Respiratory System Surgeries and Procedures

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First Edition, 2012

ISBN 978-81-323-4535-0

Published by:
The English Press
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
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Rhinoplasty and Septoplasty

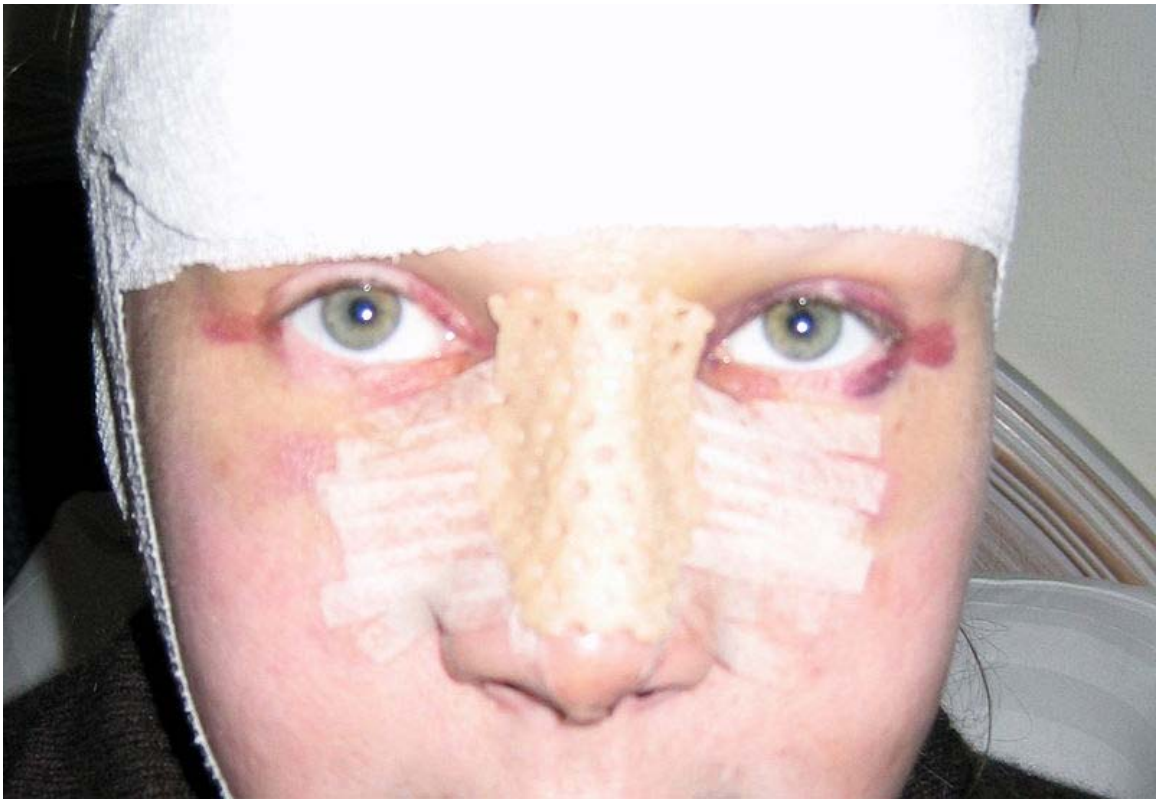
Rhinoplasty

Rhinoplasty (Greek: *Rhinos*, "Nose" + *Plassein*, "to shape"), commonly referred to as **nose reshaping** or a **nose job**, is a surgical procedure which is usually performed by either an otolaryngologist (head and neck surgeon), maxillofacial surgeon, or plastic surgeon in order to improve the function (reconstructive surgery) or the appearance (cosmetic surgery) of a human nose. Rhinoplasty can be performed to meet aesthetic goals or for reconstructive purposes to correct trauma, birth defects or breathing problems. Rhinoplasty can be combined with other surgical procedures such as chin augmentation to enhance the aesthetic results.

History

Reconstructive nose surgery was first developed by Sushruta, an important Ayurvedic physician in ancient India, who is often regarded as the "father of plastic surgery."Sushruta first described nasal reconstruction in his text *Sushruta Samhita* circa 500 BC. He and his later students and disciples used rhinoplasty to reconstruct noses that were amputated as a punishment for crimes. The techniques of forehead flap rhinoplasty he developed are practiced almost unchanged to this day. This knowledge of plastic surgery existed in India up to the late 18th century as can be seen from the reports published in *Gentleman's Magazine* (October, 1794).

A book written in Latin titled De Curtorum Chirurgia Per Insitionem - meaning The Surgery of Defects by Implantations - was published in 1597, and was written by Gaspare Tagliacozzi, professor or surgery and anatomy at the University of Bologna describes operations carried out to repair faces that had been wounded in battle. It is illustrated with diagrams, including the rhinoplasty, in which the patient's nose was attached to a flap of skin from his upper arm (bicep) and tells how he stayed like that for about three weeks until the skin from his arm had attached itself properly. After a further two weeks the flap of skin was shaped so it resembled a nose and the process was complete.



Patient, three days post-op. Procedures included dorsal bone reduction and re-setting and refinement of nasal tip cartilage. The typical orbital discoloration is also present due to trauma and disruption of blood vessels around the eyes. Also present is a splint.

The precursors to the modern rhinoplasty surgeons include Johann Dieffenbach (1792–1847) and Jacques Joseph (1865–1934), who used external incisions for nose reduction surgery. John Orlando Roe (1848–1915) is credited with performing the first intranasal rhinoplasty in the U.S. in 1887.

Prior to the 1970s, all rhinoplasty surgeries were performed via the intranasal approach, which is often called closed rhinoplasty. However, in 1973, Dr. Wilfred S. Goodman published an article entitled "External Approach to Rhinoplasty" which helped initiate a shift in rhinoplasty techniques to what has become known as the open rhinoplasty. The open rhinoplasty technique was further refined and popularized by Dr. Jack Anderson in his article "Open rhinoplasty: an assessment". The open approach to rhinoplasty gained in popularity during that time, but it was used mainly for first-time rhinoplasty surgery and not for revision rhinoplasty.

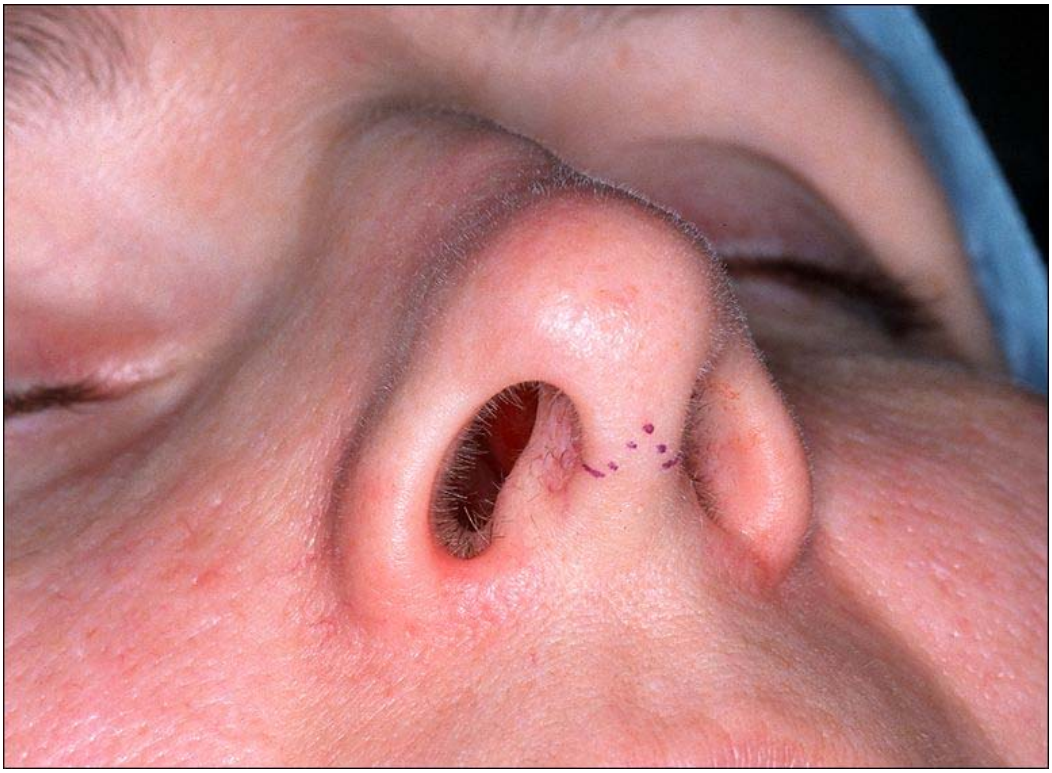
In 1987 Dr. Jack P. Gunter, who trained under Dr. Anderson, published an article describing the merits of the open rhinoplasty approach for secondary rhinoplasty. This was a major shift in the approach to treating nasal deformities that arose from a previous rhinoplasty.

Surgical procedures and types

Surgical approach: Open vs. closed

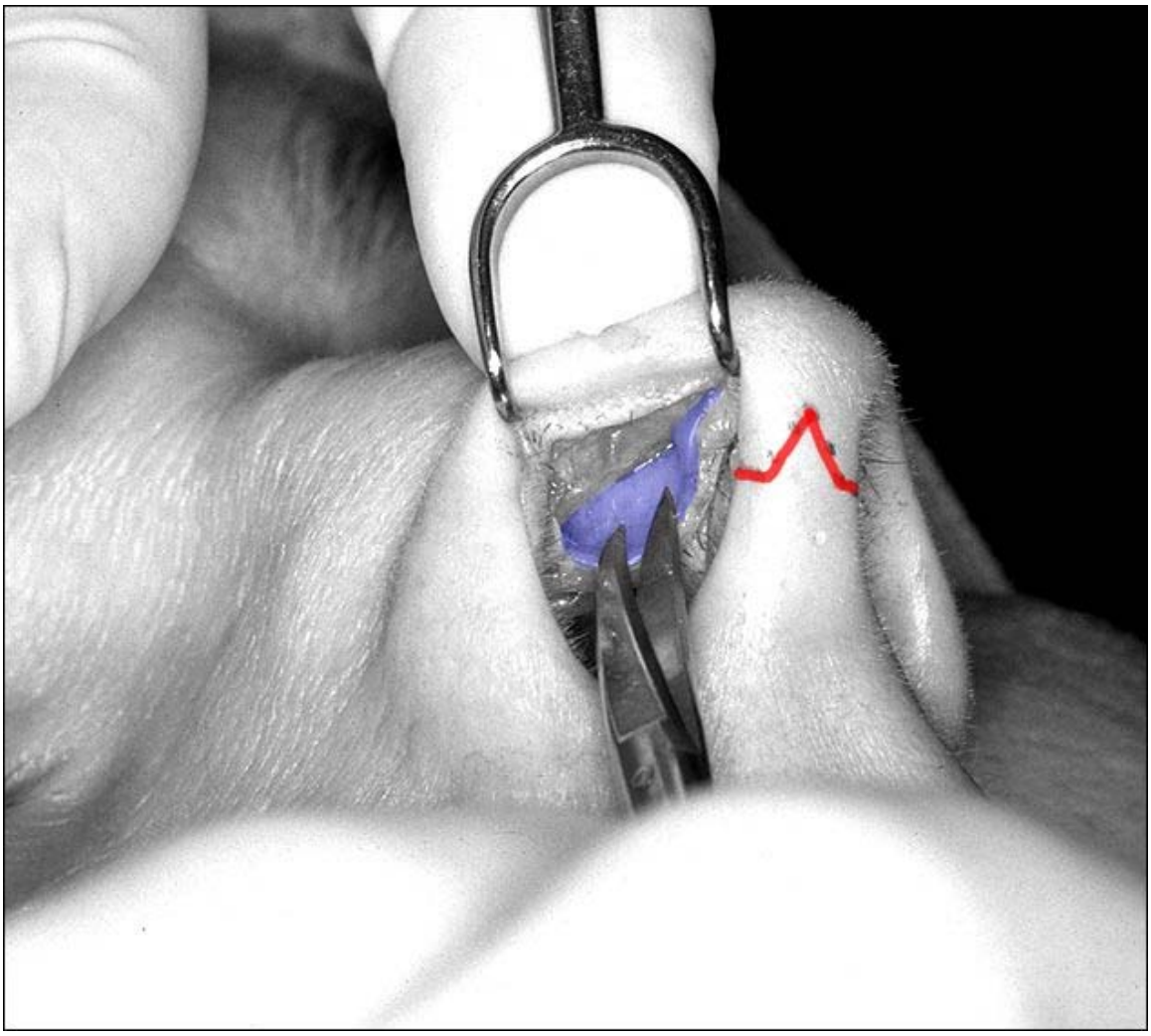
Rhinoplasty can be performed under a general anesthetic, sedation, or with local anesthetic. Initially, local anesthesia, which is a mixture of lidocaine and epinephrine, is injected to numb the area and temporarily reduce vascularity. There are two possible approaches to the nose: closed approach and open approach. In closed rhinoplasty, incisions are made inside the nostrils. In open rhinoplasty, also known as a Coronal Forehead Lift, an additional inconspicuous incision is made across the columella (the bit of skin that separates the nostrils). The surgeon first separates the skin and soft tissues of the nose from the underlying structures. The cartilage and bone are reshaped, and the incisions are sutured closed. Some surgeons use a stent or packing inside the nose, followed by tape or stent on the outside.

In some cases, the surgeon may shape a small piece of the patient's own cartilage or bone, as a graft, to strengthen or change the shape of the nose. Usually the cartilage is harvested from the septum. If there isn't enough septum cartilage, which can occur in revision rhinoplasty, cartilage can be harvested from the concha of the ear or the ribs. In the rare case where bone is required, it is harvested from the cranium, the hip, or the ribs. Sometimes a synthetic implant may be used to augment the bridge of the nose.



Skin incision for an open rhinoplasty. The incision may be “v-shaped” or a “stair-step” shaped incision. This aids the surgeon in attaining a precise closure and for camouflaging the resulting scar.

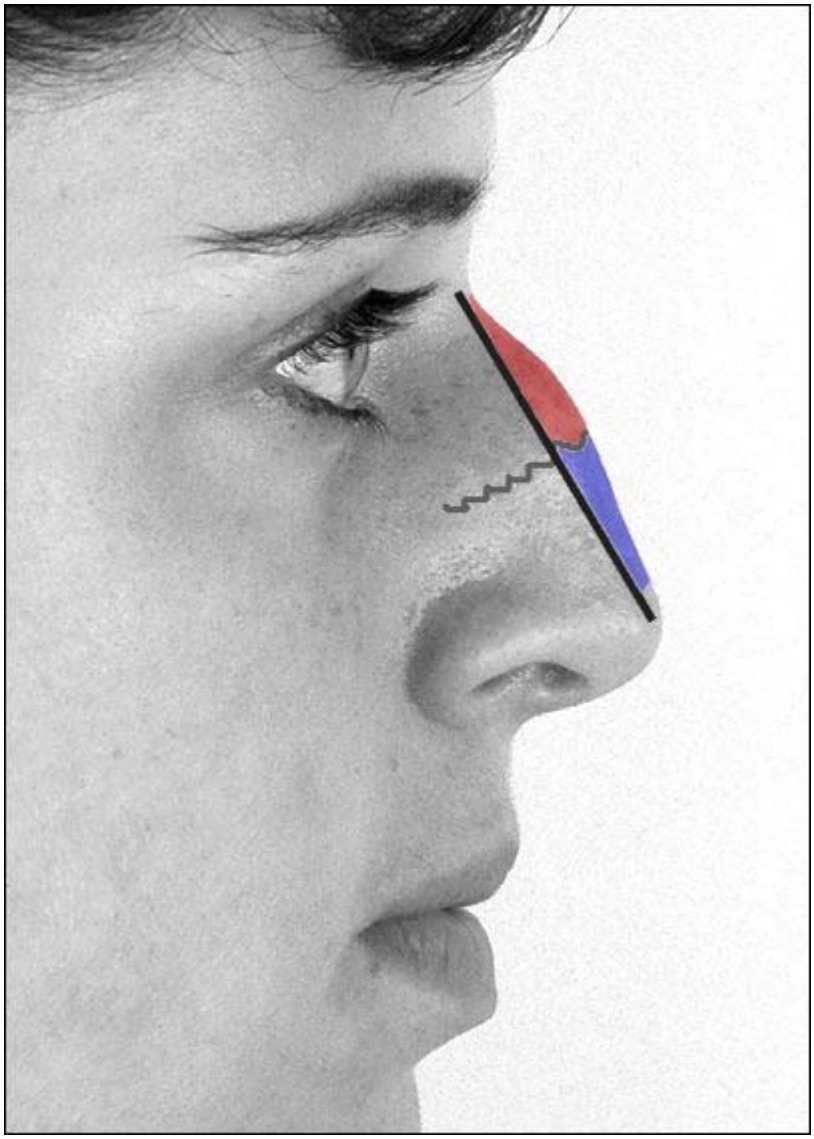
The incisions for a rhinoplasty are hidden inside the nose, with the exception of a small incision across the base of the nose, depicted by the dotted line.



Exposing the cartilages inside the nose

The incisions allow the surgeon to see the size and shape of the cartilages and bones on the inside of the nose, so that they can be altered.

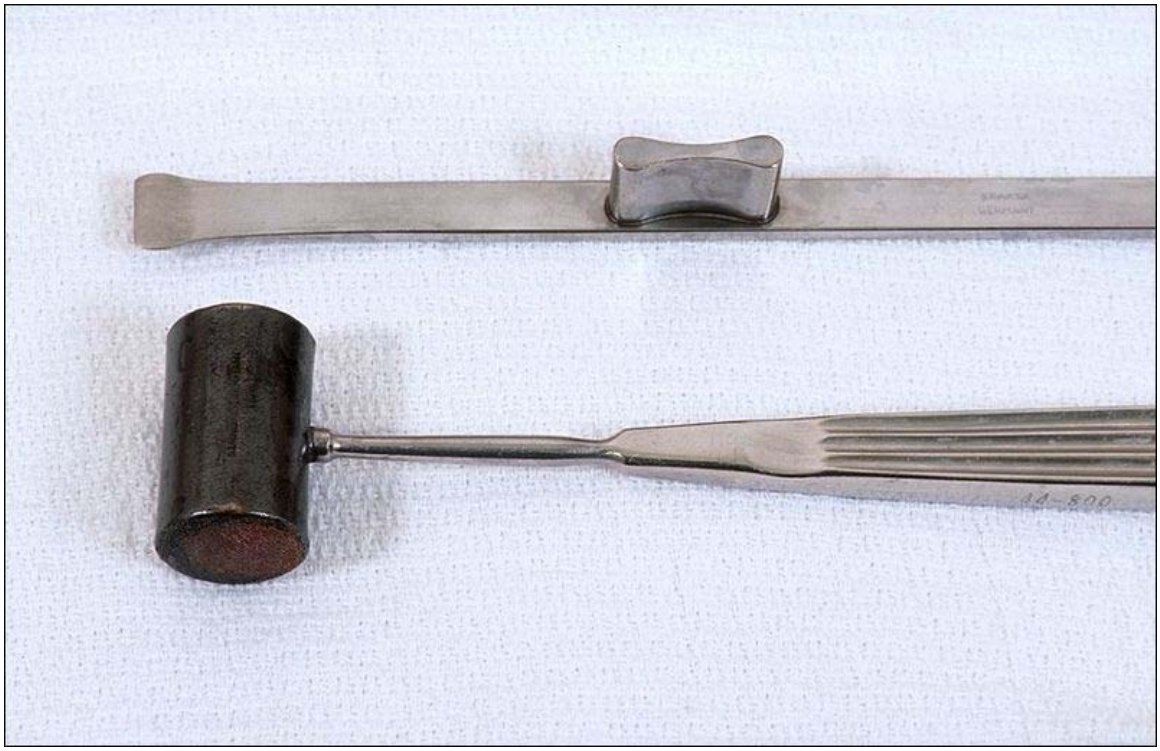
Here, the scissors are pointing out the lower lateral cartilage (in blue), which is one of the cartilages that gives the tip of the nose its shape. The red line shows the location of the planned incision across the bottom of the nose.



Planning excision of a nasal hump

Once the skin has been lifted from the bone and cartilage framework of the nose, often the first task is to remove a hump, if one is present. Part of the hump is made of bone, and part of the hump is cartilage.

In the photograph, the black line shows the desired profile. The nose is made of bone above the scalloped grey line and cartilage below that line. The part of the hump made of bone is shaded red, and the part of the hump made of cartilage is shaded blue.



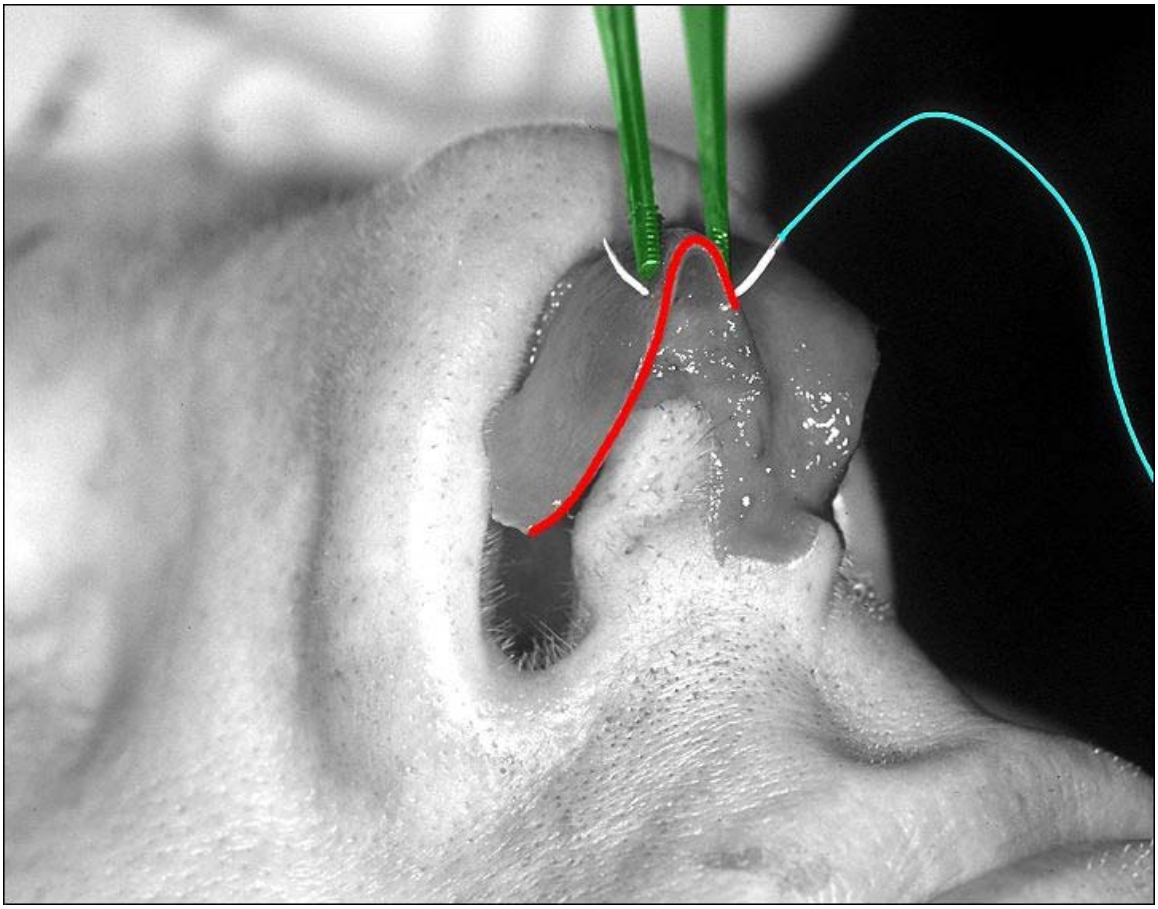
Rhinoplasty osteotome and hammer

The soft cartilage of the hump is removed with a scalpel, and the bony hump is often removed with a chisel, shown at the top of this photograph. "Osteotome" is the medical term for a chisel. This photograph also shows the copper hammer that is used with the osteotome.

Rhinoplasty rasps

After the main part of the hump is removed with an osteotome, files are used to smooth out the remaining bone. The files are also called rasps, and they come in different shapes, orientations, and grades.

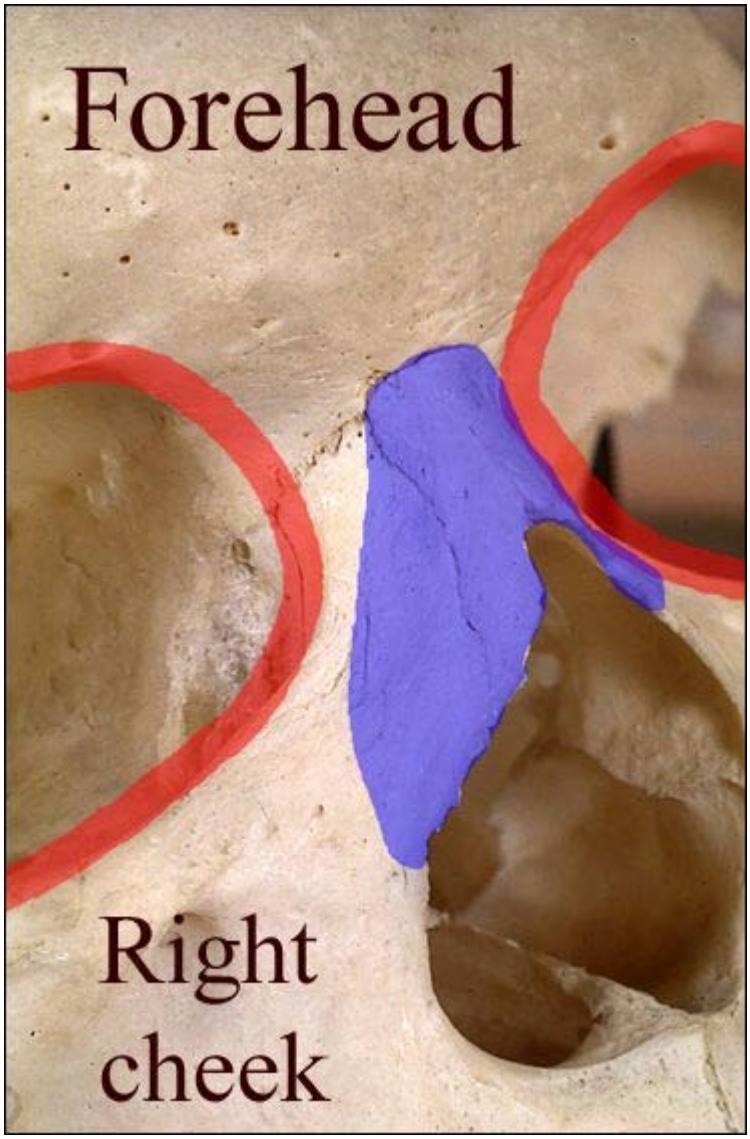
Some surgeons use rasps to remove the entire hump, foregoing use of the osteotome.



One technique to narrow the nasal tip

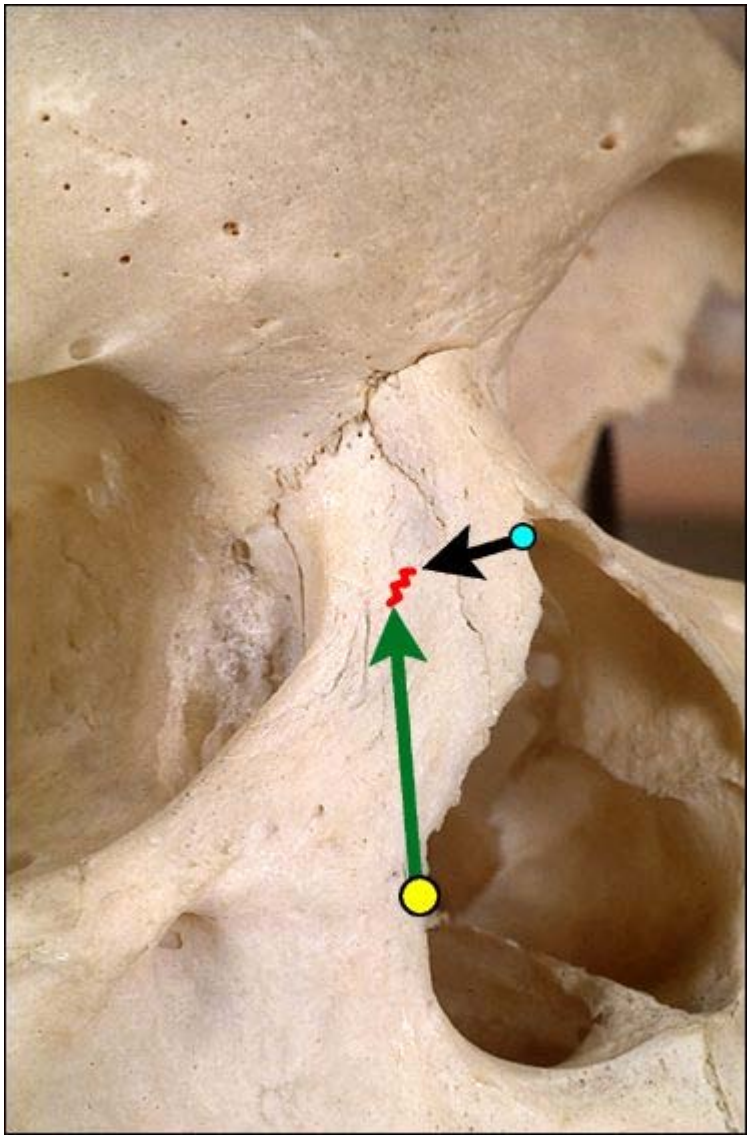
A common complaint is that the tip of the nose is too wide. Many surgical techniques are available to narrow the tip of the nose, depending on what is causing the excess width.

In this photo, a suture is being placed to narrow the tip of the nose. The red line outlines the edge of the tip cartilage, which is narrowed when the suture tightens the fold of the cartilage at its apex. The suture is in light blue, ending in the needle, which appears white in the photograph. The cartilage is being held in place with tweezers, which are shaded green.



The nasal bones

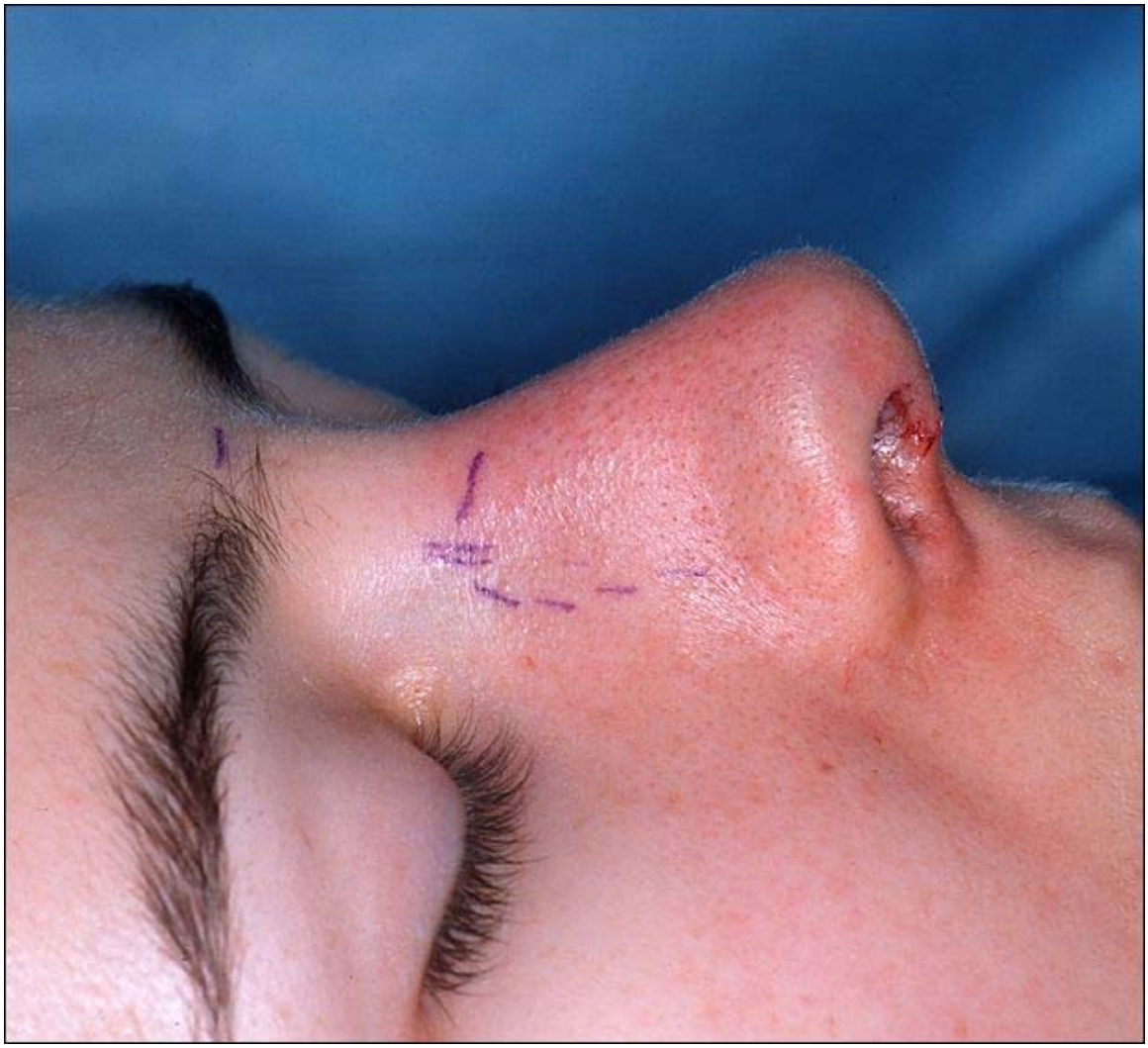
If the position of the nasal bones gives excess width to the upper part of the nose, the bones are moved inward, to a more narrow position. This skull shows in blue the position of the bones in the nose. For orientation, the eye sockets are outlined in red.



Designing the cuts in the nasal bones

To narrow a nasal bone, two cuts are made in the bone with a tiny chisel: one cut starting at the yellow dot and extending up along the green arrow, and another cut starting at the blue dot and extending out along the black arrow. The piece of bone thus loosened from the skull is pushed inward, narrowing the nose.

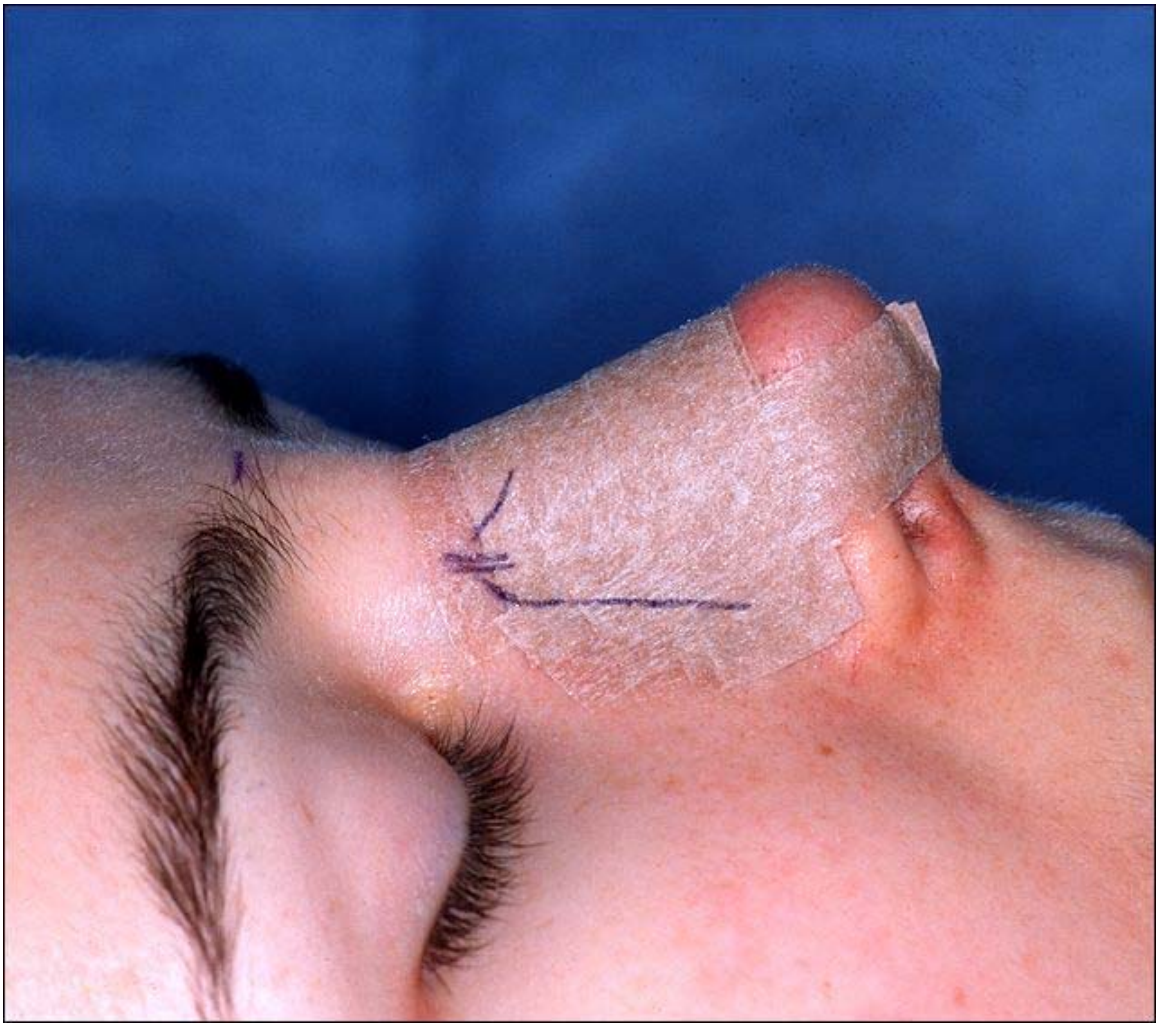
These chisel cuts are made from underneath the skin, so there is no scar in the area after healing.



At the end of the rhinoplasty

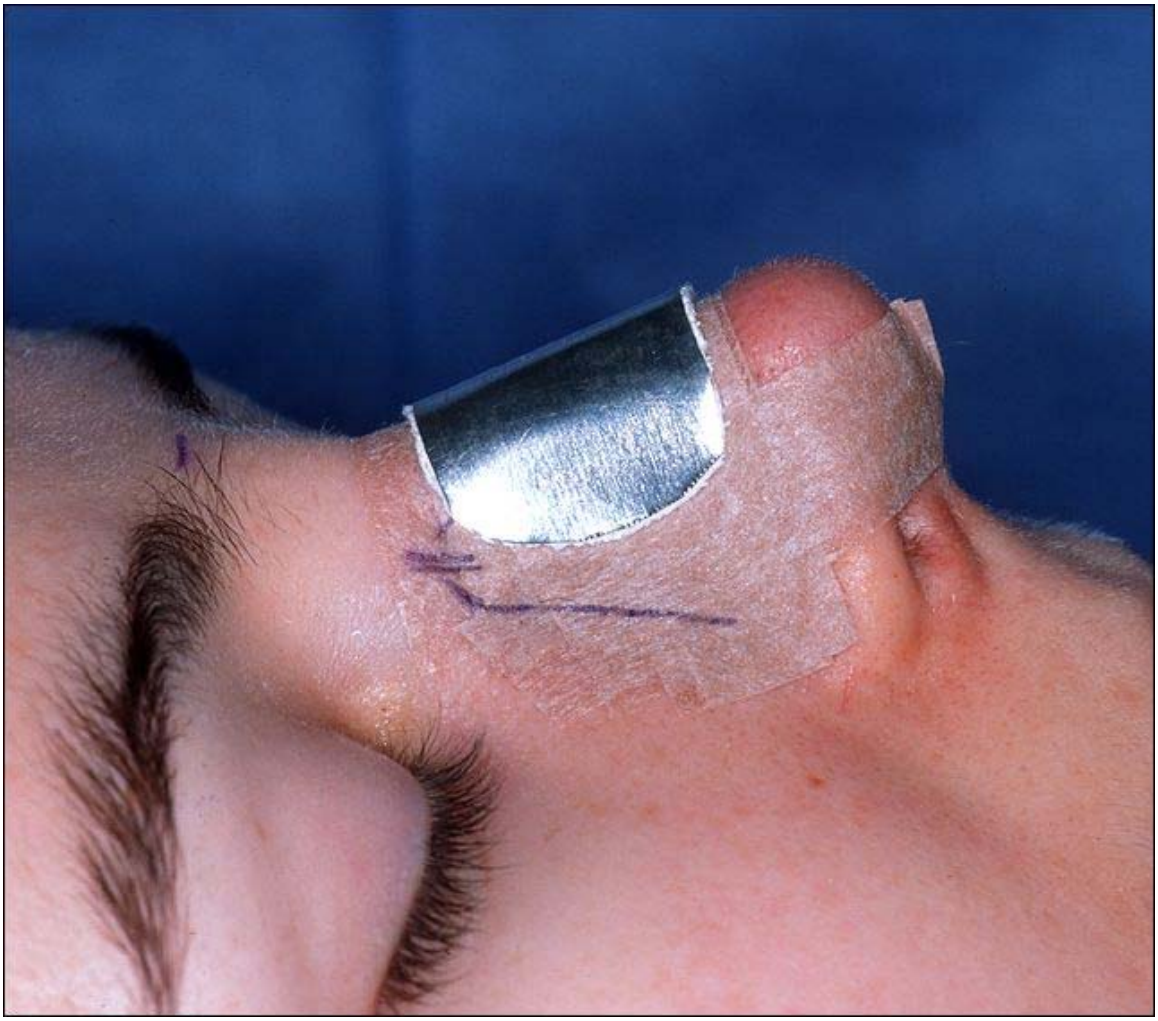
At the end of the procedure, after the incisions are closed, the nose is dressed, to hold it securely in place as it heals.

This photo shows the nose just before the dressing and splint are placed. The purple marks on the nose guided the surgeon in making accurate cuts in the bone during surgery.



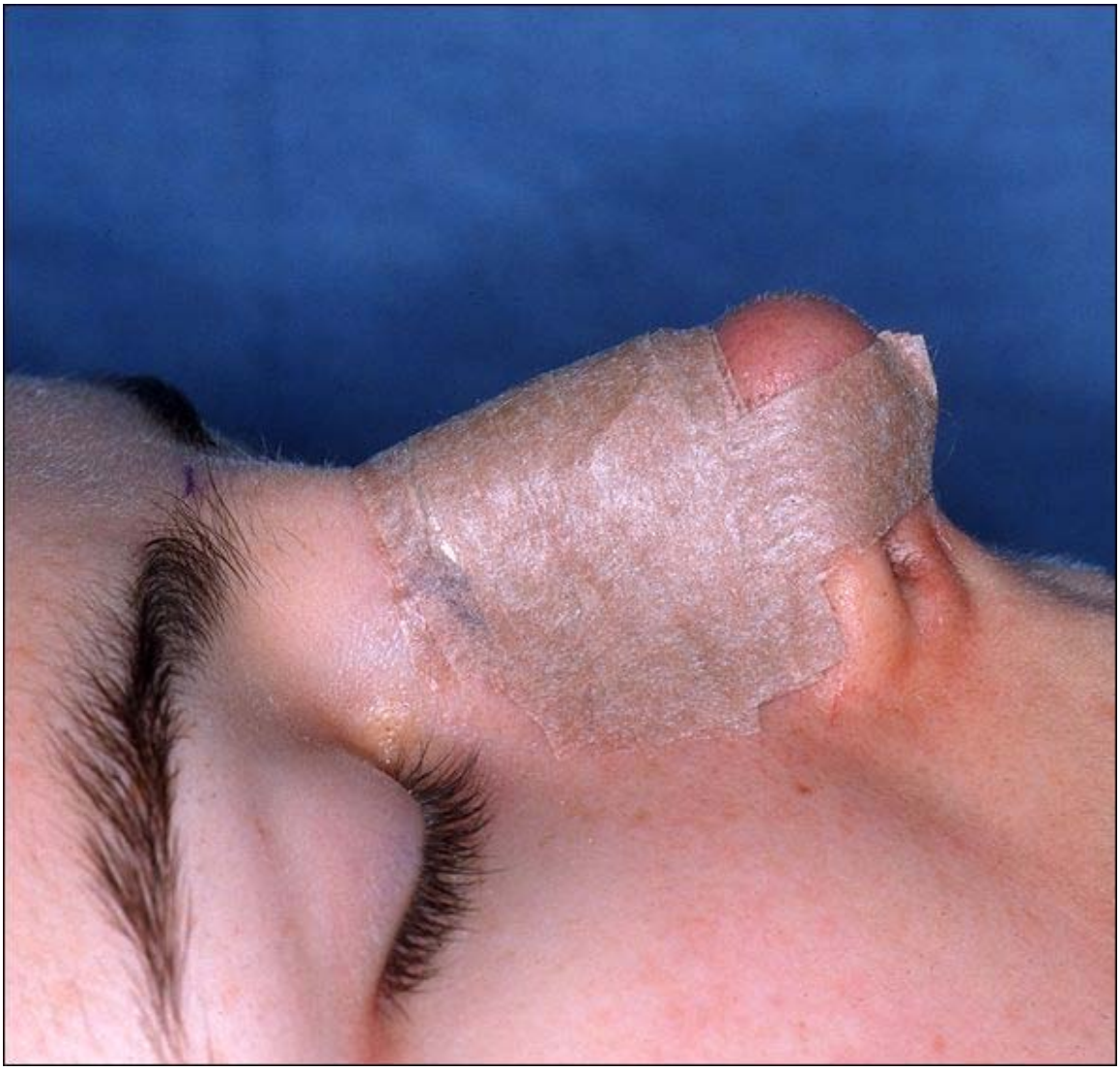
Taping the nose, in preparation for the metal splint

Preparing for the metal splint: the nose is first covered with paper tape in a manner to help maintain the nose's new shape.



Metal nasal splint in place

After taping, the metal splint is designed and cut and shaped, and it is placed on the nose.



Metal nasal splint has been taped on the nose

The metal splint is then covered with the tape, to hold it in place. The operation is now completed. The dressing will be removed in one week.

Primary and secondary

Primary rhinoplasty refers to first-time rhinoplasty whether it is performed for aesthetic, functional, or reconstructive purposes.

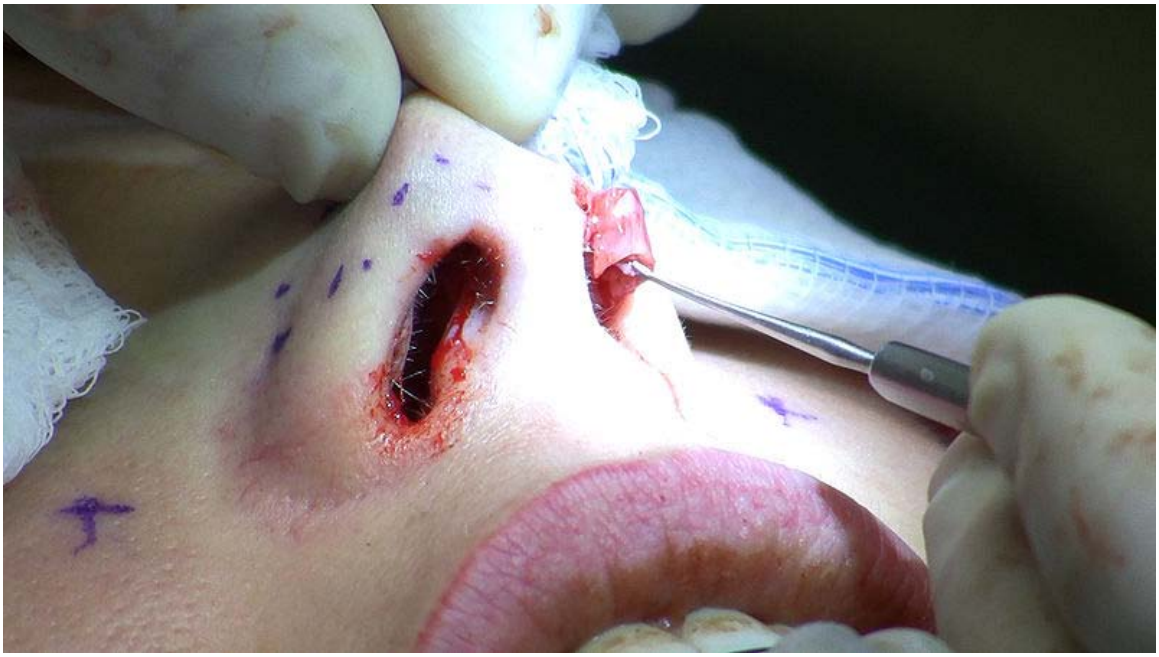
Revision rhinoplasty, also known as secondary rhinoplasty, is a nose operation performed to correct or revise an unsatisfactory outcome from a previous rhinoplasty. An unsatisfactory outcome occurs from 5% to 20% of rhinoplasties. There are two main reasons for performing secondary rhinoplasty. Patients often seek secondary rhinoplasty to correct a cosmetic deformity of the nose. A patient may be unsatisfied with all or part

of a previous "nose reshaping.”. A nasal fracture may not have been reduced enough, or too much. A prominent or bulbous nasal tip may have not been addressed appropriately, or over-aggressively. The nose may looked pinched, it may look like a parrot’s beak, or like a boxer’s nose. There are many ways in which previous nose surgery may have left a nose aesthetically unappealing to a patient. The second reason is functional. The original nasal surgery may have been carried out to help with difficulties in breathing, and the outcome may have been unsatisfactory. Alternatively, the original surgery may have been performed for cosmetic reasons, but may have disrupted a normal physiologic mechanism involving the inspiration or expiration of air, making it difficult to breathe. Secondary rhinoplasty is a procedure often said to be extremely complicated. Because the nasal framework has often been destroyed or deformed from previous surgery, revision rhinoplasty experts frequently must reconstruct the support structures of the nose using cartilage grafts from either the ear (auricular cartilage graft) or from rib cartilage (costal cartilage graft). Most revision rhinoplasty specialists perform secondary rhinoplasty via the open approach. This allows the surgeon to directly visualize the deformity. Advances in rhinoplasty techniques, such as stabilization of rib cartilage grafts and utilization of the open approach, now allow satisfactory results in secondary rhinoplasty that were not possible in the past.

Functional and reconstructive

Reconstructive rhinoplasty refers to restoring the normal shape and function of the nose following damage from a traumatic accident, autoimmune disorder, intra-nasal drug abuse, previous injudicious cosmetic surgery, cancer involvement, or congenital abnormality. Rhinoplasty can restore skin coverage, recreate normal contours, and re-establish nasal airflow. To improve nasal breathing function, a septoplasty may also be performed. If there is turbinate hypertrophy, an inferior turbinectomy can be performed.

Rhinoplasty may be sought in the aftermath of traumatic deformity. Traumatic accidents are the most common cause of nasal deformity. Typically the nasal bones are broken and displaced. Occasionally, the nasal cartilages are disrupted or displaced, and in the worst cases the nasal dorsum is collapsed. Rhinoplasty allows shaving of the displaced bony humps, and re-alignment of the nasal bones after they are cut. When cartilage is disrupted, stitching of the cartilage for re-suspension, or use of cartilage grafts to camouflage depressions allows re-establishment of normal nasal contour. When the dorsum is collapsed, grafts of rib cartilage, ear cartilage, or cranial bone can be used to restore continuity to the dorsum. Although synthetic implants are also available for augmenting the nasal dorsum, cartilage or bone graft from the patient’s own body poses fewer risks of infection or rejection.



The lower lateral cartilage (greater alar cartilage) exposed through the left nostril for modification during a rhinoplasty.

Rhinoplasty is sometimes sought for a collapsed nose due to septum perforation. Autoimmune problems such as Wegener's Granulomatosis, Sarcoidosis, Churg-Strauss Syndrome, and Relapsing Polychondritis can lead to creation of a hole in the nasal septum, and loss of support in the dorsum leading to a saddle nose deformity. Intra nasal use of drugs such as cocaine, or extreme abuse of nasal decongestant sprays can similarly cause septum perforation and nasal dorsum collapse. Dorsum reconstruction is accomplished through the use of rib cartilage or bone grafts.

Rhinoplasty to correct nasal obstruction following injudicious cosmetic surgery is common. Reconstructive rhinoplasty after injudicious cosmetic surgery allows the restoration of normal breathing. When nasal cartilages are over-aggressively trimmed during rhinoplasty, the nose can appear pinched and nasal potency compromised. Patients complain of nasal blockage that is worsened by attempts at deep inspiration. Internal cartilage grafts to support the nasal tip (batton grafts) or widen the middle vault of the nose (spreader grafts) can be quite effective in restoring normal breathing. These grafting techniques will increase the size of the nasal tip and widen the dorsum.

Rhinoplasty for skin cancer excision also exists. Excision of skin cancers from the nose can lead to loss of internal support as well as external skin coverage. Skin cancer excision in the nose is commonly accomplished via the Mohs' technique. Once the cancer is removed, reconstructive rhinoplasty aims to provide skin coverage utilizing techniques such as skin graft, local skin flaps, or pedicle flaps. If cancer resection leads to loss of tissue in the area of the nasal tip, cartilage grafts are utilized to maintain support and prevent long-term distortion, by the force of scar contracture.

Rhinophyma is the late stage manifestation of a skin condition known as Rosacea, where the skin is infected with acne roseacea. The skin in the area of the nasal tip becomes red, thickened, and enlarged as exemplified by W C Fields. Although known acne treatments such as antibiotics and Acutane can halt the progression of this disease, thickening of the skin and obscuring of the nasal tip landmarks can only be remedied by surgical correction. Currently, laser excision of thickened abnormal skin represents the best option in rhinoplasty for Rhinophyma. The CO2 laser and the Erbium YAG laser are the most effective types of laser for this disorder.

Vascular malformations and cleft lip anomalies are relatively common causes of congenital nasal deformities. In vascular malformations, the disease process can cause distortions of the skin and underlying structure of the nose. In cleft palate abnormalities, the size, position, and orientation of the nasal tip cartilages may be distorted. Rhinoplasty for reconstruction of vascular malformations can involve laser treatment of the skin and possible surgical excision. When the underlying cartilage structure is disturbed, cartilage grafts and stitching of the native nasal cartilages can help improve nasal appearance. In cleft lip patients, reconstructive rhinoplasty allows re-orientation of the nasal tip cartilages. Additional refinements with cartilage grafts to the tip are also frequently employed.

Ethnic

Although techniques and methods employed during rhinoplasty surgeries are the same regardless of ethnicity, there are some trends that apply to patients of certain ethnic backgrounds, due to their similar anatomic features. East Asian patients often want their noses to appear narrower and their bridges higher. If very little elevation of the bridge is desired, the nasal bones can be cut and moved towards the midline. This technique will narrow the bridge and also cause a slight elevation in the dorsum. East Asian patients who seek greater augmentation of the bridge of their nose require implants. A variety of alloplastic implants including Gore-Tex, Med-Por, or silicone can be used. Tissues from the patient's own body (autologous) can be used for augmentation, in order to reduce the risk of complications such as infection or extrusion. Septum cartilage, rib cartilage (costal cartilage), ear cartilage (auricular cartilage), and fascia are being often used. In non surgical rhinoplasty, filler materials such as hyaluronic acid or calcium based microspheres can be injected under the skin, in the bridge of the nose. These injections however, are non permanent lasting between six months to a year.

Patients of African descent commonly seek narrowing of wide nostrils in a procedure known as alar base reduction. This procedure may include removing sections of the base of the nostrils or sections of the nose where it meets the face. Risk of keloid scar formation is very low, if the patient has not had keloids in the past. The tip of the nose can be restructured by removing tiny sections of cartilage to give the nose more definition, or adding cartilage grafts to provide additional structure to the nasal tip.

Non-surgical

Non-surgical rhinoplasty refers to reshaping the nose with injectable substances rather than surgical means of altering the shape and structure of the nose. It is also called a "non-surgical nose job", and can be performed in the outpatient setting without anesthesia. Another non-surgical option used by some people are flexible "nose inserts" that are placed in the nostril area between the nose tip and back of the nose. The nose inserts reshape one's nose only while worn. A non-surgical nose job is not permanent and only lasts about a month.

Recovery

The patient returns home after the surgery. Most surgeons recommend antibiotics, pain medications, and steroid medication after surgery. Most people choose to remain home for a week, although it is safe to be outdoors. If there are external sutures, they are usually removed 4 to 5 days after surgery. The external cast is removed at one week. If there are internal stents, they are usually removed at four days to two weeks. The periorbital bruising usually lasts two weeks. Due to wound healing, there is moderate shifting and settling of the nose over the first year.

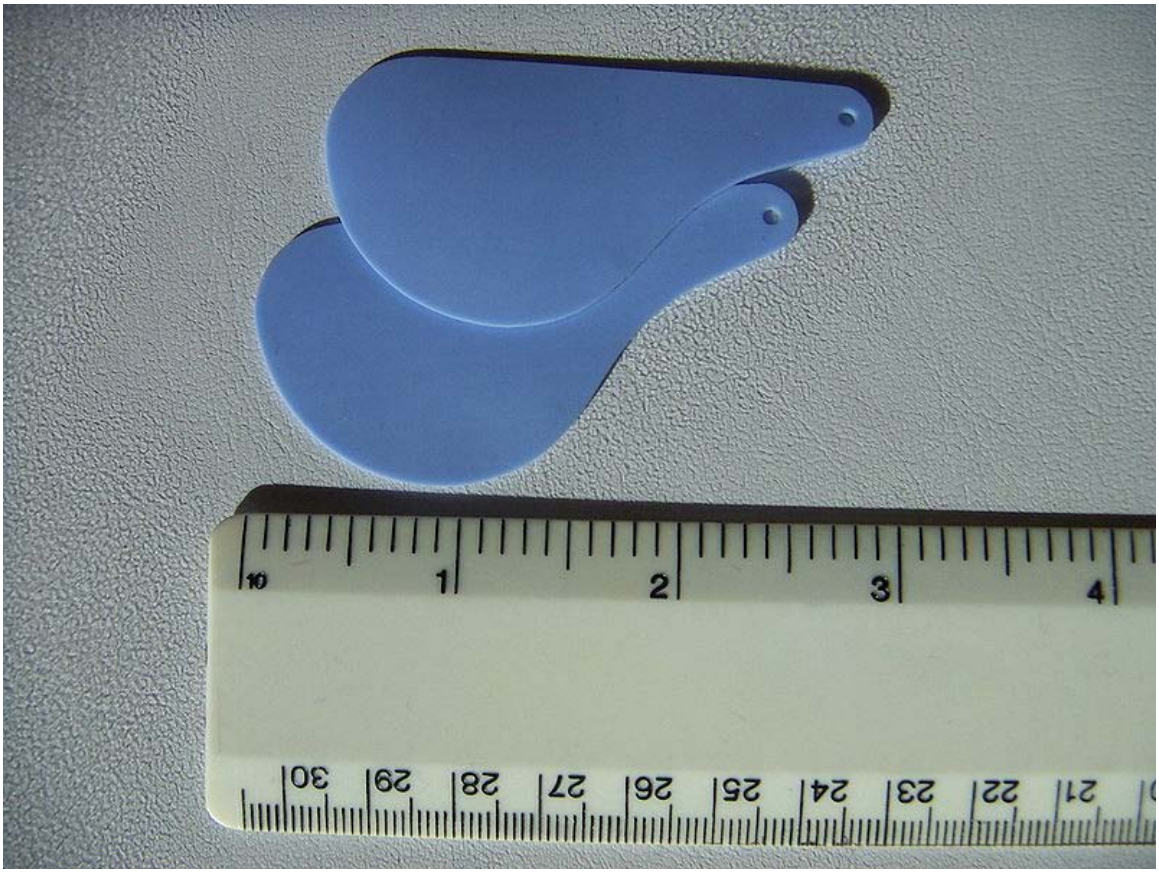
Health risks

Although rhinoplasty is usually considered to be safe and successful, several complications can arise. Post operative bleeding is uncommon and often resolves without needing treatment. Infection is rare and can occasionally progress to an abscess that requires surgical drainage under general anesthetic. Adhesions, which are scars that form to bridge across the nasal cavity from the septum to the turbinates, are also rare but cause nasal obstruction to breathing and usually need to be cut away. A hole can be inadvertently made at the time of surgery in the septum, called a septal perforation. This can cause chronic nose bleeding, crusting, difficult breathing and whistling with breathing.

If too much of the underlying structure of the nose (cartilage and/or bone) is removed, this can cause the overlying nasal skin to have little shape resulting in a "polly beak" deformity. Likewise if the septum is not supported, the bridge of the nose can sink resulting in a "saddle nose" deformity. The tip of the nose can be over-rotated causing the nostrils to be too visible and creating a pig-like look. If the cartilages of the tip of the nose are over-resected, this can cause a pinched look to the tip. If an incision is made across the collumella (open approach rhinoplasty) there can be variable degree of numbness to the nose that may take months to resolve.

Septoplasty

Septoplasty is a corrective surgical procedure done to straighten the nasal septum, the partition between the two nasal cavities. Ideally, the septum should run down the center of the nose. When it deviates into one of the cavities, it narrows that cavity and impedes airflow. Often the inferior turbinate on the opposite side enlarges, which is termed *compensatory hypertrophy*. Nasal obstructions caused by serious deviations frequently lead to chronic sinus problems. Turbinate reduction may also be advised to further enlarge the nasal cavities. If turbinate resection is indicated, special care should be taken to avoid over-resection leading to empty nose syndrome. Most surgeries are completed in 90 minutes or less, not including recovery time.



Typical flexible splints that may be used in septoplasty. They are held in place in the nose with a stitch through the hole, and are typically removed seven to 10 days after surgery.

Procedure

Because the deviation is a result of a cartilage and/or bone surplus, the procedure usually involves an excision of a portion of any of these tissues. Under general or local anesthesia, the surgeon works through the nostrils, making an incision in the lining of the septum to reach the cartilage targeted in the operation. Often an "L" strut of cartilage in

the dorsal and caudal areas (1 cm width or more) is preserved for structural support. After excess cartilage and bone have been taken out, the septum may then be stabilized with small plastic tubes, splints, or sutures.

Post-operation

Considerable swelling and bruising can be expected. The nasal cavities may or may not be packed, and a piece of gauze is taped the septal mucosa with catgut can avoid the use of nasal packing, a nasal clip or tamponade. The suturing will promptly prevent bleeding and synaechae formation as well as septal perforation due to the pressure necrosis by the pack.

Chapter 2

Tracheo-Oesophageal Puncture and Pneumonectomy

Tracheo-oesophageal puncture

A **tracheo-oesophageal puncture** (or **tracheoesophageal puncture**) is a surgically created hole between the trachea (windpipe) and the esophagus (the tubal pathway between the throat and the stomach) in a person who has had a total laryngectomy, a surgery where the larynx (voice box) is removed. The purpose of the puncture is to restore a person's ability to speak after the vocal cords have been removed. This involves creation of a fistula between trachea and oesophagus, puncturing the short segment of tissue or "common wall" that typically separates these two structures. A voice prosthesis is inserted into this puncture. The prosthesis keeps food out of the trachea but lets air into the esophagus for oesophageal speech.

A laryngectomized person is required to breathe through a permanent breathing hole in the neck, called a tracheostoma. When a laryngectomized person occludes the tracheostoma, completely blocking exhaled air to leave the body through that pathway, exhaled air is directed through the voice prosthesis. This air enters the esophagus and escapes through the mouth. During this process, as the air passes through the upper tissues of the esophagus and lower throat, it allows for vibration of the tissues of the pharyngoesophageal segment (also called PE-segment, neoglottis or pseudoglottis). This vibration creates a sound that serves to replace the sound the vocal cords previously produced. This type of speech is called tracheoesophageal speech. It is the most popular method of voice restoration after total laryngectomy., Other methods of alaryngeal speech (i e speech without vocal cords) are esophageal speech, and artificial larynx speech. Studies show that tracheoesophageal speech is found to be closer to normal speech than esophageal speech and is often reported to be better, both in terms of naturalness as well as how well it is understood, when compared to esophageal speech and electrolarynx speech. The first report on a tracheoesophageal puncture dates back to 1932 when a laryngectomized patient was said to use a hot ice pick to create a

tracheoesophageal puncture in himself. This enabled him to speak by forcing air through the puncture when closing off the tracheostoma with a finger.

Puncture procedures

There are two tracheo-esophageal puncture procedure types: Primary and secondary puncture. Initially, the procedure was described as a secondary procedure and later also as a primary procedure.

Primary tracheoesophageal puncture: This procedure is performed during the total laryngectomy surgery. After removal of the larynx and creation of the tracheostoma, the puncture is made through the back wall of the trachea into the front wall of the esophagus. The main advantages of a primary puncture are: 1) that a second surgery to create the puncture is avoided (including the related costs and risks) and: 2) that the patient will be able to speak within a few weeks after total laryngectomy.

There are cases where a primary procedure cannot be performed. For example, this procedure cannot be used when there is complete separation of the tracheoesophageal wall where the puncture would otherwise be placed (for example, in case a portion of the esophagus is removed requiring an anastomosis, or "reconnection" of structures in the region). In that case, a sufficient period of recovery and wound healing would be required. A secondary puncture could then be placed. Secondary tracheoesophageal puncture: This procedure refers to a puncture that is placed anytime after the total laryngectomy surgery. The decision to use a primary or secondary puncture can vary greatly. Secondary puncture can be performed when: 1) primary puncture was not possible, 2) for re-puncture after closure of a previous tracheoesophageal puncture, 3)because of physician or patient preference, and 4) in case failure of esophageal or electrolarynx speech if this was chosen as the initial speech option.

Placement of the voice prosthesis

There are two different methods that can be used to place the voice prosthesis: Primary placement: A voice prosthesis is placed into the puncture immediately after it is created. During the immediate postoperative period, the patient is fed through a feeding tube, either inserted directly into the stomach or through a more temporary version than extends from the nose into the stomach. This tube is removed when the patient is able to eat enough by mouth to maintain nutritional needs; this can be as early as the second day following surgery. Speech production with the voice prosthesis is initiated when the surgical area has healed, after clearance by the surgeon. The advantages of this method are: 1) the voice prosthesis stabilizes the TE wall, 2) the flanges of the device protect the puncture against leakage of fluids, stomach acids and other stomach contents, 3) there is no irritation or pressure from a stenting catheter, used to maintain the puncture opening until a voice prosthesis can be placed, 4) patients become quickly familiar with their prosthesis care as they receive instructions while hospitalized, 5) the patient will not have to undergo an outpatient procedure during which the voice prosthesis needs to be fitted,

6) many patients can learn to speak before the start of any post-operative radiation therapy (if indicated) 7) the patient can focus on voice production immediately, as wound healing allows.

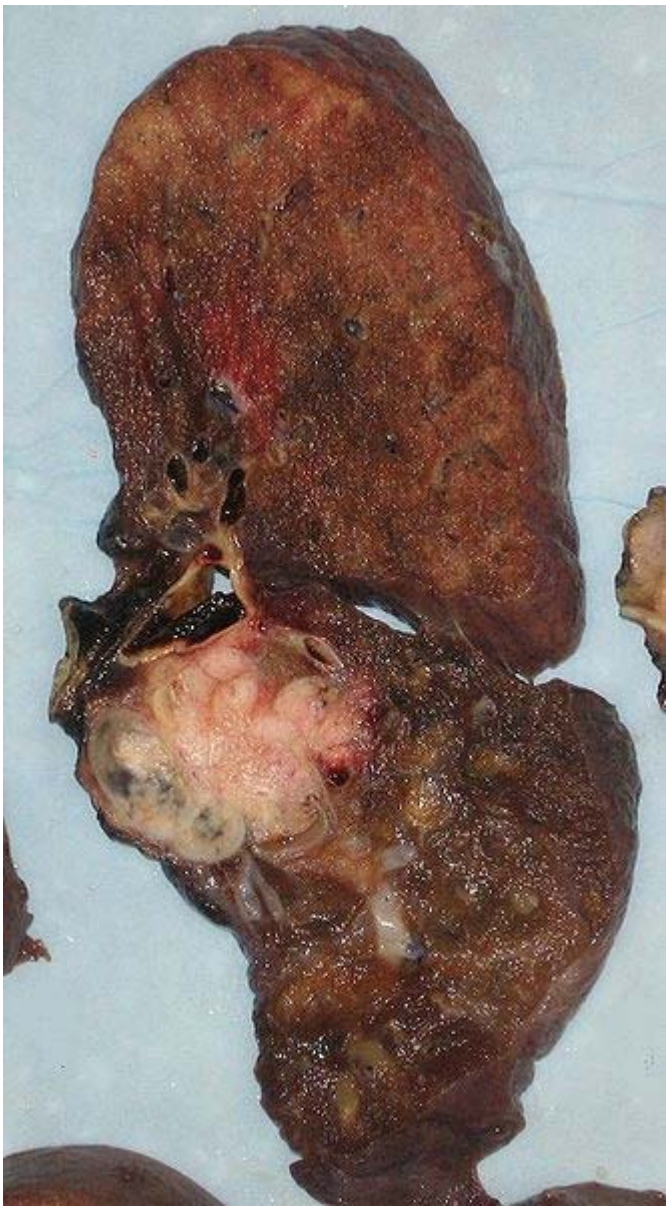
Another advantage is that generally, the voice prosthesis placed at the time of surgery lasts relatively long and requires no early frequent replacements. The only disadvantage is that the patient will need to use a feeding tube for a few days.

Delayed placement: Instead of the voice prosthesis, a catheter (red rubber, Silastic Foley catheter, Ryle's tube) is introduced through the puncture into esophagus. The tube is sometimes utilized for feeding the patient during the immediate post operative period, or the patient has a standard feeding tube for feeding. The voice prosthesis is placed after the patient is able to eat sufficiently by mouth and speech production is initiated when healing has completed, after clearance by the surgeon. The advantage of this method is that the patient may be fed through the catheter, not requiring standard tube feeding. The primary disadvantage is that the patient will have to undergo an outpatient procedure to have the voice prosthesis placed. Another disadvantage can be the need for more frequent replacements early after fitting of the voice prosthesis due to changes in the length of the puncture.

Indications

Indications include voice rehabilitation for patients who are undergoing a total laryngectomy (primary puncture) or patients who have had a total laryngectomy in the past (secondary puncture). Contra-indications are mainly related to the use of the voice prosthesis and not the puncture procedure itself. It is important to have healthy tissue at the puncture site. This will help ensure the voice prosthesis is properly supported. Poor tissue condition at the puncture site can be a contra-indication for TE puncture. It is also important that the patient candidacy be taken into account. Patients must be able to understand and manage proper prosthesis maintenance and monitor for complications or device problems. Bleeding disorders, anxiety disorders, dementia, poor vision and poor manual dexterity are all factors that may negatively interfere with successful voice restoration using tracheoesophageal techniques and should be discussed further with an appropriate healthcare provider who is knowledgeable in this topic.

Pneumonectomy



Appearance of the cut surface of a pneumonectomy specimen containing a lung cancer, here a Squamous cell carcinoma (the whitish tumor near the bronchi).

A **pneumonectomy** (or pneumectomy) is a surgical procedure to remove a lung. Removal of just one lobe of the lung is specifically referred to as a lobectomy, and that of a segment of the lung as a wedge resection (or segmentectomy).

Indications

The most common reason for a pneumonectomy is to remove tumourous tissue arising from lung cancer. In the days prior to the use of antibiotics in tuberculosis treatment, tuberculosis was sometimes treated surgically by pneumonectomy.

The operation will reduce the respiratory capacity of the patient; before conducting a pneumonectomy, the surgeon will evaluate the ability of the patient to function after the lung tissue is removed. After the operation, patients are often given an incentive spirometer to help exercise their remaining lung and to improve breathing function.

A rib or two is sometimes removed to allow the surgeon better access to the lung.

Types

There are two types of pneumonectomy:

1. **Simple pneumonectomy**: removal of just the affected lung
2. **Extrapleural pneumonectomy** (EPP): removal of the affected lung, plus part of the diaphragm, the parietal pleura (lining of the chest) and the pericardium (lining of the heart) on that side. The linings are replaced by Gore-Tex in this radical and painful surgery that is used primarily for treatment of malignant mesothelioma. This technique produces the best long-term survival rates for this serious and fatal disease.

History

Pioneering dates

- 1895: first pneumonectomy in multiple stages by William Macewen on a patient with tuberculosis and emphysema
- 1931: first successful pneumonectomy in two stages by Rudolph Nissen on a patient with crush injury to the thorax
- 1932: first lobectomy, by Harold Brunn
- 1933: first successful single-stage total pneumonectomy by Graham and Singer
- 1939: first segmentectomy, by Churchill and Belsey

Chapter 3

Lung Transplantation

Lung transplantation, or **pulmonary transplantation** is a surgical procedure in which a patient's diseased lungs are partially or totally replaced by lungs which come from a donor. While lung transplants carry certain associated risks, they can also extend life expectancy and enhance the quality of life for end-stage pulmonary patients.

Qualifying conditions

Lung transplantation is the therapeutic measure of last resort for patients with end-stage lung disease who have exhausted all other available treatments without improvement. A variety of conditions may make such surgery necessary. As of 2005, the most common reasons for lung transplantation in the United States were:

- 27% chronic obstructive pulmonary disease (COPD), including emphysema;
- 16% idiopathic pulmonary fibrosis;
- 14% cystic fibrosis;
- 12% idiopathic (formerly known as "primary") pulmonary hypertension;
- 5% alpha 1-antitrypsin deficiency;
- 2% replacing previously transplanted lungs that have since failed;
- 24% other causes, including bronchiectasis and sarcoidosis.

Contraindications

Despite the severity of a patient's respiratory condition, certain preexisting conditions may make a person a poor candidate for lung transplantation. These conditions include:

- concurrent chronic illness (e.g. congestive heart failure, kidney disease, liver disease);
- current infections, including HIV and hepatitis, although more and more often Hepatitis C patients are both being transplanted and are also being used as donors if the recipient is Hepatitis C positive.
- current or recent cancer;

- current use of alcohol, tobacco, or illegal drugs;
- age;
- psychiatric conditions;
- history of noncompliance with medical instructions.

History

The history of organ transplants began with several attempts that were unsuccessful due to transplant rejection. Animal experimentation by various pioneers, including Vladimir Demikhov and Dominique Metras, during the 1940s and 1950s, first demonstrated that the procedure was technically feasible. James Hardy of the University of Mississippi performed the first human lung transplant in 1963. Following a left lung transplantation, the patient survived for 18 days. From 1963-1978, multiple attempts at lung transplantation failed because of rejection and problems with anastomotic bronchial healing. It was only after the invention of the heart-lung machine, coupled with the development of immunosuppressive drugs such as cyclosporine, that organs such as the lungs could be transplanted with a reasonable chance of patient recovery.

The first successful transplant surgery involving the lungs was a heart-lung transplant, performed by Dr. Bruce Reitz of Stanford University on a woman who had idiopathic pulmonary hypertension.

- 1983: First successful long term single lung transplant (Tom Hall) by Joel Cooper (Toronto)
- 1986: First successful long term double lung transplant (Ann Harrison) by Joel Cooper (Toronto)
- 1988: First successful long term double lung transplant for cystic fibrosis by Joel Cooper (Toronto)

Transplant requirements

Requirements for potential donors

There are certain requirements for potential lung donors, due to the needs of the potential recipient. In the case of living donors, this is also in consideration of how the surgery will affect the donor.

- healthy;
- size match; the donated lung or lungs must be large enough to adequately oxygenate the patient, but small enough to fit within the recipient's chest cavity;
- age;
- blood type.

Requirements for potential recipients

While each transplant center is free to set its own criteria for transplant candidates, certain requirements are generally agreed upon:

- end-stage lung disease;
- has exhausted other available therapies without success;
- no other chronic medical conditions (e.g. heart, kidney, liver);
- no current infections or recent cancer. There are certain cases where preexisting infection is unavoidable, as with many patients with cystic fibrosis. In such cases, transplant centers, at their own discretion, may accept or reject patients with current infections of *B. cepacia* or *MRSA*.
- no HIV or hepatitis;
- no alcohol, smoking, or drug abuse;
- within an acceptable weight range (marked undernourishment or obesity are both associated with increased mortality);
- age (single vs. double tx);
- acceptable psychological profile;
- has social support system;
- financially able to pay for expenses; (in places where medical care is paid for directly by the patient)
- able to comply with post-transplant regimen. A lung transplant is a major operation, and following the transplant, the patient must be willing to adhere to a lifetime regimen of medications as well as continuing medical care.

Medical tests for potential transplant candidates

Patients who are being considered for placement on the organ transplant list must undergo an extensive series of medical tests in order to evaluate their overall health status and suitability for transplant surgery.

- blood typing; the blood type of the recipient must match that of the donor due to certain antigens that are present on donated lungs. A mismatch of blood type can lead to a strong response by the immune system and subsequent rejection of the transplanted organs;
- tissue typing; ideally, the lung tissue would also match as closely as possible between the donor and the recipient, but the desire to find a highly compatible donor organ must be balanced against the patient's immediacy of need;
- Chest X-ray - PA & LAT, to verify the size of the lungs and the chest cavity;
- pulmonary function tests;
- CT Scan (High Resolution Thoracic & Abdominal);
- Bone mineral density scan;
- MUGA (Gated cardiac blood pool scan);
- Cardiac stress test (Dobutamine/Thallium scan);
- ventilation/perfusion (V/Q) scan;
- electrocardiogram;

- cardiac catheterization;
- echocardiogram.

Lung allocation score

Prior to 2005, donor lungs within the United States were allocated by the United Network for Organ Sharing on a first-come, first-serve basis to patients on the transplant list. This was replaced by the current system, in which prospective lung recipients of age of 12 and older are assigned a lung allocation score or LAS, which takes into account various measures of the patient's health. The new system allocates donated lungs according to the immediacy of need rather than how long a patient has been on the transplant list. Patients who are under the age of 12 are still given priority based on how long they have been on the transplant waitlist. The length of time spent on the list is also the deciding factor when multiple patients have the same lung allocation score.

Patients who are accepted as good potential transplant candidates must carry a pager with them at all times in case a donor organ becomes available. These patients must also be prepared to move to their chosen transplant center at a moment's notice. Such patients may be encouraged to limit their travel within a certain geographical region in order to facilitate rapid transport to a transplant center.

Types of lung transplant

Lobe

A lobe transplant is a surgery in which part of a living donor's lung is removed and used to replace part of recipient's diseased lung. This procedure usually involves the donation of lobes from two different people, thus replacing a single lung in the recipient. Donors who have been properly screened should be able to maintain a normal quality of life despite the reduction in lung volume.

Single-lung

Many patients can be helped by the transplantation of a single healthy lung. The donated lung typically comes from a donor who has been pronounced brain-dead.

Double-lung

Certain patients may require both lungs to be replaced. This is especially the case for people with cystic fibrosis, due to the bacterial colonisation commonly found within such patients' lungs; if only one lung were transplanted, bacteria in the native lung could potentially infect the newly transplanted organ.

Heart-lung

Some respiratory patients may also have severe cardiac disease which would necessitate a heart transplant. These patients can be treated by a surgery in which both lungs and the heart are replaced by organs from a donor or donors.

A particularly involved example of this has been termed a "domino transplant" in the media. First performed in 1987, this type of transplant typically involves the transplantation of a heart and lungs into recipient A, whose own healthy heart is removed and transplanted into recipient B.

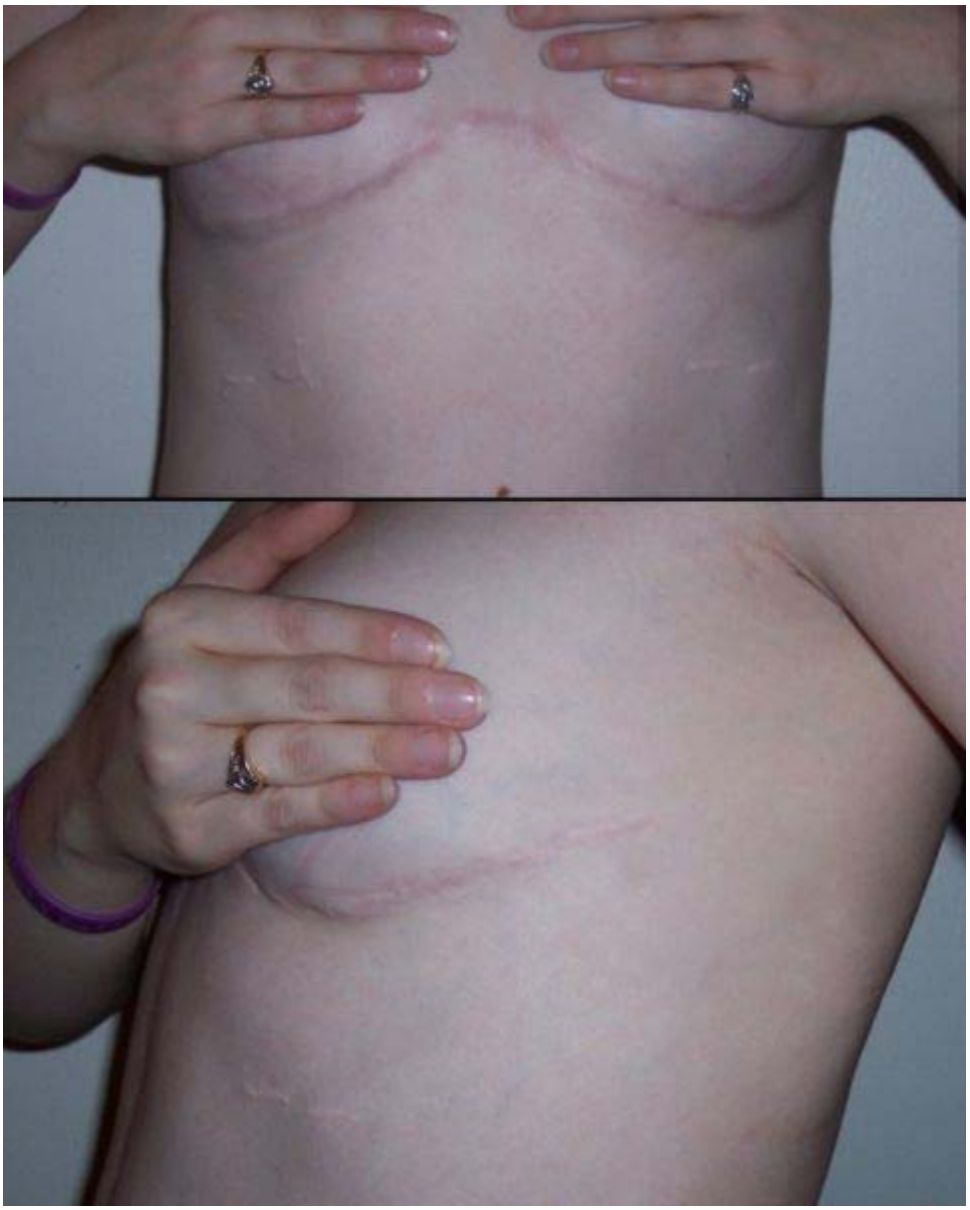
Procedure

While the precise details of surgery will depend on the exact type of transplant, there are many steps which are common to all of these procedures. Prior to operating on the recipient, the transplant surgeon inspects the donor lung(s) for signs of damage or disease. If the lung or lungs are approved, then the recipient is connected to an IV line and various monitoring equipment, including pulse oximetry. The patient will be given general anesthesia, and a machine will breathe for him or her.

It takes about one hour for the pre-operative preparation of the patient. A single lung transplant takes about four to eight hours, while a double lung transplant takes about six to twelve hours to complete. A history of prior chest surgery may complicate the procedure and require additional time.

Lobe

Single-lung



Incision scarring from a double lung transplant.

In single-lung transplants, the lung with the worse pulmonary function is chosen for replacement. If both lungs function equally, then the right lung is usually favored for removal because it avoids having to maneuver around the heart, as would be required for excision of the left lung.

In a single-lung transplant the process starts out after the donor lung has been inspected and the decision to accept the donor lung for the patient has been made. An incision is

generally made from under the shoulder blade around the chest, ending near the sternum. An alternate method involves an incision under the breastbone. In the case of a singular lung transplant the lung is collapsed, the blood vessels in the lung tied off, and the lung removed at the bronchial tube. The donor lung is placed, the blood vessels reattached, and the lung reinflated. To make sure the lung is satisfactory and to clear any remaining blood and mucus in the new lung a bronchoscopy will be performed. When the surgeons are satisfied with the performance of the lung the chest incision will be closed.

Double-lung

A double-lung transplant, also known as a bilateral transplant, can be executed either sequentially, en bloc, or simultaneously. Sequential is more common than en bloc. This is effectively like having two separate single-lung transplants done.

The transplantation process starts after the donor lungs are inspected and the decision to transplant has been made. An incision is then made from under the patient's armpit, around to the sternum, and then back towards the other armpit; this is known as a clamshell incision. In the case of a sequential transplant the recipients lung with the poorest lung functions is collapsed, the blood vessels tied off, and cut at the corresponding bronchi. The new lung is then placed and the blood vessels reattached. To make sure the lung is satisfactory before transplanting the other a bronchoscopy is performed. When the surgeons are satisfied with the performance of the new lung, surgery on the second lung will proceed. In 10% to 20% of double-lung transplants the patient is hooked up to a heart-lung machine which pumps blood for the body and supplies fresh oxygen.

Post-operative care

Immediately following the surgery, the patient is placed in an intensive care unit for monitoring, normally for a period of a few days. The patient is put on a ventilator to assist breathing. Nutritional needs are generally met via total parenteral nutrition, although in some cases a nasogastric tube is sufficient for feeding. Chest tubes are put in so that excess fluids may be removed. Because the patient is confined to bed, a urinary catheter is used. IV lines are used in the neck and arm for monitoring and giving medications. After a few days, barring any complications, the patient may be transferred to a general inpatient ward for further recovery. The average hospital stay following a lung transplant is generally one to three weeks, though complications may require a longer period of time. After this stage, patients are typically required to attend rehabilitation gym for approximately 3 months to regain fitness. Light weights, exercise bike, treadmill, stretches and more are all a part of the rehabilitation programme.

There may be a number of side effects following the surgery. Because certain nerve connections to the lungs are cut during the procedure, transplant recipients cannot feel the urge to cough or feel when their new lungs are becoming congested. They must therefore make conscious efforts to take deep breaths and cough in order to clear secretions from the lungs. Their heart rate responds less quickly to exertion due to the cutting of the

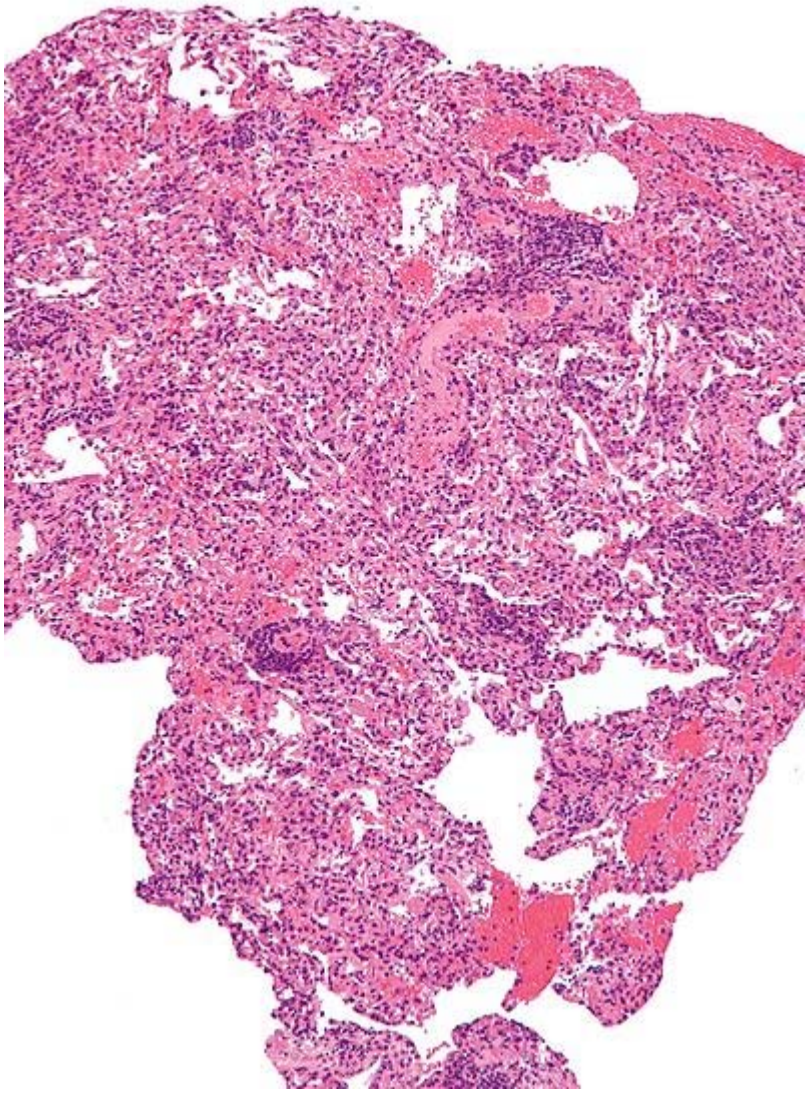
vagus nerve that would normally help regulate it. They may also notice a change in their voice due to potential damage to the nerves that coordinate the vocal cords.

Miscellaneous

Post-transplant patients are held from driving for the first 3 months pending an assessment of the patient's capacity to drive; this assessment is usually performed by an occupational therapist. Eyesight, physical ability to do simple actions such as check blind spots, wear a seat belt safely without the wound site being affected and hand eye coordination are all assessed.

Hygiene becomes more important in every day living due to the Immunosuppressant drugs which are required every day to prevent transplant rejection. Lack of a strong immune system leaves transplant recipients vulnerable to infections. Care must be taken into food preparation and hygiene as gastroenteritis becomes more of a risk.

Risks



Micrograph showing lung transplant rejection. Lung biopsy. H&E stain.

As with any surgical procedure, there are risks of bleeding and infection. The newly transplanted lung itself may fail to properly heal and function. Because a large portion of the patient's body has been exposed to the outside air, sepsis is a possibility, so antibiotics will be given to try to prevent that. Other complications include Post-transplant lymphoproliferative disorder, a form of lymphoma due to the immune suppressants, and gastrointestinal inflammation and ulceration of the stomach and esophagus.

Transplant rejection is a primary concern, both immediately after the surgery and continuing throughout the patient's life. Because the transplanted lung or lungs come from another person, the recipient's immune system will "see" it as an invader and attempt to neutralize it. Transplant rejection is a serious condition and must be treated as soon as possible.

Signs of rejection:

- fever;
- flu-like symptoms, including chills, dizziness, nausea, general feeling of illness, night sweats;
- increased difficulty in breathing;
- worsening pulmonary test results;
- increased chest pain or tenderness;
- increase or decrease in body weight of more than 2 kilograms in a 24'hour period.

In order to prevent transplant rejection and subsequent damage to the new lung or lungs, patients must take a regimen of immunosuppressive drugs. Patients will normally have to take a combination of these medicines in order to combat the risk of rejection. This is a lifelong commitment, and must be strictly adhered to. The immunosuppressive regimen is begun just before or after surgery. Usually the regimen includes cyclosporine, azathioprine and corticosteroids, but as episodes of rejection may reoccur throughout a patient's life, the exact choices and dosages of immunosuppressants may have to be modified over time. Sometimes tacrolimus is given instead of cyclosporine and mycophenolate mofetil instead of azathioprine.

The immunosuppressants that are needed to prevent organ rejection also introduce some risks. By lowering the body's ability to mount an immune reaction, these medicines also increase the chances of infection. Antibiotics may be prescribed in order to treat or prevent such infections. In turn, infection may increase the risk of rejection, and generally an interaction may prevail between both risks. Certain medications may also have nephrotoxic or other potentially harmful side-effects. Other medications may also be prescribed in order to help alleviate these side effects. There is also the risk that a patient may have an allergic reaction to the medications. Close follow-up care is required in order to balance the benefits of these drugs versus their potential risks.

Chronic rejection, meaning repeated bouts of rejection symptoms beyond the first year after the transplant surgery, occurs in approximately 50% of patients. Such chronic rejection presents itself as bronchiolitis obliterans, or less frequently, atherosclerosis.

Prognosis

These statistics are based on data from 2008. The source data made no distinction between living and deceased donor organs, nor was any distinction made between lobar, single, and double lung transplants.

	1 year survival	5 years survival	10 years survival
Lung transplant	83.6%	53.4%	28.4%
Heart-lung transplant	73.8%	46.5%	28.3%

Transplanted lungs typically last three to five years before showing signs of failure.

Chapter 4

Heart-Lung Transplant and Laryngectomy

Heart-lung transplant

Intervention:
Heart–lung transplant

ICD-10 code:	
ICD-9 code:	33.6
MeSH	D016041
Other codes:	

A **heart–lung transplant** is a procedure carried out to replace both heart and lungs in a single operation. Due to a shortage of suitable donors, it is a rare procedure; only about a hundred such transplants are performed each year in the USA.

Qualifying conditions

Most candidates for heart–lung transplants have life-threatening damage to both their heart and lungs. In the US, most prospective candidates have between twelve and twenty-four months to live. At any one time, there are about 250 people registered for heart–lung transplantation at the United Network for Organ Sharing (UNOS) in the USA, of which around forty will die before a suitable donor is found.

Conditions which may necessitate a heart–lung transplant include:

- Congenital problems (defects present at birth) affecting the heart and lungs (48%);
- Pulmonary hypertension (20%);
- Cystic fibrosis (2%);

- A second transplant after the first transplant was rejected or failed to operate satisfactorily (4%).

Candidates for a heart–lung transplant are usually required to be:

- Under 55 years old;
- Have no other medical conditions (e.g. AIDS, Diabetes, Hepatitis);
- Mentally sound;
- Capable of following a post-operative regimen of exercise and immunosuppressant drugs.

History

Dr. Norman Shumway laid the groundwork for heart lung transplantation with his experiments into heart transplantation at Stanford in the mid 1960s. Shumway conducted the first adult heart transplant in the US in 1968.

Building on his research at Stanford, Dr. Bruce Reitz performed the first successful heart–lung transplant on Mary Gohlke in 1981 at Stanford Hospital. The transplant team at Stanford is the longest continuously active team performing these transplants.

Procedure

The patient is anesthetised. When the donor organs arrive, they are checked for fitness; if any organs show signs of damage, they are discarded and the operation cancelled. Some patients are concerned that their organs will be removed and the donor organs won't be suitable. Since this is a possibility, it is standard procedure that the patient is not operated on until the donor organs arrive and are judged suitable, despite the time delay this involves.

Once suitable donor organs are present, the surgeon makes an incision starting above and finishing below the sternum, cutting all the way to the bone. The skin edges are retracted to expose the sternum. Using a bone saw, the sternum is cut down the middle. Rib spreaders are inserted in the cut, and spread the ribs to give access to the heart and lungs of the patient.

The patient is connected to a heart–lung machine, which circulates and oxygenates blood. The surgeon removes the failing heart and lungs. Most surgeons endeavour to cut blood vessels as close as possible to the heart to leave room for trimming, especially if the donor heart is of a different size than the original organ.

The donor heart and lungs are positioned and sewn into place. As the donor organs warm up to body temperature, the lungs begin to inflate. The heart may fibrillate at first – this occurs because the cardiac muscle fibres are not contracting synchronously. Internal paddles can be used to apply a small electric shock to the heart to restore proper rhythm.

Once the donor organs are functioning normally, the heart–lung machine is withdrawn, and the chest is closed.

Post-operation

Most patients spend several days in intensive care after the operation. If there are no complications (e.g. infection, rejection), some are able to return home after just two weeks in hospital. Patients will be given anti-rejection drugs, and antibiotics to prevent infection. A schedule of frequent follow up visits is necessary.

Statistics

The success rate of heart–lung transplants has improved a lot in recent years. The British National Health Service states that the survival rate is now around 85%, one year after the transplant was performed.

In 2004, there were only 39 heart–lung transplants performed in the entire United States and only 75 worldwide. By comparison, in that same year there were 2,016 heart and 1,173 lung transplants.

Laryngectomy

	Intervention: Laryngectomy
ICD-10 code:	
ICD-9 code:	30.2 30.3 30.4
MeSH	D007825
Other codes:	

Laryngectomy is the removal of the larynx and separation of the airway from the mouth, nose and esophagus. The laryngectomee breathes through an opening in the neck, a stoma. It is done in cases of laryngeal cancer. However, many laryngeal cancer cases are now treated only with radiation and chemotherapy or other laser procedures, and laryngectomy is performed when those treatments fail to conserve the larynx. laryngectomy is also performed to individuals with other types of head and neck cancer.

Voice replacement

- Voice functions are generally replaced with a voice prosthesis placed in the tracheo esophageal puncture created by the surgeon. The voice prosthesis vibrates the esophageal tissue in lieu of the larynx.

- A second method is the use of an electrolarynx. An electrolarynx is an external device that is placed against the neck and creates vibration that the speaker then articulates. The sound has been characterized as mechanical and robotic.

- A third method is called esophageal speech. The speaker pushes air into the esophagus and then pushes it back up, articulating speech sounds to speak. This method is time-consuming and difficult to learn and is seldom used by laryngectomees.

Uses

Laryngectomies number about 60,000 in the United States. Perhaps 10,000 laryngeal cancer cases are treated annually, but only about 3,000 people are laryngectomized. Because it is a relatively rare cancer and because the post-operative care is complex in achieving a functional result, laryngeal cancer patients should be treated at or at least consult a major federally designated cancer center, where the fields of surgery, radiology, chemotherapy, speech-language pathology are integrated in head and neck departments.

Most laryngeal cancers in the UK are glottic, meaning they start in the vocal cords within the larynx. Glottic cancers tend to be picked up at an early stage, as they cause a hoarse voice very quickly. About 90 out of every 100 people (90%) with T1 glottic cancers are cured with radiotherapy alone. But most of the remaining 10 out of every 100 people (10%) will be cured with surgery after their radiotherapy.

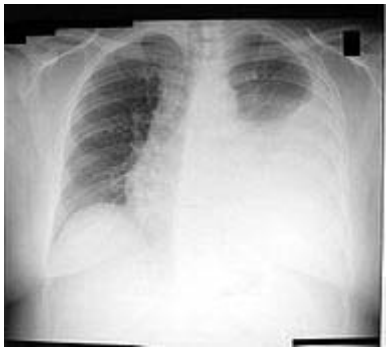
In animals

Laryngectomies may be applied to dogs as a debarking procedure.

Chapter 5

Thoracentesis

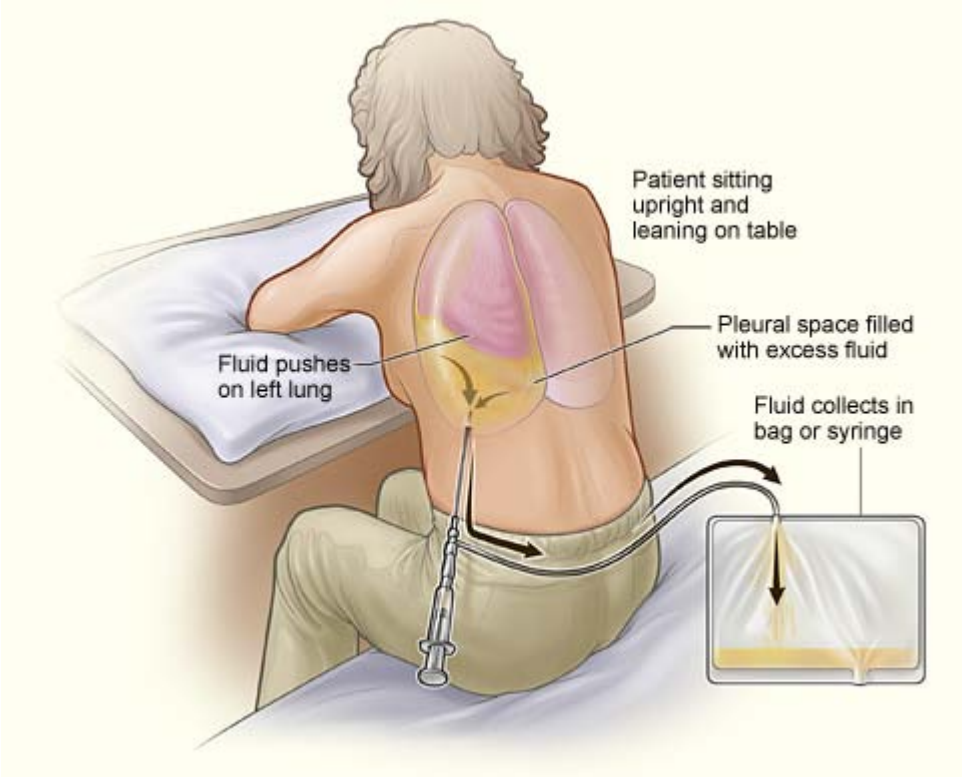
Intervention:
Thoracentesis



Chest X-ray showing a left-sided pleural effusion (right side of image). This can be treated with thoracentesis.

ICD-10 code:	
ICD-9 code:	34.91
Other codes:	**OPCS-4.2**T12.3

Thoracentesis is an invasive procedure to remove fluid or air from the pleural space for diagnostic or therapeutic purposes. A cannula, or hollow needle, is carefully introduced into the thorax, generally after administration of local anesthesia. The procedure was first described in 1852.



The illustration shows a person having thoracentesis. The person sits upright and leans on a table. Excess fluid from the pleural space is drained into a bag.

The recommended location varies depending upon the source. It is critical that the patient hold his or her breath to avoid piercing of the lung. Some sources recommend the midaxillary line, in the ninth intercostal space.

Indications

This procedure is indicated when unexplained fluid accumulates in the chest cavity outside the lung. In more than 90% of cases analysis of pleural fluid yields clinically useful information. If a large amount of fluid is present, then this procedure can also be used therapeutically to remove that fluid and improve patient comfort and lung function.

The most common causes of pleural effusions are cancer, congestive heart failure, pneumonia, and recent surgery. In countries where tuberculosis is common, this is also a common cause of pleural effusions.

When cardiopulmonary status is compromised (i.e. when the fluid or air has its repercussions on the function of heart and lungs), due to air (significant pneumothorax), fluid (pleural fluid) or blood (hemothorax) outside the lung, then this procedure is usually replaced with tube thoracostomy, the placement of a large tube in the pleural space.

Contraindications

An uncooperative patient or a coagulation disorder that can not be corrected are absolute contraindications.

Relative contraindications include cases in which the site of insertion has known bullous disease (e.g. emphysema), use of positive end-expiratory pressure and only one functioning lung (due to diminished reserve). The aspiration should not exceed 1L as there is a risk of development of pulmonary edema.

Complications

Major complications are pneumothorax (3-30%), hemopneumothorax, hemorrhage, hypotension (low blood pressure due to a vasovagal response) and reexpansion pulmonary edema.

Minor complications include a dry tap (no fluid return), subcutaneous hematoma or seroma, anxiety, dyspnea and cough (after removing large volume of fluid).

The use of ultrasound for needle guidance can minimize the complication rate.

Interpretation of pleural fluid analysis

Several diagnostic tools are available to determine the etiology of pleural fluid.

Transudate versus exudate

First the fluid is either transudate or exudate.

A transudate is defined as pleural fluid to serum total protein ratio of less than 0.5, pleural fluid to serum LDH ratio < 0.6, and absolute pleural fluid LDH < 200 IU or < 2/3 of the normal serum.

An exudate is any fluid that filters from the circulatory system into lesions or areas of inflammation. Its composition varies but generally includes water and the dissolved solutes of the main circulatory fluid such as blood. In the case of blood: it will contain some or all plasma proteins, white blood cells, platelets and (in the case of local vascular damage) red blood cells.

Exudate

- hemorrhage
- Infection
- Inflammation
- Malignancy
- Iatrogenic
- Connective tissue disease
- Endocrine disorders
- Lymphatic disorders vs Constrictive pericarditis

Transudate

- Congestive heart failure
- Nephrotic syndrome
- Hypoalbuminemia
- Cirrhosis
- Atelectasis
- trapped lung
- Peritoneal dialysis
- Superior vena cava obstruction

Amylase

A high amylase level (twice the serum level or the absolute value is greater than 160 Somogy units) in the pleural fluid is indicative of either acute or chronic pancreatitis, pancreatic pseudocyst that has dissected or ruptured into the pleural space, cancer or esophageal rupture.

Glucose

This is considered low if pleural fluid value is less than 50% of normal serum value. The differential diagnosis for this is:

- rheumatoid effusion.The levels are characteristically low (<15 mg/dL).
- lupus effusion
- bacterial empyema
- malignancy
- tuberculosis
- esophageal rupture (Boerhaave syndrome)

pH

Normal pleural fluid pH is approximately 7.60. A pleural fluid pH below 7.30 with normal arterial blood pH has the same differential diagnosis as low pleural fluid glucose.

Triglyceride and cholesterol

Chylothorax (fluid from lymph vessels leaking into the pleural cavity) may be identified by determining triglyceride and cholesterol levels, which are relatively high in lymph. A triglyceride level over 110 mg/dl and the presence of chylomicrons indicate a chylous effusion. The appearance is generally milky but can be serous.

The main cause for chylothorax is rupture of the thoracic duct, most frequently as a result of trauma or malignancy (such as lymphoma).

Cell count and differential

The number of white blood cells can give an indication of infection. The specific subtypes can also give clues as to the type on infection. The amount of red blood cells are an obvious sign of bleeding.

Cultures and stains

If the effusion is caused by infection, microbiological culture may yield the infectious organism responsible for the infection, sometimes before other cultures (e.g. blood cultures and sputum cultures) become positive. A Gram stain may give a rough indication of the causative organism. A Ziehl-Neelsen stain may identify tuberculosis or other mycobacterial diseases.

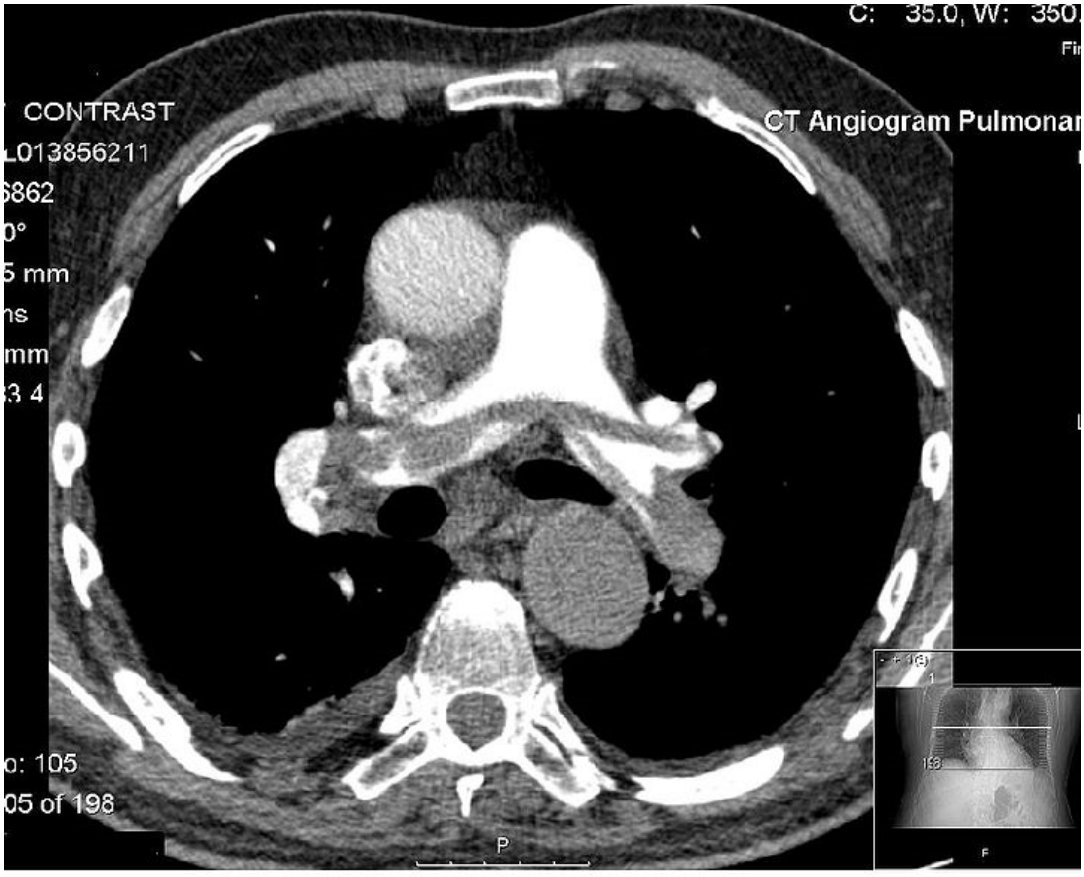
Cytology

Cytology is an important tool in identifying effusions due to malignancy. The most common causes for pleural fluid are lung cancer, metastasis from elsewhere and mesothelioma. The latter often presents with an effusion. Normal cytology results do not reliably rule out malignancy, but make the diagnosis more unlikely.

Chapter 6

CT Pulmonary Angiogram and Ventilation/Perfusion Scan

CT pulmonary angiogram



Example of a CTPA, demonstrating a saddle embolus. The white area above the center is the pulmonary artery, opacified by radiocontrast. Inside it, the grey matter is blood clot. The black areas on either side are the lungs, with around it the chest wall.

CT pulmonary angiogram (CTPA) is a medical diagnostic test that employs computed tomography to obtain an image of the pulmonary arteries. Its main use is to diagnose pulmonary embolism (PE).

Diagnostic use

CTPA was introduced in the 1990s as an alternative to ventilation/perfusion scanning, which relies on radionuclide imaging of the blood vessels of the lung. It is regarded as a highly sensitive and specific test for pulmonary embolism.

CTPA is typically only requested if pulmonary embolism is suspected clinically. If the probability of PE is considered low, a blood test called D-dimer may be requested. If this is negative and risk of a PE is considered negligible, then CTPA or other scans are generally not performed. Most patients will have undergone a chest X-ray before CTPA is requested.

After initial concern that CTPA would miss smaller emboli, a 2007 study comparing CTPA directly with ventilation/perfusion scanning found that CTPA identified more emboli without decreasing the risk of long-term complications compared to V/Q scanning.

Contraindications

CTPA is generally avoided in pregnancy due to the amount of ionizing radiation required, which may damage the fetus.

CTPA is contraindicated in known or suspected allergy to contrast media or in renal failure (where contrast agents could worsen the renal function).

Acquisition

The best results are obtained using multidetector computed tomography (MDCT) scanners.

An intravenous cannula is required for the administration of the 50-150 ml. of radiocontrast. This is injected, usually automatically, by a syringe driver, at a rate of 4 ml./second. Many hospitals use bolus tracking, where the scan commences when the contrast is detected at the level of the proximal pulmonary arteries. If this is done manually, scanning commences about 10–12 seconds after the injection has started. Slices of 1-3 mm. are performed at 1-3 mm. intervals, depending on the nature of the scanner (single- versus multidetector).

State of the art CT machines can complete a scan in approximately five seconds and it is possible to complete the entire procedure (set-up, injection and scanning) in the space of five minutes.

Interpretation

On CTPA, the pulmonary vessels are filled with contrast, and appear white. Any mass filling defects (embolus or other matter such as fat or amniotic fluid) appears darker. Generally, the scan should be complete before the contrast reaches the left side of the heart and the aorta, which could result in artifacts.

Ventilation/perfusion scan

A **ventilation/perfusion lung scan**, also called a V/Q lung scan, is a type of medical imaging using scintigraphy and medical isotopes to evaluate the circulation of air and blood within a patient's lungs, in order to determine the ventilation/perfusion ratio. The ventilation part of the test looks at the ability of air to reach all parts of the lungs, while the perfusion part evaluates how well blood circulates within the lungs.

Uses

This test is most commonly done in order to check for the presence of a blood clot or abnormal blood flow inside the lungs (such as a pulmonary embolism or PE), although computed tomography with radiocontrast is now more commonly used for this purpose. The V/Q scan may be used in some circumstances where radiocontrast would be inappropriate, as in renal failure.

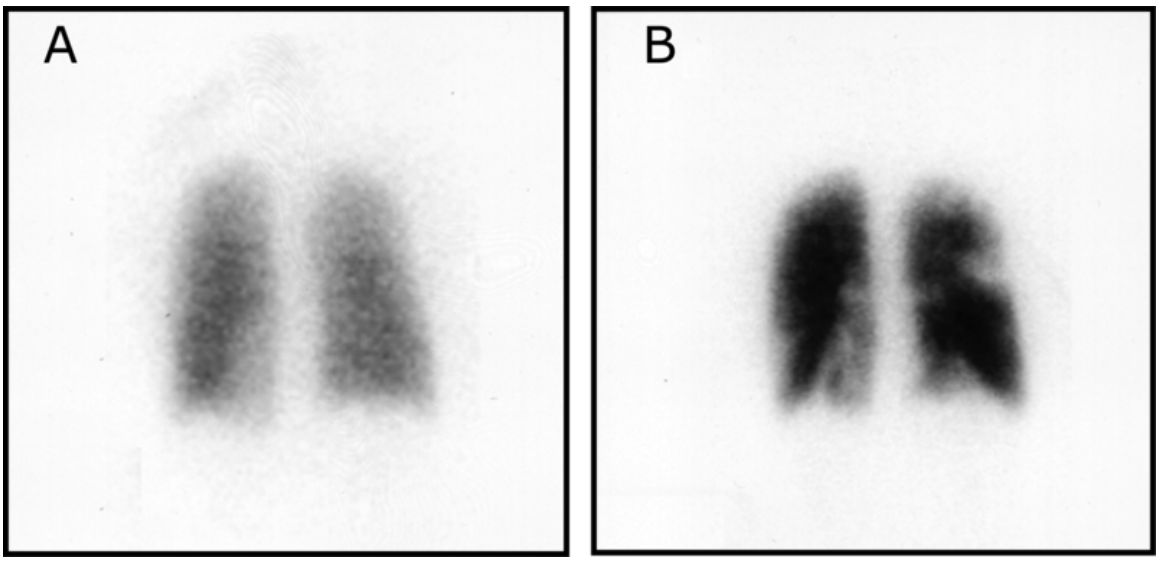
A V/Q lung scan may be performed in the case of serious lung disorders such as Chronic obstructive pulmonary disease (COPD) or pneumonia as well as a lung performance quantification tool pre- and post-lung lobectomy surgery.:)

Procedure

The ventilation and perfusion phases of a V/Q lung scan are performed together and may include a chest x-ray for comparison or to look for other causes of lung disease. A defect in the perfusion images requires a mismatched ventilation defect to be indicative of pulmonary embolism.

In the ventilation phase of the test, a gaseous radionuclide such as xenon or technetium DTPA in an aerosol form is inhaled by the patient through a mouthpiece or mask that covers the nose and mouth. The perfusion phase of the test involves the intravenous injection of radioactive technetium macro aggregated albumin (Tc99m-MAA). A gamma camera acquires the images for both phases of the study.

Significance of results



Ventilation-perfusion scintigraphy in a woman taking oral contraceptives and valdecoxib with a pulmonary embolism. (A) After inhalation of 20.1 mCi of Xenon-133 gas, scintigraphic images were obtained in the posterior projection, showing uniform ventilation to lungs. (B) After intravenous injection of 4.1 mCi of Technetium-99m-labeled macroaggregated albumin, scintigraphic images were obtained, shown here in the posterior projection. This and other views showed decreased activity in the following regions: apical segment of right upper lobe, anterior segment of right upper lobe, superior segment of right lower lobe, posterior basal segment of right lower lobe, anteromedial basal segment of left lower lobe, and lateral basal segment of left lower lobe.

V/Q Scan Interpretation

Result	Interpretation	Significance
Normal	No perfusion deficit	Excludes pulmonary thromboembolism
Low probability	Perfusion deficit with matched ventilation deficit	Non diagnostic
Intermediate probability	Perfusion deficit that corresponds to parenchymal abnormality on chest x-ray	Non diagnostic
High probability	Multiple segmental perfusion deficits with normal ventilation	Diagnostic for pulmonary thromboembolism

Decreased uptake of the inhaled radioisotope may indicate an impaired ability to breathe, airway obstruction, or possible pneumonia.

Decreased circulation of the injected MAA indicates a problem with blood flow into or within the lungs. A localized area of decreased uptake, usually in a wedge shaped (or pie shaped) configuration with normal ventilation images (mismatched defect) suggests a pulmonary embolus or blood clot in the lungs, which leads to reduced perfusion.

Risks

Although this test uses radioactive materials, the total amount of radiation exposure is low. In order to decrease the radiation exposure in pregnant patients, the total radioactive dose may be decreased or the ventilation phase omitted. Computed tomography with radiocontrast can alternatively be performed. If breastfeeding, patient must be counselled to refrain from this activity for approximately 24 hours.

Chapter 7

Pneumonia Severity Index

The **pneumonia severity index [PSI]** or **PORT Score** is a clinical prediction rule that medical practitioners can use to calculate the probability of morbidity and mortality among patients with community acquired pneumonia.

Despite sometimes being used to predict the need for hospitalization in people with pneumonia, the PORT score was not developed to do so and should not be used in that way. Mortality prediction is similar to that when using CURB-65.

Development of the PSI

The rule uses demographics (whether someone is older, and is male or female), the coexistence of co-morbid illnesses, findings on physical examination and vital signs, and essential laboratory findings. This study demonstrated that patients could be stratified into five risk categories, Risk Classes I-V, and that these classes could be used to predict 30-day survival.

Data Source for Derivation & Validation

The rule was derived then validated with data from 38,000 patients from the MedisGroup Cohort Study for 1989, comprising 1 year of data from 257 hospitals across the US who used the MedisGroup patient outcome tracking software built and serviced by Mediqual Systems (Cardinal Health). One significant caveat to the data source was that patients who were discharged home or transferred from the MedisGroup hospitals could not be followed at the 30-day mark, and were therefore assumed to be "alive" at that time. Further validation was performed with the Pneumonia Patient Outcomes Research Team [PORT] (1991) cohort study. This categorization method has been replicated by others and is comparable to the CURB-65 in predicting mortality.

Usage & Application of the PSI

The purpose of the PSI is to classify the severity of a patient's pneumonia to determine the amount of resources to be allocated for care. Most commonly, the PSI scoring system has been used to decide whether patients with pneumonia can be treated as outpatients or as (hospitalized) inpatients. A **Risk Class I** pneumonia patient can be sent home on oral antibiotics. A **Risk Class II-III** pneumonia patient may be sent home with IV antibiotics or treated and monitored for 24 hours in hospital. Patients with **Risk Class IV-V** pneumonia patient should be hospitalized for treatment.

The PSI Algorithm

The PSI Algorithm is detailed below. An online, automated PSI calculator is available on the US AHRQ website.

Step 1: Stratify to Risk Class I vs. Risk Classes II-V	
Presence of:	
Over 50 years of age	Yes/No
Altered mental status	Yes/No
Pulse ≥125/minute	Yes/No
Respiratory rate >30/minute	Yes/No
Systolic blood pressure <90 mm Hg	Yes/No
Temperature <35°C or ≥40°C	Yes/No
History of:	
Neoplastic disease	Yes/No
Congestive heart failure	Yes/No
Cerebrovascular disease	Yes/No
Renal disease	Yes/No
Liver disease	Yes/No
If any "Yes", then proceed to Step 2	
If all "No" then assign to **Risk Class I**	
Step 2: Stratify to Risk Class II vs III vs IV vs V	
Demographics	**Points Assigned**
If Male	+Age (yr)
If Female	+Age (yr) - 10
Nursing home resident	+10

Comorbidity	
Neoplastic disease	+30
Liver disease	+20
Congestive heart failure	+10
Cerebrovascular disease	+10
Renal disease	+10
Physical Exam Findings	
Altered mental status	+20
Pulse ≥125/minute	+20
Respiratory rate >30/minute	+20
Systolic blood pressure <90 mm Hg	+15
Temperature <35°C or ≥40°C	+10
Lab and Radiographic Findings	
Arterial pH <7.35	+30
Blood urea nitrogen ≥30 mg/dl (9 mmol/liter)	+20
Sodium <130 mmol/liter	+20
Glucose ≥250 mg/dl (14 mmol/liter)	+10
Hematocrit <30%	+10
Partial pressure of arterial O2 <60mmHg	+10
Pleural effusion	+10
∑ <70 = **Risk Class II**	
∑ 71-90 = **Risk Class III**	
∑ 91-130 = **Risk Class IV**	
∑ >130 = **Risk Class V**	

PSI Derivation and Validation Data

	Medisgroup Study (1989)				**PORT Validation Study (1991) Cohort**					
	Derivation Cohort		**Validation Cohort**		**Inpatients**		**Outpatients**		**All Patients**	
Risk Class	**no. of pts**	**% died**	**no. of pts**	**% died**	**no. of pts**	**% died**	**no. of pts**	**% died**	**no. of pts**	**% died**
I	1,372	0.4	3,034	0.1	185	0.5	587	0.0	772	0.1
II (<70)	2,412	0.7	5,778	0.6	233	0.9	244	0.4	477	0.6
III (71–90)	2,632	2.8	6,790	2.8	254	1.2	72	0.0	326	0.9

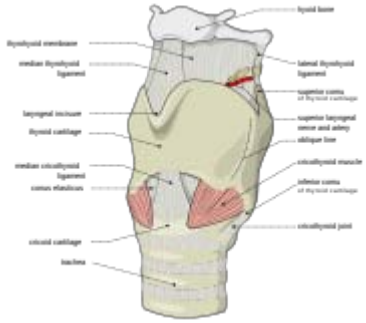
IV (91–130)	4,697	8.5	13,104	8.2	446	9.0	40	12.5	486	9.3
V (>130)	3,086	31.1	9,333	29.2	225	27.1	1	0.0	226	27.0
Total	**14,199**	10.2	**38,039**	10.6	**1343**	8.0	**944**	0.6	**2287**	5.2

Note: % Died refers to 30-day mortality.

Chapter 8

Cricothyrotomy

Intervention:
Cricothyrotomy



In cricothyrotomy, the incision or puncture is made through the cricothyroid membrane in between the thyroid cartilage and the cricoid cartilage.

ICD-10 code:

ICD-9 code: 31.1

MeSH D014140

Other codes:

A **cricothyrotomy** (also called **thyrocricotomy**, **cricothyroidotomy**, **inferior laryngotomy**, **intercricothyrotomy**, **coniotomy** or **emergency airway puncture**) is an incision made through the skin and cricothyroid membrane to establish a patent airway during certain life-threatening situations, such as airway obstruction by a foreign body, angioedema, or massive facial trauma. Cricothyrotomy is nearly always performed as a last resort in cases where orotracheal and nasotracheal intubation are impossible or contraindicated. Cricothyrotomy is easier and quicker to perform than tracheotomy, does not require manipulation of the cervical spine, and is associated with fewer complications. However, while cricothyrotomy may be life-saving in extreme

circumstances, this technique is only intended to be a temporizing measure until a definitive airway can be established.

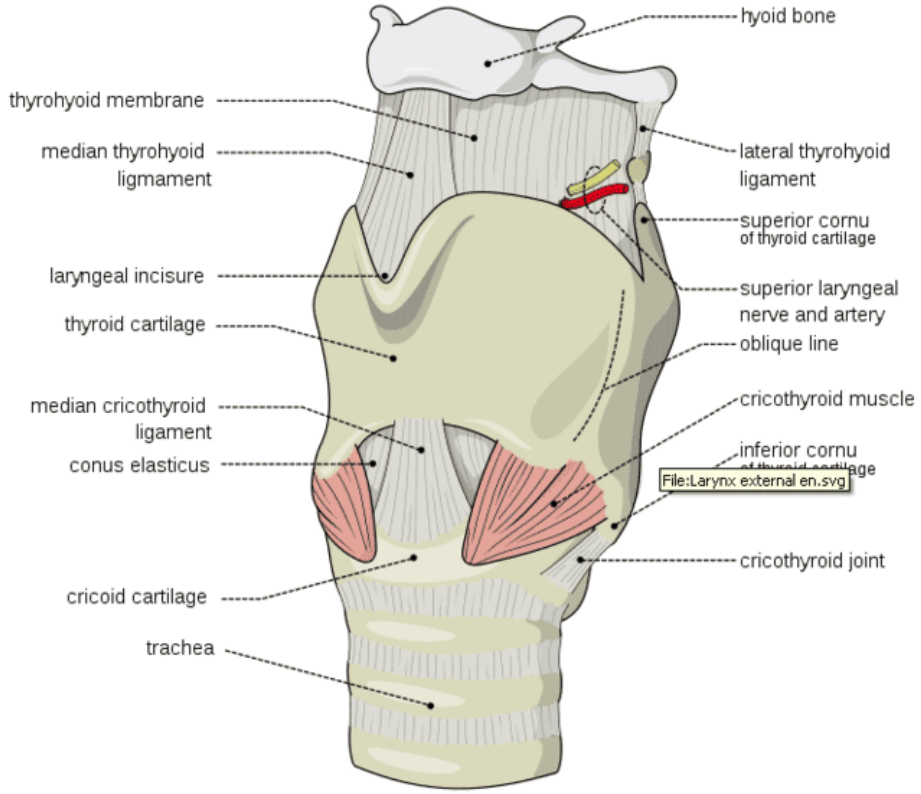
Indications

- Can't intubate
- Can't ventilate
- Severe facial or nasal injuries (that do not allow oral or nasal tracheal intubation)
- Massive midfacial trauma
- Possible cervical spine trauma preventing adequate ventilation
- Anaphylaxis
- Chemical inhalation injuries

Contraindications

- Inability to identify landmarks (cricothyroid membrane)
- Underlying anatomical abnormality (tumor)
- Tracheal transection
- Acute laryngeal disease due to infection or trauma
- Small children under 10 years old (a 12–14 gauge catheter over the needle may be safer)

Procedure



In cricothyrotomy, the incision or puncture is made through the cricothyroid membrane in between the thyroid cartilage and the cricoid cartilage.

The procedure was first described in 1805 by Vicq d'Azyr, a French surgeon and anatomist. A cricothyrotomy is generally performed by making a vertical incision on the skin of the neck just below the "Adam's apple", or thyroid cartilage, then making another transverse incision in the cricothyroid membrane which lies deep to this point. One then inserts a tube into this opening, which allows one to breathe for the patient with a machine or bag.

Technique

In a typical cricothyrotomy procedure, a scalpel is used to create a 1 cm vertical incision through the skin and the cricothyroid membrane, and the resulting hole is opened by either inserting the scalpel handle into the wound and rotating 90 degrees or by using a clamp. A tracheostomy tube or endotracheal tube with a 6 or 7 mm internal diameter is then inserted, the cuff is inflated, and the tube is secured. A bag-valve device with the highest available concentration of oxygen is used to provide ventilation, the success of which is assessed by bilateral ausculation and observation of the rise and fall of the chest.

No attempts are made to remove the tracheostomy or endotracheal tube in a prehospital setting.

Cricothyrotomy in popular media

On the TV show *M*A*S*H*, Father Mulcahy performs an emergency cricothyrotomy on a patient. With the direction of Dr. Pierce via radio, he uses a pen knife and an eye dropper to perform the operation. Needless to say, this would be extremely dangerous in real life. Even under ideal, clinical conditions, a cricothyrotomy is difficult and requires specific tools, preparation and a practiced knowledge of anatomy. There are many major blood vessels and nerves in the neck and cutting there, even with the best of intentions carries a high risk of harming the patient.

In the 1980 Nicolas Roeg film "Bad Timing," Theresa Russell's character Milena Flaherty has an emergency cricothyrotomy performed following an intentional overdose.

In Grey's Anatomy, emergency cricothyrotomy is mentioned in at least three episodes:

- In “Owner of a Lonely Heart,” Cristina almost performs an emergency cricothyrotomy on a patient who swallowed a light bulb. Before she is able to do so, however, Dr. Burke shows up and takes the patient to an operating room where he proceeds to perform an emergency thoracotomy.
- In “The Heart of the Matter,” Izzie performs her first “emergency crike” on Camille, a niece of Chief of Surgery Dr. Richard Webber.
- In "I Saw What I Saw" Alex performs a "crike" on the patient who later dies.

In the ER episode, "Reason to Believe" Dr. Kerry Weaver performs an emergency cricothyrotomy on a student. She is shooting a news segment on childhood obesity in an elementary school cafeteria when one of the students begins to choke; after the heimlich maneuver fails, she performs a cricothyrotomy with a kitchen knife and a drinking straw. It is also used many other times, especially in the trauma room, when an airway can't be established.

In the movie, "Playing God" (1997), David Duchovny plays a famed LA surgeon, stripped of his license due to drug abuse, who finds himself witnessing a gun fight at a bar. He saves a mafia crime figure by performing an emergency cricothyrotomy. This endears him with the mafia family and drives the plot forward.

In the BBC3 medical drama Bodies, the main protagonist Rob Lake, a newly appointed obstetrics and gynaecology registrar (played by Max Beesley), is called to a patient who is having difficulty breathing due to anaphylaxis. Lake calls for emergency assistance, but impatient and fearing for the patient's life decides to undertake a cricothyrotomy himself - a procedure he has not been trained in. The procedure is unsuccessful and the patient dies before help arrives. The guilt surrounding the event combined with the covering up by his consultant provides an important backdrop to the further development of the character and his relationship with his consultant.

Chapter 9

Bronchoscopy and Positive Pressure Ventilation

Bronchoscopy

A physician performing bronchoscopy.

Bronchoscopy is a technique of visualizing the inside of the airways for diagnostic and therapeutic purposes. An instrument (bronchoscope) is inserted into the airways, usually through the nose or mouth, or occasionally through a tracheostomy. This allows the practitioner to examine the patient's airways for abnormalities such as foreign bodies, bleeding, tumors, or inflammation. Specimens may be taken from inside the lungs. The construction of bronchoscopes ranges from rigid metal tubes with attached lighting devices to flexible optical fiber instruments with realtime video equipment.

History

A German, Gustav Killian, performed the first bronchoscopy in 1897. From then until the 1970s, rigid bronchoscopes were used exclusively. Killian used rigid bronchoscopy to remove a pork bone. The procedure was done in an awake patient using topical cocaine as a local anesthetic.

An American, [Nathan Faux], refined the rigid bronchoscope in the 1920s, using this rigid tube to visually inspect the trachea and mainstem bronchi.

A Japanese, Shigeto Ikeda, invented the flexible bronchoscope in 1966. The flexible scope initially employed fiberoptic bundles requiring an external light source for illumination. These scopes had outside diameters of approximately 5 mm to 6 mm, with an ability to flex 180 degress and to extend 120 degrees, allowing entry into lobar and segmental bronchi. More recently, fiberoptic scopes have been replaced by bronchoscopes with a charge coupled device (CCD) video chip located at their distal extremity.

Types

Rigid

Rigid bronchoscopy is used for retrieving foreign objects. Massive hemoptysis, defined as loss of >600 mL of blood in 24 hours, is a medical emergency and should be addressed with initiation of intravenous fluids and examination with rigid bronchoscopy. The larger lumen of the rigid bronchoscope versus the narrow lumen of the flexible bronchoscope allows for therapeutic approaches such as electrocautery to help control the bleeding.

Flexible (fiberoptic)

A flexible bronchoscope is longer and thinner than a rigid bronchoscope. It contains a fiberoptic system that transmits an image from the tip of the instrument to an eyepiece or video camera at the opposite end. Using Bowden cables connected to a lever at the hand piece, the tip of the instrument can be oriented, allowing the practitioner to navigate the instrument into individual lobe or segment bronchi. Most flexible bronchoscopes also include a channel for suctioning or instrumentation, but these are significantly smaller than those in a rigid bronchoscope.

Flexible bronchoscopy causes less discomfort for the patient than rigid bronchoscopy and the procedure can be performed easily and safely under moderate sedation. It is the technique of choice nowadays for most bronchoscopic procedures.

Purposes

Diagnostic

- To view abnormalities of the airway
- To obtain tissue specimens of the lung in a variety of disorders. Specimens may be taken from inside the lungs by biopsy, bronchoalveolar lavage, or endobronchial brushing.
- To evaluate a person who has bleeding in the lungs, possible lung cancer, a chronic cough, sarcoidosis

Therapeutic

- To remove secretions, blood, or foreign objects lodged in the airway
- Laser resection of tumors or benign tracheal and bronchial strictures
- Stent insertion to palliate extrinsic compression of the tracheobronchial lumen from either malignant or benign disease processes
- Bronchoscopy is also employed in percutaneous tracheostomy

- Tracheal intubation of patients with difficult airways is often performed using a flexible bronchoscope

Procedure

Bronchoscopy can be performed in a special room designated for such procedures, operating room, intensive care unit, or other location with resources for the management of airway emergencies. The patient will often be given antianxiety and antisecretory medications (to prevent oral secretions from obstructing the view), generally atropine, and sometimes an analgesic such as morphine. During the procedure, sedatives such as midazolam or propofol may be used. A local anesthetic is often given to anesthetise the mucous membranes of the pharynx, larynx, and trachea. The patient is monitored during the procedure with periodic blood pressure checks, continuous ECG monitoring of the heart, and pulse oximetry.

A *flexible* bronchoscope is inserted with the patient in a sitting or supine position. Once the bronchoscope is inserted into the upper airway, the vocal cords are inspected. The instrument is advanced to the trachea and further down into the bronchial system and each area is inspected as the bronchoscope passes. If an abnormality is discovered, it may be sampled, using a brush, a needle, or forceps. Specimen of lung tissue (transbronchial biopsy) may be sampled using a real-time x-ray (fluoroscopy). Flexible bronchoscopy

can also be performed on intubated patients, such as patients in intensive care. In this case, the instrument is inserted through an adapter connected to the tracheal tube.

Rigid bronchoscopy is performed under general anesthesia. Rigid bronchoscopes are too large to allow parallel placement of other devices in the trachea; therefore the anesthesia apparatus is connected to the bronchoscope and the patient is ventilated through the bronchoscope.

Recovery

Although most patients tolerate bronchoscopy well, a brief period of observation is required after the procedure. Most complications occur early and are readily apparent at the time of the procedure. The patient is assessed for respiratory difficulty (stridor and dyspnea resulting from laryngeal edema, laryngospasm, or bronchospasm). Monitoring continues until the effects of sedative drugs wear off and gag reflex has returned. If the patient has had a transbronchial biopsy, doctors may take a chest x-ray to rule out any air leakage in the lungs (pneumothorax) after the procedure. The patient will be hospitalized if there occurs any bleeding, air leakage (pneumothorax), or respiratory distress.

Complications and Risks

Besides the risks associated with the drug used, there are also specific risks of the procedure. Although a rigid bronchoscope can scratch or tear airways or damage the vocal cords, the risk of bronchoscopy is limited. Complications from fiberoptic bronchoscopy remain extremely low. Common complications include excessive bleeding following biopsy. A lung biopsy also may cause leakage of air, called pneumothorax. Pneumothorax occurs in less than 1% of lung biopsy cases . Laryngospasm is a rare complication but may sometimes require intubation. Patients with tumors or significant bleeding may experience increased difficulty breathing after a bronchoscopic procedure, sometimes due to swelling of the mucous membranes of the airways.

Positive pressure ventilation

In emergency medicine **positive pressure ventilation** (PPV) refers to the process of forcing air into the lungs of a (usually apneic or dyspneic) patient, usually using a bag valve mask (BVM) or mechanical ventilator.

"NIPPV" is an abbreviation for "nasal intermitent positive pressure ventilation" or "non-invasive positive pressure ventilation".

During normal breathing, air is drawn into the lungs from the outside by the expansion of the chest wall and contraction of the diaphragm to increase volume inside the thoracic cavity. If the airway is sealed, the expansion of the thoracic cavity creates negative pressure inside the lungs relative to the atmospheric pressure outside the body. Hence, during normal breathing air is said to be drawn into the lungs by negative pressure. Positive pressure ventilation, however, works by forcing air into the lungs and thereby increasing the pressure inside the airway relative to the outside. Hence the name "positive pressure." Aside from the obvious advantage of ventilating an otherwise apneic or dyspneic patient, PPV can be effectively used in the treatment of flail segments, which characteristically render negative pressure breathing ineffective, but does not impede PPV.

Positive pressure ventilation is also used in fire fighting to blow smoke out of a room or structure.

Chapter 10

Mechanical Ventilation

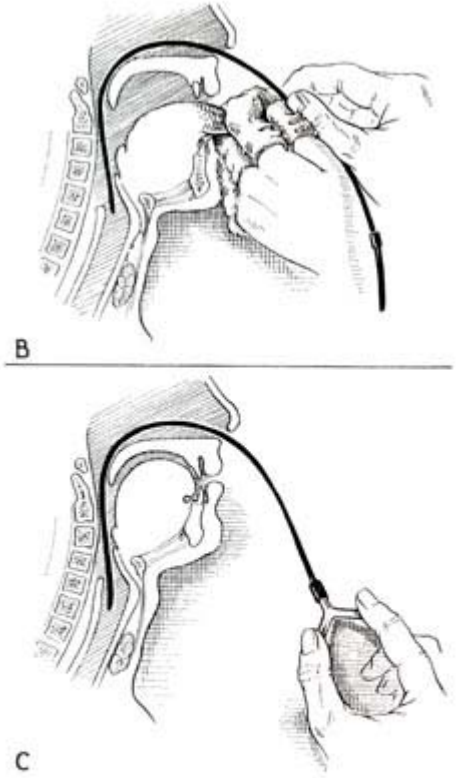


FIGURE 69.—Continued. B. Forward fixation of larynx with left hand, by holding tongue forward with gauze-covered fingers. With the right hand, the catheter is rapidly advanced through the nares and past the glottis as the patient inspires deeply. If he is comatose, a mouth gag is used, and the epiglottis is picked up with the left forefinger. The catheter is then guided through the larynx. C. Advancement of catheter into trachea by intermittent suction over Y-tube. Once it is in trachea, it is moved back and forth to stimulate coughing.

Nasotracheal intubation

In medicine, **mechanical ventilation** is a method to mechanically assist or replace spontaneous breathing.

This may involve a machine called a ventilator or the breathing may be assisted by a physician or other suitable person compressing a bag or set of bellows. Traditionally divided into negative-pressure ventilation, where air is essentially sucked into the lungs, or positive pressure ventilation, where air (or another gas mix) is pushed into the trachea.

It can be used as a short term measure, for example during an operation or critical illness (often in the setting of an intensive care unit). It may be used at home or in a nursing or rehabilitation institution if patients have chronic illnesses that require long-term ventilatory assistance.

Owing to the anatomy of the human pharynx, larynx, and esophagus and the circumstances for which ventilation is required then additional measures are often required to "secure" the airway during positive pressure ventilation to allow unimpeded passage of air into the trachea and avoid air passing into the esophagus and stomach. Commonly this is by insertion of a tube into the trachea which provides a clear route for the air. This can be either an endotracheal tube, inserted through the natural openings of mouth or nose or a tracheostomy inserted through an artificial opening in the neck. In other circumstances simple airway maneuvres, an oropharyngeal airway or laryngeal mask airway may be employed. If the patient is able to protect their own airway such as in non-invasive ventilation or negative-pressure ventilation then no airway adjunct may be needed.

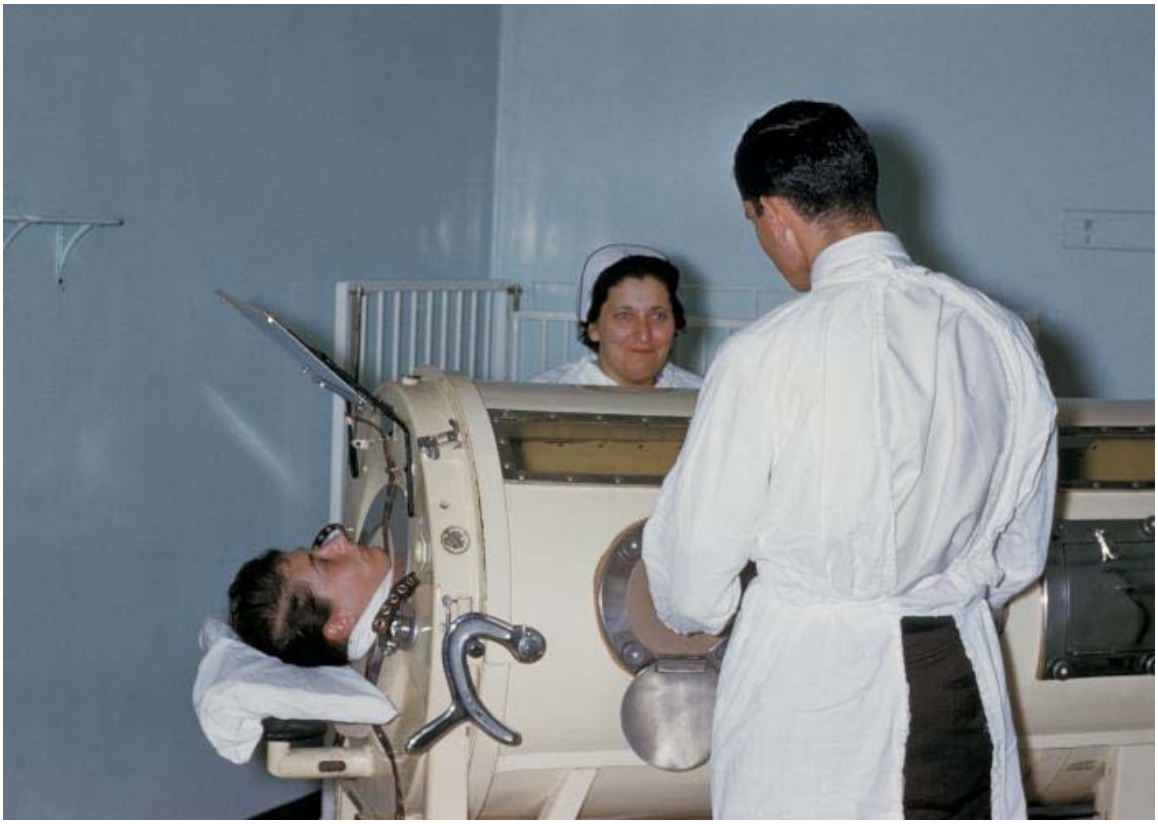
Mechanical ventilation is often a life-saving intervention, but carries many potential complications including pneumothorax, airway injury, alveolar damage, and ventilator-associated pneumonia..

In many healthcare systems prolonged ventilation as part of intensive care is a limited resource (in that there are only so many patients that can receive care at any given moment). It is used to support a single failing organ system (the lungs) and cannot reverse any underlying disease process (such as terminal cancer). For this reason there can be (occasionally difficult) decisions to be made about whether it is suitable to commence someone on mechanical ventilation. Equally many ethical issues surround the decision to discontinue mechanical ventilation.

History

The Roman physician Galen may have been the first to describe mechanical ventilation: "If you take a dead animal and blow air through its larynx [through a reed], you will fill its bronchi and watch its lungs attain the greatest distention." Vesalius too describes ventilation by inserting a reed or cane into the trachea of animals. In 1908 George Poe demonstrated his mechanical respirator by asphyxiating dogs and seemingly bringing them back to life.

Negative pressure machines



An Iron Lung

The iron lung, also known as the Drinker and Shaw tank, was developed in 1929 and was one of the first negative-pressure machines used for long-term ventilation. It was refined and used in the 20th century largely as a result of the polio epidemic that struck the world in the 1940s. The machine is effectively a large elongated tank, which encases the patient up to the neck. The neck is sealed with a rubber gasket so that the patient's face (and airway) are exposed to the room air.

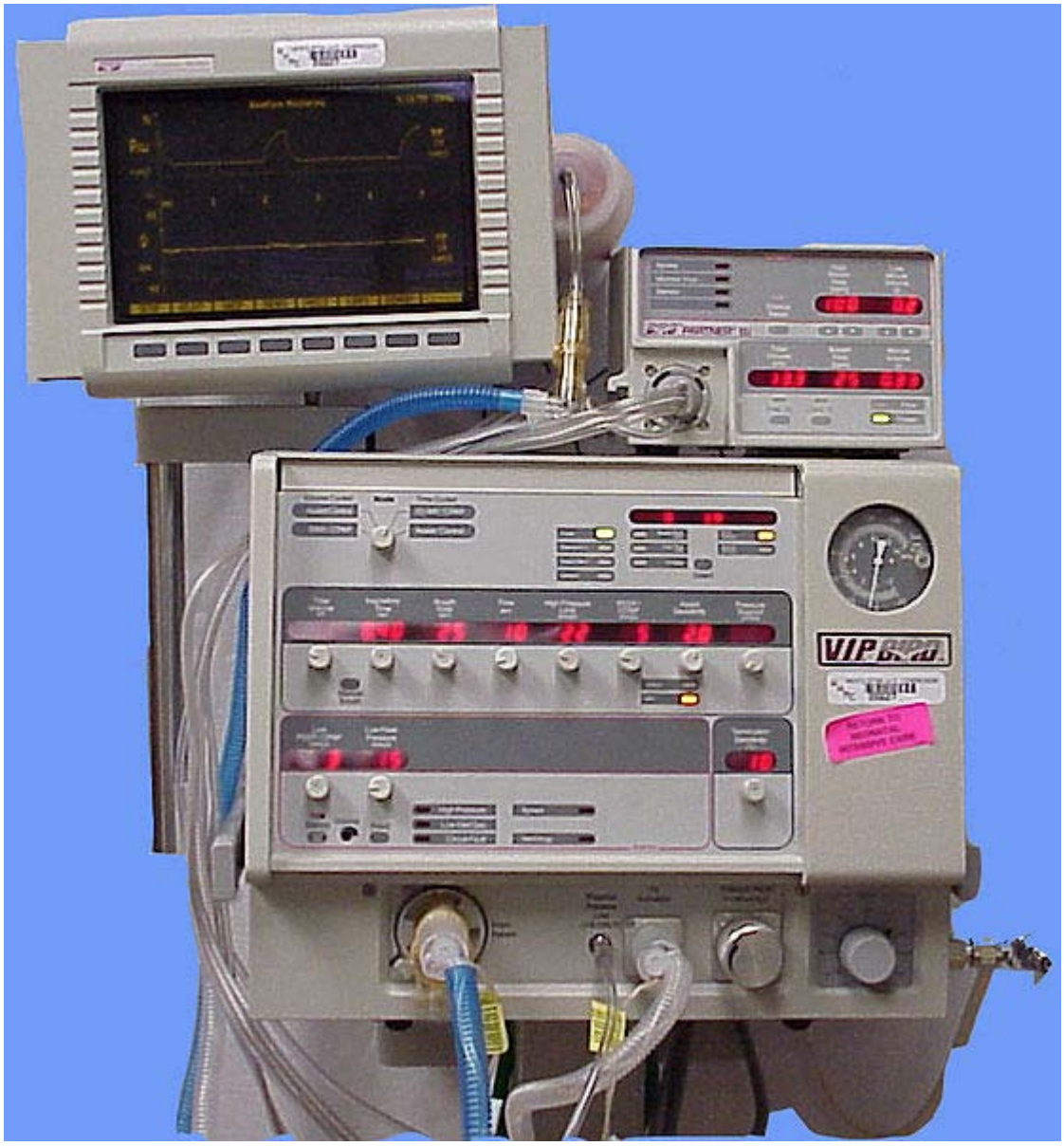
While the exchange of oxygen and carbon dioxide between the bloodstream and the pulmonary airspace works by diffusion and requires no external work, air must be moved into and out of the lungs to make it available to the gas exchange process. In spontaneous breathing, a negative pressure is created in the pleural cavity by the muscles of respiration, and the resulting gradient between the atmospheric pressure and the pressure inside the thorax generates a flow of air.

In the iron lung by means of a pump, the air is withdrawn mechanically to produce a vacuum inside the tank, thus creating negative pressure. This negative pressure leads to expansion of the chest, which causes a decrease in intrapulmonary pressure, and increases flow of ambient air into the lungs. As the vacuum is released, the pressure inside the tank equalizes to that of the ambient pressure, and the elastic coil of the chest and lungs leads

to passive exhalation. However, when the vacuum is created, the abdomen also expands along with the lung, cutting off venous flow back to the heart, leading to pooling of venous blood in the lower extremities. There are large portholes for nurse or home assistant access. The patients can talk and eat normally, and can see the world through a well-placed series of mirrors. Some could remain in these iron lungs for years at a time quite successfully.

Today, negative pressure mechanical ventilators are still in use, notably with the Polio Wing Hospitals in England such as St. Thomas' (by Westminster in London) and the John Radcliffe in Oxford. The prominent device used is a smaller device known as the cuirass. The cuirass is a shell-like unit, creating negative pressure only to the chest using a combination of a fitting shell and a soft bladder. Its main use is in patients with neuromuscular disorders who have some residual muscular function. However, it was prone to falling off and caused severe chafing and skin damage and was not used as a long term device. In recent years this device has re-surfaced as a modern polycarbonate shell with multiple seals and a high pressure oscillation pump in order to carry out biphasic cuirass ventilation.

Positive pressure machines



Neonatal mechanical ventilator

The design of the modern positive-pressure ventilators were mainly based on technical developments by the military during World War II to supply oxygen to fighter pilots in high altitude. Such ventilators replaced the iron lungs as safe endotracheal tubes with high volume/low pressure cuffs were developed. The popularity of positive-pressure ventilators rose during the polio epidemic in the 1950s in Scandinavia and the United States and was the beginning of modern ventilation therapy. Positive pressure through manual supply of 50% oxygen through a tracheostomy tube led to a reduced mortality rate among patients with polio and respiratory paralysis. However, because of the sheer

amount of man-power required for such manual intervention, mechanical positive-pressure ventilators became increasingly popular.

Positive-pressure ventilators work by increasing the patient's airway pressure through an endotracheal or tracheostomy tube. The positive pressure allows air to flow into the airway until the ventilator breath is terminated. Subsequently, the airway pressure drops to zero, and the elastic recoil of the chest wall and lungs push the tidal volume -- the breath—out through passive exhalation.

Indications for use

Mechanical ventilation is indicated when the patient's spontaneous ventilation is inadequate to maintain life. It is also indicated as prophylaxis for imminent collapse of other physiologic functions, or ineffective gas exchange in the lungs. Because mechanical ventilation only serves to provide assistance for breathing and does not cure a disease, the patient's underlying condition should be correctable and should resolve over time. In addition, other factors must be taken into consideration because mechanical ventilation is not without its complications (*see below*)

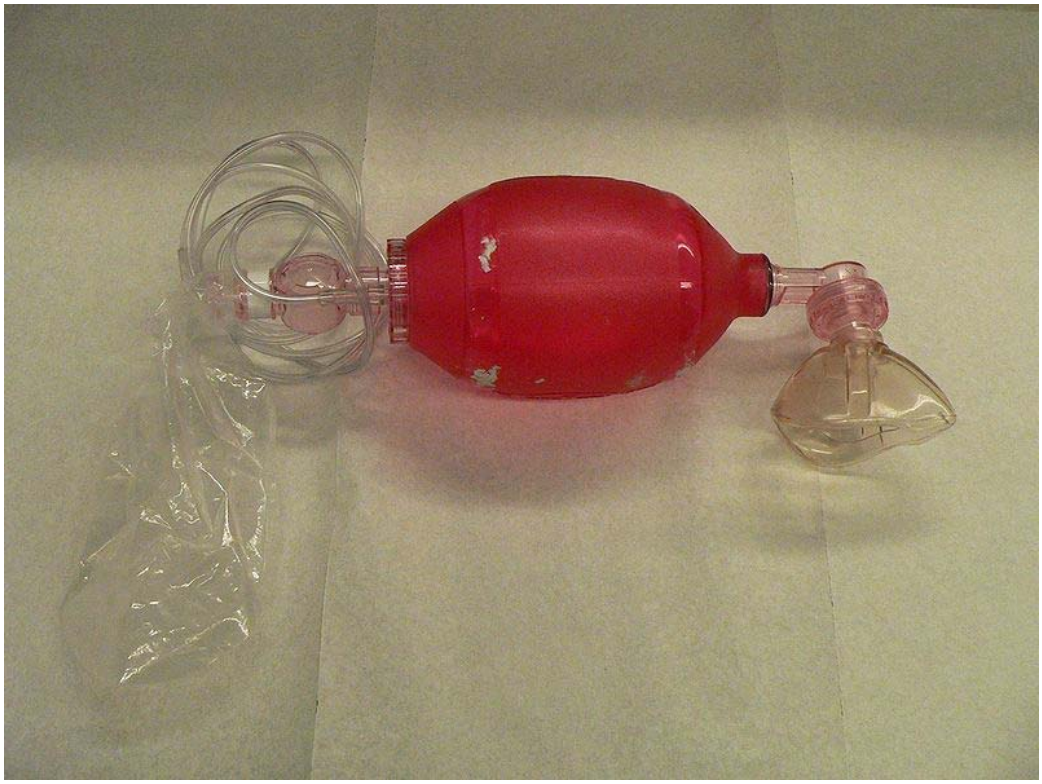
Common medical indications for use include:

- Acute lung injury (including ARDS, trauma)
- Apnea with respiratory arrest, including cases from intoxication
- Chronic obstructive pulmonary disease (COPD)
- Acute respiratory acidosis with partial pressure of carbon dioxide (pCO_2) > 50 mmHg and pH < 7.25, which may be due to paralysis of the diaphragm due to Guillain-Barré syndrome, Myasthenia Gravis, spinal cord injury, or the effect of anaesthetic and muscle relaxant drugs
- Increased work of breathing as evidenced by significant tachypnea, retractions, and other physical signs of respiratory distress
- Hypoxemia with arterial partial pressure of oxygen (PaO_2) with supplemental fraction of inspired oxygen (FiO_2) < 55 mm Hg
- Hypotension including sepsis, shock, congestive heart failure
- Neurological diseases such as Muscular Dystrophy and Amyotrophic Lateral Sclerosis

Types of ventilators

Ventilation can be delivered via:

- Hand-controlled ventilation such as:



SMART BAG MO Bag-Valve-Mask Resuscitator

    - Bag valve mask
    - Continuous-flow or Anaesthesia (or T-piece) bag
- A mechanical ventilator. Types of mechanical ventilators include:
    - Transport ventilators. These ventilators are small, more rugged, and can be powered pneumatically or via AC or DC power sources.
    - ICU ventilators. These ventilators are larger and usually run on AC power (though virtually all contain a battery to facilitate intra-facility transport and as a back-up in the event of a power failure). This style of ventilator often provides greater control of a wide variety of ventilation parameters (such as inspiratory rise time). Many ICU ventilators also incorporate graphics to provide visual feedback of each breath.
        - NICU ventilators. Designed with the preterm neonate in mind, these are a specialized subset of ICU ventilators which are designed to deliver the smaller, more precise volumes and pressures required to ventilate these patients.

- PAP ventilators. these ventilators are specifically designed for non-invasive ventilation. this includes ventilators for use at home, in order to treat sleep apnea.

Modes of ventilation

Conventional ventilation

The modes of ventilation can be thought of as classifications based on how to control the ventilator breath. Traditionally ventilators were classified based on how they determined when to stop giving a breath. The three traditional categories of ventilators are listed below. As microprocessor technology is incorporated into ventilator design, the distinction among these types has become less clear as ventilators may use combinations of all of these modes as well as flow-sensing, which controls the ventilator breath based on the flow-rate of gas versus a specific volume, pressure, or time.

Breath termination

Modes of ventilation are classified by the means that they determine the inspired breath is complete. This is sensed by either pressure or volume.

- Volume ventilation - A predetermined tidal volume (V_t) is set for the patient and is delivered with each inspiration. The amount of pressure necessary to deliver this volume will fluctuate from breath to breath based on the resistance and compliance of the patient and ventilator circuit. If the tidal volume is set at 500ml, the ventilator will continue to inspire gas until it reaches its goal. Upon completion of the inspired volume, the ventilator will open a valve allowing the patient to passively exhale.

- Pressure ventilation - A predetermined peak inspiratory pressure (PIP) is determined based on the patient's condition and pathophysiology. The ventilator will flow gas into the patient until this set pressure is reached. Upon reaching the preset PIP, the ventilator allows for passive exhalation. Caution and close observation must be given in this mode due to potential for either hypoventilation or hyperventilation because the tidal volume is variable.

Several manufactures have incorporated features from both of theses modes in an attempt to accommodate patients needs.
These modes are flow-variable, volume-targeted, pressure-regulated, time-limited modes (for example, pressure regulated volume control - PRVC). This means that instead of providing an exact tidal volume each breath, a target volume is set and the ventilator will vary the inspiratory flow at each breath to achieve the target volume at the lowest possible peak pressure. The inspiratory time (T_i) limits the length of the inspiratory cycle and therefore the I:E ratio. Pressure regulated modes such as PRVC, Auto-flow (Draeger)or Average Volume Assured Pressure Support (AVAPS) from Philips can most

easily be thought of as turning a volume mode into a pressure mode with the added benefit of maintaining more control over tidal volume than with strictly pressure-control.

Breath initiation

The other method of classifying mechanical ventilation is based on how to determine when to start giving a breath. Similar to the termination classification noted above, microprocessor control has resulted in a myriad of hybrid modes that combine features of the traditional classifications. Note that most of the timing initiation classifications below can be combined with any of the termination classifications listed below.

- Assist Control (AC). In this mode the ventilator provides a mechanical breath with either a pre-set tidal volume or peak pressure every time the patient initiates a breath. Traditional assist-control used only a pre-set tidal volume—when a preset peak pressure is used this is also sometimes termed Intermittent Positive Pressure Ventilation or IPPV. However, the initiation timing is the same—both provide a ventilator breath with every patient effort. In most ventilators a back-up minimum breath rate can be set in the event that the patient becomes apnoeic. Although a maximum rate is not usually set, an alarm can be set if the ventilator cycles too frequently. This can alert that the patient is tachypneic or that the ventilator may be auto-cycling (a problem that results when the ventilator interprets fluctuations in the circuit due to the last breath termination as a new breath initiation attempt).
- Synchronized Intermittent Mandatory Ventilation (SIMV). In this mode the ventilator provides a pre-set mechanical breath (pressure or volume limited) every specified number of seconds (determined by dividing the respiratory rate into 60 seconds - thus a respiratory rate of 12 results in a 5 second cycle time). Within that cycle time the ventilator waits for the patient to initiate a breath using either a pressure or flow sensor. When the ventilator senses the first patient breathing attempt within the cycle, it delivers the preset ventilator breath. If the patient fails to initiate a breath, the ventilator delivers a mechanical breath at the end of the breath cycle. Additional spontaneous breaths after the first one within the breath cycle do not trigger another SIMV breath. However, SIMV may be combined with pressure support (see below). SIMV is frequently employed as a method of decreasing ventilatory support (weaning) by turning down the rate, which requires the patient to take additional breaths beyond the SIMV triggered breath.
- Controlled Mechanical Ventilation (CMV). In this mode the ventilator provides a mechanical breath on a preset timing. Patient respiratory efforts are ignored. This is generally uncomfortable for children and adults who are conscious and is usually only used in an unconscious patient. It may also be used in infants who often quickly adapt their breathing pattern to the ventilator timing.
- Pressure Support Ventilation (PSV). When a patient attempts to breathe spontaneously through an endotracheal tube, the narrowed diameter of the airway results in higher resistance to airflow, and thus a higher work of breathing. PSV was developed as a method to decrease the work of breathing in-between ventilator mandated breaths by providing an elevated pressure triggered by

spontaneous breathing that "supports" ventilation during inspiration. Thus, for example, SIMV might be combined with PSV so that additional breaths beyond the SIMV programmed breaths are supported. However, while the SIMV mandated breaths have a preset volume or peak pressure, the PSV breaths are designed to cut short when the inspiratory flow reaches a percentage of the peak inspiratory flow (e.g. 10-25%). New generation of ventilators provides user-adjustable inspiration cycling off threshold, and some even are equipped with automatic inspiration cycling off threshold function. This helps the patient ventilator synchrony. The peak pressure set for the PSV breaths is usually a lower pressure than that set for the full ventilator mandated breath. PSV can be also be used as an independent mode.

- Continuous Positive Airway Pressure (CPAP). A continuous level of elevated pressure is provided through the patient circuit to maintain adequate oxygenation, decrease the work of breathing, and decrease the work of the heart (such as in left-sided heart failure — CHF). Note that no cycling of ventilator pressures occurs and the patient must initiate all breaths. In addition, no additional pressure above the CPAP pressure is provided during those breaths. CPAP may be used invasively through an endotracheal tube or tracheostomy or non-invasively with a face mask or nasal prongs.
- Positive end-expiratory pressure (PEEP) is functionally the same as CPAP, but refers to the use of an elevated pressure during the expiratory phase of the ventilatory cycle. After delivery of the set amount of breath by the ventilator, the patient then exhales passively. The volume of gas remaining in the lung after a normal expiration is termed the *functional residual capacity* (FRC). The FRC is primarily determined by the elastic qualities of the lung and the chest wall. In many lung diseases, the FRC is reduced due to collapse of the unstable alveoli, leading to a decreased surface area for gas exchange and intrapulmonary shunting (*see above*), with wasted oxygen inspired. Adding PEEP can reduce the work of breathing (at low levels) and help preserve FRC.

APRV (Airway Pressure Release Ventilation)

APRV begins from an elevated baseline (called P_{high} or measured high pressure) and achieves tidal ventilation with a brief release of the P_{high}. This brief release allows CO_2 removal through passive exhalation secondary to elastic recoil. The exhalation time (T_{low}) is shortened to usually less than one second to prevent alveolar derecruitment and collapse - it is essentially CPAP with a brief release.

Ever increasing empirical evidence and clinical experience is showing that APRV is the primary mode to use when ventilating a patient with ARDS or ALI (Acute Lung Injury).

Advantages to APRV ventilation include: decreased airway pressures, decreased minute ventilation, decreased dead-space ventilation, promotion of spontaneous breathing, almost 24 hour a day alveolar recruitment, decreased use of sedation, near elimination of neuromuscular blockade, optimized arterial blood gas results, mechanical restoration of FRC (functional residual capacity), a positive effect on cardiac output (due to the

negative inflection from the elevated baseline with each spontaneous breath), increased organ and tissue perfusion, potential for increased urine output due to increased renal perfusion.

A patient with ARDS on average spends 8 to 11 days on a mechanical ventilator; APRV may reduce this time significantly and therefore reduce the incidence of VAP (ventilator acquired pneumonia), a risk that increases with each hour an intubated patient spends on the ventilator (VAP rate is 100% at 100 days on the vent) and carries with it a near 50% mortality rate. So, hospitals that are reporting a 0% incidence of VAP, may be improperly coding or improperly reporting.

** A controlled clinical trial testing APRV against the current ARDSNet protocol must be initiated.*

High Frequency Ventilation (HFV)

Sensormedics 3100 High Frequency ventilator

High-Frequency Ventilation refers to ventilation that occurs at rates significantly above that found in natural breathing (as high as 240-900 "breaths" per minute). Within the category of high-frequency ventilation, the three principal types are high-frequency jet ventilation (HFJV), high-frequency flow interruption (HFFI), and high-frequency oscillatory ventilation (HFOV).

High Frequency Jet Ventilation employs a endotracheal tube adaptor in place for the normal 15 mm ET tube adaptor. A high pressure ‘’jet’’ of gas flows out of the adaptor and into the airway. This jet of gas occurs for a very brief duration, about 0.02 seconds,

and at high frequency: 4-11 hertz. Tidal volumes ≤ 1 ml/Kg are used during HFJV. This combination of small tidal volumes delivered for very short periods of time create the lowest possible distal airway and alveolar pressures produced by a mechanical ventilator. Exhalation is passive. Jet ventilators utilize various I:E ratios--between 1:1.1 and 1:12--to help achieve optimal exhalation. Conventional mechanical breaths are sometimes used to aid in reinflating the lung. Optimal PEEP is used to maintain alveolar inflation and promote ventilation-to-perfusion matching. Jet ventilation has been shown to reduce ventilator induced lung injury by as much as 20%.

"HFFI" operates similarly to a conventional ventilator, providing increased circuit pressure during the inspiratory phase and dropping back to PEEP during the expiratory phase.

In "HFOV" the pressure wave is driven by an electromagnetically controlled diaphragm similar to a loudspeaker. Because this can rapidly change the volume in the circuit, HFOV can produce a pressure that is lower than ambient pressure during the expiratory phase. This is sometimes called "active" expiration. In both types of high-frequency ventilation the pressure wave that is generated at the ventilator is markedly attenuated by passage down the endotracheal tube and the major conducting airways. This helps protect the alveoli from volutrauma that occurs with traditional positive pressure ventilation. Although the alveoli are kept at a relatively constant volume, similar to CPAP, other mechanisms of gas exchange allow ventilation (the removal of CO_2) to occur without tidal volume exchange. Ventilation in HFOV is a function of frequency, amplitude, and I:E ratio and is best described graphically as the area under the curve of an oscillatory cycle. Amplitude is analogous to tidal volume in conventional ventilation; larger amplitudes remove more CO_2. Seemingly paradoxical, lower frequencies remove more CO_2 in HFOV whereas in conventional ventilation the opposite is true. As frequency decreases, there is less attenuation of the pressure wave transmitted to the alveoli. This results in increased mixing of gas and thus ventilation. I-time is set as a percentage of total time (usually 33%). Innovations in HFOV technology (Vision α, Novalung) fascilitate a better CO2 removal, allowing for CO2 removal at higher oscillatory frequencies, without the need to modify I-time. Amplitude is a function of power and is subject to variability due to changes in compliance or resistance. Therefore, power requirements may vary significantly during treatment and from patient to patient. Patient characteristics and ventilator settings determine whether $PaCO_2$ changes may be more sensitive to amplitude or frequency manipulation. In HFOV, mean airway pressure (MAP) is delivered via a continuous flow through the patient circuit which passes through a variable restriction valve (mushroom valve) on the expiratory limb. Increasing the flow through the circuit and/or increasing the pressure in the mushroom valve increases MAP. The MAP in HFOV functions similarly to PEEP in conventional ventilation in that it provides the pressure for alveolar recruitment.

Non-invasive ventilation (Non-invasive Positive Pressure Ventilation or NIPPV)

This refers to all modalities that assist ventilation without the use of an endotracheal tube. Non-invasive ventilation is primarily aimed at minimizing patient discomfort and the complications associated with invasive ventilation. It is often used in cardiac disease, exacerbations of chronic pulmonary disease, sleep apnea, and neuromuscular diseases. Non-invasive ventilation refers only to the patient interface and not the mode of ventilation used; modes may include spontaneous or control modes and may be either pressure or volume modes.

Some commonly used modes of NIPPV include:

- Continuous positive airway pressure (CPAP).
- Bi-level Positive Airway Pressure (BIPAP). Pressures alternate between Inspiratory Positive Airway Pressure (IPAP) and a lower Expiratory Positive Airway Pressure (EPAP), triggered by patient effort. On many such devices, backup rates may be set, which deliver IPAP pressures even if patients fail to initiate a breath.(Wheatley 2000 et all)
- Intermittent positive pressure ventilation (IPPV) via mouthpiece or mask
- Biphasic Cuirass Ventilation A form of non-invasive ventilation that uses a cuirass instead of a facemask. Allows active control of both inspiration and exhalation.

Proportional Assist Ventilation (PAV)

Proportional Assist Ventilation (PAV) is a form of synchronised ventilator support based upon the Equation of Motion in which the ventilator generates pressure in proportion to the instantaneous patient effort. Unlike other modes of partial support, there is no target flow, tidal volume or pressure. PAV's objective is to allow the patient to attain ventilation and breathing pattern his ventilatory control system desires. The main operational advantages of PAV are automatic synchrony with inspiratory efforts, exhalation and adaptability to change in ventilatory demand.

Proportional Assist Ventilation Plus — PAV+ (Puritan Bennett – 840 ventilator range, **Proportional Pressure Support — PPS** (Drager Evita series)and Respironics BiPAP Vision PAV , are commercially available implementations of PAV which automatically amplify the patient's own spontaneous effort to breathe by increasing airway pressure during inspiration proportionally to a set amplification factor.
In PAV+, the level of amplification, thus the level of work of breathing, is set through a single setting (%support) and the pressure applied is continuously and automatically adjusted based on measures (including automatic assessment of Elastance and Resistance) taken throughout the inspiratory cycle to maintain an appropriate level of support.

Adaptive Support Ventilation (ASV)

Adaptive Support Ventilation (ASV) is a positive pressure mode of mechanical ventilation that is closed-loop controlled. In this mode, the frequency and tidal volume of breaths of a patient on the ventilator are automatically adjusted based on the patient's requirements. The lung mechanics data are used to adjust the depth and rate of breaths to minimize the work rate of breathing. In the ASV mode, every breath is synchronized with patient effort if such an effort exists, and otherwise, full mechanical ventilation is provided to the patient.

ASV technology was originally described as one of the embodiments of US Patent No. 4986268. In this invention, a modified version of an equation derived in physiology in 1950 to minimize the work rate of breathing in man, was used for the first time to find the optimum frequency of mechanical ventilation. The rationale was to make the patient's breathing pattern comfortable and natural within safe limits, and thereby stimulate spontaneous breathing and reduce the weaning time. A prototype of the system was built by the inventor in late 1980s. The inventor is Dr. Fleur T. Tehrani who is a university professor in the US. Shortly after the Patent was issued in 1991, Hamilton Medical, a ventilator manufacturing company, contacted the inventor and discussed marketing the technology with her. Some years later, Hamilton Medical marketed this closed-loop technique under license of this Patent as ASV.

Since the issuance of the Patent, a number of articles have been published by the inventor and her colleagues that are related to the invention, and some of them describe further advancements of the closed-loop techniques presented in the Patent.

Neurally Adjusted Ventilatory Assist (NAVA)

Neurally Adjusted Ventilatory Assist (NAVA) is a unique positive pressure mode to mechanical ventilation based on neural respiratory output, in connections with invasive and non-invasive NAVA.

The act of taking a breath is controlled by the respiratory center of the brain, which decides the characteristics of each breath, timing and size. The respiratory center sends a signal along the phrenic nerve, excites the diaphragm muscle cells, leading to muscle contraction and descent of the diaphragm dome. As a result, the pressure in the airway drops, causing an inflow of air into the lungs.

With NAVA, the electrical activity of the diaphragm (Edi) is captured, fed to the ventilator and used to assist the patient's breathing in synchrony with and in proportion to the patients own efforts, regardless of patient category or size. As the work of the ventilator and the diaphragm is controlled by the same signal, coupling between the diaphragm and the SERVO-i ventilator is synchronized simultaneously. Reference: New method permits neural control of mechanical ventilation

Choosing amongst ventilator modes

Assist-control mode minimizes patient effort by providing full mechanical support with every breath. This is often the initial mode chosen for adults because it provides the greatest degree of support. In patients with less severe respiratory failure, other modes such as SIMV may be appropriate. Assist-control mode should not be used in those patients with a potential for respiratory alkalosis, in which the patient has an increased respiratory drive. Such hyperventilation and hypocapnia (decreased systemic carbon dioxide due to hyperventilation) usually occurs in patients with end-stage liver disease, hyperventilatory sepsis, and head trauma. Respiratory alkalosis will be evident from the initial arterial blood gas obtained, and the mode of ventilation can then be changed if so desired.

Positive End Expiratory Pressure may or may not be employed to prevent atelectasis in adult patients. It is almost always used for pediatric and neonatal patients due to their increased tendency for atelectasis.

High frequency oscillation is used most frequently in neonates, but is also used as an always alternative mode in adults with severe ARDS.

Pressure Regulated Volume Control is another option.

Initial ventilator settings

The following are general guidelines that may need to be modified for the individual patient.

As a general rule, whenever possible, spontaneous breathing must be maintained or supported, to avoid muscular atrophy of the diaphragm (Ventilator Induced Dysfunction of Diaphragm, VIDD) . To limit VALI and VILI, protective ventilation pattern should be applied to the patient. If this results in severe hypercapnia, exceeding accepted levels for permissive hypercapnia (pH below 7.2), measures for extracorporeal CO2 removal (iLA Membranventilator, Novalung) should be installed at an early stage of mechanical ventilation, to terminate cascades of inflammatory response from the lung tissue, resulting in multiorgan failure respective.

Tidal volume, rate, and pressures

- For adult patients and older children
    - tidal volume(Vt) is calculated in milliliters per kilogram. Traditionally 10 ml/kg was used but has been shown to cause barotrauma, or injury to the lung by overextension, so 6 to 8 ml/kg is now common practice in ICU. Hence a patient weighing 70 kg would get a Vt of 420–480 ml. In adults a rate of 12 strokes per minute is generally used.

    - with acute respiratory distress syndrome (ARDS) a tidal volume of 6–8 ml/kg is used with a rate of 10–12 per minute. This reduced tidal volume allows for minimal volutrauma but may result in an elevated pCO_2 (due to the relative decreased oxygen delivered) but this elevation does not need to be corrected (termed *permissive hypercapnia*)
- For infants and younger children
    - without existing lung disease—a tidal volume of 4–8 ml/kg to be delivered at a rate of 30–35 breaths per minute
    - with ARDS—decrease tidal volume and increase respiratory rate sufficient to maintain pCO_2 between 45 and 55[1]. Allowing higher pCO_2 (sometimes called permissive hypercapnia) may help prevent ventilator induced lung injury

As the amount of tidal volume increases, the pressure required to administer that volume is increased. This pressure is known as the *peak airway pressure*. If the peak airway pressure is persistently above 45 cmH_2O (4.4 kPa) for adults, the risk of barotrauma is increased (*see below*) and efforts should be made to try to reduce the peak airway pressure. In infants and children it is unclear what level of peak pressure may cause damage. In general, keeping peak pressures below 30 cmH_2O (2.9 kPa) is desirable.

Monitoring for barotrauma can also involve measuring the *plateau pressure*, which is the pressure *after* the delivery of the tidal volume but *before* the patient is allowed to exhale. Normal breathing pattern involves inspiration, then expiration. The ventilator is programmed so that after delivery of the tidal volume (inspiration), the patient is not allowed to exhale for a half a second. Therefore, pressure must be maintained in order to prevent exhalation, and this pressure is the plateau pressure. Barotrauma is minimized when the plateau pressure is maintained < 30–35 cmH_2O.

Sighs

An adult patient breathing spontaneously will usually sigh about 6–8 times per hour to prevent microatelectasis, and this has led some to propose that ventilators should deliver 1½–2 times the amount of the preset tidal volume 6–8 times per hour to account for the sighs. However, such high quantity of volume delivery requires very high peak pressure that predisposes to barotrauma. Currently, accounting for sighs is not recommended if the patient is receiving 10-12 mL/kg or is on PEEP. If the tidal volume used is lower, the sigh adjustment can be used, as long as the peak and plateau pressures are acceptable.

Sighs are not generally used with ventilation of infants and young children.

Initial FiO_2

Because the mechanical ventilator is responsible for assisting in a patient's breathing, it must then also be able to deliver an adequate amount of oxygen in each breath. The FiO_2 stands for *fraction of inspired oxygen*, which means the percent of oxygen in each breath that is inspired. (Note that normal room air has ~21% oxygen content). In adult patients

who can tolerate higher levels of oxygen for a period of time, the initial FiO_2 may be set at 100% until arterial blood gases can document adequate oxygenation. An FiO_2 of 100% for an extended period of time can be dangerous, but it can protect against hypoxemia from unexpected intubation problems. For infants, and especially in premature infants, avoiding high levels of FiO_2 (>60%) is important.

Positive end-expiratory pressure (PEEP)

PEEP is an adjuvant to the mode of ventilation used to help maintain functional residual capacity (FRC). At the end of expiration, the PEEP exerts pressure to oppose passive emptying of the lung and to keep the airway pressure above the atmospheric pressure. The presence of PEEP opens up collapsed or unstable alveoli and increases the FRC and surface area for gas exchange, thus reducing the size of the shunt. For example, if a large shunt is found to exist based on the estimation from 100% FiO_2 (*see above*), then PEEP can be considered and the FiO_2 can be lowered (< 60%) in order to maintain an adequate PaO_2, thus reducing the risk of oxygen toxicity.

In addition to treating a shunt, PEEP may also be useful to decrease the work of breathing. In pulmonary physiology, compliance is a measure of the "stiffness" of the lung and chest wall. The mathematical formula for compliance (C) equals change in volume divided by change in pressure. The higher the compliance, the more easily the lungs will inflate in response to positive pressure. An underinflated lung will have low compliance and PEEP will improve this initially by increasing the FRC, since the partially inflated lung takes less energy to inflate further. Excessive PEEP can however produce overinflation, which will again decrease compliance. Therefore it is important to maintain an adequate, but not excessive FRC.

Indications. PEEP can cause significant haemodynamic consequences through decreasing venous return to the right heart and decreasing right ventricular function. As such, it should be judiciously used and is indicated for adults in two circumstances.

- If a PaO_2 of 60 mmHg cannot be achieved with a FiO_2 of 60%
- If the initial shunt estimation is greater than 25%

If used, PEEP is usually set with the minimal positive pressure to maintain an adequate PaO_2 with a safe FiO_2. As PEEP increases intrathoracic pressure, there can be a resulting decrease in venous return and decrease in cardiac output. A PEEP of less than 10 cmH_2O (1 kPa) is usually safe in adults if intravascular volume depletion is absent. Lower levels are used for pediatric patients. Older literature recommended routine placement of a Swan-Ganz catheter if the amount of PEEP used is greater than 10 cmH_2 for hemodynamic monitoring. More recent literature has failed to find outcome benefits with routine PA catheterisation when compared to simple central venous pressure monitoring. If cardiac output measurement is required, minimally invasive techniques, such as oesophageal doppler monitoring or arterial waveform contour monitoring may be sufficient alternatives. PEEP should be withdrawn from a patient until adequate PaO_2 can be maintained with a FiO_2 < 40%. When withdrawing, it is decreased through 1–2

cmH_2O decrements while monitoring haemoglobin-oxygen saturations. Any unacceptable haemoglobin-oxygen saturation should prompt reinstitution of the last PEEP level that maintained good saturation.

Positioning

Prone (face down) positioning has been used in patients with ARDS and severe hypoxemia. It improves FRC, drainage of secretions, and ventilation-perfusion matching (efficiency of gas exchange). It may improve oxygenation in > 50% of patients, but no survival benefit has been documented.

Sedation and Paralysis

Most intubated patients receive intravenous sedation through a continuous infusion or scheduled dosing to help with anxiety or psychological stress. Sedation also helps the patient tolerate the constant irritation of the endotracheal tube in their mouth, pharynx and trachea. Without some form of sedation and analgesia, it is common for patients to "fight" the ventilator. This fighting increases work of breathing and may cause further lung injury. Daily interruption of sedation is commonly helpful to the patient for reorientation and appropriate weaning. These interruptions are frequently described as "sedation vacations" and have been shown to reduce the time patients stay on mechanical ventilation.

It is not uncommon for patients on a mechanical ventilator to be given a muscle relaxant or paralytic to aid in ventilation. These "neuromuscular blockades" prevent skeletal muscle from contracting and thereby stop all patient movement including respiratory efforts. These types of pharmaceutical agents must always be given in conjunction with sedation as the effects of the paralytics is not only uncomfortable but would cause significant psychological stress and anxiety.

Prophylaxis

- To protect against ventilator-associated pneumonia, patients' beds are often elevated to about 30°.
- Deep vein thrombosis prophylaxis with heparin or sequential compression device is important in older children and adults.
- A histamine receptor (H2) blocker or proton-pump inhibitor may be used to prevent gastrointestinal bleeding, which has been associated with mechanical ventilation

Modification of settings

In adults when 100% FiO_2 is used initially, it is easy to calculate the next FiO_2 to be used and easy to estimate the shunt fraction. The estimated shunt fraction refers to the amount of oxygen not being absorbed into the circulation. In normal physiology, gas exchange

(oxygen/carbon dioxide) occurs at the level of the alveoli in the lungs. The existence of a shunt refers to any process that hinders this gas exchange, leading to wasted oxygen inspired and the flow of un-oxygenated blood back to the left heart (which ultimately supplies the rest of the body with unoxygenated blood).

When using 100% FiO_2, the degree of shunting is estimated by subtracting the measured PaO_2 (from an arterial blood gas) from 700 mmHg. For each difference of 100 mmHg, the shunt is 5%. A shunt of more than 25% should prompt a search for the cause of this hypoxemia, such as mainstem intubation or pneumothorax, and should be treated accordingly. If such complications are not present, other causes must be sought after, and PEEP should be used to treat this intrapulmonary shunt. Other such causes of a shunt include:

- Alveolar collapse from major atelectasis
- Alveolar collection of material other than gas, such as pus from pneumonia, water and protein from acute respiratory distress syndrome, water from congestive heart failure, or blood from haemorrhage

When to withdraw mechanical ventilation

Withdrawal from mechanical ventilation—also known as weaning—should not be delayed unnecessarily, nor should it be done prematurely. Patients should have their ventilation considered for withdrawal if they are able to support their own ventilation and oxygenation, and this should be assessed continuously. There are several objective parameters to look for when considering withdrawal, but there is no specific criteria that generalizes to all patients.

Trials of spontaneous breathing have been shown to accurately predict the success of spontaneous breathing. (Yang K, Tobin MJ. A prospective study of indexes predicting the outcome of weaning from mechanical ventilation. N Engl J Med 1991;324:1445–1450).

Connection to ventilators

There are various procedures and mechanical devices that provide protection against airway collapse, air leakage, and aspiration:

- Face mask - In resuscitation and for minor procedures under anaesthesia, a face mask is often sufficient to achieve a seal against air leakage. Airway patency of the unconscious patient is maintained either by manipulation of the jaw or by the use of *nasopharyngeal* or *oropharyngeal airway*. These are designed to provide a passage of air to the pharynx through the nose or mouth, respectively. Poorly fitted masks often cause nasal bridge ulcers, a problem for some patients. Face masks are also used for non-invasive ventilation in conscious patients. A full face mask does not, however, provide protection against aspiration.

- Laryngeal mask airway - The laryngeal mask airway (LMA) causes less pain and coughing than a tracheal tube. However, unlike tracheal tubes it does not seal against aspiration, making careful individualised evaluation and patient selection mandatory.
- *Tracheal intubation* is often performed for mechanical ventilation of hours to weeks duration. A tube is inserted through the nose (nasotracheal intubation) or mouth (orotracheal intubation) and advanced into the trachea. In most cases tubes with inflatable cuffs are used for protection against leakage and aspiration. Intubation with a cuffed tube is thought to provide the best protection against aspiration. Tracheal tubes inevitably cause pain and coughing. Therefore, unless a patient is unconscious or anaesthetized for other reasons, sedative drugs are usually given to provide tolerance of the tube. Other disadvantages of tracheal intubation include damage to the mucosal lining of the nasopharynx or oropharynx and subglottic stenosis.
- Esophageal obturator airway - sometimes used by emergency medical technicians and basic EMS providers not trained to intubate. It is a tube which is inserted into the esophagus, past the epiglottis. Once it is inserted, a bladder at the tip of the airway is inflated, to block ("obturate") the esophagus, and oxygen is delivered through a series of holes in the side of the tube which is then forced into the lungs.
- *Cricothyrotomy* - Patients who require emergency airway management, in whom tracheal intubation has been unsuccessful, may require an airway inserted through a surgical opening in the cricothyroid membrane. This is similar to a tracheostomy but a cricothyrotomy is reserved for emergency access.
- *Tracheostomy* - When patients require mechanical ventilation for several weeks, a tracheostomy may provide the most suitable access to the trachea. A tracheostomy is a surgically created passage into the trachea. Tracheostomy tubes are well tolerated and often do not necessitate any use of sedative drugs. Tracheostomy tubes may be inserted early during treatment in patients with pre-existing severe respiratory disease, or in any patient who is expected to be difficult to wean from mechanical ventilation, i.e., patients who have little muscular reserve.
- *Mouthpiece* - Less common interface, does not provide protection against aspiration. There are lipseal mouthpieces with flanges to help hold them in place if patient is unable.

Terminology

Terminology used in the field of mechanical ventilation and respiratory support:

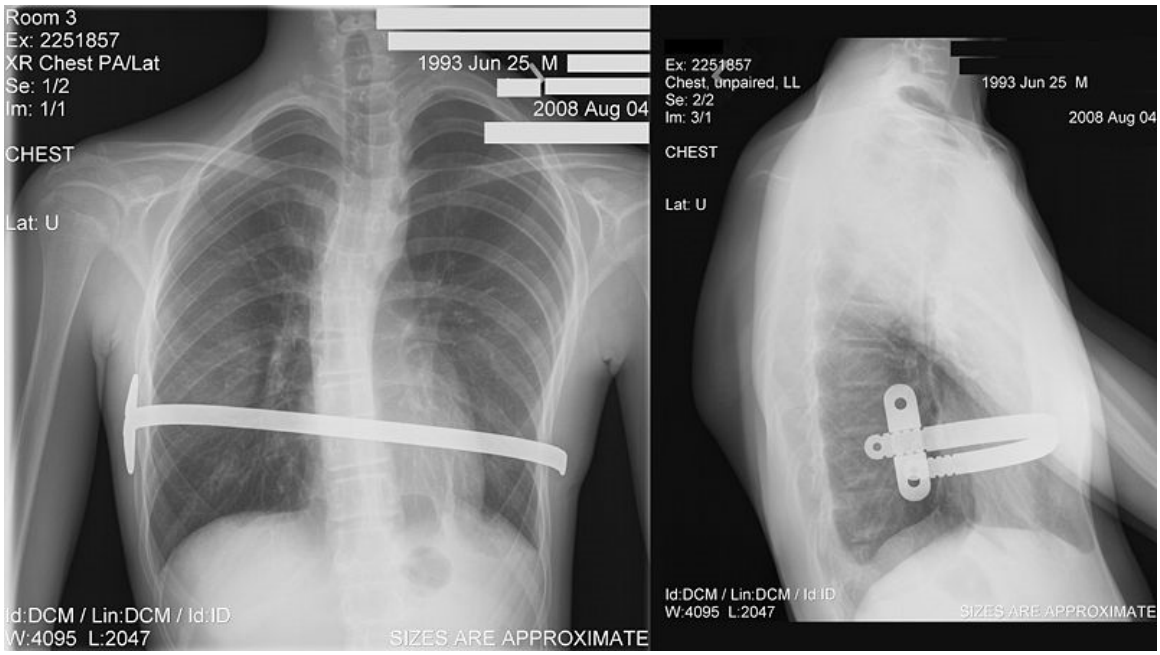
- APRV Airway pressure release ventilation
- ASB Assisted spontaneous breathing—also *ASV* = assisted spontaneous ventilation
- ASV Adaptive support ventilation—a patented technology—closed-loop mechanical respiration, a further development of MMV. Can also stand for assisted spontaneous ventilation.
- ATC Automatic tube compensation
- Automode Automode

- BCV Biphasic Cuirass Ventilation
- BIPAP Bilevel Positive Airway Pressure
- CMV Continuous mandatory ventilation
- CPAP Continuous positive airway pressure
- CPPV Continuous positive pressure ventilation
- EPAP Expiratory positive airway pressure
- HFV High frequency ventilation
    - HFFI High frequency flow interruption
    - HFJV High frequency jet ventilation
    - HFOV High frequency oscillatory ventilation
    - HFPPV High frequency positive pressure ventilation
- ILV Independent lung ventilation—separate sides positive pressure ventilation.
- IPAP Inspiratory positive airway pressure
- IPPV Intermittent positive pressure ventilation
- IRV Inversed ratio ventilation— mechanical ventilation with switched respiration phases/time rate.
- LFPPV Low frequency positive pressure ventilation
- MMV Mandatory minute volume
- NAVA Neurally Adjusted Ventilatory Assist
- NIF Negative inspiratory force—amount of force generated by a patient against a closed valve; greater than 20 cmH_2O indicates an adequately strong diaphragm.
- NIV Non-invasive ventilation
- PAP Positive airway pressure
- PAV and PAV+ Proportional assist ventilation and proportional assist ventilation plus
- *P*/*F* ratio Ratio of PaO_2 off an ABG and FiO_2 off the ventilator. $P/F < 200$ indicates ARDS, $P/F < 300$ indicates ALI
- PCMV (P-CMV) Pressure controlled mandatory ventilation
- PCV Pressure controlled ventilation or PC Pressure control—pressure-controlled, fully mechanical ventilation.
- PEEP Positive end-expiratory pressure
- PNPV Positive negative pressure ventilation—switching pressure mechanical ventilation
- PPS Proportional pressure support
- PRVC Pressure regulated volume controlled ventilation
- PSV Pressure Support Ventilation or PS—supported spontaneous respiration
- RSBI Rapid shallow breathing index—ratio of breath rate divided by the tidal volume. RSBI<105 declares a patient can be extubated and maintain themselves. Also indicates patient has a good chance of staying extubated.
- (S) IMV (Synchronized) intermittent mandatory ventilation
- S-CPPV Synchronized continuous positive pressure ventilation
- S-IPPV Synchronized intermittent positive pressure ventilation
- TNI Therapy with nasal insufflation—nasal high-flow mechanical ventilation for respiration support.
- VCMV (V-CMV) Volume controlled mandatory ventilation

- VCV Volume controlled ventilation or VC, Volume Control—volume-controlled, fully mechanical ventilation.
- VS Volume Support
- ZAP Zero airway pressure—spontaneous respiration under atmospheric pressure.

Chapter 11

Nuss Procedure



X-Ray of a 15 year old male after undergoing the procedure

The **Nuss procedure** is a minimally-invasive procedure, invented by Dr. Donald Nuss for treating pectus excavatum. He developed it at Children's Hospital of The King's Daughters, in Norfolk, Virginia. The operation typically takes approximately two hours.

Through two small incisions in the side of the chest, an introducer is pushed along posterior to the sternum and ribs, and anterior to the heart and lungs. Then a concave stainless steel bar is slipped under the sternum, through the incisions in the side of the chest. A third, smaller incision is made to insert a thoracoscope (small camera) used to help guide the bar. Taller patients, older patients, or patients requiring extensive

correction may receive two or more bars. All bars may be placed through two incisions or additional incisions may be made. The bar is then flipped, and the sternum pops out. To support the bar and keep it in place a metal plate called a stabilizer may be inserted with the bar on one side of the torso. PDS sutures may also be used in addition to the stabilizer. The stabilizer fits around the bar and into the ribcage. The bar and stabilizer are secured with sutures that dissolve in about six months.

Some surgeons have achieved excellent results using only pericostal sutures, without the use of stabilizers. For older children who have more ossified bones, an additional option the surgeon has is to make an incision across the sternum so the bar is attached with a wire to the sternum to avoid bar displacement. Older children's bones do not conform as easily to the bar, thus increasing the risk of bar displacement, so the wire attaching the bar directly to the sternum may help avoid a second surgery to correct bar displacement.

Eventually, the bar is secured with muscle tissue that regrows during the recovery time. Although initially recommended only for younger patients, the Nuss procedure is now commonly used on patients in their thirties and forties with excellent results.

Postoperative evaluation indicates a significant improvement in pulmonary function studies and a high proportion of patients report improvements in well being and an increase in exercise tolerance.

Although this procedure is categorized as "minimally invasive", one must not infer that recovery from this procedure is minimal. Post-operative pain control can be quite challenging thus requiring multi-modal pain management, such as epidural. Nurses who attend these patients post operation generally concur that this operation is one of the more difficult recoveries of any operations for children.

Recovery

Recovery time is generally four to five days as an in-patient, depending on the patient age, activity level, co-morbities and post-operative complications (if any), followed by time at home to overcome the pain and to let the bar settle into place. Patients younger than fifteen often require only two to four weeks at home after being discharged from the hospital for recovery. However, older children and adults typically require a greater recovery time due to the increased ossification (and thus decreased flexibility) of their bones.

In this case, the difficulty and length of recovery should be carefully considered prior to making the decision to undergo the operation, as the limitations to lifestyle, functionality and comfort can be dramatic for many months. This cannot be understated for older children, which is why many doctors do not recommend this procedure unless medically necessary (i.e. not for cosmetic reasons). Fully grown adults may require from four weeks to many months before they can resume normal activities, including work. For six to twenty-four hours after the operation, the patient generally will have a Foley catheter to minimize risk of movement that could displace bar, and because the epidural can interfere

with normal urination. The patient may also receives thoracic epidural analgesia in the back for two to five days depending on patient recovery.

For six weeks, physicial activity should be limited (i.e. no running or strenuous physical activity, and lifting is limited to ten pounds or less). Walking for exercise and breathing exercises aid in recovery. It is sometimes suggested that weight-training should be limited or eliminated for up to three months. It is also recommended that any sports where contact may occur should be avoided. However, aerobic sports are encouraged, as results after bar removal are best maintained in patients who have stimulated their cardiopulmonary systems while the bar is in place. After a period of six to ten months the athletic skills are almost completely recovered

Bar removal

After a period of two to four years, the surgical stainless steel bar is removed from the patient's chest. This outpatient procedure lasts approximately ninety minutes. The patient stays at the hospital for a few hours.

Complications

Iatrogenic damage to the heart and lungs during the procedure is a concern. Scopes (cameras) are often utilized by the surgical team to minimize this risk. There is still an extremely minor risk of abrasion or puncture.

Air in the chest (pneumothorax) is one of the more frequent complications. A chest tube may be required or aggressive breathing exercises and close monitoring may be adequate.

With the use of stabilizers and PDS sutures, bar displacement rarely occurs. If these methods of bar fixation are not used, bar displacement may occur. This can be quite painful and requires some sort of intervention: either bar removal, or repositioning of the bar with some sort of bar fixation. Patients should understand prior to the surgery that if bar displacement occurs soon after surgery, a second surgery will be immediately required which is even a more difficult recovery as the patient is already weakened and in pain. High impact trauma, such as car accidents can dislodge the bars, causing extreme pain. This is the reason for the restriction on driving, because a sudden defensive maneuver, such as a jerk of the steering wheel, could dislodge the bar up to six weeks directly after the surgery.

Other complications which may occur include hemothorax, pleural effusion, pericarditis, wound infection and pneumonia and acquired scoliosis. Vigorous incentive spirometry is used to prevent pneumonia. Some patients are allergic to one of the components of stainless steel. As a result, allergy testing is now routinely done prior to surgery. In the event of an allergy, a titanium bar will be used.

Older children may also struggle with adjusting to living in their changed bodies during the several months of healing due to the pain and limitations.

Again, it is very important to be fully aware that although the surgery may be minimally invasive, the recovery process and risks of complications (and consequences thereof) are not minimal.

Chapter 12

Cardiopulmonary Resuscitation

CPR being performed on a mannequin

Cardiopulmonary resuscitation (**CPR**) is an emergency procedure which is attempted in an effort to return life to a person in cardiac arrest. It is indicated in those who are unresponsive with no breathing or only gasps. It may be attempted both in and outside of a hospital.

CPR involves chest compressions at a rate of at least 100 per minute in an effort to create artificial circulation by manually pumping blood through the heart. In addition the rescuer may provide breaths by either exhaling into their mouth or utilizing a device that pushes air into the lungs. The process of externally providing ventilation is termed artificial respiration. Current recommendations place emphasis on high quality chest compressions over artificial respirations and a method involving only chest compressions is recommended for untrained rescuers.

CPR alone is unlikely to restart the heart; its main purpose is to restore partial flow of oxygenated blood to the brain and heart. It may delay tissue death and extend the brief window of opportunity for a successful resuscitation without permanent brain damage. An administering of an electric shock to the heart, termed defibrillation, is usually needed to restore a viable or "perfusing" heart rhythm. Defibrillation is only effective for certain heart rhythms, namely ventricular fibrillation or pulseless ventricular tachycardia, rather than asystole or pulseless electrical activity. CPR may however induce a shockable rhythm. CPR is generally continued until the person regains return of spontaneous circulation (ROSC) or is declared dead.

Indications

CPR is indicated for any person who is unresponsive with no breathing or only gasps as breathing as it is most likely that they are in cardiac arrest. If a person still has a pulse, but is not breathing (respiratory arrest), artificial respirations are more appropriate. However, many people often have difficulty detecting a pulse and CPR may thus be used.

Methods

CPR training: CPR is being administered while a second rescuer prepares for defibrillation.

In 2010, the American Heart Association and International Liaison Committee on Resuscitation updated their CPR guidelines. The importance of high quality CPR (sufficient rate and depth without excessively ventilating) was emphasized. The order of interventions was changed for all age groups except newborns from airway, breathing, chest compressions (ABC) to chest compressions, airway, breathing (CAB). An exception to this recommendation is for those who are believed to be in a respiratory arrest (drowning, etc.).

Standard

A universal compression to ventilation ratio of 30:2 is recommended for adult and in children and infant if only a single rescuer is present.[:8] If at least 2 rescuers are present a ratio of 15:2 is preferred in children and infants.[:8] In newborns a rate of 3:1 is recommended unless a cardiac cause is known in which case a 15:2 ratio is reasonable. If an advanced airway such as an endotracheal tube or laryngeal mask airway is in place delivery of respirations should occur without pauses in compressions at a rate of 8-10 per minute. The recommended order of interventions is chest compressions, airway, breathing or CAB in most situations. With a compression rate of at least 100 per minute in all groups.[:8] Recommended compression depth in adults and children is about 5 cm

(2 inches) and in infants it is 4 cm (1.5 inches. As of 2010 the Resuscitation Council (UK) still recommends ABC for children. As it can be difficult to determine the presence or absence of a pulse the pulse check has been removed for lay providers and should not be performed for more than 10 seconds by health care providers. In adults rescuers should use two hands for the chest compressions, while in children they should use one, and with infants two fingers (index and middle fingers).

Compression only

Compression only (hands-only or cardiocerebral resuscitation) CPR is a technique that involves chest compressions without artificial respiration. It is recommended as the method of choice for the untrained rescuer or those who are not proficient as it is easier to perform and instructions are easier to give over the phone.[1] In adults with out-of-hospital cardiac arrest, compression-only CPR by the lay public has a higher success rate than standard CPR. The exceptions are cases of drownings, drug overdose, and arrest in children. Children who receive compression only CPR have the same outcomes as those who received no CPR. The method of delivering chest compressions remains the same, as does the rate (at least 100 per minute). It is hoped that the use of compression only delivery will increase the chances of the lay public delivering CPR.

Interposed abdominal compression

Interposed abdominal compressions may be beneficial in the in hospital environment. There is however no evidence of benefit pre hospital or in children.

Internal cardiac massage

Internal cardiac massage is the process of cardiac massage carried out through a surgical incision into the chest cavity. This distinguishes the process from conventional, external cardiac massage, which is carried out by compression near the sternum during cardiopulmonary resuscitation.

Effectiveness

Type of Arrest	ROSC	Survival Source
Witnessed In-Hospital Cardiac Arrest	48%	22%
Unwitnessed In-Hospital Cardiac Arrest	21%	1%
Bystander Cardiocerebral Resuscitation	40%	6%
Bystander Cardiopulmonary Resuscitation	40%	4%
No Bystander CPR (Ambulance CPR)	15%	2%
Defibrillation within 3–5 minutes	74%	30%

Used alone, CPR will result in few complete recoveries, and those who do survive often develop serious complications. Estimates vary, but many organizations stress that CPR

does not "bring anyone back," it simply preserves the body for defibrillation and advanced life support. However, in the case of "non-shockable" rhythms such as Pulseless Electrical Activity (PEA), defibrillation is not indicated, and the importance of CPR rises. On average, only 5–10% of people who receive CPR survive. The purpose of CPR is not to "start" the heart, but rather to circulate oxygenated blood, and keep the brain alive until advanced care (especially defibrillation) can be initiated. As many of these patients may have a pulse that is impalpable by the layperson rescuer, the current consensus is to perform CPR on a patient who is not breathing.

Studies have shown the importance of immediate CPR followed by defibrillation within 3–5 minutes of sudden VF cardiac arrest improve survival. In cities such as Seattle where CPR training is widespread and defibrillation by EMS personnel follows quickly, the survival rate is about 30 percent. In cities such as New York, without those advantages, the survival rate is only 1–2 percent.

In most cases, there is a higher proportion of patients who achieve a Return of Spontaneous Circulation (ROSC), where their heart starts to beat on its own again, than ultimately survive to be discharged from hospital. This is due to medical staff either being ultimately unable to address the cause of the arrhythmia or cardiac arrest, or in some instances due to other co-morbidities, due to the patient being gravely ill in more than one way.

Compression-only CPR is less effective in children than in adults, as cardiac arrest in children is more likely to have a non-cardiac cause. In a 2010 prospective study of cardiac arrest in children (age 1–17), for arrests with a non-cardiac cause provision by bystanders of conventional CPR with rescue breathing yielded a favorable neurological outcome at one month more often that did compression-only CPR (OR 5.54; 95% confidence interval 2.52–16.99). For arrests with a cardiac cause in this cohort, there was no difference between the two techniques (OR 1.20; 95% confidence interval 0.55–2.66). This is consistent with American Heart Association guidelines for parents.

Pathophysiology

CPR is used on people in cardiac arrest in order to oxygenate the blood and maintain a cardiac output to keep vital organs alive. Blood circulation and oxygenation are required to transport oxygen to the tissues. The brain may sustain damage after blood flow has been stopped for about four minutes and irreversible damage after about seven minutes. Typically if blood flow ceases for one to two hours, the cells of the body die. Because of that CPR is generally only effective if performed within seven minutes of the stoppage of blood flow. The heart also rapidly loses the ability to maintain a normal rhythm. Low body temperatures as sometimes seen in near-drownings prolong the time the brain survives. Following cardiac arrest, effective CPR enables enough oxygen to reach the brain to delay brain death, and allows the heart to remain responsive to defibrillation attempts.

Adjunct devices

While several adjunctive devices are available none other than defibrillation as of 2010 have consistently been found to be better than standard CPR for out of hospital cardiac arrest. These devices can be split in to three broad groups - timing devices, those that assist the rescuer to achieve the correct technique, especially depth and speed of compressions, and those which take over the process completely.

Timing devices

They can feature a metronome (an item carried by many ambulance crews) in order to assist the rescuer in getting the correct rate. Some units can also give timing reminders for performing compressions, breathing and changing operators.

Manual assist devices

Studies have shown that audible and visual prompting can improve the quality of CPR and prevent the decrease of compression rate and depth that naturally occurs with fatigue, and to address this potential improvement, a number of devices have been developed to help improve CPR technique.

These items can be devices to placed on top of the chest, with the rescuers hands going over the device, and a display or audio feedback giving information on depth, force or rate, or in a wearable format such as a glove. Several published evaluations show that these devices can improve the performance of chest compressions.

As well as use during actual CPR on a cardiac arrest victim, which relies on the rescuer carrying the device with them, these devices can also be used as part of training programs to improve basic skills in performing correct chest compressions.

Certain defibrillation pads are capable of performing similar function, in that they may display rate and depth of compressions. Additionally, a certain algorithm may allow them to monitor electrical activity even during CPR.

Automatic devices

There are also some automated devices available which take over the chest compressions for the rescuer. These have several advantages: they allow rescuers to focus on performing other interventions; they do not fatigue and begin to perform less effective compressions, as humans do; and they are able to perform effective compressions in limited-space environments such as air ambulances, where manual compressions are difficult. These devices use either pneumatic (high-pressure gas) or electrical power sources to drive a compressing pad on to the chest of the patient. One such device, known as the LUCAS, was developed at the University Hospital of Lund, is powered by the compressed oxygen supplies already standard in ambulances and hospitals, and has

undergone numerous clinical trials, showing a marked improvement in coronary perfusion pressure and return of spontaneous circulation.

Another system called the AutoPulse is electrically powered and uses a large band around the patients chest which contracts in rhythm in order to deliver chest compressions. This is also backed by clinical studies showing increased successful return of spontaneous circulation.

Prevalence

Chance of receiving CPR

Various studies suggest that in out-of-home cardiac arrest, bystanders, lay persons or family members attempt CPR in between 14% and 45% of the time, with a median of 32%. This indicates that around a third of out-of-home arrests have a CPR attempt made on them. However, the effectiveness of this CPR is variable, and the studies suggest only around half of bystander CPR is performed correctly.

There is a clear correlation between age and the chance of CPR being commenced, with younger people being far more likely to have CPR attempted on them prior to the arrival of emergency medical services. It was also found that CPR was more commonly given by a bystander in public than when an arrest occurred in the patient's home, although health care professionals are responsible for more than half of out-of-hospital resuscitation attempts. This is supported by further research, which suggests that people with no connection to the victim are more likely to perform CPR than a member of their family. This is likely because of the shock experienced by finding a family member in need of CPR; it is easier to remain calm - and think clearly - when the person in need of CPR is a complete stranger, as in this case one will not be as frightened.

There is also a correlation between the cause of arrest and the likelihood of bystander CPR being initiated. Lay persons are most likely to give CPR to younger cardiac arrest victims in a public place when it has a medical cause; victims in arrest from trauma, exsanguination or intoxication are less likely to receive CPR.

Finally, it has been claimed that there is a higher chance of CPR being performed if the bystander is told to only perform the chest compression element of the resuscitation.

Chance of receiving CPR in time

CPR is only likely to be effective if commenced within 6 minutes after the blood flow stops, because permanent brain cell damage occurs when fresh blood infuses the cells after that time, since the cells of the brain become dormant in as little as 4–6 minutes in an oxygen deprived environment and the cells are unable to survive the reintroduction of oxygen in a traditional resuscitation. Research using cardioplegic blood infusion resulted in a 79.4% survival rate with cardiac arrest intervals of 72±43 minutes, traditional methods achieve a 15% survival rate in this scenario, by comparison. New research is

currently needed to determine what role CPR, electroshock, and new advanced gradual resuscitation techniques will have with this new knowledge A notable exception is cardiac arrest occurring in conjunction with exposure to very cold temperatures. Hypothermia seems to protect by slowing down metabolic and physiologic processes, greatly decreasing the tissues' need for oxygen. There are cases where CPR, defibrillation, and advanced warming techniques have revived victims after substantial periods of hypothermia.

Society and culture

Portrayed effectiveness

CPR is often severely misrepresented in movies and television as being highly effective in resuscitating a person who is not breathing and has no circulation. A 1996 study published in the New England Journal of Medicine showed that CPR success rates in television shows was 75% for immediate circulation, and 67% survival to discharge. This gives members of the public an unrealistic expectation of a successful outcome. When educated on the actual survival rates, the proportion of patients over 60 years of age desiring CPR should they suffer a cardiac arrest drops from 41% to 22%.

Stage CPR

Chest compressions are capable of causing significant local blunt trauma, including bruising or fracture of the sternum or ribs. Performing CPR on a healthy person may or may not disrupt normal heart rhythm, but regardless the technique should not be performed on a healthy person because of the risk of trauma.

The portrayal of CPR technique on television and film often is purposely incorrect. Actors simulating the performance of CPR may bend their elbows while appearing to compress, to prevent force from reaching the chest of the actor portraying the victim. Other techniques, such as substituting a mannequin torso for the "victim" in some shots, may also be used to avoid harming actors.

Self-CPR hoax

A form of "self-CPR" termed "Cough CPR" was the subject of a hoax chain e-mail entitled "How to Survive a Heart Attack When Alone" which wrongly cited "ViaHealth Rochester General Hospital" as the source of the technique. Rochester General Hospital has denied any connection with the technique.

Rapid coughing has been used in hospitals for brief periods of cardiac arrhythmia on monitored patients. One researcher has recommended that it be taught broadly to the public.

However, “cough CPR” cannot be used outside the hospital because the first symptom of cardiac arrest is unconsciousness in which case coughing is impossible, although myocardial infarction (heart attack) may occur to give rise to the cardiac arrest, so a patient may not be immediately unconscious. Further, the vast majority of people suffering chest pain from a heart attack will not be in cardiac arrest and CPR is not needed. In these cases attempting “cough CPR” will increase the workload on the heart and may be harmful. When coughing is used on trained and monitored patients in hospitals, it has only been shown to be effective for 90 seconds.

The American Heart Association (AHA) and other resuscitation bodies do not endorse "Cough CPR", which it terms a misnomer as it is not a form of *resuscitation*. The AHA does recognize a limited legitimate use of the coughing technique: "This coughing technique to maintain blood flow during brief arrhythmias has been useful in the hospital, particularly during cardiac catheterization. In such cases the patients ECG is monitored continuously, and a physician is present."

History

Sign showing old Silvester and Holger-Nielsen methods of resuscitation

In the 19th century, Doctor H. R. Silvester described a method (The Silvester Method) of artificial respiration in which the patient is laid on their back, and their arms are raised above their head to aid inhalation and then pressed against their chest to aid exhalation. The procedure is repeated sixteen times per minute. This type of artificial respiration is occasionally seen in films made in the early part of the 20th century.

A second technique, called the Holger Neilson technique, described in the first edition of the Boy Scout Handbook in the United States in 1911, described a form of artificial respiration where the person was laid on their front, with their head to the side, resting on the palms of both hands. Upward pressure applied at the patient's elbows raised the upper body while pressure on their back forced air into the lungs, essentially the Silvester Method with the patient flipped over. This form is seen well into the 1950s (it is used in an episode of *Lassie* during the Jeff Miller era), and was often used, sometimes for comedic effect, in theatrical cartoons of the time. This method would continue to be shown, for historical purposes, side-by-side with modern CPR in the Boy Scout Handbook until its ninth edition in 1979. The technique was later banned from first-aid manuals in the UK.

However, it was not until the middle of the 20th century that the wider medical community started to recognize and promote artificial respiration combined with chest compressions as a key part of resuscitation following cardiac arrest. The combination was first seen in a 1962 training video called "The Pulse of Life" created by James Jude, Guy Knickerbocker and Peter Safar. Jude and Knickerbocker, along with William Kouwenhoven and Joseph S. Redding had recently discovered the method of external chest compressions, whereas Safar had worked with Redding and James Elam to prove the effectiveness of artificial respiration. It was at Johns Hopkins University where the technique of CPR was originally developed. The first effort at testing the technique was performed on a dog by Redding, Safar and JW Perason. Soon afterward, the technique was used to save the life of a child. Their combined findings were presented at annual Maryland Medical Society meeting on September 16, 1960 in Ocean City, and gained rapid and widespread acceptance over the following decade, helped by the video and speaking tour they undertook. Peter Safar wrote the book *ABC of resuscitation* in 1957. In the U.S., it was first promoted as a technique for the public to learn in the 1970s.

Artificial respiration was combined with chest compressions based on the assumption that active ventilation is necessary to keep circulating blood oxygenated, and the combination was accepted without comparing its effectiveness with chest compressions alone. However, research over the past decade has shown that assumption to be in error, resulting in the AHA's acknowledgment of the effectiveness of chest compressions alone.

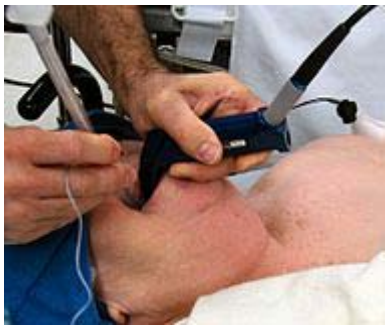
In other animals

It is entirely feasible to perform CPR on animals, including cats and dogs. The principles and practices are virtually identical to CPR for humans. One difference is that resuscitation is usually done through the animal's nose, not the mouth. One is cautioned to only perform CPR on unconscious animals to avoid the risk of being bitten and that animals, depending on species, have a lower bone density than humans, causing bones to become weakened after CPR is performed.

Chapter 13

Tracheal Intubation

Intervention:
Tracheal intubation



Anesthesiologist using the Glidescope to intubate the trachea of a morbidly obese elderly person with challenging airway anatomy

ICD-10 code:	
ICD-9 code:	96.04
MeSH	D007442
Other codes:	

Tracheal intubation, usually simply referred to as **intubation**, is the placement of a flexible plastic tube into the trachea (windpipe) to maintain an open airway or to serve as a conduit through which to administer certain drugs. It is frequently performed in critically injured, ill or anesthetized patients to facilitate ventilation of the lungs, including mechanical ventilation, and to prevent the possibility of asphyxiation or airway obstruction. The most widely used route is orotracheal, in which an endotracheal tube is passed through the mouth and vocal apparatus into the trachea. In a nasotracheal procedure, an endotracheal tube is passed through the nose and vocal apparatus into the trachea. Other methods of intubation involve surgery and include the cricothyrotomy

(used almost exclusively in emergency circumstances) and the tracheotomy, used primarily in situations where a prolonged need for airway support is anticipated.

Because it is an invasive and extremely uncomfortable medical procedure, intubation is usually performed after administration of general anesthesia and a neuromuscular-blocking drug. It can however be performed in the awake patient with local or topical anesthesia, or in an emergency without any anesthesia at all. Intubation is normally facilitated by using a conventional laryngoscope, flexible fiberoptic bronchoscope or video laryngoscope to identify the glottis, though other devices and techniques are available. After the trachea has been intubated, a balloon cuff is typically inflated near the far end of the tube to help secure it in place, to prevent leakage of respiratory gases, and to protect the tracheobronchial tree from receiving undesirable material such as stomach acid. The tube is then secured to the face or neck and connected to a T-piece, anesthesia breathing circuit, bag valve mask device, or a mechanical ventilator. Once there is no longer a need for ventilatory assistance and/or protection of the airway, the tracheal tube is removed; this is referred to as extubation of the trachea (or decannulation, in the case of a surgical airway such as a cricothyrotomy or a tracheotomy).

For centuries, tracheotomy was considered the only reliable method for intubation of the trachea. However, because only a minority of patients survived the operation, physicians undertook tracheotomy only as a last resort, on patients who were nearly dead. It was not until the late 19th century however that advances in anatomy and physiology, as well an appreciation of the germ theory of disease, had improved the outcome of this operation to the point that it could be considered an acceptable treatment option. Also at that time, advances in endoscopic instrumentation had improved to such a degree that direct laryngoscopy had become a viable means to secure the airway by the non-surgical orotracheal route. By the mid-20th century, the tracheotomy as well as endoscopy and non-surgical tracheal intubation had evolved from rarely employed procedures to becoming essential components of the practices of anesthesiology, critical care medicine, emergency medicine, gastroenterology, laryngology, pulmonology and surgery.

Tracheal intubation can be associated with minor complications such as broken teeth or lacerations of the tissues of the upper airway. It can also be associated with potentially fatal complications such as pulmonary aspiration of stomach contents which can result in a severe and sometimes fatal chemical aspiration pneumonitis, or unrecognized intubation of the esophagus which can lead to potentially fatal anoxia. Because of this, the potential for difficulty or complications due to the presence of unusual airway anatomy or other uncontrolled variables is carefully evaluated before undertaking tracheal intubation. Alternative strategies for securing the airway must always be readily available. The incidence of serious complications is unacceptably high when undertaken by practitioners lacking adequate training and experience.

Indications

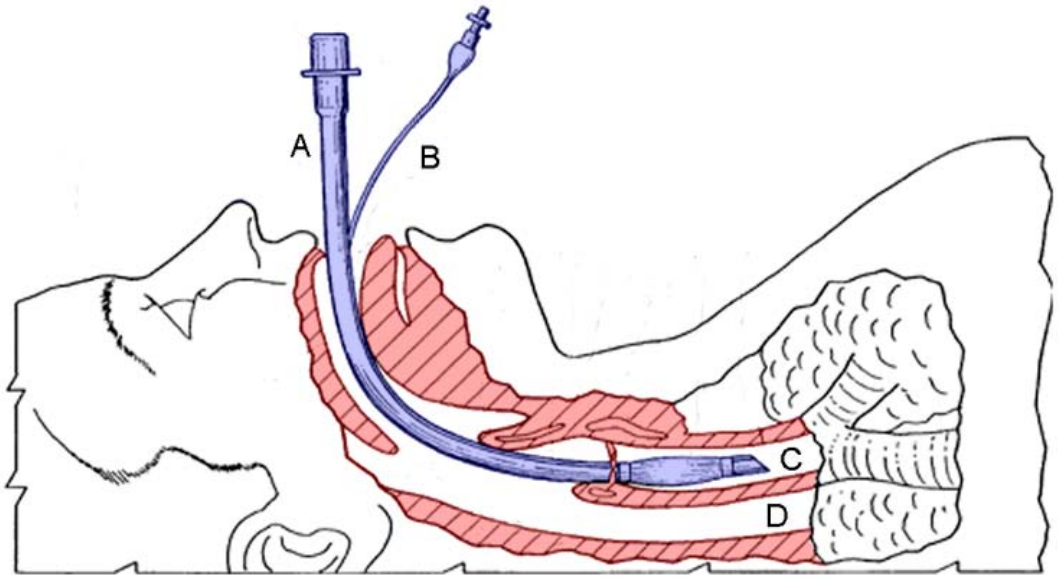


Diagram of an endotracheal tube that has been inserted into the trachea:
A - endotracheal tube (blue)
B - cuff inflation tube with pilot balloon
C - trachea
D - esophagus

Tracheal intubation is indicated in a variety of situations when illness or a medical procedure prevents a person from maintaining a clear airway, breathing, and oxygenating the blood. In these circumstances, oxygen supplementation using a simple face mask is inadequate.

Depressed level of consciousness

Perhaps the most common indication for tracheal intubation is for the placement of a conduit through which nitrous oxide or volatile anesthetics may be administered. General anesthetic agents, opioids, and neuromuscular-blocking drugs may diminish or even abolish the respiratory drive. Although it is not the only means to maintain a patent airway during general anesthesia, intubation of the trachea provides the most reliable means of oxygenation and ventilation and the greatest degree of protection against regurgitation and pulmonary aspiration.

Damage to the brain (such as from a massive stroke, non-penetrating head injury, intoxication or poisoning) may result in a depressed level of consciousness. When this becomes severe to the point of stupor or coma (defined as a score on the Glasgow Coma Scale of less than 8), dynamic collapse of the extrinsic muscles of the airway can obstruct

the airway, impeding the free flow of air into the lungs. Furthermore, protective airway reflexes such as coughing and swallowing may be diminished or absent. Tracheal intubation is often required to restore patency (the relative absence of blockage) of the airway and protect the tracheobronchial tree from pulmonary aspiration of gastric contents.

Hypoxemia

Intubation may be necessary for a patient with decreased oxygen content and oxygen saturation of the blood caused when their breathing is inadequate (hypoventilation), suspended (apnea), or when the lungs are unable to sufficiently transfer gasses to the blood. Such patients, who may be awake and alert, are typically critically ill with a multisystem disease or multiple severe injuries. Examples of such conditions include cervical spine injury, multiple rib fractures, severe pneumonia, acute respiratory distress syndrome (ARDS), or near-drowning. Specifically, intubation is considered if the arterial partial pressure of oxygen (PaO_2) is less than 60 millimeters of mercury (mm Hg) while breathing an inspired O_2 concentration (FIO_2) of 50% or greater. In patients with elevated arterial carbon dioxide, an arterial partial pressure of CO_2 ($PaCO_2$) greater than 45 mm Hg in the setting of acidemia would prompt intubation, especially if a series of measurements demonstrate a worsening respiratory acidosis. Regardless of the laboratory values, these guidelines are always interpreted in the clinical context.

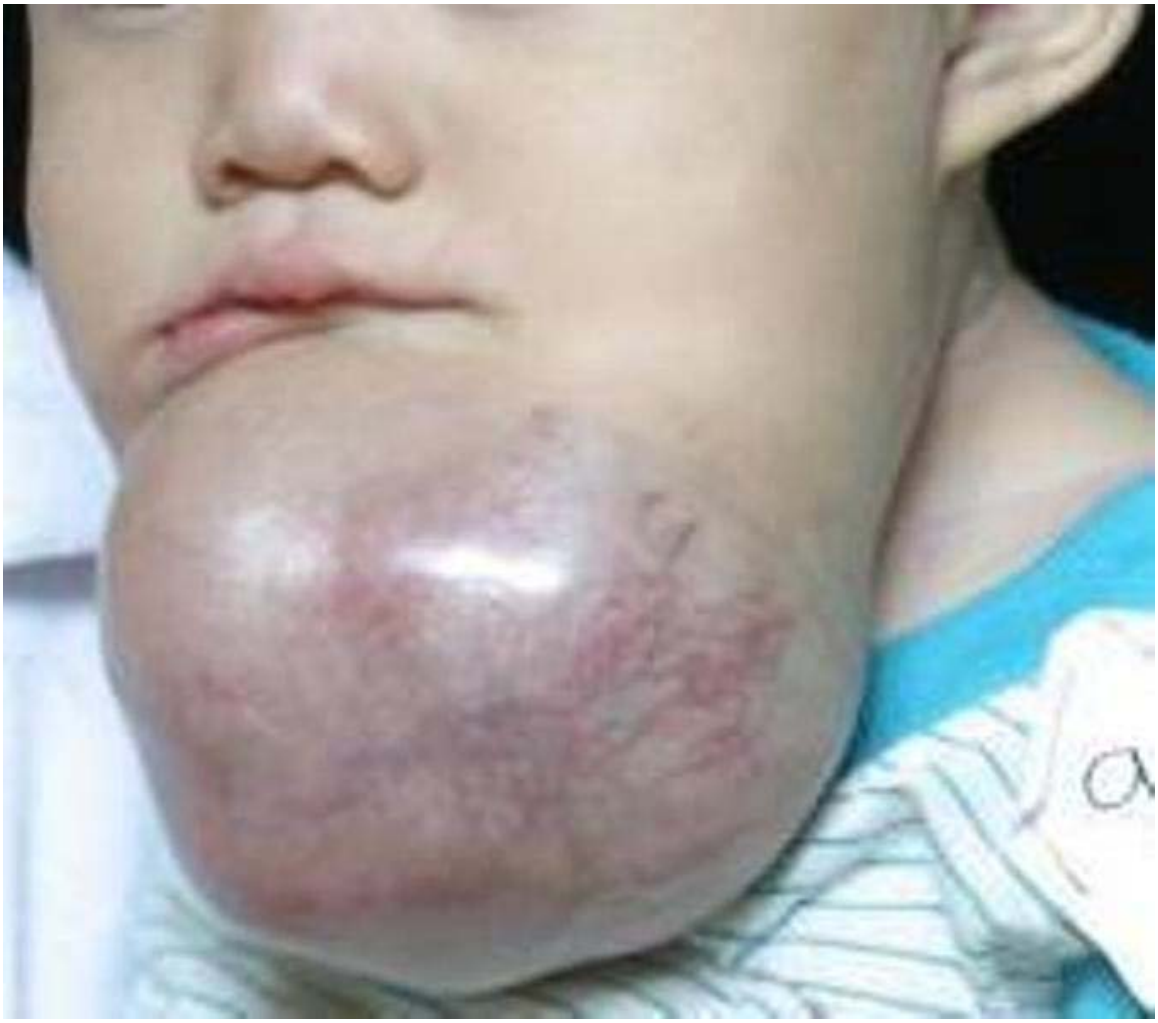
Airway obstruction

Actual or impending airway obstruction is a common indication for intubation of the trachea. Life-threatening airway obstruction may occur when a foreign body becomes lodged in the airway; this is especially common in infants and toddlers. Severe blunt or penetrating injury to the face or neck may be accompanied by swelling and an expanding hematoma, or injury to the larynx, trachea or bronchi. Airway obstruction is also common in people who have suffered smoke inhalation or burns within or near the airway. Sustained generalized seizure activity and angioedema are other common causes of life-threatening airway obstruction which may require tracheal intubation to secure the airway.

Manipulation of the airway

Diagnostic or therapeutic manipulation of the airway (such as bronchoscopy, laser therapy or stenting of the bronchi) may intermittently interfere with the ability to breathe; intubation may be necessary in such situations.

Predicting difficulty



Tracheal intubation is anticipated to be difficult in this child with a massive ameloblastoma

Tracheal intubation is not a simple procedure and the consequences of failure are grave. Therefore the patient is carefully evaluated for potential difficulty or complications beforehand. This involves taking the medical history of the patient and performing a physical examination, the results of which can be scored against one of several classification systems. The proposed surgical procedure (e.g., surgery involving the head and neck, or bariatric surgery) may lead one to anticipate difficulties with intubation. Many individuals have unusual airway anatomy, such as those who have limited movement of their neck or jaw, or those who have tumors, deep swelling due to injury or to allergy, developmental abnormalities of the jaw, or excess fatty tissue of the face and neck. Using conventional laryngoscopic techniques, intubation of the trachea can be difficult or even impossible in such patients. This is why all persons performing tracheal intubation must be familiar with alternative techniques of securing the airway. Use of the

flexible fiberoptic bronchoscope and similar devices has become among the preferred techniques in the management of such cases. However, these devices require a different skill set than that employed for conventional laryngoscopy and are expensive to purchase, maintain and repair.

When taking the patient's medical history, the subject is questioned about any significant signs or symptoms, such as difficulty in speaking or difficulty in breathing. These may suggest obstructing lesions in various locations within the upper airway, larynx, or tracheobronchial tree. A history of previous surgery (e.g., previous cervical fusion), injury, radiation therapy, or tumors involving the head, neck and upper chest can also provide clues to a potentially difficult intubation. Previous experiences with tracheal intubation, especially difficult intubation, intubation for prolonged duration (e.g., intensive care unit) or prior tracheotomy are also noted.

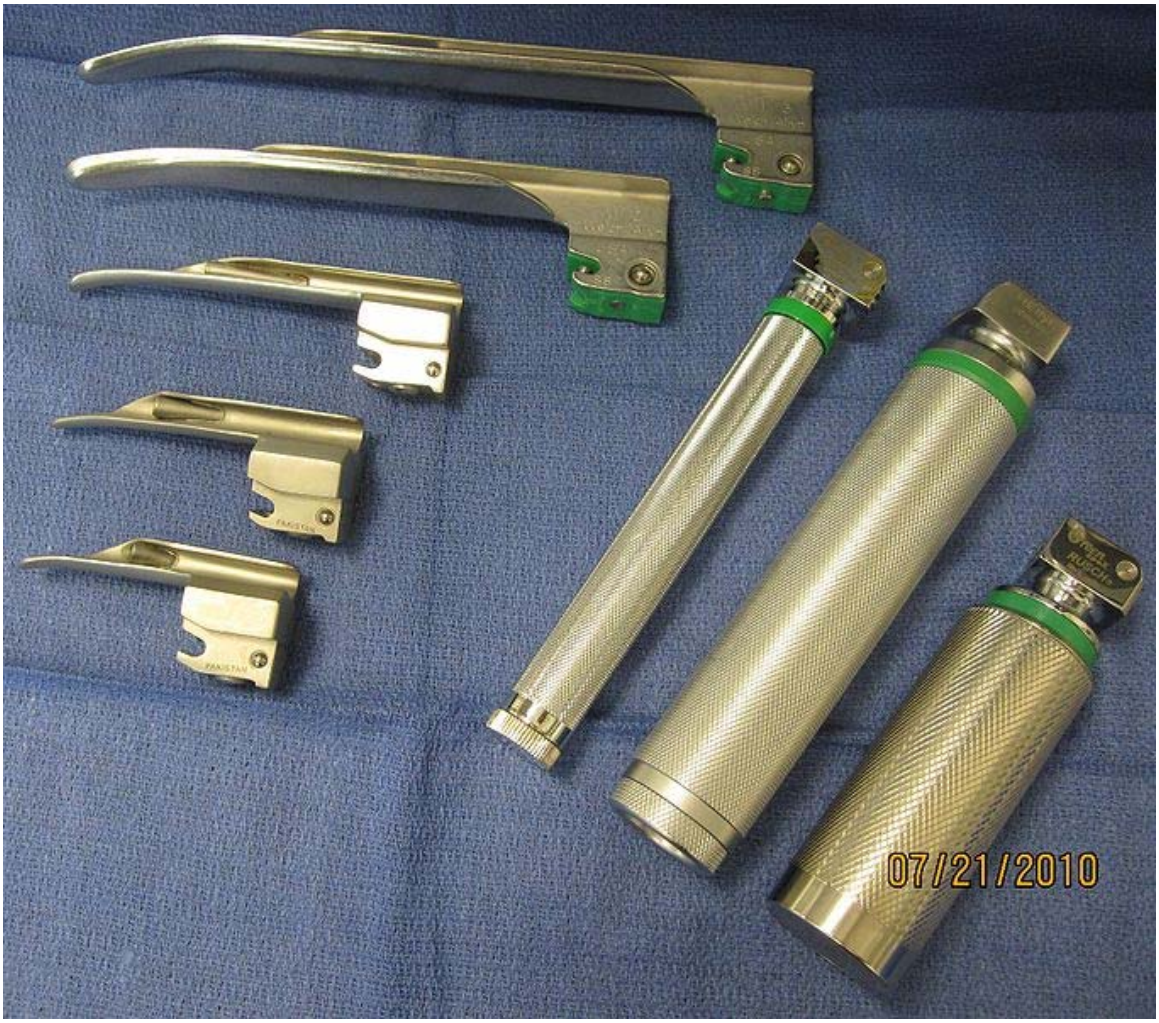
A detailed physical examination of the airway is important, particularly:

- the range of motion of the cervical spine: the subject should be able to tilt the head back and then forward so that the chin touches the chest.
- the range of motion of the jaw (the temporomandibular joint): three of the subject's fingers should be able to fit between the upper and lower incisors.
- the size and shape of the upper jaw and lower jaw, looking especially for problems such as maxillary hypoplasia (an underdeveloped upper jaw), micrognathia (an abnormally small jaw), or retrognathia (misalignment of the upper and lower jaw).
- the thyromental distance: three of the subject's fingers should be able to fit between the Adam's apple and the chin.
- the size and shape of the tongue and palate relative to the size of the mouth.
- the teeth, especially noting the presence of prominent maxillary incisors, any loose or damaged teeth, or crowns.

Many classification systems have been developed in an effort to predict difficulty of tracheal intubation, including the Cormack-Lehane grading system, the Intubation Difficulty Scale (IDS), and the Mallampati score. The Mallampati score is drawn from the observation that the size of the base of the tongue influences the difficulty of intubation. It is determined by looking at the anatomy of the mouth, and in particular the visibility of the base of palatine uvula, faucial pillars and the soft palate. Although such medical scoring systems may aid in the evaluation of patients, no single score or combination of scores can be trusted to specifically detect all and only those patients who are difficult to intubate. Furthermore, one study of experienced anesthesiologists, on the widely used Cormack–Lehane classification system, found they did not score the same patients consistently over time, and that only 25% could correctly define all four grades of the widely used Cormack–Lehane classification system. Under certain emergency circumstances (e.g., severe head trauma or suspected cervical spine injury), it may be impossible to fully utilize these the physical examination and the various classification systems to predict the difficulty of tracheal intubation. In such cases, alternative techniques of securing the airway must be readily available.

Equipment

Laryngoscopes



Laryngoscope handles with an assortment of Miller blades (large adult, small adult, child, infant and newborn)

Laryngoscope handle with an assortment of Macintosh blades (large adult, small adult, child, infant and newborn)

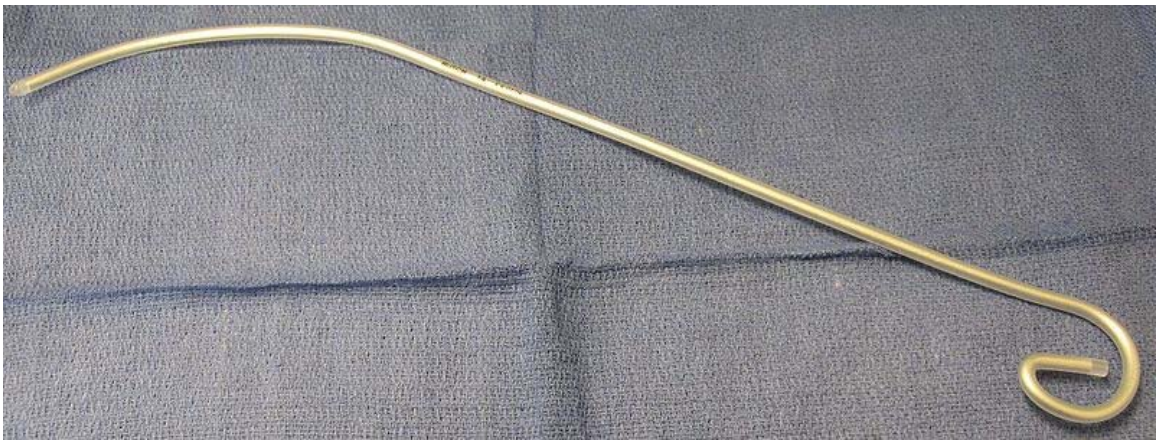
The vast majority of tracheal intubations involve the use of a viewing instrument of one type or another. The modern conventional laryngoscope consists of a handle containing batteries that power a light and a set of interchangeable blades, which are either straight or curved. This device is designed to allow the laryngoscopist to directly view the larynx. Due to the widespread availability of such devices, the technique of blind digital intubation of the trachea is rarely practiced today, although it may still be useful in certain emergency situations, such as natural or man-made disasters.

The decision to use a straight or curved laryngoscope blade depends partly on the specific anatomical features of the airway, and partly on the personal experience and preference

of the laryngoscopist. The Macintosh blade is the most widely used curved laryngoscope blade, while the Miller blade is the most popular style of straight blade. Both Miller and Macintosh laryngoscope blades are available in sizes 0 (infant) through 4 (large adult). There are many other styles of straight and curved blades, with accessories such as mirrors for enlarging the field of view and even ports for the administration of oxygen. These specialty blades are primarily designed for use by anesthetists and otolaryngologists, most commonly in the operating room.

Fiberoptic layngoscopes have become increasingly available since the 1990s. In contrast to the conventional laryngoscope, these devices allow the laryngoscopist to indirectly view the larynx. This provides a significant advantage in situations where the operator needs to see around an acute bend in order to visualize the glottis, and deal with otherwise difficult intubations. Video laryngoscopes are specialized fiberoptic laryngoscopes that use a digital video camera sensor to allow the operator to view the glottis and larynx on a video monitor. Other "noninvasive" devices which can be employed to assist in tracheal intubation are the laryngeal mask airway (used as a conduit for endotracheal tube placement) and the AirTraq.

Stylets



An endotracheal tube stylet, useful in facilitating orotracheal intubation

An intubating stylet is a malleable metal wire designed to be inserted into the endotracheal tube to make the tube conform better to the upper airway anatomy of the specific individual. This aid is commonly used with a difficult laryngoscopy. Just as with laryngoscope blades, there are also several types of available stylets, such as the Verathon Stylet, which is specifically designed to follow the 60° blade angle of the GlideScope video laryngoscope.

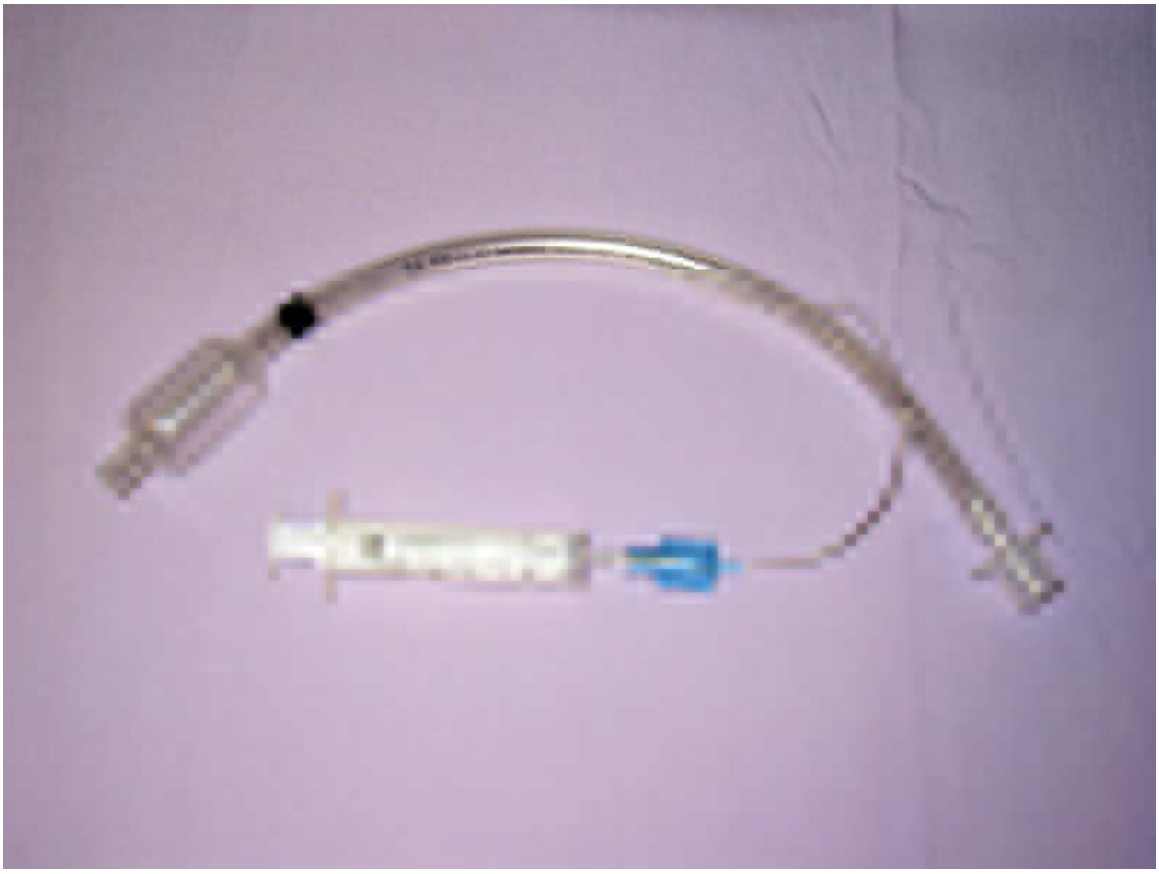
The Eschmann tracheal tube introducer (often incorrectly referred to as a "gum elastic bougie") is specialized type of stylet used to facilitate difficult intubation. This flexible device is 60 cm (24 in) in length, 15 French (5 mm diameter) with a small "hockey-stick" angle at the far end. Unlike a traditional intubating stylet, the Eschmann tracheal tube

introducer is typically inserted directly into the trachea and then used as a guide over which the endotracheal tube can be passed (in a manner analogous to the Seldinger technique). As the Eschmann tracheal tube introducer is considerably less rigid than a conventional stylet, this technique is considered to be a relatively atraumatic means of tracheal intubation.

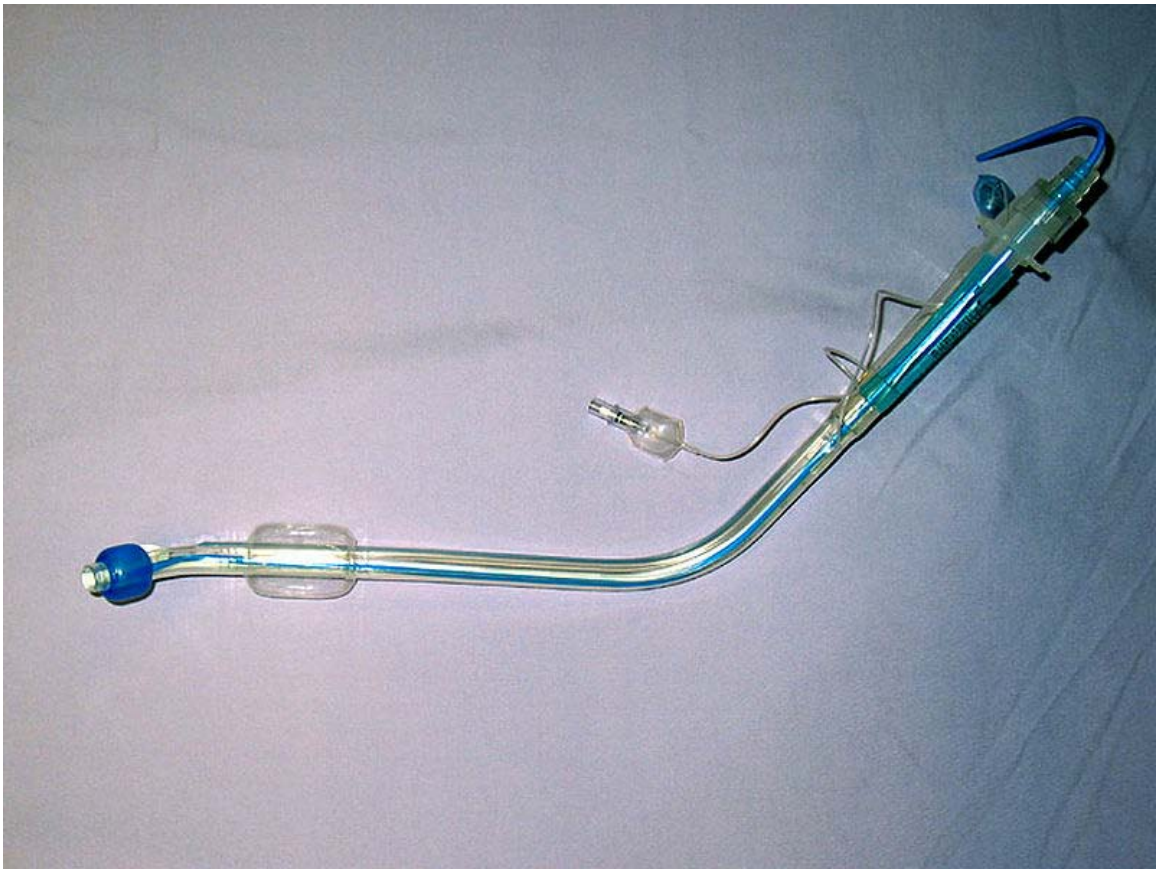
The tracheal tube exchanger is a hollow catheter, 56 to 81 cm (22.0 to 31.9 in) in length, that can be used for removal and replacement of tracheal tubes without the need for laryngoscopy. The Cook Airway Exchange Catheter (CAEC) is another example of this type of catheter; this device has a central lumen (hollow channel) through which oxygen can be administered.

The lighted stylet is a device that employs the principle of transillumination to facilitate blind orotracheal intubation (an intubation technique in which the laryngoscopist does not view the glottis).

Tracheal tubes



A cuffed endotracheal tube, constructed of polyvinyl chloride



A Carlens double-lumen endotracheal tube, used for thoracic surgical operations such as VATS lobectomy

A tracheal tube is a catheter that is inserted into the trachea for the primary purpose of establishing and maintaining a patent (open and unobstructed) airway. Tracheal tubes are frequently used for airway management in the settings of general anesthesia, critical care, mechanical ventilation and emergency medicine. Many different types of tracheal tubes are available, suited for different specific applications. An endotracheal tube is a specific type of tracheal tube that is nearly always inserted through the mouth (orotracheal) or nose (nasotracheal). It is a breathing conduit designed to be placed into the airway of critically injured, ill or anesthetized patients in order to perform mechanical positive pressure ventilation of the lungs and to prevent the possibility of aspiration or airway obstruction. The endotracheal tube has a fitting designed to be connected to a source of pressurized gas such as oxygen. At the other end is an orifice through which such gases are directed into the lungs and may also include a balloon (referred to as a cuff). The tip of the endotracheal tube is positioned above the carina (before the trachea divides to each lung) and sealed within the trachea so that the lungs can be ventilated equally. A tracheostomy tube is another type of tracheal tube; this 2–3-inch-long (51–76 mm) curved metal or plastic tube is inserted into a tracheostomy stoma or a cricothyrotomy incision.

Tracheal tubes can be used to ensure the adequate exchange of oxygen and carbon dioxide, to deliver oxygen in higher concentrations than found in air, or to administer other gases such as helium, nitric oxide, nitrous oxide, xenon, or certain volatile anesthetic agents such as desflurane, isoflurane, or sevoflurane. They may also be used as a route for administration of certain medications such as bronchodilators, inhaled corticosteroids, and drugs used in treating cardiac arrest such as atropine, epinephrine, lidocaine and vasopressin.

Originally made from latex rubber, most modern endotracheal tubes today are constructed of polyvinyl chloride. Tubes constructed of silicone rubber, wire-reinforced silicone rubber or stainless steel are also available for special applications. For human use, tubes range in size from 2 to 10.5 mm (0.1 to 0.4 in) in internal diameter. The size is chosen based on the patient's body size, with the smaller sizes being used for infants and children. Most endotracheal tubes have an inflatable cuff to seal the tracheobronchial tree against leakage of respiratory gases and pulmonary aspiration of gastric contents, blood, secretions and other fluids. Uncuffed tubes are also available, though their use is limited mostly to children (in small children, the cricoid cartilage is the narrowest portion of the airway and usually provides an adequate seal for mechanical ventilation).

In addition to cuffed or uncuffed, preformed endotracheal tubes are also available. The oral and nasal RAE tubes (named after the inventors Ring, Adair and Elwyn) are the most widely used of the preformed tubes.

Various types of endotracheal tubes are available that have endobronchial as well as endotracheal channels (Carlens, White and Robertshaw tubes). These tubes are typically coaxial, with two separate channels and two separate openings. They incorporate an endotracheal lumen which terminates in the trachea and an endobronchial lumen, the distal tip of which is positioned 1–2 cm into the right or left mainstem bronchus. There is also the Univent tube, which has a single tracheal lumen and an integrated endobronchial blocker. These tubes enable one to ventilate both lungs, or either lung independently. Single-lung ventilation (allowing the lung on the operative side to collapse) can be useful during thoracic surgery, as it can facilitate the surgeon's view and access to other relevant structures within the thoracic cavity.

The "armored" endotracheal tubes are cuffed, wire-reinforced silicone rubber tubes. They are much more flexible than polyvinyl chloride tubes, yet they are difficult to compress or kink. This can make them useful for situations in which the trachea is anticipated to remain intubated for a prolonged duration, or if the neck is to remain flexed during surgery. Most armored tubes have a Magill curve, but preformed armored RAE tubes are also available. Another type of endotracheal tube has four small openings just above the inflatable cuff, which can be used for suction of the trachea or administration of intratracheal medications if necessary. Other tubes (such as the Bivona Fome-Cuf tube) are designed specifically for use in laser surgery in and around the airway.

Methods to confirm tube placement

No single method for confirming tracheal tube placement has been shown to be 100% reliable. Accordingly, the use of multiple methods for confirmation of correct tube placement is now widely considered to be the standard of care. Such methods include direct visualization as the tip of the tube passes through the glottis. With a properly positioned tracheal tube, equal bilateral breath sounds will be heard upon listening to the chest with a stethoscope, and no sound upon listening to the area over the stomach. Equal bilateral rise and fall of the chest wall will be evident with ventilatory excursions. A small amount of water vapor will also be evident within the lumen of the tube with each exhalation and there will be no gastric contents in the tracheal tube at any time.

Ideally, at least one of the methods utilized for confirming tracheal tube placement will be a measuring instrument. Waveform capnography has emerged as the gold standard for the confirmation of tube placement within the trachea. Other methods relying on instruments include the use of a colorimetric end-tidal carbon dioxide detector, a self-inflating esophageal bulb, or an esophageal detection device. The distal tip of a properly positioned tracheal tube will be located in the mid-trachea, roughly 2 cm (1 in) above the bifurcation of the carina; this can be confirmed by chest x-ray. If the tracheal tube is inserted too far into the trachea, the tip will often be located within the right main bronchus, because this bronchus has a less acute angle than the left.

Special situations

Emergencies

Tracheal intubation in the emergency setting can be difficult with the fiberoptic bronchoscope due to blood, vomit, or secretions in the airway and poor patient cooperation. Because of this, patients with massive facial injury, complete upper airway obstruction, severe hypoventilation, or profuse upper airway bleeding are poor candidates for fiberoptic intubation. Fiberoptic intubation under general anesthesia typically requires two skilled individuals. Success rates of only 83–87% have been reported using fiberoptic techniques in the emergency department, with significant nasal bleeding occurring in up to 22% of patients. These drawbacks limit the use of fiberoptic bronchoscopy somewhat in urgent and emergent situations.

Personnel experienced in direct laryngoscopy are not always immediately available in certain settings that require emergency tracheal intubation. For this reason, specialized devices have been designed to act as bridges to a definitive airway. Such devices include the laryngeal mask airway, cuffed oropharyngeal airway and the esophageal-tracheal combitube (Combitube). Other devices such as rigid stylets, the lightwand (a blind technique) and indirect fiberoptic rigid stylets, such as the Bullard scope, Upsher scope and the WuScope can also be used as alternatives to direct laryngoscopy. Each of these devices have its own unique set of benefits and drawbacks, and none of them is effective under all circumstances.

Rapid-sequence induction and intubation

Rapid sequence induction and intubation (RSI) is a particular method of induction of general anesthesia, commonly employed in emergency operations and other situations where patients are assumed to have a "full stomach". The objective of RSI is to minimize the possibility of regurgitation and pulmonary aspiration of gastric contents during the induction of general anesthesia and subsequent tracheal intubation. RSI traditionally involves preoxygenating the lungs with a tightly-fitting oxygen mask, followed by the sequential administration of an intravenous sleep-inducing agent and a rapidly-acting neuromuscular-blocking drug, before intubation of the trachea.

One important difference between RSI and routine tracheal intubation is that the practitioner does not manually assist the ventilation of the lungs after the onset of general anesthesia and cessation of breathing, until the trachea has been intubated and the cuff has been inflated. Another key feature of RSI is the application of manual pressure to the cricoid cartilage, often referred to as the "Sellick maneuver", prior to instrumentation of the airway and intubation of the trachea.

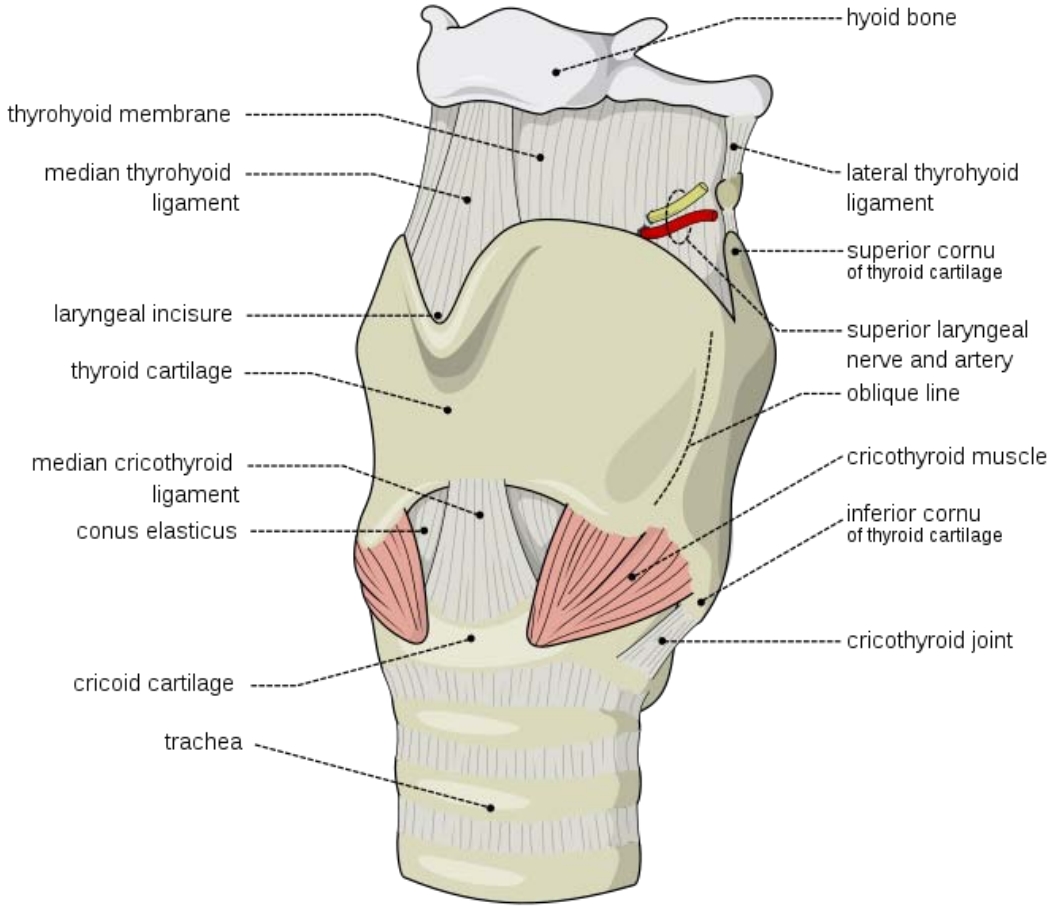
Since the introduction of RSI, there has been controversy regarding virtually every aspect of this technique, including:

- choice of induction drug, dose and method of administration.
- avoidance of manual ventilation before tracheal intubation.
- optimal position and whether the head-up, head-down, or horizontal supine position is the safest for induction of anesthesia in full-stomach patients.
- application of cricoid pressure (the Sellick maneuver).

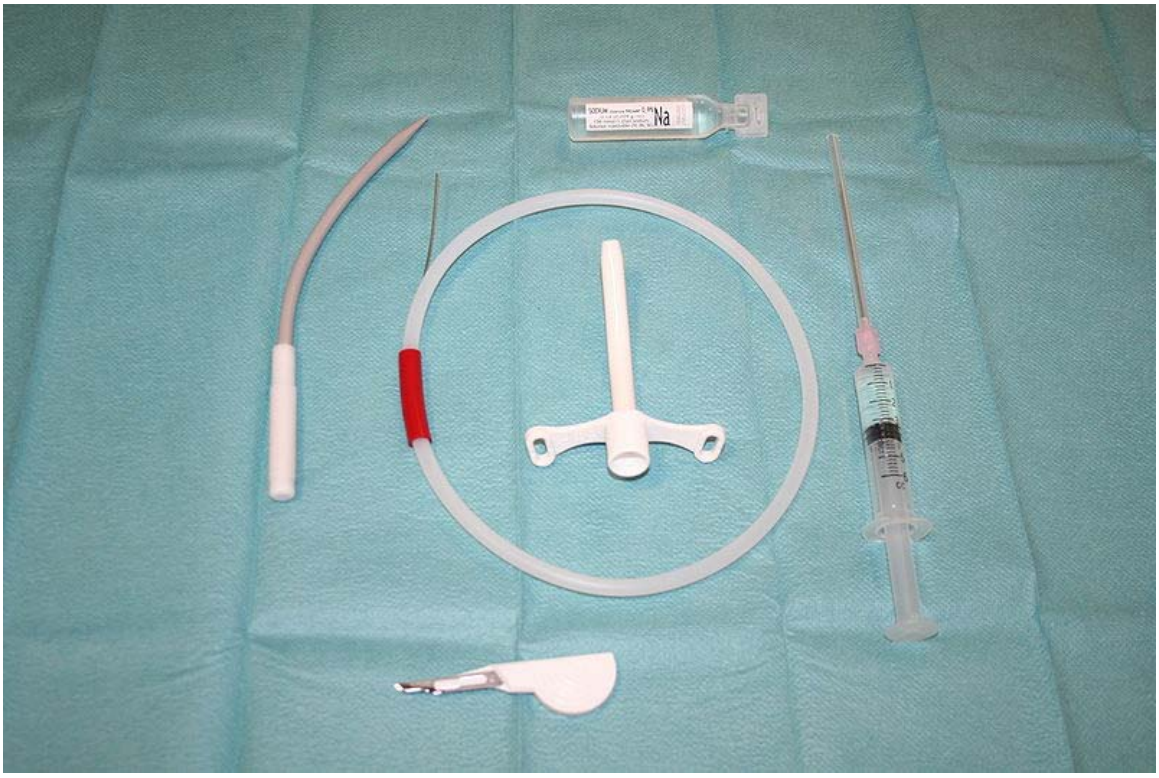
Named for British anesthetist Brian Arthur Sellick (1918–1996) who first described the procedure in 1961, the goal of the Sellick maneuver is to minimize the possibility of regurgitation and pulmonary aspiration of gastric contents. Cricoid pressure has been widely used during RSI for nearly fifty years, despite a lack of compelling evidence to support this practice. The initial article by Sellick was based on a small sample size at a time when high tidal volumes, head-down positioning and barbiturate anesthesia were the rule. Beginning around 2000, a significant body of evidence has accumulated which questions the effectiveness of the Sellick maneuver. The application of cricoid pressure may in fact displace the esophagus laterally instead of compressing it as described by Sellick. Cricoid pressure may also compress the glottis, which can obstruct the view of the laryngoscopist and actually cause a delay in securing the airway.

The Sellick maneuver is often confused with the "BURP" (Backwards Upwards Rightwards Pressure) maneuver. While both of these involve digital pressure to the anterior aspect (front) of the laryngeal apparatus, the purpose of the latter is to improve the view of the glottis during laryngoscopy and tracheal intubation, rather than to prevent regurgitation.

Cricothyrotomy



In cricothyrotomy, the incision or puncture is made through the cricothyroid membrane in between the thyroid cartilage and the cricoid cartilage



Cricothyrotomy kit

A cricothyrotomy is an incision made through the skin and cricothyroid membrane to establish a patent airway during certain life-threatening situations, such as airway obstruction by a foreign body, angioedema, or massive facial trauma. A cricothyrotomy is nearly always performed as a last resort in cases where orotracheal and nasotracheal intubation are impossible or contraindicated. Cricothyrotomy is easier and quicker to perform than tracheotomy, does not require manipulation of the cervical spine and is associated with fewer complications.

The quickest and easiest method to perform this technique is the needle cricothyrotomy (also referred to as a percutaneous dilational cricothyrotomy), in which a large-bore (12–14 gauge) intravenous catheter is used to puncture the cricothyroid membrane. Oxygen can then be administered through this catheter via jet insufflation. However, while needle cricothyrotomy may be life-saving in extreme circumstances, this technique is only intended to be a temporizing measure until a definitive airway can be established. While needle cricothyrotomy can provide adequate oxygenation, the small diameter of the cricothyrotomy catheter is insufficient for elimination of carbon dioxide (ventilation). After one hour of apneic oxygenation through a needle cricothyrotomy, one can expect a $PaCO_2$ of greater than 250 mm Hg and an arterial pH of less than 6.72, despite an oxygen saturation of 98% or greater. A more definitive airway can be established by performing a surgical cricothyrotomy, in which a 5 to 6 mm (0.20 to 0.24 in) endotracheal tube or tracheostomy tube can be inserted through a larger incision.

Several manufacturers market prepackaged cricothyrotomy kits, which enable one to use either a wire-guided percutaneous dilational (Seldinger) technique, or the classic surgical technique to insert a polyvinylchloride catheter through the cricothyroid membrane. The kits may be stocked in hospital emergency departments and operating suites, as well as ambulances and other selected pre-hospital settings.

Tracheotomy

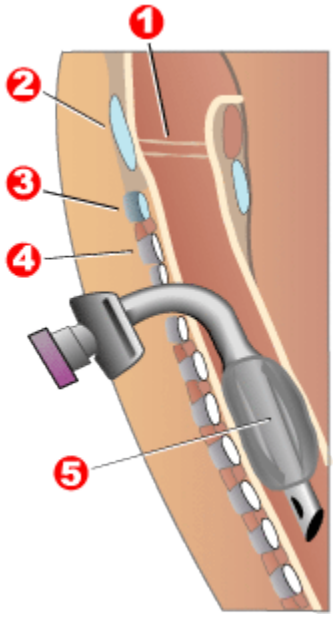


Diagram of a tracheostomy tube in the trachea:
1 - Vocal folds
2 - Thyroid cartilage
3 - Cricoid cartilage
4 - Tracheal rings
5 - Balloon cuff

Tracheotomy consists of making an incision on the front of the neck and opening a direct airway through an incision in the trachea. The resulting opening can serve independently as an airway or as a site for a tracheostomy tube to be inserted; this tube allows a person to breathe without the use of their nose or mouth. The opening may be made by a scalpel or a needle (referred to as surgical and percutaneous techniques respectively) and both techniques are widely used in current practice. In order to limit the risk of damage to the recurrent laryngeal nerves (the nerves that control the voicebox), the tracheotomy is performed as high in the trachea as possible. If only one of these nerves is damaged, the patient's voice may be impaired (dysphonia); if both of the nerves are damaged, the patient will be unable to speak (aphonia). British theoretical physicist Stephen Hawking lost his ability to speak after surgeons performed a tracheotomy in an effort to prevent recurrent pneumonia. In the acute setting, indications for tracheotomy are similar to those for cricothyrotomy. In the chronic setting, indications for tracheotomy include the need

for long-term mechanical ventilation and removal of tracheal secretions (e.g., comatose patients, or extensive surgery involving the head and neck).

Children

A premature infant weighing 990 grams (35 ounces), intubated and requiring mechanical ventilation in the neonatal intensive-care unit

There are significant differences in airway anatomy and respiratory physiology between children and adults, and these are taken into careful consideration before performing tracheal intubation of any pediatric patient. The differences, which are quite significant in infants, gradually disappear as the human body approaches a mature age and body mass index.

For infants and young children, orotracheal intubation is easier than the nasotracheal route. Nasotracheal intubation carries a risk of dislodgement of adenoids and nasal bleeding. Despite the greater difficulty, nasotracheal intubation route is preferable to orotracheal intubation in children undergoing intensive care and requiring prolonged intubation because this route allows a more secure fixation of the tube. As with adults, there are a number of devices specially designed for assistance with difficult tracheal intubation in children. Confirmation of proper position of the tracheal tube is accomplished as with adult patients.

Because the airway of a child is narrow, a small amount of glottic or tracheal swelling can produce critical obstruction. Inserting a tube that is too large relative to the diameter of the trachea can cause swelling. Conversely, inserting a tube that is too small can result in inability to achieve effective positive pressure ventilation due to retrograde escape of gas through the glottis and out the mouth and nose (often referred to as a "leak" around the tube). An excessive leak can usually be corrected by inserting a larger tube or a cuffed tube.

The tip of a correctly positioned tracheal tube will be in the mid-trachea, between the collarbones on an anteroposterior chest radiograph. The correct diameter of the tube is that which results in a small leak at a pressure of about 25 cm (10 in) of water. The appropriate inner diameter for the endotracheal tube is estimated to be roughly the same diameter as the child's little finger. The appropriate length for the endotracheal tube can be estimated by doubling the distance from the corner of the child's mouth to the ear canal. For premature infants 2.5 mm (0.10 in) internal diameter is an appropriate size for the tracheal tube. For infants of normal gestational age, 3 mm (0.12 in) internal diameter is an appropriate size. For normally nourished children 1 year of age and older, the following formulae estimate the proper diameter and depth of insertion for tracheal tubes:

- Internal diameter of tube (mm) = (patient's age in years + 16) / 4
- Appropriate depth of insertion of orotracheal tube (cm) = 12 + (patient's age in years / 2)

Complications

Tracheal intubation is generally considered the best method for airway management under a wide variety of circumstances, as it provides the most reliable means of oxygenation and ventilation and the greatest degree of protection against regurgitation and pulmonary aspiration. However, tracheal intubation requires a great deal of clinical experience to master and serious complications may result even when properly performed.

Four anatomic features must be present for orotracheal intubation to be straightforward: adequate mouth opening (full range of motion of the temporomandibular joint), sufficient pharyngeal space (determined by examining the hypopharynx), sufficient submandibular space (distance between the thyroid cartilage and the chin, the space into which the tongue must be displaced in order for the larygoscopist to view the glottis), and adequate

extension of the cervical spine at the atlanto-occipital joint. If any of these variables is in any way compromised, intubation should be expected to be difficult.

Minor complications are common after laryngoscopy and insertion of an orotracheal tube. These are typically of short duration, such as sore throat, lacerations of the lips or gums or other structures within the upper airway, chipped, fractured or dislodged teeth, nasal injury, Other complications which are common but potentially more serious include increased or irregular heartbeat, high blood pressure, elevated intracranial and introcular pressure, and bronchospasm.

More serious complications include laryngospasm, perforation of the trachea or esophagus, pulmonary aspiration of gastric contents or other foreign bodies, fracture or dislocation of the cervical spine, temporomandibular joint or arytenoid cartilages, decreased oxygen content, elevated arterial carbon dioxide, and vocal cord weakness. In addition to these complications, tracheal intubation via the nasal route carries a risk of dislodgement of adenoids and potentially severe nasal bleeding. Newer technologies such as flexible fiberoptic laryngoscopy have fared better in reducing the incidence of some of these complications, though the most frequent cause of intubation trauma remains a lack of skill on the part of the laryngoscopist.

Complications may also be severe and long-lasting or permanent, such as vocal cord damage, esophageal perforation and retropharyngeal abscess, bronchial intubation, or nerve injury. They may even be immediately life-threatening, such as laryngospasm and negative pressure pulmonary edema (fluid in the lungs), aspiration, unrecognized esophageal intubation, or accidental disconnection or dislodgement of the tracheal tube. Potentially fatal complications more often associated with prolonged intubation and/or tracheotomy include abnormal communication between the trachea and nearby structures such as the innominate artery (tracheoinnominate fistula) or esophagus (tracheoesophageal fistula). Other significant complications include airway obstruction due to loss of tracheal rigidity, ventilator-associated pneumonia and narrowing of the glottis or trachea. The cuff pressure is monitored carefully in order to avoid complications from over-inflation, many of which can be traced to excessive cuff pressure restricting the blood supply to the tracheal mucosa. A 2000 Spanish study of bedside percutaneous tracheotomy reported overall complication rates of 10–15% and procedural mortality of 0%, which is comparable to those of other series reported in the literature from the Netherlands and the United States.

Inability to secure the airway, with subsequent failure of oxygenation and ventilation is a life-threatening complication which if not immediately corrected leads to hypoxia, brain damage, cardiovascular collapse, and death. When performed improperly, the associated complications (e.g., unrecognized esophageal intubation) may be rapidly fatal. Without adequate training and experience, the incidence of such complications is unacceptably high. For example, among paramedics in several United States urban communities, unrecognized esophageal or hypopharyngeal intubation has been reported to be 6% to 25%. Among providers at the basic emergency medical technician (EMT-B) level, reported success rates for tracheal intubation are as low as 51%. In one study, nearly half

of patients with misplaced tracheal tubes died in the emergency room. Because of this, recent editions of the American Heart Association's *Guidelines for Cardiopulmonary Resuscitation* have de-emphasized the role of tracheal intubation in favor of other airway management techniques such as bag-valve-mask ventilation, the laryngeal mask airway and the Combitube.

One complication—unintentional and unrecognized intubation of the esophagus—is both common (as frequent as 25% in the hands of inexperienced personnel) and likely to result in a deleterious or even fatal outcome. In such cases, oxygen is inadvertently administered to the stomach, from where it cannot be taken up by the circulatory system, instead of the lungs. If this situation is not immediately identified and corrected, death will ensue from cerebral and cardiac anoxia.

Of 4,460 claims in the American Society of Anesthesiologists (ASA) Closed Claims Project database, 266 (approximately 6%) were for airway injury. Of these 266 cases, 87% of the injuries were temporary, 5% were permanent or disabling, and 8% resulted in death. Difficult intubation, age older than 60 years, and female gender were associated with claims for perforation of the esophagus or pharynx. Early signs of perforation were present in only 51% of perforation claims, whereas late sequelae occurred in 65%.

Alternatives

Although it offers the greatest degree of protection against regurgitation and pulmonary aspiration, tracheal intubation is not the only means to maintain a patent airway. Alternative techniques for airway management and delivery of oxygen or other breathing gases include the laryngeal mask airway, i-gel, cuffed oropharyngeal airway, CPAP mask, nasal BiPAP mask, simple face mask, and nasal cannula.

History

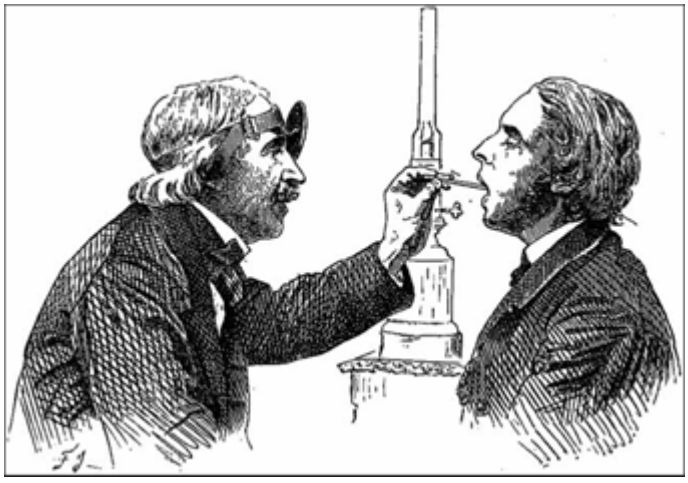
The earliest known depiction of a tracheotomy is found on two Egyptian tablets dating back to around 3600 BC. The 110-page Ebers Papyrus, an Egyptian medical papyrus which dates to roughly 1550 BC, also makes reference to the tracheotomy. Tracheotomy was described in the Rigveda, a Sanskrit text of ayurvedic medicine written around 2000 BC in ancient India. The Sushruta Samhita from around 400 BC is another text from the Indian subcontinent on ayurvedic medicine and surgery that mentions tracheotomy. Asclepiades of Bithynia (c. 124–40 BC) is often credited as being the first physician to perform a non-emergency tracheotomy. Galen of Pergamon (AD 129–199) clarified the anatomy of the trachea and was the first to demonstrate that the larynx generates the voice. In one of his experiments, Galen used bellows to inflate the lungs of a dead animal. Ibn Sīnā (980–1037) described the use of tracheal intubation to facilitate breathing in 1025 in his 14-volume medical encyclopedia, *The Canon of Medicine*. In the 12th century medical textbook *Al-Taisir*, Ibn Zuhr (1092–1162)—also known as Avenzoar—of Al-Andalus provided a correct description of the tracheotomy operation.

The first detailed descriptions of tracheal intubation and subsequent artificial respiration of animals were from Andreas Vesalius (1514–1564) of Brussels. In his landmark book published in 1543, *De humani corporis fabrica*, he described an experiment in which he passed a reed into the trachea of a dying animal whose thorax had been opened and maintained ventilation by blowing into the reed intermittently. Antonio Musa Brassavola (1490–1554) of Ferrara successfully treated a patient suffering from peritonsillar abscess by tracheotomy. Brassavola published his account in 1546; this operation has been identified as the first recorded successful tracheotomy, despite the many previous references to this operation. Towards the end of the 16th century, Hieronymus Fabricius (1533–1619) described a useful technique for tracheotomy in his writings, although he had never actually performed the operation himself. Fabricius was the first to introduce the idea of a tracheostomy tube. In 1620 the French surgeon Nicholas Habicot (1550–1624) published a report of four successful tracheotomies. In 1714, anatomist Georg Detharding (1671–1747) of the University of Rostock performed a tracheotomy on a drowning victim.

Despite the many recorded instances of its use since antiquity, it was not until the early 19th century that the tracheotomy finally began to be recognized as a legitimate means of treating severe airway obstruction. In 1852, French physician Armand Trousseau (1801–1867) presented a series of 169 tracheotomies to the Académie Impériale de Médecine. 158 of these were performed for the treatment of croup, and 11 were performed for "chronic maladies of the larynx". Between 1830 and 1855, more than 350 tracheotomies were performed in Paris, most of them at the Hôpital des Enfants Malades, a public hospital, with an overall survival rate of only 20–25%. This compares with 58% of the 24 patients in Trousseau's private practice, who fared better due to greater postoperative care.

In 1871, the German surgeon Friedrich Trendelenburg (1844–1924) published a paper describing the first successful elective human tracheotomy to be performed for the purpose of administration of general anesthesia. In 1888, Sir Morell Mackenzie (1837–1892) published a book discussing the indications for tracheotomy. In the early 20th century, tracheotomy became a life-saving treatment for patients afflicted with paralytic poliomyelitis who required mechanical ventilation. In 1909, Philadelphia laryngologist Chevalier Jackson (1865–1958) described a technique for tracheotomy that is used to this day.

Laryngoscopy and non-surgical techniques



The laryngoscopy. From García, 1884

In 1854, a Spanish singing teacher named Manuel García (1805–1906) became the first man to view the functioning glottis in a living human. In 1858, French pediatrician Eugène Bouchut (1818–1891) developed a new technique for non-surgical orotracheal intubation to bypass laryngeal obstruction resulting from a diphtheria-related pseudomembrane. In 1880, Scottish surgeon William Macewen (1848–1924) reported on his use of orotracheal intubation as an alternative to tracheotomy to allow a patient with glottic edema to breathe, as well as in the setting of general anesthesia with chloroform. In 1895, Alfred Kirstein (1863–1922) of Berlin first described direct visualization of the vocal cords, using an esophagoscope he had modified for this purpose; he called this device an autoscope.

In 1913, Chevalier Jackson was the first to report a high rate of success for the use of direct laryngoscopy as a means to intubate the trachea. Jackson introduced a new laryngoscope blade that incorporated a component that the operator could slide out to allow room for passage of an endotracheal tube or bronchoscope. Also in 1913, New York surgeon Henry H. Janeway (1873–1921) published results he had achieved using a laryngoscope he had recently developed. Another pioneer in this field was Sir Ivan Whiteside Magill (1888–1986), who developed the technique of awake blind nasotracheal intubation, the Magill forceps, the Magill laryngoscope blade, and several apparati for the administration of volatile anesthetic agents. The Magill curve of an endotracheal tube is also named for Magill. Sir Robert Reynolds Macintosh (1897–1989) introduced a curved laryngoscope blade in 1943; the Macintosh blade remains to this day the most widely used laryngoscope blade for orotracheal intubation.

Between 1945 and 1952, optical engineers built upon the earlier work of Rudolph Schindler (1888–1968), developing the first gastrocamera. In 1964, optical fiber technology was applied to one of these early gastrocameras to produce the first flexible fiberoptic endoscope. Initially used in upper GI endoscopy, this device was first used for laryngoscopy and tracheal intubation by Peter Murphy, an English anesthetist, in 1967. The concept of using a stylet for replacing or exchanging orotracheal tubes was introduced by Finucane and Kupshik in 1978, using a central venous catheter.

By the mid-1980s, the flexible fiberoptic bronchoscope had become an indispensable instrument within the pulmonology and anesthesia communities. The digital revolution of the 21st century has brought newer technology to the art and science of tracheal intubation. Several manufacturers have developed video laryngoscopes which employ digital technology such as the CMOS active pixel sensor (CMOS APS) to generate a view of the glottis so that the trachea may be intubated.