Tracheal Stenosis

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TRACHEAL STENOSIS

INTRODUCTION

Tracheal stenosis affects 4-13% of adults and occurs in 1-8% of neonates after prolonged intubation in the USA.¹

The definition of tracheal stenosis is not characterised by precise anatomic parameters as one would expect. Stenosis of the trachea signifies a functional impairment; with peak expiratory flow rates changing from 100% in a normal trachea with a diameter of 2cm to 30% in a trachea less than 5mm.² Most patients who sought treatment did so due to becoming symptomatic, while some were discovered incidentally while undergoing a general anaesthetic.

ANATOMY OF THE TRACHEA

The trachea extends from the lower body of the cricoids to the top of the carina spur. Average tracheal length was found to be 11.8cm, with a range of 10 to 13cm.³ There are approximately 2 cartilaginous rings per cm for a total of 18 to 22 rings. These C shaped rings form the anterior and lateral walls of the trachea. The posterior wall is membranous. The internal diameter of the trachea measures about 2.3cm laterally and about 1.8cm anteroposteriorly. Looked at laterally, the trachea starts in the subcutaneous position at the cricoids level and ends in a prevertebral plane at the level of the carina. The proximal trachea is cervical and becomes mediastinal at the sternal notch. When the head is flexed the trachea can become completely mediastinal.

Conversely when the head is extended a longer portion of the trachea becomes cervical. The blood supply is as follows: It is segmental and approaches the trachea laterally. The upper trachea is perfused by the inferior thyroid artery, while the lower trachea is perfused by the bronchial arteries with contributions from the subclavian, internal mammary, innominate, internal thoracic and the supreme in intercostals arteries.

Importantly the recurrent laryngeal nerves course posterolaterally to the trachea in the groove between the trachea and the oesophagus and enter the larynx between the cricoids and the thyroid cartilages immediately anterior to the inferior cornua of the thyroid cartilage.
The definition of subglottic is that part of the larynx below the true vocal cords\(^4\), although some define its lower border as the cricoid cartilage\(^5\). The definitions are inconsistent\(^4\). For our purposes we will use the former definition.

![Figure 1: Tracheal Anatomy](image)

### PHYSICS OF AIR FLOW \(^6\)

Flow through a tube, whether through the trachea, circulation, or any other orifice, can be difficult to measure. It is important to distinguish between flow and velocity, which can be often confused. Flow, often denoted as \(Q\), is defined as the volume passing a particular surface area per unit time and is often denote as ml/s or L/min. Whereas velocity is the speed of fluid at a particular point in space. Flowing fluids in tubes possess velocity and pressure that can be used to analyze incompressible flow by using the Bernoulli equation, which states that

\[
P + \frac{1}{2} \rho U^2 = P
\]

Where \(P\) is pressure, \(\rho\) is fluid density, \(U\) is velocity and \(P\) is constant pressure. In this form of the Bernoulli equation, pressure decreases as velocity increases. In the flow inside a tube, velocity decreases as area increases.

Flow can be measured using the average velocity of the fluid across a tube. In the laminar flow, the velocity has parabolic shape, with slower velocities along the edges because of friction, whereas turbulent flow has a flattened velocity profile. Turbulent flow is inefficient, and the energy needed to move a given volume is greater for turbulent flow than for laminar flow.
Most commonly the flow needed to be measured by anaesthesiologists is not laminar, and the Bernoulli equation cannot be applied because it describes frictionless flows. The transition from laminar to turbulent flows depends on the type of fluid, the speed of the flow, and the shape of the flow.

Figure 2: Differences between Laminar and Turbulent flow.
These fluid factors are combined in a ratio called the Reynolds number (Re):

\[ \text{Re} = \frac{\rho UL}{\mu} \]

Where \( \rho \) is the density of the fluid, \( U \) is the mean velocity, \( L \) is the characteristic length of the flow, and \( \mu \) is the viscosity of the fluid. For flow through a tube of circular cross section, transition from laminar to turbulent flow occurs at a critical value of Re. A large Reynolds number indicates that viscous forces are not important at large scales of flow.

Using the definition of Reynolds number, we can see that a large diameter with rapid flow, where the density of the fluid is high tend towards turbulence. Also, rapid changes in diameter, as occurs in tracheal stenosis, may lead to turbulent flow. If flow in a tube passes through a sudden restriction, the turbulent flow is proportional to the area of the orifice and the square root of the pressure drop through the orifice as opposed to its direct proportionality to pressure gradient is laminar flow. Understanding the physics of airflow becomes an important concept in the diagnosis and treatment of tracheal stenosis.\(^7\)

**AETIOLOGY**

Partial or complete narrowing of the subglottic area may be congenital or acquired.

**A] CONGENITAL**

Stenosis is said to be congenital in the absence of a history of intubation or other acquired causes.\(^8\) Congenital laryngeal webs account for approximately 5% of congenital anomalies of the larynx, with 75% occurring at the glottis level and the rest occurring at the subglottic or supraglottic level. Most severe cases are diagnosed in childhood.

**B] ACQUIRED**

Trauma is the most common cause of stenosis in both children and adults. Approximately 90% of all cases of acquired subglottic stenosis in children and adults result from endotracheal intubation. The reported rate of stenosis following intubation ranges from 0.9 to 0.3%.\(^4\)

Intubation causes injury at the level of the glottis due to the pressure between the arytenoid cartilages. Intubation causes injury in the subglottis due to the complete cartilaginous ring or can cause injury distally in the trachea. Pressure or motion of the tube against the cartilage framework may cause ischaemia and necrosis.

Duration of intubation is the most important factor in the development of stenosis. Severe injury has been reported after 17 hours, but it may occur much sooner. A 7-10 day period of ICU intubation is acceptable, but the risk of laryngotraacheal injury increases drastically after that.
Size of the tube is also important. Tubes should be no larger than 7-8mm in diameter for an adult male, and 6-7mm for a female... internal diameter. Stenosis should also be secondary to foreign body, infection, inflammation, or chemical irritation. Respiratory epithelium is susceptible to injury. Initial oedema, vascular congestion, and acute inflammation can progress to ulceration and local infection with growth of granulation tissue. Finally, fibroblast proliferation, scar formation, and contracture can occur and result in stenosis.

Systemic factors may increase the risk of injury and include the following:

1. Gastric acid reflux: This was noted in patients who were intubated for a short time (some even less than 24 hours), but developed stenosis. The explanation put forward was that regurgitation of gastric secretions occurred, collecting above the cuff, causing inflammation and fibrosis.9
2. Chronic illness
3. Immunocompromised patient
4. Anaemia
5. Neutropenia
6. Toxicity
7. Poor perfusion
8. Radiation therapy

Others include the following:

1. External trauma, penetrating and blunt
2. Tracheostomy, especially a high tracheostomy or cricothyroidotomy
3. Percutaneous tracheostomy
4. Chondroradionecrosis after radiation therapy may occur up 20 years later
5. Chronic infection

Chronic inflammatory diseases include the following:

1. Wegener granulomatosis
2. Sarcoidosis
3. Relapsing Polychondritis
4. Chronic inflammation secondary to gastro oesophageal reflux and other conditions
5. Neoplasm
PATHOPHYSIOLOGY

Congenital stenosis has two main types, membranous and cartilaginous.

In membranous stenosis, fibrous soft tissue thickening is caused by increased connective tissue or hyperplastic dilated mucus glands with the absence of inflammation. Membranous stenosis is usually circumferential and may extend upwards to include the true vocal folds.

In cartilaginous stenosis, thickening of the cricoids cartilage most commonly occurs, causing a shelf-like plate of cartilage and leaving a small posterior opening. Cartilaginous stenosis is less common than membranous stenosis.

Acquired subglottic stenosis is secondary to localized trauma to subglottic structures. Usually, injury is caused by endotracheal intubation or high tracheostomy tube placement. If irritation persists, the original oedema and inflammation progress to ulceration and granulation tissue formation. This may or may not involve chondritis with destruction of the underlying cricoids cartilage and loss of frame work support.

When the source of irritation is removed, healing occurs with fibroblast proliferation. Scar formation, and contracture, leading to stenosis or complete occlusion of the airway.

DIAGNOSIS OF TRACHEAL STENOSIS AND PREOPERATIVE EVALUATION

Adults with mild congenital stenosis are usually asymptomatic, and they are diagnosed after a difficult intubation or during endoscopy for other reasons.

Patients with acquired stenosis are diagnosed from a few days to 10 years or more following initial injury. The majority of cases are diagnosed within a year. Symptoms include the following:

- Dyspnoea
- Stridor
- Hoarseness
- Brassy cough
- Recurrent pneumonitis
- Cyanosis.
- Progressive exercise intolerance.
- Haemoptysis
Symptoms may appear gradually or abruptly according to the underlying pathology.

Stridor at rest when the diameter of the trachea reaches 5mm or less, dysphagia and hoarseness due to recurrent laryngeal nerve involvement. If the lesion is obstructing one or more of the main stem bronchi, patients may have recurring bouts of pneumonitis. Cyanosis is a late and ominous sign, signalling complete occlusion of the airway.

All too often the diagnosis of adult onset asthma is made and treated with bronchodilators and steroids. Patients complain of constant shortness of breath that is unresponsive to treatment. Monophasic wheezing is present and can be unilateral if lesion is distal to the carina. If symptoms and/or radiographic infiltrates do not resolve within four to six weeks, bronchoscopy should be considered.\(^{10}\)

Grillo states: “\textit{Any patient that has received ventilatory support in the recent past or even not so recent past, who develops signs and symptoms of upper airway obstruction, has an organic lesion until proven otherwise.}”\(^{11}\)

**INVESTIGATIONS**

**A) LABORATORY STUDIES**

In the absence of a prior history of trauma or when suggested by other findings, evaluate for inflammatory or infectious causes, including the following:

- Wegener granulomatosis
- Relapsing polychondritis
- Syphilis
- TB
- Sarcoidosis
- Leprosy
- Diphtheria
- Scleroma

**B) IMAGING**

Patients with narrowed airways should be carefully observed while diagnostic studies are underway. Full monitoring of these patients is recommended.
C] CHEST X-RAY

The chest x-ray is generally not useful. It is often normal on initial examination. Retrospectively an abnormality of the tracheal lumen is sometimes seen.2

D] CT SCAN

Is a useful adjuvant to evaluate extratracheal or extrabronchial involvement by tumour as well as oesophageal and mediastinal invasion. It is of little use in benign stenosis other than defining the exact location and gross extension of the obstruction. Toyota et al describe how three-dimensional figures of the trachea and a virtual bronchoscopic movie were obtained from multi-slice CT to evaluate the stenotic region and to simulate fibroscopic tracheal intubation, respectively.

After induction of general anaesthesia with propofol, a tracheal tube was successfully passed through the stenotic region under the guide of a fibroscope as simulated in the virtual movie. They concluded that multi-slice CT is useful for preoperative airway evaluation for patients with stenosis and distortion of the trachea.12

E] BARIUM STUDY OF THE OESOPHAGUS

For tumour investigation, barium study will identify oesophageal involvement by invasion of tumoural process of extrinsic compression.

F] AORTIC ARCH ANGIOGRAMS

In selected cases of cancer, when cervical exenteration is planned (removal of larynx, portion of trachea, and oesophagus, and frequent mediastinal tracheostomy), aortic arch angiograms will identify tumour involvement of the four arteries supplying the brain.
These can be very useful in these patients. The flow volume loops may show various anomalies:

- A delay in reaching peak expiratory flow.
- A truncation of peak expiratory and inspiratory flow.
- An abrupt drop of expiratory flow at the end of expiration.
• In an asthmatic one could see flattening of the expiratory curve. This occurs predominantly in late expiration, with slowing of terminal flow rates. Peak flows are maintained, but the flow volume curve becomes more convex towards the horizontal axis.
• In tracheal stenosis (fixed upper airway obstruction): there is flattening of the inspiratory and expiratory phases. The primary effect occurs early in expiration and results in a truncated, flat topped flow volume curve, with a normal late expiratory portion of the flow volume curve.

It’s important to remember that the quality of the flow volume loops is totally dependent on the patients’ effort and cooperation and that tracings obtained may not have the shapes expected.

G] ENDOSCOPY

Bronchoscopy remains the primary procedure in the diagnostic workup of tracheal stenosis and is key in defining the characteristic features, extent and location of the stenosis.

Bronchoscopy in a patient with post intubation stenosis shows:
• Circumferential narrowing less than 2cm in length.
• A thin membrane that extends into the lumen
• A long segment of eccentric soft tissue thickening

Patients with stenosis related to TB will have granulation tissue with friable and ulcerated mucosa, whereas those with sarcoidosis may demonstrate a raised cobblestone appearance of the mucosa.

Patients with Wegener granulomatosis may have inflammatory ulcers, plaques, or granulomatous tissues.

Patients with amyloid will have thickened tracheal segments corresponding to areas of amyloid deposits.

In general, there would be mucosal oedema and erythema. Awake fibreoptic bronchoscopy allows examination of the vocal cords to determine if the recurrent laryngeal nerve is involved, it also allows for evaluation of dynamic airway obstruction during respiration if present.
MEDICAL MANAGEMENT

- Any underlying medical cause must be addressed (e.g., control of infectious aetiology, inflammatory causes such as Wegener granulomatosis).
- Antireflux management
- Proton pump inhibitor (e.g., omeprazole, 20 mg PO bid or equivalent)
- Ranitidine, 300 mg PO bid-qid, if proton pump inhibitor is not an option
- Dietary and lifestyle modification; crucial but often overlooked in antireflux management
- Use of systemic steroids in early stenosis is an option but has not been thoroughly investigated.
- In active inflammatory states of the subglottis, such as granulation tissue, inhaled steroids are of potential benefit (e.g., Flovent 220, 2 puffs twice a day for 2 weeks; this is an offlabel use based on the author's own experience).

SURGICAL MANAGEMENT

The goals of treatment are either cure or palliation. The optimal management of post intubation tracheal stenosis is not well defined. Brichet, DuPont, et al, designed a therapeutic algorithm in cooperation with thoracic surgeons, ENT’s, anaesthetists and pulmonologists. They proposed rigid bronchoscopy with Nd-YAG laser resection or stent implantation as a first line of treatment, depending on the type of stenosis (web like vs complex).

In patients with web like stenosis. Sleeve resection was proposed when laser treatment (up to three sessions) failed. In patients with complex stenosis, operability was assessed 6 months after stent implantation. If patients were judged operable, the stent was removed and the patient underwent surgery if the stenosis recurred. This approach, they suggest, including initial conservative treatment, depending on the type of the stenosis, appears to be applicable to almost all patients and allows secondary surgery to be performed with the patient in good condition.
Bronchoscopic examination is paramount in patients with tracheal pathology. This exam will determine the nature of the lesion, length, location and degree of obstruction. If the obstruction is moderate to severe, bronchoscopic examination can be deferred until definitive treatment is chosen. Rigid bronchoscopic examination is usually chosen in the non surgical treatment of these patients. Rigid bronchoscopy allows coring out of tumours, provides a means for ventilation, and may tamponade a source of bleeding.

**A] IRRADIATION**

Squamous cell carcinoma and adenoid cystic carcinoma respond to radiation. However, used alone it is not a definitive treatment, and most tumours recur after a few years. However radiation can be used as an adjunct to other methods. The advisability of preoperative radiation is questionable as the incidence of tracheal dehiscence is higher.14
B] DILATATION

Dilatation can be used for the management of tracheal obstruction in emergency situations or in a planned approach to determine if surgical resection will be needed. Simple dilatation is often not a definitive treatment as recurrence occurs. It should be used a temporizing measure until a more definitive treatment can be undertaken. Dilatation is recommended for mature, firm stenosis or those with cartilaginous components. Ideally, it is performed under direct visualization with a means of securing the airway. Dilatation can be performed with smooth round dilators, gradual dilatations with ventilating bronchoscopes of increasing diameters, or dilating balloons passed through flexible bronchoscopes. The risk of oedema and mucosal trauma increases with multiple dilatations, making this method of treatment unpopular. Steroids can be used to minimize oedema after these dilatations. Steroids can delay the synthesis of collagen in the early stages of scar formation. However they can also delay wound healing and cause cartilage resorption. In addition, local injection of steroids or mitomycin C may staunch the recurrence of scar formation at the site of the stricture.

C] LASER

Lasers deliver energy to achieve cutting, coagulation, and vaporization with great precision and micro haemostasis. The end result is less preoperative oedema. The CO2 laser has a wavelength of 10.6µm and is used for lesions involving soft tissues. It can deliver power from less than 1W to 100W. When operating on the airways, it is used in the range of 3 to 6 W. However the CO2 laser cannot coagulate vessels larger than 0.5mm in size and depends on an optic delivery system.

Endoscopic laser treatment includes radial incision and dilatation incision. Radial cuts are made into the fibrotic segment. This allows a planned tear into the stenosis and can potentially provide better results with dilatation before stenting. Lasers are also used for the debridement of obstructive lesions of recurrent respiratory papillomatosis and produces minimal scaring despite repeated use. The CO2 laser is also used as a treatment for glottis webs or for acquired subglottic stenosis.

The Nd-YAG laser has become the laser of choice in the treatment of obstructive lesions because it is able to reach distant corners of the tracheal bronchial anatomy. This laser can be used in concentric stenosis and palliation of tracheal malignancies. However, endoscopists are unable to control the depth of penetration (up to 10mm depending on the wattage and exposure time) with this type of laser, putting patients at risk for perforation.

The potassium titanyl phosphate (KTP) or argon laser has also been used in the airway. This laser is frequently used in the paediatric airway because of its small
diameter fibres and its coagulating effect on soft tissue. It has a tissue penetration of 4mm and is useful for vascular lesions as well. The KTP laser can be used with a fiberoptic delivery system, making its delivery more precise. Lasers cannot destroy the root of the tumour, and recurrence is frequent after laser ablation. If definitive surgical treatment is to be undertaken for patients, lasers should not be used because they can destroy healthy tissue that is adjacent to the lesion, which could compromise future anastomotic sites of the surgeon.

Before any laser or cautery use in the airway, typical safety precautions need to occur. These include lowering the FiO₂ to 30%, ensuring that the endotracheal tube or other combustible materials are well away from the laser, and the universal donning of laser protective glasses.

**D]STENTS**

Stents can have multiple uses in this patient population. They can be used as palliation for patients have tumours that are too extensive for surgery, patients with benign lesions but extensive strictures or patients with trachea destroyed by multiple reconstruction attempts.

They can be used as temporizing measures until the patient is ready for surgery or as an adjunct to surgery to stabilize the trachea. Ideally stents should have several characteristics: they should establish the airway with minimal morbidity and mortality, have limited migration, be easily removable, maintain luminal patency without ischemia or erosion, induce minimal granulation tissue formation and be economically affordable. No stent currently has these characteristics.

The advantage of an airway stent is that it supports the airway against collapse or external compression and impedes extension of the tumour into the lumen. Stents can safely be placed in patients undergoing external beam radiation or brachytherapy: however they can burn or break when exposed to Nd:YAG laser energy, the effects of electrocautery, to the effects of argon laser plasma coagulation.

Silicone stents are favoured because they protect from collapse and ingrowths of tumours, they are less irritating and so less associated with inflammation. They are easily removed and exchanged, resist external compression and cause minimal formation of granulation tissue. However they cannot conform to irregular airways. Complication include: Mucus plugging, migration, malposition, infection. Self expanding metal stents are also used; they are less inhibitory to respiratory cilia. They can be positioned using bronchoscopy. However, tumour ingrowths can occur. They can also collapse, fracture, and occlude with granulation tissue.

Metal stents are used mainly in malignant strictures and silicone in benign, since there seems to be less granulation tissue formation with silicone.
i) Anaesthesia for Stent Placement
An experienced team is needed for optimal care, working on close cooperation with the surgeon.
Sedative premeds should be used with caution and only in the very anxious patient because of the dangers of hypoventilation and further airway obstruction. An anticholinergic agent can be selected to decrease secretions.

It is important to remember that that changing a spontaneously breathing patient to positive pressure ventilation can result in a partial obstruction becoming a complete one. The bronchoscope entering the lesion can completely obstruct the trachea. Therefore pre-oxygenation is vital and may take longer than usual due to decreased airflow and Tidal Volume.

Sedation with dexmedetomidine is recommended or with Ketamine, since sedation is achieved without airway compromise and with amnesia.

For initial bronchoscopy, local anaesthetics can be used to anesthetize the airway. Conacher et al believe that instillation of local anaesthetics and inhalational induction are contraindicated in these patients and the surest way to secure the airway is with rigid bronchoscopy.\textsuperscript{15} They so have the possibility decreasing forced expiratory volume in the first second of expiration and forced vital capacity, further exacerbating the inspiratory airflow limitation by inhibiting airway dilator responses and may cause deep sedation when absorbed in large quantity.

Induction needs to be tailored to the patients’ lesions and their medical history. Traditionally it was recommended that the patient be kept breathing spontaneously and neuromuscular blockade avoided. However some do state that control of the airway is best after an induction agent like propofol and a short acting agent\textsuperscript{16}. The extent and the fixed vs dynamic characteristics of the lesion can help guide anaesthetic choices.

Periglottic dynamic collapse can potentially make intubation difficult and thus maintenance of muscular tone and spontaneous respiration may be advantageous.

Similarly, immediate subglottic stenosis can make intubating impossible. In these patients, awake sedated bronchoscopy leading to control of the airway is recommended. LMA’s can be used with proximal lesions to allow ventilation and access for fibre optic bronchoscopy.

If IV induction is chosen, the medications are tailored to the patients’ health, the type and duration of surgery, and the type of therapy used. Regimens are typical for all critically ill patients. TIVA with propofol and remifentanil are used when rigid bronchoscopy are used. Obtundation of airway reflexes by opioids needs to be balanced against possible CO2 retention. Titrated doses of ketamine, propofol, etomidate can be used. The focus of induction is shifted to rapid airway control,
because mask ventilation may be difficult and the higher pressures can cause gastric distension.

For mid tracheal lesions there is often room to seat an ETT cephalad to the stricture. Jet ventilation can then be used. It can be hard to raise the inspired oxygen concentration and flow can be inhibited.

In extreme cases, cardiopulmonary bypass can be instituted if airway control cannot be achieved with a rigid bronchoscope. The patient should be fully awake at the end of the procedure, with all airway reflexes intact.

ii) Ventilation

Typical midtracheal lesions from ETT damage will require a decrease in respiratory rate to allow an increase in inspiratory and exhalation times. With higher inspiratory pressures made possible by intubation, it is reasonable that only the exhalation times would need to be lengthened because exhalation is purely a passive process. If hypotension is encountered after initiation of positive pressure ventilation, differential diagnosis needs to include breath stacking due to obstructed exhalation, along with the more common issues of pneumothorax, drug effect, myocardial ischaemia and so on.

Jet ventilation is often used for diagnostic and therapeutic procedures. If the jet catheter is supraglottic, care must be taken to aim the jet at the lumen of the stenosis to avoid direct trauma to adjacent tissue. If the catheter is passed through the stenotic lesion, hyperinflation must be considered a threat. Prolonged jet ventilation will necessitate arterial co2 sampling along with standard monitoring.

iii) Complications

Repeated obstruction by sticky secretions seems to be most common problem as seen by Brichet et al, in 18 patients studied. Downward migration of the stent was noted in two patients and granuloma obstruction of vocal cords was the other common complication.
SURGERY
Resection and reconstruction with primary anastomosis are considered the treatment of choice for managing most lesions of the trachea. In the case of malignant lesions, one must be certain that there is no extensive tracheal involvement, no deep invasion of the mediastinum and no metastasis of the tumour. Adenoid cystic carcinoma is an exception because long survivals are noted in patients with metastasis in which case surgery has proved beneficial.

A) RECONSTRUCTIVE SURGERY

i) Patient selection
Patients must have a lesion known to be resectable. The exact location of the lesion must be known as well as its length. The glottis must be functional, otherwise surgery will be in vain. Candidates with neuromuscular disorders or severe pulmonary pathology that will most likely require post operative mechanical ventilation are not good candidates for tracheal resection as early extubation is desirable to prevent wound dehiscence. Patients should also be weaned from ventilation prior to surgery. Patients receiving steroid therapy will need to have them tapered off because steroids induce poor wound healing and are a cause of attenuated restenosis. Steroids should be discontinued 2 to 4 weeks before surgery is undertaken.

ii) Timing of surgery
Resection should not be undertaken if active inflammation or infection at the site of surgery is present. These conditions will most likely lead to restenosis or worse, wound dehiscence.

B) TRACHEAL MOBILIZATION AND RELEASE PROCEDURES

This allows longer segments of the trachea to be resected with primary anastomosis to be performed with minimal tension on the fresh anastomosis to avoid dehiscence.

Head flexion is usually done by the anaesthetist. The procedures are:
- Head flexion
- Anterior pretracheal digital dissection
- Suprathyroid laryngeal release
- Suprhyoid laryngeal release
- Intrapericardial right pulmonary hilar release.
C] SURGICAL APPROACHES

i) High and mid tracheal lesions
Patients are positioned supine with an inflatable bag between the scapulae so that the neck is in full extension that is easily reversible with inflation of the air bag. Surgery proceeds through a generous collar incision with or without an upper sternotomy extension.

ii) Low tracheal lesions
Patients may be positioned above if head extension brings the diseased segment of the trachea in the cervical region. If not, the patient is positioned in the left lateral decubitus position with the neck flexed. Surgery then proceeds through a right posterolateral thoracotomy in the 4th intercostals space. Laryngeal manoeuvres as well as intrapericardial right pulmonary release may also be done here to lessen traction on the anastamosis.

iii) Carinal lesions
A right posterolateral thoracotomy is the most frequent approach, again with the patient’s neck flexed. The surgical field includes the neck, anterior chest, and right arm. Median sternotomy for limited carinal resection may be adequate. For extensive involvement of the trachea and right mainstem bronchus, bilateral submammary trans-sternal thoracotomy may be needed. Only rarely is left thoracotomy done because exposure of the carina is poor due to the aorta overlying the left hilum.

Before performing an end to end anastamosis, traction sutures are placed and tentative approximation done. For tracheal surgery approached by a cervical incision, the anaesthesiologist will deflate the bag between the patients scapulae and lift the head of the patient to about 30° which will result in cervical flexion. If excessive traction seems to be present, a laryngeal release manoeuvre will be performed. A guardian stitch is placed between the skin of the chin and the skin of the anterior chest to achieve flexion of about 35°. This stitch is left in place for 7 to 10 days, serves as a reminder to the patient not to extend the neck to avoid traction on the anastamosis. It is surprisingly well tolerated by patients. Early extubation is desirable as post operative ventilation carries the risk of an ETT cuff lying on fresh anastamosis and positive airway pressure that can lead to wound necrosis or dehiscence.

D] Anaesthesia

i) General considerations
The airway is shared between the surgeon and the anaesthetist. The surgeon must have maximal free access to the airway and an unobstructed surgical field with no interference by an ETT. Double lumen tubes are not indicated because
they carry the risk of trauma at the site of the lesion and their bulk interferes with 
the surgical field.

The anaesthetist must provide adequate ventilation and oxygenation to a patient 
with a pre-operative critical airway, followed by an intra-operative transacted 
airway that may be oedematous due to multiple manipulations and also because 
of cervical flexion positioning.

Pre-operative sedation requires good judgement and will dictated by tightness of 
the obstruction. For patients with moderate obstruction, decreasing anxiety may 
be beneficial as quieter breathing results in a fall in airway resistance. For patients 
with a severely narrowed airway, respiratory depression must be avoided at all 
costs.

Antsialogues should also be used with great caution as drying of secretions may 
cause a mucus plug that can obstruct an already tight lumen. It is best to defer all 
medication until the patient is in the supervised surroundings of the operating 
room.

**ii) Pre-operative assessment**

The anaesthetist should know the underlying pathology of the lesion as well as 
being familiar with its anatomic characteristics and the severity of obstruction. All 
the diagnostic studies should be closely examined.

A detailed history should be obtained. Active smoking, difficulty in clearing 
secretions, exercise tolerance, the capabilities of tolerating the supine position are 
specifically looked for. A history of previous intubation should be recorded. 
Associated cardiopulmonary disease is identified and corrected if time allows. 
Physical examination should be done, concentrating on the airway. The trachea 
should be palpated, neck mobility in extremes of position checked. A full 
respiratory system exam, looking for stridor at rest and during maximal expiration 
with the mouth opened. Difficulties with mask ventilation should be anticipated.

A thorough cardiac exam with needed investigations should done. 
Routine blood work is usually all that is needed unless the patient’s condition 
warrants it.

**iii) Equipment required for tracheal resection**

1. Anaesthesia machine capable of delivering up to 20l/min 
2. Assortment of ETT’s: 
   - PVC tubes in various sizes 
   - Extra long ETT’s 
   - Armoured tubes 
3. High frequency positive pressure ventilator 
4. A second anaesthesia machine. 
5. Fibreoptic 

Full monitoring, along with a nerve stimulator
An arterial line placed in the Left arm as compression of the inominate artery will render inaccurate blood pressure readings. CV-line placement is needed only if the patient’s condition indicates. EEG monitoring is also recommended to monitor brain function during inominate artery clamping. A warming blanket, nasogastric tube, Foleys catheter and eye protection are very important.

iv) Induction
Induction in these patients requires time and patience. The surgeon should be ready with a set of rigid bronchoscopes in case of obstruction.

Following 5 mins or more of pre-oxygenation with 100% oxygen, slow and gentle inhalational induction with the patient breathing spontaneously is the safest and most recommended method.

High flow O₂ should be used and ventilation can be assisted now and then, but spontaneous ventilation must be maintained. When an adequate depth is reached, topicalization of the airway with local anaesthetics is done and mask ventilation resumed.

Muscle relaxants should be avoided. They should only be given once the airway is secured, and ventilation verified.

Awake intubation should also be considered in those whom bronchoscopy is not going to be done.

Some have advocated IV induction, including the use of a depolarizing muscle relaxant. They did not report any adverse outcomes. In some reports CPB was on standby, with both the femoral artery and vein cannulated.

The procedure usually starts with rigid bronchoscopy to define the lesion visually. If the airway lumen is less than 5mm because of stenosis, dilatation will be performed first. A look through the rigid bronchoscope by the anaesthetist will help guide the size of ETT to be used. The ETT is passed through the lesion or kept above, depending on whether the tube can be secured in the trachea properly.

Great care should be taken if the ETT is passed through the lesion as tissue dislodgement, bleeding and oedema can occur. Also the lumen can be lost because of the thickness of the ETT’s plastic membrane that may encroach on the available stenotic cross sectional area.

v) Maintenance
This can either be done with incremental doses of IV induction agents have been reported along with use of volatile, or either agent exclusively. Opiods along with the above can also be done.
One should bear in mind that short acting agents should be used, since ideally the patient should be extubated. Muscle relaxants that are easily reversed, agents like cis-atracurium or atracurium is recommended.

**Ventilation methods**
Ventillation must be assured in the face of an open airway. Gas exchange can be done in 5 ways:

Low frequency jet ventilation consists of manually triggering O₂ delivery under high pressure through a ventilation pathway (small catheter, ETT, bronchoscope...). This method usually delivers high tidal volume (V₆). Case reports using manual jet ventilation go back to the 1970’s. For high tracheal lesions, IV or inhalational induction was carried out and the trachea was intubated orally with a small uncuffed ETT. The lung was ventilated using IPPV with mixture of O₂ and nitrous oxide with or without a volatile. Upon opening the trachea, a long narrow catheter was inserted through the ETT and passed into the distal trachea.

The catheter was then attached to an oxygen source and ventilation triggered manually, delivering O₂ 100% at high pressures. The pressure should be adjusted to 0 to 8 atm. The O₂ concentration, reaching the lungs with this technique is not 100%, as air is entrained in the distal trachea at the surgical opening (Venturi Principal). The patients lungs ventilated in this manner until the anastamosis was completed, after which the catheter withdrawn and IPPV resumed through the ETT, which was either advanced through the anastamosis or kept well above it.

This technique was also used for independent lung ventilation for carinal resection. Two small catheters were inserted in the ETT and placed in each mainstem bronchus. Each was connected to a different source so that each lung could be ventilated independently, compensating for different compliances.

The advantage of jet ventilation is good and free access to the surgical field, the surgeon being able to work around a small catheter.

Disadvantages include possible hypercarbia due to hypoventilation, excessive movement of the catheter tip, blood and other debris entrainment into the distal trachea, spraying of blood across the surgical field cause by high flow O₂ , movement of the lungs and mediastinum, high Tidal volume with possible hemodynamic repercussions, catheter plugging by the debris, contamination of the surgical field with the catheter

A patent airway for gas outflow must be ascertained before using jet ventilation to avoid gas trapping to avoid barotrauma.
If the degree of stenosis is severe and this method is used, slow respiratory rates should be used to permit long expiratory time. Also the position of the catheter tip must be identified as a tip inserted too far may produce barotrauma.

High frequency ventilation
There are three modes of high frequency ventilation:

- **High frequency positive pressure ventilation (HFPPV)**
  Deliver $V_T$ the size of the anatomic dead space at a rate of 1Hz-2Hz (60 breaths/min=1Hz) using a ventilator with negligible internal compliance so that the $V_T$ used is what is set. There is no air entrainment, so the lung receives only fresh gas.

- **High frequency jet ventilation (HFJV)** delivers pulses of small jets of gas derived from a high pressure source. Air entrainment does occur so that the concentration of $O_2$ reaching the lungs is lower than what is set to be delivered, rate 1.7 – 6 Hz.

- **High frequency oscillation ventilation (HFOV)** delivers $V_T$ of 50 to 80ml at a rate of 6.7 – 40 Hz.

Advantages of HFV, include improved gas mixing and accelerated diffusion which results in good gas exchange, the presence of auto PEEP due to continuous positive airway pressure which increases FRC and decreases V/Q mismatch and also decreases the risk of atelectasis, minimal hemodynamic repercussion, unobstructed surgical field, minimal lung expansion and mediastinum movement providing the surgeon, with a quiet field, decrease risk of the aspiration of blood and other debris into the distal airway due to continuous outflow of gases, and less catheter displacement.

vi) **Distal tracheal intubation and intermittent positive pressure ventilation**

High and mid tracheal surgery
This is the most frequently used method of ventilation.
The trachea is intubated above the lesion. Once the trachea is opened the ETT is simply pushed across the gap and positioned by the surgeon in the distal trachea

Disadvantages to this technique are:
- Trachea rupture
- Tissue dislodgement
- Bleeding
- Obstructed surgical field
- Contamination of the field.

The method of choice of Pinsonneault and others is following tracheal intubation above or below the lesion, the lungs are ventilated using IPPV. Once the trachea is resected by the surgeon, the proximal ETT is pulled back, but kept in the trachea, and a new sterile ETT is inserted by the surgeon, through the surgical field, into the distal trachea if the tracheal lesion is high, or in the left mainstem
bronchus if the lesion is near the carina or the carina itself. Sterile tubings are then attached to the ETT and passed to the anaesthesiologist so that IPPV can resume.

Once the stenotic segment is excised, end to end anastomosis is carried out. For this stage of the operation, short intermittent apnoeic periods are permitted, during which the ETT is removed from the trachea during suturing. There is no optimal time for apnoea periods. The patient should have been receiving 100% Oxygen, to fill the FRC and vitals should be monitored closely. They suggest a maximum of three minutes, even if SpO₂ is above 98%.

Once suturing has been done, the distal tube can be removed and the proximal ETT advanced beyond the anastamosis, either in the distal trachea or the mainstem bronchus.

Suggested ways to secure the proximal ETT for re-advancement in case of accidental extubation are:

- Before pulling back the proximal ETT a suture or surgical tape is passed through the Murphy’s eye can be secured on the surgical drapes, or a sterile flexible
- A long stylet can be passed retrogradely through the ETT and secured on one end by the anaesthesiologist and on the other end by the surgeon.

Low tracheal and carinal surgery
For precarinal lesions where the stump is very short, a standard ETT may pass endobronchially as the total length of the cuff plus the plastic segment distal to the cuff may be longer than the stump.

The surgery can be carried out by one lung ventilation if tolerated by the patient. The pulmonary artery can also be clamped on the non ventilated side, thus reducing shunting.

An alternative is to intubate both mainstem bronchi with separate ETT’s and to apply CPAP to the non dependant lung, or to ventilate both lungs with two anaesthesia machines or to connect both ETT’s to one machine and ventilate. Another method would be to use manual jet or HFV to the non ventilated lung.

Spontaneous ventilation
There have been some case reports on the use of spontaneous ventilation for tracheal resection and repair of trachea-oesophageal fistula. In all cases the maintenance was with boluses of an IV agent e.g. Propofol, and oxygen was delivered via a small catheter at high flows. Patients had good outcomes in all cases but the operating conditions where less than ideal, with the patient coughing/and or disturbing the surgeon with movement. Boluses of propofol did stop this but this required stopping surgery. Other shortcomings where hypercarbia and acidosis, aspiration of blood and debris.
CARDIOPULMONARY BYPASS

This was apparently popular in the 1960’s. While it does seem to be ideal to ensure gaseous exchange, CPB is fraught with risk.

Systemic anticoagulation augments the chances of bleeding, especially if the dissection is extensive and complicated lung manipulation unavoidable.

The duration of surgery is increased in all cases, with the patient requiring longer intubation, which is contra-indicated in end to end anastamosis repair.

Wang et al describe a case of a patient requiring urgent tracheal surgery, where CBP was used for a brief period. They initially began with a spinal anaesthetic, followed by femoral artery cannulation. Once the airway was secured, conventional one lung ventilation ensued and CPB was stopped.17

The use of CBP does seem to be in those with a severely obstructed airway, life threatening obstruction and in the paediatric population in whom airway manoeuvres are limited.

POST OPERATIVE AIRWAY MANAGEMENT

A small ETT or tracheostomy tube, or T-Tube with the upper limb 0.5 to 1cm below the vocal cords can be inserted at the end of surgery in cases where glottis oedema is a concern, or for patients requiring ventilatory support. The ETT or tracheostomy tube should be uncuffed.

Tracheostomy should be done distal to the anastamosis and humidified air should be provided. The ETT should be removed as early as possible.

If the patient requires reintubation, it is best done using a flexible fibre optic bronchoscope. The tip of the ETT should not be near the anastamosis.

Clearance of secretions with suctioning and chest physiotherapy is important as is keeping the patient in a head up position to reduce swelling

CONCLUSION

Major advances in surgical and anaesthesia techniques have been achieved over the years, making more procedures possible, safe and worthwhile for patients. Team work consisting of communication, coordination and cooperation between surgeon and anaesthesiologist is mandatory. Meticulous planning and anticipation of problems cannot be emphasized enough.
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