cartilage is partly inset beneath the cricoid cartilage. It terminates at the point at which the lateral walls of the right and left main bronchi branch out from the lower trachea. The carinal spur is useful as a more definite landmark for the termination of the trachea, since it is clearly definable bronchoscopically and radiologically. The average adult human trachea measures 11 cm in length, varying roughly in proportion to the height of the patient. There are approximately two tracheal cartilaginous rings/centimeter of trachea, ranging from 18 to 22 rings. It must be remembered that the subglottic laryngeal airway measures 1.5 to 2.0 cm in length before the trachea is reached. Except for some cases of congenital stenosis with circumferential O rings of the trachea, the only completely circular cartilage in the upper airway is the cricoid cartilage with its broad posterior plate.

The potential for presentation of the trachea in the neck is of critical importance, not only from the standpoint of surgical access to the trachea but also from the standpoint of the ease of reconstruction following the resection of any length of the trachea. In the young, particularly when there is no obesity, hyperextension of the neck will deliver more than 50 per cent of the trachea into the neck. In the kyphotic aged person, particularly if obesity is present, the cricoid cartilage may be located at the level of the sternal notch, and even the

most vigorous hyperextension may fail to deliver any of the trachea into the neck. There are changes in the anatomic position of the trachea from an essentially subcutaneous one at the cricoid cartilage level to a prevertebral position at the carinal level. The course is thus obliquely caudal and dorsal with the patient standing in the erect position. In the kyphotic aged patient, lateral projection becomes increasingly horizontal. The slight extensibility and flexibility of the trachea in youth diminishes with increasing age. Calcification of the cartilage also occurs with age and with injury.

The blood supply of the trachea is of special importance in resection and reconstruction of the trachea. The upper part of the trachea is principally supplied by branches of the inferior thyroid artery. The lower portion of the trachea is supplied by branches of the bronchial artery with contributions from the subclavian, supreme intercostal, internal thoracic, and innominate arteries. These vessels supply branches anteriorly to the trachea and posteriorly to the esophagus, arriving at the trachea through lateral pedicles of tissue. The longitudinal anastomoses between these vessels are very fine. Transverse intercartilaginous arteries branch ultimately into a submucosal capillary network. Excessive division of the lateral tissues by circumferential dissection of the trachea can easily destroy this blood supply, leading to serious and sometimes disastrous complications.

The relationship of the recurrent nerves to the trachea and the esophagus and the point of entry of these nerves into the larynx have been well described and need not be repeated here. The relationship of the trachea to the thyroid gland is similarly well known. The isthmus crosses the trachea at the second and third cartilaginous rings. Intimate adherence of the medial portions of both lobes of the thyroid gland to the trachea is observed at this same level laterally. Because of this intimate adherence, it may become necessary to remove a lobe or sometimes the entire thyroid gland in surgically managing a tumor in the upper portion of the trachea. Posteriorly, the esophagus has a common interface through areolar tissue with the membranous tracheal wall. The blood supply of the esophagus and membranous tracheal wall are intimately linked. Anteriorly, the innominate artery courses obliquely across the anterior surface of the trachea, and below this the aorta arches backward across the left tracheobronchial angle. Here the left recurrent nerve arrives at its place in the tracheoesophageal groove.

The lymph nodes adjacent to the trachea are stations in the pathways from the lungs and mediastinum and are well known to the surgeon who treats thoracic neoplasms. The lymphatics of the trachea have been less well studied. Gross observations of the clinical behavior of tumor metastatic from the trachea have been made. Metastases appear to involve the most closely adjacent groups of tracheal lymph nodes. Metastases to the nodes on the side opposite that on which the primary lesion lies or metastases to the carina from lower tracheal tumors are common. More remote metastases to scalene nodes or to other cervical nodes have not often been seen.

Radiologic Evaluation

The primary diagnostic techniques for tracheal abnormalities are radiologic study and bronchoscopy. All too often a plain chest x-ray film is considered to be normal, but on closer inspection an abnormality of the tracheal air column is seen. Relatively simple radiologic techniques without the use of contrast media will delineate tracheal pathologic features when

suspected. The location of the lesion, its linear extent, extratracheal involvement, and, important to the surgeon, the amount of airway uninvolved by the process can be determined. In addition to standard views of the chest in various projections centered high enough to show tracheal detail, anteroposterior filtered tracheal views of the entire airway from the larynx to the carina are obtained. Lateral neck view, using soft tissue technique with the patient swallowing and the neck hyperextended to bring the trachea up above the clavicles, is useful to define pathologic conditions in the upper trachea. Fluoroscopy not only demonstrates functional asymmetry of the vocal cords, if present, but also may give additional information about the extent of the lesion and collapse of the airway if malacia is present. Spot films usually are all that are required. In some cases, polytomography (anteroposterior and lateral views) gives additional detail, particularly of mediastinal involvement. Barium esophagography is useful to define esophageal involvement by extrinsic compression or invasion. Computed tomography offers little over standard radiologic techniques except to define an extratracheal component. The exact role of magnetic resonance imaging has yet to be defined. The ability, however, to use sagittal and coronal views has been helpful in certain cases and may give more accurate detail than standard radiographic techniques.

Airway Management

Crucial to the management of all problems of the trachea is the ability to control the airway. Tracheal tumors and postintubation stenosis may present as emergency airway problems. Endotracheal intubation may be impossible and even dangerous by leading to complete airway obstruction, especially in patients with high tracheal lesions. Simple maneuvers to elevate the head of the patient, administration of cool mist and oxygen, and careful sedation may allow control of the airway to be accomplished in a semielective manner. Control of the airway in this setting is best accomplished in the operating room in which an assortment of rigid bronchoscopes, dilators, biopsy forceps, and even instruments to perform emergency tracheostomy are available. Anesthesia, as in elective tracheal operation, is best accomplished by inhalation technique. This requires patience on the part of the anesthesiologist and surgeon to allow the patient to become adequately anesthetized. Induction of anesthesia deep enough to allow rigid bronchoscopy may take as long as 20 minutes. Paralyzing agents should not be used, thus avoiding the lethal combination of airway obstruction and an apneic patient.

The initial evaluation should be performed with a rigid bronchoscope carefully inserted through the vocal cords stopping just proximal to the level of obstruction. Rigid telescopes can be used to assess the obstruction. Most tumors, even those causing nearly total obstruction, will allow a rigid bronchoscope to be passed beyond. Once the status of the distal airway has been assessed, the tumor can be partially removed with biopsy forceps to determine its consistency and vascularity. For most tumors, the tip of the rigid bronchoscope can be used to "core out" most of the tumor. Tumor can then be grasped with biopsy forceps and removed. If bleeding ensues, the bronchoscope may be passed into the distal airway for ventilation. The bronchoscope serves to tamponade the bleeding. Direct application of epinephrine-soaked pledgets helps to control any persistent oozing. Very rarely have we had to resort to direct cautery (with insulated electrodes) in these situations. The use of the laser has become popular in the management of malignant structures, but we find it time-consuming, costly, and rarely advantageous when compared with the preceding technique.

Postintubation stenosis poses a slightly different problem in airway control. Attempting to pass a large rigid bronchoscope beyond a tough, inflammatory stricture may be impossible, result in tracheal rupture, or cause total airway obstruction secondary to bleeding or edema. For these strictures, Jackson dilators passed through the rigid bronchoscope under direct vision and an assortment of graduated rigid bronchoscopes can be used to effectively dilate postintubation stenoses. By gradually dilating these tight, rigid strictures, the risk of perforation and bleeding is minimized. Racemic epinephrine and steroids are often used in the first 24 to 48 hours to minimize postdilatation edema.

It is important to understand that dilatation or endotracheal removal of malignant and inflammatory structures, whether mechanically or by laser, is only a temporary measure. In the case of inflammatory stricture, restenosis will usually develop within days to weeks. The use of these techniques in emergent situations will allow for more thorough evaluation of the patient and for surgery to be performed electively. Many patients are taking high doses of steroids at the time of presentation, having been treated for refractory asthma. By establishing an airway, the steroids may be tapered and discontinued and surgery performed without the threat of impaired healing. Dilatations may have to be performed repeatedly during the interval of steroid tapering.

The preceding maneuvers are also sometimes used at the time of elective surgery if the patient has presented with a stable airway. This allows assessment of the distal airway, placement of an endotracheal tube, and provision of an adequate lumen to prevent carbon dioxide accumulation early in the procedure. At the time of tracheal resection, this tube can be pulled back or removed and a sterile cuffed endotracheal tube (Tovell tube) inserted into the distal airway. Sterile connecting tubing is passed to the anesthesiologist and is connected to allow ventilation of the patient. It can be removed whenever necessary for suctioning or placement of sutures. At the conclusion of the operation, the original endotracheal tube is advanced into the distal airway and the sutures are tied. The patient should be breathing spontaneously at the end of the procedure so that extubation can be performed in the operating room. High-frequency ventilation has been used with equal success intraoperatively, but we have been quite satisfied with the techniques described. High-frequency ventilation is especially useful in certain complex carinal reconstructions.

Tracheostomy may be necessary in certain individuals as the only way to secure control of the airway. One should always remember to place the tracheostomy through the most damaged portion of the trachea, thereby preserving the maximal amount of normal trachea for subsequent reconstruction. If tracheostomy is contemplated at the completion of tracheal resection, it should be performed at least two rings away from the anastomosis, and the anastomosis should be protected with the thyroid gland or strap muscles to avoid contamination of the suture line. This will lessen the likelihood of subsequent dehiscence or stenosis. A tracheostomy tube should *never* be placed through the anastomosis.

Release Maneuvers

Most tracheal operations can be performed without release maneuvers. Of 327 tracheal resections performed for postintubation stenosis, laryngeal release was required in only 27 (8.3 per cent). Of 119 tracheal resections performed for primary and secondary tumors of the trachea, laryngeal release was required in only 18 (15 per cent).

Careful assessment of each patient's condition is necessary to establish the safe limits of the extent of tracheal resection. This will aid in planning the incision and positioning the patient. Previous operations (including mediastinoscopy), disease process, extent of the lesion, age, and body habitus are important factors in deciding which patients are likely to require a release maneuver. The pathologic location is also important in determining which release procedures will be of benefit. Certain maneuvers are more effective for achieving additional length when performed for disease in the cervical trachea, whereas others are more effective for the intrathoracic trachea. A release maneuver is primarily performed to prevent unnecessary tension on the anastomosis and to avoid the need for extensive mobilization of the trachea, which might jeopardize the lateral blood supply.

Cervical Tracheal Operations

The simplest maneuver to gain added length after tracheal resection is flexion of the neck and mobilization of the anterior, and to a lesser extent the posterior, surface of the trachea, avoiding the lateral blood supply to the trachea. Flexion of the neck between 15 and 35 degrees may yield up to 4.5 cm of additional length or the equivalent of seven tracheal rings. Flexion beyond this may achieve up to 1.5 cm of added length. When these simple maneuvers fail to give sufficient length, a Montgomery suprahyoid laryngeal release is performed, generally before the anastomosis is completed. When the maneuver is performed, an additional 1.5 cm of length can be obtained.

If additional length is still needed, a partial median sternotomy with extension into the right hemithorax or right thoracotomy will allow access to the right hilum and inferior pulmonary ligament. Mobilization in such a fashion may provide an additional 1.5 cm. Dissection of the pulmonary artery and vein intrapericardially will add an additional 1.0 cm. Division and reimplantation of the left main bronchus is rarely if ever necessary, but it may give an extra 2.5 cm. If these procedures fail to allow a safe anastomosis, a T-tube can be placed between the proximal and distal ends of the trachea and local muscle flaps rotated in to create a muscle tube, which will establish an airway.

Intrathoracic Tracheal and Carinal Operations

Flexion of the head and mobilization of the anterior and posterior surfaces of the trachea are also important for these lesions. Even in the intrathoracic position, these procedures will allow the trachea to migrate into the thorax. Laryngeal release for intrathoracic tracheal problems has not been helpful in gaining additional length. The maneuvers described for cervical tracheal anastomosis are helpful in achieving length in the thorax.

Mobilization of the right hilum and inferior pulmonary ligament should be done first. A U-shaped incision in the pericardium inferior to the inferior pulmonary vein will allow the hilar structures and bronchus to advance. Additional length may be obtained by completely incising the pericardium around the hilar vessels. We have tried to preserve a posteriorly based pedicle of tissue that includes a bronchial artery and some lymphatics whenever we have completely incised the pericardium in such a fashion. If still further length is required, two possibilities exist: dividing the left mainstem bronchus and reimplanting it into the bronchus intermedius or, if division of the trachea has been close to the carina, the proximal

trachea can be divided in the neck and advanced as a "sleeve" of trachea to anastomose to the carina. The two proximal ends should be brought out as a double-barrelled stoma. Such extreme measures should be used only when no other alternatives exist. Special mention should be made of those resections involving the carina. Attempting to "recreate" a carina by joining the left and right mainstem bronchus will not allow much, if any, advancement. Length can be obtained only by advancement of the trachea from above.

Midtracheal Operations

Lesions located in the midtrachea can benefit from all of the release maneuvers described.

Laryngeal release may predispose the patient to aspiration, and there will be more difficulty with liquids than with solid food. In time, this resolves in virtually every patient. We have seen little of this problem since adopting the Montgomery technique of suprahyoid release.

Tracheal Tumors

Occurrence and Clinical Presentation

Primary tracheal tumors are rare. It is important to be aware of their behavior, however, since their rarity makes them easily overlooked diagnostically. About two thirds of the primary tracheal tumors are of two histologic types - squamous cell carcinoma and adenoid cystic carcinoma, formerly called cylindroma. These two types occur in about the same numbers. The remaining one third of the tumors are widely distributed in a heterogenous group of tumors, malignant or benign. A variety of secondary tumors involves the trachea. They include carcinomas of the larynx, thyroid, lung, and esophagus. Rarely, tumors may metastasize to the submucosa of the trachea or to the mediastinum, with secondary invasion of the trachea. Thus, carcinoma of the breast and mediastinal lymphoma may invade the trachea. Incompletely removed neoplasms of the main bronchus, such as carcinoid tumors, also may invade the carina.

Tracheal tumors may present insidiously. Their most common symptoms and signs are cough (37 per cent), hemoptysis (41 per cent), and the signs of progressive airway obstruction, including shortness of breath on exertion (54 per cent), wheezing and stridor (35 per cent), and less commonly, dysphagia or hoarseness (7 per cent). Wheezing in particular may cause diagnostic error. It is not commonly appreciated that this may be a predominant symptom of a tracheal tumor for a prolonged period. Standard chest roentgenograms usually show clear lung fields, and, on this basis, the physician assumes that no organic mass lesion is present. Patients are often treated for adult-onset asthma. Hemoptysis, also, may not be pursued aggressively in the face of an apparently normal chest x-ray field. Another presentation is with unilateral or bilateral recurrent attacks of pneumonitis, which may respond to antibiotic treatment but then recur.

Signs and symptoms may vary with the type of tumor. Hemoptysis is prominent in patients with squamous cell carcinoma and usually leads to earlier diagnosis. The presence of hoarseness as an early symptom may signify advanced disease. Adenoid cystic carcinoma

more often presents with wheezing or stridor as a predominant symptom, leading to delay in diagnosis. Only a little more than a quarter of these patients have hemoptysis early in their course. Dyspnea, however, may be a prominent symptom. The mean duration of symptoms prior to diagnosis in patients with squamous cell carcinoma of the trachea was only 4 months, but with adenoid cystic carcinoma, the mean duration was 18 months. In some benign tumors or low-grade malignant tumors of the trachea, the mean duration for carriage of an incorrect diagnosis was up to 4 years. The mean duration of symptoms of miscellaneous malignant tumors was 11 months.

Diagnosis

Endoscopy is frequently the means by which a tracheal tumor is discovered in a patient who is being studied for hemoptysis of unknown origin. A high tracheal tumor may be overlooked if a flexible endoscope is passed through a previously introduced endotracheal tube or if the endoscopist is not in the habit of looking carefully at the proximal portion of the trachea. The same hazard faces the endoscopist who uses a rigid bronchoscope. When a lesion is not obstructing or is of such radiologic extent that a surgical approach seems indicated in any case, endoscopy is deferred to the time of potential resection. However, when the surgical team is not trained or experienced in the management of tracheal tumors, preliminary bronchoscopy may be done to visualize the tumor. Biopsy must be done with good judgment so that an excessively vascular tumor will not be stimulated to brisk hemorrhage. Hemorrhage in the case of a very vascular carcinoid tumor, for example, may be life-endangering or precipitate the need for emergency surgical treatment. Biopsy of the rare hemangiomatous lesion of the trachea can be lethal. If preliminary biopsy is not done prior to the time of projected surgical approach, accurate frozen section facilities must be available. Particularly in adenoid cystic carcinoma, which is notorious for submucosal spread, biopsies at a distance from the tumor may be necessary to determine resectability. Endoscopic examination of the esophagus also has a place with extensive tumors.

Pathologic Features

In a series of 198 patients with primary tumors of the trachea treated at the Massachusetts General Hospital between 1962 and 1989, 70 had squamous cell carcinoma, and the rest were a mixed group. The mean age of the patients with squamous cell carcinoma was 58 years, in contrast with 43 years for those with adenoid cystic carcinoma. In the latter group, the age spread was much wider.

Squamous cell carcinoma may be either exophytic or ulcerative. It may also be multiple and scattered over a considerable distance in the trachea. The tumor metastasizes to the regional lymph nodes and, in its more aggressive and late forms, invades mediastinal structures. In general, its progress appears to be relatively rapid in comparison with adenoid cystic carcinoma. A number of these patients have returned with a second squamous cell carcinoma of the lung or oropharynx.

Adenoid cystic carcinoma often has a very prolonged course of clinical symptoms, sometimes extending for years. Following treatment, it may be many years before a recurrence is noted. Adenoid cystic carcinoma may extend over long distances submucosally in the airways and also perineurally. It spreads to regional lymph nodes, although less

characteristically than does squamous cell carcinoma. Although it may invade the thyroid gland or the muscular coats of the esophagus by contiguity, adenoid cystic carcinoma that has not been surgically interfered with frequently displaces the mediastinal structures before actually invading them. Metastases to the lungs are not uncommon. They may grow very slowly over a period of many years and remain asymptomatic until they are huge. Metastases to bone and other organs occur.

Among the other *malignant lesions* seen in the trachea in this series of 198 patients were ten carcinoid tumors clearly originating in the trachea and not in the main bronchi, two spindle cell sarcomas, one adenocarcinoma, one adenosquamous carcinoma, four mucoepidermoid carcinomas, one chondrosarcoma, one carcinosarcoma, one small cell carcinoma, one primary melanoma, and one malignant fibrous histiocytoma.

The *benign lesions* consisted of neurofibroma, chondroma, chondroblastoma, leiomyoma, granular cell tumor, paragangliomas, hemangioma, pleomorphic adenoma. A number of patients were seen with several varieties of squamous papillomas. They included solitary squamous papillomas and papillomatosis, either widespread or of a confluent, often verrucous, type.

Secondary tumors involving the trachea have been noted in 81 patients. Esophageal carcinoma (ten patients), in particular, may be a cause of a fistula between the esophagus and the trachea or the left main bronchus. Similarly, an occasional aggressive carcinoma of the lung (29 patients) will result in a fistula, as both trachea and esophagus are involved from the mediastinum. It is probable that some of the oat cell carcinomas of the trachea that have been reported may have arisen in the lung and invaded the trachea.

Both papillary and follicular carcinoma of the thyroid gland and mixed varieties of the two carcinomas may invade the trachea primarily (38 patients), usually at the level of the isthmus. Thus, a patient initially presenting with hemoptysis may have carcinoma of the thyroid gland. Invasion of the trachea by thyroid carcinoma is best managed by resection with airway reconstruction. Localized extension of tumor may also require partial esophageal resection or radical resection including laryngectomy with mediastinal tracheostomy. More commonly, invasion is seen following prior thyroidectomy for carcinoma in which the surgeon was aware that he or she was shawing off the tumor from the trachea. In such cases, concurrent or early resection of the involved trachea would be considered.

Treatment

When the primary tracheal tumor is circumscribed, has not metastasized remotely, has not involved an excessive length of trachea, and has not invaded the mediastinum deeply, the best primary treatment is *resection with primary reconstruction* of the airway. Considerable experience is required to make the judgment of whether a tumor can be safely resected with sufficient tissue to provide a potentially curative margin and yet primarily reconstruct the airway. This is even more crucial when the tumor lies in the lower portion of the trachea or at the carinal level and when an airway has to be finally reconstructed at the time of the original surgery. Particularly difficult are patients with adenoid cystic carcinoma in whom an apparently clear resection may show, on frozen sections, microscopic tumor at the resection margins.

Both squamous cell carcinoma and adenoid cystic carcinoma of the trachea are usually responsive to *irradiation,* with varying long-term results. In general, curative irradiation will have about the same effects on squamous cell carcinoma as on carcinoma of the lung, that is, variable palliation extending, in general, not much longer than a couple of years and with ultimate recurrence. Adenoid cystic carcinoma may respond for even longer periods than that, for 3 to 7 years. These are very general statements. Although some investigators have advised preoperative irradiation, particularly in the management of adenoid cystic carcinoma, many prefer to reserve radiation for the postoperative phase, applying it particularly when there are involved lymph nodes, when there is microscopic tumor in lymphatics or nerve sheaths or at the resection margin, and when the margins appear to be too small. The same approach has been applied to other primary tracheal tumors.

The total world experience in the management of tracheal tumors is small enough that it is difficult to be categoric about optimal treatment. Results to date, however, strongly indicate that the approach just described is soundly based. By comparing patients with squamous cell carcinoma and adenoid cystic carcinoma treated by the vigorous protocol described with those patients treated prior to the institution of extirpational surgery with modern techniques of resection and reconstruction, it can be seen that remarkable progress has been achieved. As might be expected, excellent long-term results have been obtained with those benign tumors amenable to excision and also with the miscellaneous group of low-grade malignant tumors of other varieties. In general, cure has rarely been achieved when recurrent tumors have been resected, except for local recurrences of carcinoid tumors at the carina. Long-term palliation, however, has been achieved with the less malignant thyroid neoplasms invading the trachea. In a number of these patients, the ultimate cause of death was the appearance of remote metastases in bones or elsewhere in the body rather than at the local site for relief of airway obstruction.

In some cases in which the larynx is extensively involved by tumor, it is not possible to salvage the organ, and laryngotracheal resection must be done. Conversely, when only a portion of the larynx is involved, it is possible, by individually designed procedures to salvage a functioning larynx with reconstruction of the airway.

Of the total number of tumors seen, approximately one third are clearly incurable when first seen and are not amenable to surgical resection at all. Two thirds are amenable to primary resection with reconstruction of the airway. In a rare patient with a very extensive tumor that involves a large proportion of the trachea but has not spread distantly or invaded the mediastinum, resection with reconstruction either by staged procedures or by the use of a prosthetic device may be justified. Usually, such patients have adenoid cystic carcinoma, since squamous cell carcinomas extending over a long length of trachea have often also invaded the mediastinum beyond the point of possible extirpation.

When extirpation is not possible either because of the extent of the tumor or because of the age or medical condition of the patient, primary irradiation appears to be a reasonable palliative modality.

In some patients with adenoid cystic carcinoma obstructing the trachea, it is probably worthwhile to do a palliative resection if reconstruction can be done with safety, despite the presence of pulmonary metastases, because of the prolonged course these patients follow.

In a trachea acutely obstructed by tumor that cannot be removed by a primary resection because of the extent of the tumor, immediate palliation may be achieved by removing the bulk of obstructing tumor endotracheally, as described earlier. This allows the opportunity for the institution of radiotherapy. Removal can be done either with morcellating biopsy forceps (the older technique) or by the application of newer physical modalities, most usefully that of the laser for destruction of endobronchial tumor. The laser is not applicable, however, as a primary method of treatment of most tracheal tumors, since it cannot destroy the base of the tumor without destroying the tracheal wall. It does have application, however, for multiple squamous papillomas of the trachea.

Ultimately, as a tumor recurs and lasering is no longer possible because of the extension of the tumor through the tracheal wall, additional palliation to prevent strangulation can sometimes be given by the judicious insertion of a silicone rubber T-tube that will span the airway and allow the patient to breathe despite the presence of the tumor. Obviously, this cannot be applied if such a tumor extends below the carina.

Our largest experience with tracheal resection for secondary tumors invading the trachea has been with thyroid neoplasms. Twenty-two patients (12 with papillary, 3 with follicular, 4 with mixed papillary and follicular, and 3 with undifferentiated carcinoma) have undergone resection - 16 patients with airway reconstruction and 6 patients with cervicomediastinal en bloc resection with mediastinal tracheostomy. Eleven patients had prior thyroidectomy. Ten of those having airway restitution required cylindric tracheal resection, 5 patients had resection of the trachea with a portion of the larynx, and 1 patient had a wedge resection. Three patients who had laryngotracheal resection also needed esophagectomy. Colon reconstruction was used.

Fifteen of the 16 patients having airway reconstruction had good surgical results with speech preservation. One died of complications caused by prior irradiation. One of six patients who underwent radical resection died postoperatively. Six of the 20 survivors died of recurrence in 1.66 to 9 years, and two others died of other diseases. Three patients who had known pulmonary metastases at the time of palliative operation are alive between 2 and 2.66 years postoperatively, and a fourth patient who had pulmonary metastases is alive 6.17 years later. Eight patients are alive without disease from 6 months to 8.75 years later. Only two patients had airway recurrence.

When technically feasible, resection and primary reconstruction of the trachea that has been invaded by carcinoma of the thyroid gland should be done when no extensive metastases are present. It offers prolonged palliation, avoidance of suffocation from bleeding and obstruction, and an opportunity for cure. In carefully selected patients with massive regional involvement, radical excision with laryngectomy and esophagectomy is also appropriate.

Surgical Resection of Tracheal Tumors

The management of tracheal tumors by surgical resection represents only one general category of problems for which resection and reconstruction of the trachea are required. The problems of managing tumors are often more difficult because of unpredictability of the extent of a lesion.

Tracheal resection in general was limited for many years by the belief that only 2 cm of the trachea - about four rings - could be removed and the ends dependably anastomosed by primary suture. The application of various techniques of anatomic mobilization has permitted the resection of approximately one half of the trachea with primary reconstruction on a dependable and predictable basis. Simple cervical flexion, which delivers the cervical trachea into the mediastinum, has been the most useful single maneuver for extending the resection of the trachea with primary repair. In a young person who is not obese and who has reasonably supple tissues, more than one half of the trachea may frequently be removed with primary reconstruction. With increasing age, kyphosis, obesity, and pathologic changes, the portion of the trachea that can be so removed and reconstructed becomes much less. If additional length is necessary, the measures mentioned previously in the section on tracheal release maneuvers may be necessary.

In all dissections of the trachea, a critical matter is the careful preservation of the lateral segmental blood supply, the gentle and precise handling of all tissues, and precision of anastomosis.

Tumors of the upper portion of the trachea are generally approached through a collar incision with, if necessary, a vertical extension through the upper sternum. Since the extent of some tumors is not fully predictable even after preoperative x-ray films and bronchoscopy, it is generally wise to position a patient so that extension of incisions may be made, if necessary. The incisions just described may be extended by carrying the sternal division down further and then angling it into the right fourth interspace to add a thoracotomy to the cervical and mediastinal exposure. Tumors of the lower portion of the trachea are approached most easily thorough a posterolateral thoracotomy. Laryngeal release adds no additional length for distal tracheal resection. Flexing the neck and freeing the anterior pretracheal plane have been the most helpful maneuvers to gain additional length, as has intrapericardial release of the pulmonary vessels.

When a tumor involves the carina, various reconstructive techniques are used. Unless the tumor is very small, it is rarely adaptable to reconstruction by approximating the right and left main bronchus to form a new carina and then attaching it to the trachea. Such suturing anchors the carina very low in the mediastinum, and if more trachea has been excised, approximation is not possible. More commonly, either the right or left main bronchus is sutured to the trachea, and a lateral anastomosis of the other bronchus to the lower portion of the tracheal wall above the initial anastomosis is performed.

If a recurrent laryngeal nerve is involved by tumor, the nerve is sacrificed. The nerves are usually identified and carefully saved when possible. Local paratracheal lymph nodes are excised with the specimen when possible. Extensive lymph node dissection cannot be done for fear of destroying the blood supply to the residual portion of the trachea. In tumors high in the trachea, partial removal of the lower part of the larynx may have to be done. Individually designed procedures are necessary to preserve a functional larynx. Sometimes, portions of the esophagus and other adjacent structures must be resected.

Resection is usually controlled with frozen sections to be certain that the margins are clear. Adenoid cystic carcinoma, in particular, may extend such distances that total resection of all microscopic disease is not possible, and postoperative irradiation must be used.

Tracheal Stenosis

Strictures of the trachea may result from a number of different general causes. Congenital stenoses are rare. Post-traumatic strictures occur, particularly when there has been tracheal separation. The most common type of stenosis is still the result of iatrogenic disease, namely, that which results from intubation, usually for ventilatory support. Infections occasionally cause stenosis of the trachea, including tuberculosis, histoplasmosis, diphtheria, and rhinoscleroma. A miscellaneous group of diseases also causes strictures or at least tracheal obstruction. They include sarcoid, relapsing polychondritis, and amyloid disease restricted to the airway, tracheopathia osteoplastica, and a small group of truly idiopathic stenoses without history of previous insult or infection. We will focus on the most common form of tracheal stenosis: postintubation stenosis.

Postintubation Tracheal Stenosis

The two principal strictures that follow intubation are strictures at the level of the tracheostomy stomas and those at the level of the tracheostomy cuff. The upper strictures usually occur in patients who are being maintained on ventilators. It may be assumed from indirect evidence that the cause is cicatricial healing of the stomal opening that had eroded the anterior and lateral walls of the trachea at the site of the stoma. Although this injury can be surgically abetted and although invasive infection may also play a role, it appears to be due most often to leverage against the stoma by the tracheostomy tube because of improperly suspended heavy equipment. It is apt to occur in a patient receiving prolonged support through a tracheostomy tube. Since the original defect was anterior and lateral, the cicatricial stenosis occurs here, producing an A-shaped stenosis when viewed through the bronchoscope with the patient supine.

In contrast, a high-pressure cuff or a low-pressure cuff used in a high-pressure range by overinflation will produce circumferential pressure injury in the trachea. As healing occurs, stenosis results in a circumferential fashion. If erosion has been deep and has destroyed the cartilages, the resulting stenosis will under no circumstances be amenable to cure even by the most prolonged stenting, since there is no normal tracheal mural architecture left. Varying degree of depth of erosion are of course seen.

Cuffs on endotracheal tubes may also produce this lesion. Since endotracheal tubes are usually used for the initial intubation, those patients in whom stenosis develops even after only 48 hours of ventilation will usually have had only an endotracheal tube. In many such patients, the injury consists of a massive cicatricial stenosis of scar tissue within the tracheal lumen, although the cartilages are not totally destroyed and may even be relatively intact. Endotracheal tubes may also cause glottic stenosis and stenosis at the cricoid level, but these are not true tracheal lesions. It is important, however, to be aware of this possibility prior to considering repair of a tracheal lesion, since it is disastrous to do corrective surgery on the trachea and then discover that there is an inadequately functioning glottis above it. A number of cases of severe stenosis, which have resulted from cricothyroidotomy, have also been seen in the subglottic region. High stomas in elderly patients who are kyphotic and in whom the tube gradually erodes back through the cricoid cartilage may also produce subglottic stenosis. A large-bore endotracheal tube may produce erosion and stenosis at the cricoid level. Repair of strictures involving the subglottic larynx is much more difficult than repair of strictures of

the trachea alone.

Because of inflammation, varying degrees of thinning of the cartilages may also occur in the segment between the site of a tracheal stoma and the level of a cuff stenosis below. Sometimes, this area may become malacic. In addition, malacia may be caused at the level of a cuff. Additional lesions that are not truly strictures but are caused by tracheostomy tube injuries are tracheoesophageal fistula and tracheal innominate arterial fistula. The esophageal fistula is seen most often in patients who have nasogastric feeding tubes in place for long periods in addition to an inflated cuff in the trachea. The pressure of these two foreign bodies acts as an erosive pincer. Anterior erosion of the tracheal wall was seen more often when high-pressure cuffs were routinely used or when the tip of a tube angled forward. They sometimes led to erosion directly into the innominate artery as it crosses the trachea. A more common cause of innominate artery hemorrhage is the low placement of a tracheostomy tube so that the tube itself rests on the elevated artery and erodes through it at the inferior margin of the stoma. Such lesions are, therefore, seen most often in children and young adults, since their tracheas are more mobile and rise up into the neck along with the innominate artery upon hyperextension. These last lesions are avoidable by placing the tracheostomy in an appropriate position at the level of the second and third tracheal rings, rather than with reference to the sternal notch.

Clinical Presentation

Most patients with postintubation stenosis have signs of upper airway obstruction. The patient initially complains of shortness of breath on exertion. Progressive shortness of breath then develops even at rest, with wheezing and stridor. Occasionally, episodes of unilateral or bilateral pneumonitis will give a clue. Cyanosis is a very late sign. It must be remembered that any patient who shows signs of upper airway obstruction must be considered to have an organic lesion of the trachea, particularly if he or she has been subjected to intubation for ventilatory support at any time in the relatively recent past. In practice, many of these patients have been diagnosed as having adult-onset asthma despite the historic record of recent intubation.

Tracheoesophageal fistula presents a picture of a patient who suddenly has far more secretions than previously noted and who aspirates much when attempts are made to swallow. Tracheal innominate arterial fistula frequently produces a premonitory hemorrhage of significant but not massive nature. Such bleeding should always be investigated bronchoscopically to be certain that one is not dealing with something more than severe tracheitis. Angiography, which may show a small false aneurysm, may be of some use.

Diagnosis

The clinical presentation and history give the presumptive diagnosis in most cases. This may be followed by radiologic evaluation. Bronchoscopy may be done separately in complex cases, but in the simpler ones, it is done concurrently with the repair if radiologic demonstration has been adequate. A word of caution should be mentioned about flexible bronchoscopy under local anesthesia. If critical airway stenosis is present, total airway obstruction may ensue from the bronchoscopy or secretions. Flexible bronchoscopy should be done only with great caution in this setting, if at all.

Treatment

Surgery for resection of benign structures of the trachea has been so well worked out and standardized that this is clearly the treatment of choice when the lesion is not excessively long, when it does not involve other more complex anatomic structures (such as the subglottic larynx), and when the surgeon has had reasonable experience so that a good result may be promised. It should be remembered that most tracheal strictures may be managed indefinitely by reinstituting a tracheostomy, dilating the stricture, and inserting a silicone rubber T-tube (Montgomery tube, E. Benson Hood Laboratories, Inc, Pembroke, MA). With such a tube, a patient can live indefinitely. His or her life is fairly normal, and the tube requires changing at infrequent intervals.

When there is no contraindication, surgical excision and end-to-end repair is the treatment of choice. Morbidity is slight, and the success rate is very high. In postintubation strictures, nearly all repairs are now done through an anterior approach, using either a collar incision or a collar incision with a vertical partial sternal division. Dissection is kept very close to the trachea, in contrast to dissection for tumor. This avoids injury to the recurrent laryngeal nerves. Stenoses are dilated prior to anesthesia if they are smaller than 6 mm in diameter in order to avoid carbon dioxide retention and resultant arrhythmias. Division is usually made below a stricture unless it is a low one; intubation is carried out across the operative field; and the strictures is carefully dissected away from the esophagus. Strictures up to half the length of the trachea may be thus removed and approximation done. In older patients, a laryngeal release may be required for additional length. Tracheostomy is rarely used. If the stricture involves the subglottic larynx, one single-stage repair of the lesion requires partial removal of the lower anterior subglottic larynx. If the stenosis is circumferential, the scar overlying the injured mucosa may be removed from the anterior surface of the posterior cricoid plate. Appropriate tailoring of the distal segment will allow repair of both of these defects in a single stage, but the technique is difficult. Temporary tracheostomy is occasionally necessary in this group of patients.

The *results of surgical treatment* of postintubation stenoses have been good. In 203 patients who underwent tracheal resection and reconstruction from 1965 to 1979, including reoperations of patients who had previous surgery and including patients from the earliest time when such lesions were repaired, the following results were obtained: there were five deaths (2 per cent), and only one occurred in a patient who underwent truly elective surgery; there were nine failures (5 percent); and 189 patients (93 per cent) had good or satisfactory results. Despite an increasing complexity of cases, even better results have occurred in more than an additional 60 patients operated upon since.

It is extremely rare for a postintubation stenotic lesion to involve more than one half of the trachea unless there has been a prior attempt at surgery. If primary reconstruction cannot be done because of the extensive involvement of the trachea, insertion of a Montgomery silicone T-tube promises an excellent long-term alternative. There is no real indication in such a case for open surgery to insert a prosthesis.

The management of acquired *tracheoesophageal fistula* has been controversial. We have taken a conservative approach, delaying fistula closure until the patient is weaned from mechanical ventilation. a gastrostomy tube is placed to drain the stomach and eliminate

possible reflux, and a jejunostomy tube is placed for feeding. Esophageal diversion will only rarely be required. Usually it is impossible owing to the high level of the fistula. Most patients require concomitant resection of the injured tracheal stenosis and closure of the esophageal fistula. It is necessary to interpose viable tissue, such as a strap muscle, between the two suture lines to prevent refistulization. Only rarely can the fistula be divided and simple closure of the esophagus and trachea be accomplished. We have treated 20 patients with acquired tracheoesophageal fistula resulting from a variety of causes. There were two deaths in the series from sepsis, both in patients requiring mechanical ventilation following transthoracic repair of distal tracheoesophageal fistulas. The fistulas were successfully closed in 16 of the remaining patients. One patient had spontaneous closure of the small fistula, and the other patient required reoperation, which was successful.

Complications

In 1986, we reported the complications following tracheal resection covering the period from 1962 to 1982. This report dealt with 86 patients undergoing resection for neoplasm (56 primary neoplasms and 30 secondary neoplasms) and 279 patients undergoing resection for postintubation injury. Complications have generally been few for upper tracheal lesions. Major complications have more often followed carinal reconstruction or laryngotracheal resections without restoration of continuity.

Laryngeal edema is managed by restricting fluid intake and administering racemic epinephrine and a short course of steroids (24 to 48 hours). The edema usually regresses within a week. Pneumonia has been extremely rare following upper tracheal resections because proper attention has been given to intraoperative management and to postoperative physiotherapy. All patients spend 1 day or more in a respiratory intensive care unit with a staff that is familiar with the management of such problems.

The most common later complication has been the formation of granulations at the suture line (Table 1). This has been less of a problem in patients having resections for tumors than in patients who have had tracheal reconstructions for inflammatory disease, as residual inflammation may be present in such cases. Granulations may usually be managed by bronchoscopic removal under light anesthesia. Often a suture is found to have worked its way into the lumen at the base of the granulations. Removal of the sutures lead to ultimate healing. In some cases, multiple bronchoscopies are necessary over time. Formation of granulations may be seen radiologically, but it is most often manifested by wheezing or minor hemoptysis. The patient must be warned in advance that this is not a cause for alarm or he or she will assume that there is recurrent tumor. Triamcinolone may be injected into the base of such granulations, but there is no clear evidence supporting its efficacy. Use of absorbable Vicryl sutures appears to prevent the problem.

Separation of anastomosis in most cases is due to excessive tension as a result of resecting too much trachea or failing to make adjunctive relaxing maneuvers to lessen the tension. Excessive circumferential dissection of the trachea, particularly distal to the point of division, may destroy the blood supply and cause separation or stenosis. Excessive resection is more likely to occur in patients with tumors (6 of 86 patients) than in patients with intubation stenosis (4 of 279 patients). In one patient, a transient air leak occurred but sealed spontaneously. Steroids have been responsible for separation in some patients and should be

completely stopped before surgery.

Table 1. Tracheal Resection - Complications

Condition	Intubation	Neoplasms
Granulations	28	10
Separation	4	6
Air leak only	-	1
Stenosis		
partial	6	3
complete	15	-
Hemorrhage	2	1
Persistent stoma	5	-
Tracheoesophageal fistula	1	-
Esophagocutaneous fistula	-	1
Wound infection	6	-
Vocal cord dysfunction	5	3
Aspiration	1	-
Hypoxemia	-	1
Laryngeal edema	1	-
Respiratory failure	-	2
Pneumonia	-	2.

If tracheal separation were to occur in the immediate postoperative phase, there would be reason to conclude that there had been a serious technical error. Reoperation might be considered to resuture the area and cover with a local muscle flap if the area was small. If the tissues do not seem appropriate for resuturing, a tracheostomy tube may be placed across the defect, to be replaced by a Montgomery silicone T-tube. A T-tube can be placed initially if a patient does not require a sealed airway. With partial restenosis, the airway that results may be tolerated and may sometimes be improved with endoscopic techniques including the laser.

In one patient, fatal hemorrhage occurred on the ninth day after resection of a carinal neoplasm, probably from the pulmonary artery and probably related to erosion between the tracheobronchial repair and an overlying pulmonary artery. He was the only patient undergoing transthoracic tracheal or carinal resection in whom a pleural or other flap was not placed around the anastomosis.

Injury to a recurrent laryngeal nerve has occurred in three patients undergoing tracheal reconstruction for neoplasm and in five patients undergoing reconstruction for postintubation injury. It was clearly the result of surgical manipulation and extension of resection.

One patient who required a repeat resection of intrathoracic trachea for plexiform neurofibroma involving the esophagus had an esophagocutaneous fistula that healed spontaneously. One patient with extensive tumor involving the carina and left main bronchus underwent carinal resection and closure of the left main bronchus without removal of the left

lung as described by Perelman and Koroleva. The patient had severe hypoxemia and tachycardia for 3 months until the residual left lung, which had a 30 per cent shunt, was finally removed.

Suture line leakage has been extremely rare also. If an airtight anastomosis without tension has been achieved at the operating table, separation almost never occurs. Minimal air leakage at a suture line may occur, although this is also exceedingly rare. Minimal leakage can be managed through suction drains and will seal without further event. Leakage did develop in one patient with end-to-end anastomosis after an extended transthoracic resection in the lowermost portion of the trachea. This leakage ultimately healed with subsequent stenosis, which required reoperation. Problems following carinal reconstruction are not pertinent to this discussion.

Innominate artery hemorrhage has not occurred following tracheal resection for tumor and end-to-end anastomosis. In fact it occurred in only two patients in more than 500 cases of benign stenosis. Careful management of the artery as described should avoid this problem.

Results of the management of complications are listed in Table 2. Good results following complications are possible if handled properly.

Table 2. Postintubation Lesions - Results of Treatment of Complications

	No	Good	Satisfactory	Failed	Death
Granulations	28	24	4	-	-
Separation	4	-	2	-	2
Restenosis	21	6	15	-	-
Malacia	3	1	-	1	1
Hemorrhage	2	1	-	-	1
Tracheoesophageal fistula	1	-	-	-	1
Vocal cord dysfunction	5	-	4	1	-
Aspiration	1	-	-	1	-
Wound infection	6	6	-	-	-
Edema	1	-	-	1	-.