INTRODUCTION:
Voice production is the most recent evolutionary development of the larynx. In humans the larynx is also responsible for protection against aspiration, production of cough, deglutition, and increasing intrathoracic and intraabdominal pressures.

ANATOMY:

CARTILAGINOUS SUPPORT:

Thyroid Cartilage:
Named after *thyrus* – a Greek word meaning shield. This cartilage protects and houses the majority of the soft tissues of the larynx. It is composed of two plates of cartilage, or lamina, which meet at the midline. The angle at which these lamina meet varies between the sexes (80° in men and 90° in women.) The thyroid also has superior and inferior horns. The inferior horns are the site of articulation with the cricoid. Articulation between the two cartilages is primarily rocking with some anteroposterior movement. The thyroid cartilage has an inner and outer perichondrium, which are tightly adherent to the cartilage on the superior and inferior edges of the cartilage but loosely adherent over the laminae. The inner perichondrium is an important landmark both conceptually and anatomically in phonosurgery.

Cricoid Cartilage:
It is shaped similar to a class ring, with the higher segment oriented posteriorly. On the superior surface of the posterior aspect are the articular facets of the arytenoid cartilages. These facets are elliptical and slope toward the arch. The exact articulation between the cricoid and arytenoid is an important concept in arytenoid adduction. Due to the cylindrical shape of the joint, when the arytenoid adducts, the vocal cord moves inferiorly. Conversely, when the arytenoid abducts the vocal cord moves superiorly. This is important when medializing a paralyzed vocal cord that is at a different level than the non-affected cord. Contrary to conventional thinking, there is no rotation of the arytenoid cartilages. The two primary motions of the arytenoids are sliding, both medially and laterally, and anterior – posterior rocking.

Arytenoid Cartilages:
The arytenoids sit on the posterior lateral aspects of the cricoid cartilage. The arytenoids are shaped like an inverted T with three processes: vocal, muscular, and apical. The vocal process attaches to the vocalis muscle and vocal ligament. The posterior and lateral cricoarytenoid muscles attach to the muscular process. The inferior aspect of the aryepiglottic fold attaches to the apical process.
Epiglottic Cartilage:
The epiglottic cartilage forms the anterior wall of the larynx. Its primary importance in protecting the airway during deglutition.

Other Cartilages:
The corniculate cartilages are cone shaped and sit directly on top of the arytenoid cartilages. The cuneiforms are found in the aryepiglottic fold. Their primary role is to provide elastic force to separate the medialized aryepiglottic folds.

LARYNGEAL MUSCLES:
The laryngeal muscles all have very specific functions in voice production and modulation. When discussing the actions of the intrinsic muscles of the larynx, it is important to state not only how they affect the position of the vocal folds, but also how they alter the mucosal properties of the cord.

- Thyroarytenoid – originates from the inner surface of the thyroid and attaches on the vocal and muscular processes of the arytenoid cartilages. The medial aspect of this muscle is known as the vocalis. It is responsible for adducting, lowering, shortening, and thickening the vocal cords.

- Posterior Cricoarytenoid – Originates from the lateral aspect of the cricoid cartilage and inserts on the muscular process of the arytenoid. It is the only abductor. It also elevates, elongates, and thins the vocal cords.

- Lateral Cricoarytenoid – This muscle adds, lowers, elongates, and thins the vocal cords.

- Interarytenoid – An unpaired muscle which adducts the cartilaginous portion of the vocal folds. It has little effect on the stiffness and tension of the cords.

- Cricothyroid – Consists of two divisions, pars oblique and pars recta. It rotates the cricoid cartilage with respect to the thyroid cartilage, as described above. This results in elongation, thinning, and lowering of the vocal cords.

NEUROANATOMY:
The vagus descends from the cranium via the jugular foramen. As it travels in the carotid sheath, it gives off a superior laryngeal branch. This nerve is responsible for providing sensory innervation to the superior aspect of the larynx and provides muscular innervation for the cricothyroid muscle. The recurrent laryngeal nerve, another branch of the vagus, descends into the chest and then heads superiorly in the tracheoesophageal groove. It is responsible for providing sensation to the inferior half of the larynx and innervates the remaining intrinsic laryngeal musculature. Though it is commonly stated that a lesion of either nerve results in a classic position of the vocal cords, this has not been found to be true. Cross-innervation, arytenoid joint fixation, and muscular scarring all contribute to the position of the paralyzed cord and make it difficult to predict the site of a lesion. Lesions high in the vagus will result in
disruption of both the superior laryngeal and recurrent laryngeal nerves, in addition to their contribution to the pharyngeal plexus, making the patient more prone to aspiration.

**VOCAL FOLD ANATOMY AND VOICE PRODUCTION:**

The understanding of voice production and the factors responsible for its control is constantly evolving.

In order to understand theory behind voice production, it is first important to understand the specific histologic anatomy of the vocal folds. Original work done by Hirano demonstrated that the vocal folds are multi-layered and contain 1) an epithelial layer, 2) three connective tissue layers, 3) the vocalis portion of the thyroarytenoid muscle.

The epithelial layer of the vocal folds forms the outer cover and contains three different types of mucosa. The upper and lower edges of the vocal fold are composed of typical respiratory (pseudostratified ciliated columnar) epithelium. The vibrating edge of the cord is covered with nonkeratinized stratified squamous epithelium. This layer is only 8 cells thick. Zones of transitional columnar epithelium separate these two areas.

The connective tissue layers, collectively known as the lamina propria, are distinguished by their various compositions of elastic and collagenous fibers. The superficial layer, which corresponds to Reinke’s space, contains scant amounts of loosely bound elastic and collagenous fibers (1). The intermediate layer contains primarily branching elastic fibers. The deep layer is composed of mostly dense collagenous fibers running parallel to the vocal cord. Together, the intermediate and deep layers of the lamina propria comprise the vocal ligament. The lamina propria has thickening at both its anterior attachment to the thyroid cartilage and its posterior attachment to the vocal process of the arytenoid.

The vocalis muscle is simply the medial fibers of the thyroarytenoid muscle. These fibers compose the muscular portion of the vocal folds. They do not attach to the vocal ligament but instead run parallel to it.

Vocal fold lubrication is crucial to effective voice production. The epithelial layer of the vocal folds contains microridges which are important in enabling spread and retention of mucous on the epithelium. This lubrication is important in maintaining the pliability of the vocal cords and prevents abrasion on forceful adduction. Fukuda et al. discovered that a poorly lubricated larynx requires 25% increased subglottic pressure and 50% more airflow to produce sound.

Though the vocal cords can be dissected into microlayers, it is far more functional to view them as cover and body. The cover is composed of the epithelial layer and the superficial connective tissue layer. The vocalis muscle comprises the body. The intermediate and deep layers of connective tissue are a transition. The body is ten times stiffer than the cover, which allows the pliable cover to alter the air passing from the subglottis. The stiffness of the cover can be altered by the actions of the cricothyroid muscle. As the cricothyroid contracts, the distance between the cricoid and thyroid cartilages increases and the vocal folds stretch. This causes the cover to have a decreased mass per unit area and decreased compliance. These changes cause an increased resistance to glottic airflow and a greater rate of vibration, which is interpreted as an increase in pitch. The reverse is also true. When producing a low pitch, the vocal folds are very compliant and absorb more of the subglottic pressure.
This demands an increased effort to produce sound. The contraction of vocalis muscle causes shortening of the body which makes the cover lax and increases compliance of the cover. The effects of these two muscles largely alter compliance and therefore the vibrations of the vocal folds.

Three important steps must happen prior to the production of voice. The first two steps are the development of tension in the vocal folds and their adduction to the midline (also known as the phonatory attack phase). The lateral cricoarytenoid and interarytenoid muscles accomplish the first two steps. The final step is the production of airflow from the lungs.

When the vocal cords are closed, air from the lungs causes increased pressure in the subglottis. This pressure increase causes the inferior aspect of the vocal cords to separate while the superior aspect remains closed. As the pressure increases further, there is a nearly simultaneous opening of the superior and inferior edges of the cord. This allows a puff of air to be released as the vocal cords are separated. As the air rushes past the cords, there is drop in pressure in the space between the cords (Bernoulli effect). This results in the closure of the lower lip of the cord. This timing difference between the inferior and superior aspects of the vocal folds is known as the vertical phase difference. The vertical phase difference is responsible for the wavelike motion of the vocal cords. As the upper folds continue to spread, the elastic properties become stronger resulting in closure of the upper folds. The pressure again begins to build in the subglottis and the cycle starts again. This wavelike motion, also seen in the horizontal plane, is readily visible along the rima glottis with videostrobolaryngoscopy. It actively contributes to shaping of the airflow from the glottis. This mucosal wave is dependent on the soft, pliable superficial lamina propria (1).

PATHOLOGY AFFECTING VOICE:

**Unilateral Vocal Cord Paralysis:** When one of the vocal cords is paralyzed, the cords are not able to meet in the midline to initiate the glottic attack. This prevents development of the subglottic pressure needed to initiate speech. Also with the cords at such a distance, the mucosal wave cannot be adequately maintained. Hoarseness and breathiness are the most common complaints but vocal abnormalities may also include easy fatigability and voice or pitch change. It is important not to assume that the immobile cords are necessarily paralyzed. Arytenoid fixation can lead to an immobile cord and direct palpation of the arytenoid cartilage and/or laryngeal EMG can rule out this possibility. Potential return of function of an immobile cord can be determined if the underlying cause is known and with the aid of LEMG. This contributes significantly to the choice of surgical procedure to correct the problem. It is also important to remember that the larynx has a number of functions in the human and dysphonia may not be the primary complaint. Patients may be suffering from dysphagia, coughing, or choking episodes, or stridor.

There are a number of different causes of unilateral vocal cord paralysis. Any entity affecting the vagus nerve along its course may result in decrease in function. The most common cause is non-laryngeal cancer which includes neoplasms of the head, neck, chest, and skull base. Neuritis associated with upper respiratory infection, syphilis, or other infectious sources may cause nerve dysfunction. Neurologic conditions such as CVA, multiple sclerosis and myasthenia gravis may also effect vocal cord functioning. General medical conditions such as diabetes mellitus may cause an isolated neuropathy giving rise to vocal paralysis. Lesions of the vagal nerve occurring higher in the brain and may present with multiple cranial nerve abnormalities.
Vocal Fold Bowing: The inability of the folds to approximate at the midline decreases the ability to produce proper speech. Though it may be a normal change in the aging patient, it is also seen with muscular atrophy secondary to nerve sectioning or central neurologic conditions. With aging, changes in the lamina propria include a loss of elastic fibers, atrophy of submucous glands, increased fibrosis, and muscle atrophy. These changes result in an increased glottic gap and a number of perceptual changes. Geriatric patients may present with hoarseness, low pitch, imprecise articulation, or breathiness.

PATIENT EVALUATION AND SELECTION:

History:

GENERAL: As always, obtaining a pertinent history is of utmost importance. One should determine the onset, duration, and severity of the dysphonia. As previously mentioned, the larynx is also crucial in protecting the lower respiratory tract and is a conduit of the upper respiratory tract. Therefore the patient may present with coughing and choking episodes, aspiration, stridor, dysphagia, or odynophagia (2). Intubation history and previous head and neck trauma are crucial pieces of information. It is important to know if the patient has had any previous laryngeal surgery or other head and neck surgery.

VOCAL: A specific vocal history is also important. Many patients who present with vocal complaints have a disease entity that does not warrant surgical treatment. Aside from onset, duration, variability, and past vocal problems, history should include pertinent medical questions such as presence of seasonal allergies, history of reflux disease, life stress, diabetes, and medications. Many patients who present for an initial evaluation of voice complaints are unfamiliar with questions of vocal use and hygiene. It is important for the physician to explain these concepts to the patient during the questioning to facilitate accurate responses and educate the patient. Questions should include voice demands at home and at work, recreational singing, and episodes of abuse i.e. sporting events. Smoking, water intake, caffeine intake, and environmental irritants are important questions about vocal hygiene.

Physical:

It is important to do an entire exam with emphasis on palpation of the neck to assess for any neck mass or goiter and cranial nerve testing. An indirect laryngeal exam, as well as a flexible laryngoscopy or videostrobe should be performed. The patient should phonate a high pitched /ee/ sound. This causes elongation of the vocal folds and causes the larynx to move superiorly. These movements aid in obtaining a complete view of the larynx. In addition to assessing vocal fold position and mobility, it is crucial to rule out carcinoma of the larynx in a patient presenting with hoarseness. A direct laryngoscopy with palpation of the arytenoids to ensure joint fixation is absent should be done prior to any surgical procedure.

The manual compression test is an easy non-invasive office procedure to help evaluate a number of voice disorders. The lateral manual compression test is particularly useful in determining whether a patient with a wide glottic gap from unilateral vocal cord paralysis or vocal bowing will benefit from a medialization thyroplasty. To perform the test, the neck should be palpated to find the superior notch and the inferior margin of the thyroid ala. The vocal cords are located along a horizontal line drawn at the midpoint of these two landmarks. The patient is asked to sustain an /a/ phonation and pressure is applied to the lateral aspects of
the thyroid cartilage. The concept is to approximate the vocal folds and decrease the glottic gap. A subjective improvement in voice quality is sufficient to state that the patient would benefit from a medialization thyroplasty though acoustic, aerodynamic, and videostroboscopic studies can be done to quantify improvement. The limitations to this test are older patients who have calcification of the thyroid cartilage, patients with obese necks, and patients with scarring of the vocal folds.

Vocal Assessment:

Despite the recent outburst of technology used to measure and quantitatively assess voice, there is no substitute for the trained ear. Taking a history gives ample time for the physician to make a qualitative assessment of the patient’s voice. Qualities such glottic fry, hard glottal attacks, breathiness, diplophonia, pitch breaks, phonation breaks, and tense phonation can be assessed.

Acoustic evaluation is the quantitative measurement of various voice characteristics. Having the patient sustain a single tone, the fundamental frequency (Fo), variations in amplitude (shimmer), and variations in pitch (jitter) can be measured. Fo may be decreased in patients with vocal abuse or poor approximation of the vocal folds. Shimmer alteration is due to decreased stability of the vocal folds. Abnormal jitter correlates with the subjective quality of hoarseness.

Videostrobolaryngoscopy (VSL) should be performed whenever possible. It allows for dynamic assessment of the vocal folds. With this view, the physician is able to differentiate between functional voice problems and those caused by subtle structural abnormalities. Pulses of light allow us to watch various parts of successive cycles to obtain a complete picture of vocal cord activity. The physician is able to evaluate symmetry of movement, aperiodicity, glottic closure configuration, and horizontal excursion amongst other variables. If the cords are functioning symmetrically, they should essentially be mirror images of each other. The lateral excursion and timing of opening/closing should be identical. Aperiodicity is a measure of irregularities in vocal fold movement. If the frequency of the strobe light is equal to the fundamental frequency, no vocal fold movement should be seen. If movement is observed followed by a static period, aperiodicity is present. The glottis may also be assessed for gap, shape, and appropriate closure (11). The shape of the glottis may be characterized as complete, anterior chink, irregular, bowed, posterior chink, hourglass, or incomplete. Horizontal excursion is a measurement of the amplitude of the cords. Measurement both pre and post-operatively can provide objective data for evaluating improvement. An additional benefit is reviewing the results with the patient immediately after performing the examination. Giving the patient a visual image of the problem helps considerably in motivation for behavioral treatment and development of goals for improvement.

Electromyography (EMG), though not routinely performed, is an excellent evaluation of specific muscle functioning. By placing electrodes into laryngeal muscles (thyroarytenoid, cricothyroid), EMGs help elucidate whether there is any re-innervation of muscles which are thought to be paralyzed. It can also help to differentiate paralysis from arytenoid joint fixation.
EMGs are also used to identify excessive muscle activity prior to the use of BOTOX for spasmodic dysphonia.

Diagnostic Tests:
If indirect or stroboscopic exam demonstrates a unilateral vocal cord paralysis with no known etiology, a specific battery of tests should be considered. A CT scan from skull base to the mediastinum should be done to evaluate the entire length of the vagus and recurrent laryngeal nerves. If the patient is a child, pregnant, or suspected to have a generalized neurologic problem, an MRI is advised instead. A barium swallow may be done to evaluate swallowing mechanism and associated dysphagia. Radioactive thyroid uptake scan or ultrasound may be done to evaluate for the presence of a nodule or tumor. Chest x-ray is performed to rule out the presence of a bronchogenic carcinoma, mediastinal adenopathy/mass, or less likely, the presence of an enlarged heart compressing the recurrent laryngeal nerve, particularly on the left side. A FTA-Abs test should be done to rule out syphilis as a cause of vocal cord paralysis.

TREATMENT OPTIONS:
The most important aspect of rehabilitating voice is defining the patient's goals.

Voice Therapy:
Assessment of patients by a speech pathologist allows for maximal medical treatment to be implemented before consideration is given to surgical treatment. Some patients develop hyperfunctional compensatory mechanisms which lead to the common complaints of voice strain, neck discomfort, and fatigue (16). Speech pathologists can help eliminate these habits and educate the patient on proper compensation techniques. Relaxation exercises, aerobic conditioning, voice exercises and other methods are all practiced by the patient to improve voice quality. Once vocal therapy has been maximized and further voice improvement is desired, surgical options may be considered. Utilizing voice therapy in treatment of unilateral vocal cord paralysis is crucial to ensuring the greatest improvement in voice.

CORD INJECTION:

Teflon
Indications:
Teflon injections are most commonly used for unilateral vocal fold paralysis with no hope for return of function in terminal patients. To ensure that function will not return, a waiting period of one year is usually observed prior to performing the procedure.

Contraindications:
Experience has shown that Teflon injections are particularly poor when the voice complaint is secondary to vocal cord atrophy, or vocal fold bowing.

Procedure:
There are a number of different approaches to injecting the vocal folds. When performing the percutaneous injection, no sedation is required and local anesthetic is used. Fiberoptic laryngoscopy is used concurrently to assure proper placement and adequacy of the injection. The lateral percutaneous approach requires the surgeon to pierce the thyroid cartilage at the level of the vocal fold. An anterior approach may be used by placing the needle through the cricothyroid membrane and angling the needle superiolaterally under direct visualization. The Teflon should be placed lateral to the vocalis muscle with great care not to disturb the endolaryngeal mucosa. The first injection should be placed anterolateral to the vocal process of the arytenoid. Teflon is injected until appropriate medialization is seen with fiberoptic laryngoscopy. Another bolus of Teflon is placed anterior to the junction of the middle and anterior one third of the cord. A transoral injection may be done under local anesthesia using indirect mirror laryngoscopy. It is extremely important to bevel the needle away from the mucosal edge to avoid an intramucosal injection. If the procedure cannot be adequately performed under local anesthesia, it may be done during a direct laryngoscopy under general anesthesia with jet ventilation. It is important not to place excessive pressure on the anterior commissure to avoid distorting the vocal cords. The needle is placed lateral to the vocal fold, 2mm deep, at the level of the vocal process. The patient is asked to phonate and further injections depend upon voice quality. It is important to assess voice quality during the procedure. If too much Teflon is injected, the results may be disastrous. If overinjection does occur, it is imperative to incise the mucosa over the site of injection and suction out the excess.

Advantages:

The procedure is inexpensive and produces immediate results. It can also be done under local anesthesia and usually results in satisfactory voice. It is important to note that these advantages, once exclusive to Teflon injection, can be provided by other surgical procedures.

Limitations:

The irreversibility of the procedure is a major concern. Teflon may only be placed in a vocal cord which has no potential for return of function. As stated above, this requires one year of waiting after initial presentation to ensure complete paralysis. The only exceptions to this is the terminally ill patient with aphonia or aspiration. If vocal fold function does return after placement of Teflon, voice quality will be poor with increased likelihood of displacement, extrusion, and granuloma formation. Teflon injection into a mobile cord will cause hardening of the cord and disruption of the normal mucosal wave. Attempts to remove a Teflon implant usually result in destruction of the vocal fold. The inability to use Teflon in cases with absent soft tissue is another criticism. This automatically eliminates its use in patients with atrophy and bowing of the vocal folds, status post cordectomy, and status post blunt laryngeal trauma. The injection of Teflon is not sufficient to medialize the cord and enhance vocal function. Patients suffering from a central neurologic problem also receive no benefit from Teflon injection. Central lesions typically disrupt superior laryngeal and pharyngeal function and therefore a procedure which narrows the glottic gap may not be sufficient to prevent aspiration. Migration of the implant and extrusion through the vocal membrane are other possible complications. Granuloma formation is the most feared complication. It can result in poor voice quality and eventually airway compromise. Because of this, Teflon is now limited by most.

Gelfoam:

Gelfoam injection is a temporary measure for treatment of unilateral vocal cord immobility. The main indications for the use of Gelfoam are temporary paralysis with glottic incompetence,
augmentation to a re-innervation procedure, contraindication to an open procedure, and as a test run before injecting a non-absorbable material.

The method involves mixing Gelfoam powder with saline immediately prior to vocal fold injection. Approximately 1g of powder can be mixed with 4cc of saline. The consistency is very important; the less viscous the solution, the quicker it will be reabsorbed. It is injected in the same manner as Teflon.

In a trial with Gelfoam, it was effective in decreasing aspiration and returning the ability to cough in all patients. Voice was improved in all patients and most patients were able to improve without the aid of speech therapy. The amount of Gelfoam present in the cord is constant for approximately one month and is fully absorbed in 8 to 10 weeks. The slow resorption allows for a gradual compensation in speech and swallowing. There is a mild mucosal edema and erythema that occurs in some patients and rare reported cases of airway compromise.

Collagen

Collagen injections are derived from bovine collagen which is modified to minimize host immune response. Collagen implants are assimilated into the surrounding tissues by an invasion of fibroblasts and deposition of new host collagen. Histologically, the collagen is similar to the deep layer of the lamina propria. Therefore, the collagen is placed within this layer of the vocal fold. Though there is some resorption of the collagen, this is offset by the deposition of host collagen thereby providing long term voice improvement. Resorption of the cartilage may be precipitated by an upper respiratory infection. There have been reports of hypersensitivity reactions with rare cases of airway compromise. Some authors still advocate the use of dermal skin tests to test for possible allergic reaction to the injections. In a series by Ford and Bless, 2 of 80 patients had a positive skin test which is consistent with the reported incidence of 3%. Recently, an increased used of Zyplast collagen, a GAX collagen, has decreased the incidence of allergic reactions.

Autologous Fat

In 1987, Brandenburg et al. reported the first use of autologous fat injection for glottic insufficiency. Since then, fat injection for a variety of etiologies has become very popular.

Indications: Fat injections have been used successfully in patients with vocal cord paralysis, vocal fold scarring, vocal fold atrophy, and intubation defect.

Contraindications: There are no definitive contraindications to fat injection

Technique: (as described by Hsiung et al. (12)). Under general anesthesia, fat is harvested from the lower abdominal pannus. The fat is cut into 1mm pieces separating it from connective tissue. The fat is then rinsed with lactated ringers followed by a methylprednisolone solution. It is then loaded into a syringe. The actual location of fat placement is dictated by the underlying pathology. For those patients with vocal cord atrophy and paralysis, the anterio- and posteriolateral areas of the middle third of the cord are injected. Injection is continued until a 50% overcorrection and convex bowing of the affected cord is seen.
Outcome: Since its first use in 1987, fat injections have gained popularity. Autologous fat is well tolerated in the vocal cord and repeated injections can be done if necessary. Unlike Teflon where overinjection can be disastrous, placing too much fat in the vocal fold does not cause significant post-operative complications. Overinjection is recommended because a certain percentage of fat will atrophy over time. Postoperative analysis reveals an improvement in glottic closure and mucosal wave production. Though there is an improvement in the breathy quality in those patients with glottic insufficiency, vocal roughness persisted after the procedure. Anterior defects corrected with fat injection have a better postoperative outcome than posterior defects.

Hsiung et al. (12) divided failure into two categories, early and late. With early failure, it was believed that it was due to 1) a large glottal gap or 2) a posterior defect not corrected with fat injection. Late failure was attributed to absorption of the fat supported by an initial improvement in voice quality.

There are still a few concerns and questions about fat injection. Knowing that there will be some reabsorption of the fat, the cord needs to be overinjected. This leads to the question of exactly how much fat results in an optimal change in voice. It is also not known whether improved vocal function is due to the amount of fat injected or softening of the vocal cords. Another uncertainty is the rate of fat absorption by the vocal tissue. If initially effective, the benefits of fat injection may last anywhere from three months to several years. Some studies have shown that despite absorption of the fat, lipocytes and fibrous connective tissue retain the contour of the vocal cord and provide long term benefit. The exact method of harvesting and preparation of the fat and its relation to absorption is still unknown. Effort should be made to minimize that amount of trauma to the fat during extraction.

TYPE I THYROPLASTY

Indications:
A Type I thyroplasty was repopularized by Isshiki in 1974. The indications for a Type I thyroplasty are unilateral or bilateral vocal fold paralysis or paresis, vocal fold bowing, and incomplete glottic closure with aspiration.

Contraindications:
There are two contraindications for performing a Type I thyroplasty. The first is in patients with a previous hemilaryngectomy. Without the support of the thyroid cartilage, the silastic implant is ineffective in medializing the scarred side. Vocal fold injection is indicated in this case. The second contraindication is previous laryngeal irradiation due to extensive scarring.

Technique: There are many variations in this procedure championed by several authors. Described below, is the technique performed by Netterville et al (6). A horizontal incision is made over the midportion of the thyroid cartilage and the cartilage exposed. A window is created in the thyroid ala approximately 8mm posterior to the anterior commissure and 3mm superior to the inferior border of the cartilage. This provides a sufficient strut inferiorly to support the implant. After the window is made, the cartilage is removed. Incisions are made in at the inferior, posterior and superior aspects of the inner perichondrium thereby creating a flap. The perichondrium is elevated from the medial aspect of the thyroid ala. While viewing the cords via fiberoptic laryngoscopy, a depth gauge is used to medialize the cords in the anterior, middle, and posterior aspects of the window and the measurements are recorded. These measurements are also taken at the superior and inferior aspects of
the window to find the relation between the true and false vocal cords. Using measurements from the various areas of the windows, an implant can be fashioned from a silastic block. The point of maximal medialization is at the level of the vocal process. Very minimal medialization is designed at the anterior commissure to prevent a strained voice. The inferior aspect of the implant is placed in the window and rotated into place. The patient is asked to phonate and voice is assessed. If medialization is not optimal, the implant can be removed and modified. The time of intralaryngeal elevation and implant placement should be minimized to prevent vocal interference by intraoperative edema.

Variations/Controversies:

**Removal of the cartilage window:**
Some authors feel that the cartilage, if left in place can migrate superiorly and medialize the false vocal cord or ventricle. If the cartilage migrates inferiorly, it may cause overmedialization of the cord resulting in a persistently strained voice quality.

**Inner perichondrium:**
Some authors prefer to leave the inner perichondrium intact stating that it decreases the incidence of graft extrusion. Netterville states that the reason for increased implant extrusion is injury to the ventricle. This occurs more frequently if a paramedian incision is used near the anterior commissure where the ventricle is located very close to the inner perichondrium. He argues that incising the inner perichondrium does not increase implant extrusion secondary to the development of a fibrous capsule around the implant.

**Implant material:**
Though some authors feel that a carved implant allows for precise results, Montgomery *et al.* (10) reports certain benefits to a pre-made implant. The inner aspect, which medializes the cord, is made of a softer plastic closer to the consistency of the surrounding tissue. The outer half is made of a harder plastic which locks into the thyroid cartilage. This prevents displacement of the cords and eases revision. Hydroxylapatite is a pre-made implant which has minimal tissue reactivity and good biocompatibility with the surrounding tissue. Gore-tex (ePTFE) is another material reported to be of benefit in medializing a paralyzed vocal cord. This material has excellent biocompatibility and can be used to medialize the cord in an incremental fashion. This technique does not require extreme precision in creating the thyroid window or shaping the implant.

**Benefits:**
Type I thyroplasty has had excellent results in voice improvement. The procedure helps to re-establish the mucosal wave in the paralyzed vocal fold. By approximating the vocal membranes, normal anatomic position is re-established and the cords are able to produce sound. The return of an intact mucosal wave is a large reason that this procedure is so effective in improving voice. This improvement is illustrated by an increased Fo and maximum phonation time. Other objective variables such as glottic closure and cord symmetry are also improved. The improvement in aspiration symptoms is even more consistent than the improvement in voice quality. Additional benefits include the ability to monitor vocal improvement during the procedure if performed under local anesthesia. Using a nasopharyngoscopy, the surgeon can ensure the implant is at the level of the true vocal cords and not medializing the false cords or the ventricle. It is both adjustable and potentially reversible. The reversibility of the procedure allows its use in a patient with potential return of vocal cord function. The implant can also be revised if the vocal cord continues to atrophy over time. When performing a Type I thyroplasty, it is important to counsel the patient on the expected voice changes post-operatively. Though initially strong in the operating room, perioperative edema will cause the
patient to be hoarse for the first ten days after the procedure. Some have noted an additional period of voice difficulty occurs 4 to 6 weeks after surgery. This eventually improves and the patient’s voice may continue to improve for the next year.

Primary medialization thyroplasty occurs at the time of extirpative surgery with known sacrifice of the recurrent laryngeal nerve in the neck. This procedure is done under general anesthesia and therefore negates the benefit of intraoperative voice evaluation. It is performed primarily in hope to eliminate the need for a tracheotomy and decrease the postoperative rehabilitation time (swallowing and speech) of patients with loss of multiple cranial nerves.

Complications of a Type I thyroplasty include persistent dysphonia, airway obstruction, implant migration, extrusion, hematoma, and infection. Poor voice quality post-operatively may be due to inadequate medialization or over-medialization of the cords. Appropriate voice assessment can only take place 4 to 6 weeks after the operation when all edema has resolved. Despite various techniques to prevent migration, occasionally the implant may move superiorly and medialize the false cord and ventricle. This calls for removal of the implant and replacement with a larger prosthesis. Extrusion into the airway is a serious complication. Though it does not occur frequently, suspicion should warrant a fiberoptic laryngoscopy and subsequent endoscopic extraction if found. Extrusion laterally can be avoided by securing the prosthesis firmly in the thyroid cartilage. In general, complications can be reduced by careful handling of the tissues, limited operative time, and meticulous hemostasis. (2).

Type I thyroplasty may not be sufficient to close a large posterior gap. It may difficult to know pre-operatively whether posterior approximation will be needed. One method proposed by Omori et al. (5) is to obtain videostroboscopic measurements prior to surgery. They assessed the posterior glottic gap as a percentage of the membranous vocal fold length. They found that is the posterior glottic gap was larger than 10% of the membranous vocal fold length, the post-operative outcome was worse and a posterior closure procedure may be warranted. If it is determined that the posterior gap is too large either pre or intra-operatively, the surgeon has the option of either creating an implant with a large posterior component or performing an arytenoid adduction (discussed later). Implants that were originally fashioned to medialize the posterior cord did so by pressing on the vocal process of the arytenoid cartilage. It has since been shown that it is more effective to fashion the implant to apply pressure to the muscular process of the arytenoid. Simply stated, the implant should have a large posterior flange, approximately 5mm in thickness to fit between the muscular process and the thyroid ala. The major advantage of this procedure is, unlike arytenoid adduction, that it does not hinder mobility of the vocal folds.

ARYTENOID ADDUCTION:

There are two major indications for an arytenoid adduction. The first reason is to close a posterior glottic gap. Given that the cricoid overlaps the thyroid posteriorly, a posterior window is not effective in medializing the posterior vocal cord. The traditional Type I thyroplasty has been shown to be ineffective in medializing the posterior cord. A simple way to assess if an arytenoid adduction is necessary is to see if the vocal processes of the arytenoid cartilages touch in the midline when the patient phonates. The second reason is if the vocal folds are not at the same caudal-rostral level. The vocal process of the arytenoid cartilage moves inferior with adduction and superior with abduction. This is due to the cylindrical shape of the cricoarytenoid joint. Some surgeons advocate an intra-
operative assessment of the vocal cord medialization. If after the silastic implant has been placed, there is a persistent posterior gap, an arytenoid adduction is performed.

The procedure is described as it is performed by Isshiki. Using a horizontal neck incision at the level of the vocal cords, the posterior border of the thyroid cartilage is exposed by transecting the strap muscles and detaching the inferior constrictor from the thyroid. It is important to identify the recurrent laryngeal nerve in this area to avoid any damage. The cricothyroid joint is then opened to allow access to the muscular process of the arytenoid cartilage. The piriform sinus mucosa is then elevated with great care to violating the piriform recess. Cricoarytenoid joint is then opened to allow exposure of the muscular process. The posterior cricoarytenoid muscle is identified and ligated from the muscular process. Two 3-0 nylon sutures are placed around the muscular process and the surrounding soft tissue. The sutures are then pulled anteriorly through the thyroid ala. The patient is asked to phonate and the appropriate force is determined to provide optimum voice results.

The only significant variation is whether or not to open the thyroarytenoid joint. Some authors believe that opening the joint results in prolapse of the arytenoid cartilage into the laryngeal lumen with overadduction of the posterior commissure.

Arytenoid adduction can be used in conjunction with medialization thyroplasty and re-innervation surgery. Currently, no other procedure corrects for a discrepancy in vocal cord level and few other procedures effectively address a wide posterior chink.

REINNERVATION SURGERY WITH ANSA CERVICALIS:

Indications: In the past few decades, there has been a surge of interest in reinnervation surgery as a therapy for unilateral vocal cord paralysis. Given that the arytenoid cartilage is mobile and the ansa cervicalis has not been disrupted, reinnervation with a nerve-muscle pedicle or recurrent laryngeal nerve – ansa cervicalis anastomosis should be considered.

Contraindications: If there is any fixation of the arytenoid cartilages, a nerve anastomosis should not be used. This procedure cannot be performed on a patient who has had disruption of the ansa cervicalis, either by surgery, trauma, or neurological process.

Neuromuscular pedicle reinnervation:
An incision is made in the lower half of the thyroid ala extending to the sternocleidomastoid muscle. The ansa cervicalis is identified overlying the jugular vein and is traced to its insertion to the anterior belly of the omohyoid muscle. Two stay sutures are placed 2-3mm proximal and distal from the insertion site. A window is made similar to that used for a Type I thyroplasty. The inner perichondrium is opened and the thyroarytenoid is incised superficially. Using the stay sutures, the muscle pedicle is sown in place. It is crucial to avoid excessive tension on the pedicle.

Ansa Cervicalis – Recurrent Laryngeal Anastomosis:
The ansa cervicalis is exposed overlying the great vessels or within the carotid sheath. The ansa is traced to either the omohyoid or sternothyroid. The nerve is sectioned at its insertion to the muscle and transposed to the tracheoesophageal groove. The recurrent laryngeal nerve is identified by retracting the superior thyroid neurovascular bundle and followed to its insertion into the larynx. The
nerve is ligated 7 –10mm from its insertion in the larynx to ensure a tension free anastomosis. The nerves are anastomosed with a neurorrhaphy (epineural repair) with 10-0 suture under magnification.

Outcomes:

Re-innervation surgery has recently gained popularity in those patients with unilateral vocal cord paralysis. Though cord injections, medialization thyroplasties, and arytenoid adduction are sufficient to medialize the cord and close the glottic gap, none of these procedures address vocal fold tone, another important component of speech production. Reinnervation surgery provides tone to the thyroarytenoid muscle and gives tension to the vocal fold. Another reason cited to perform reinnervation is to prevent vocal fold atrophy. If a medialization procedure is performed, it may need to be revised 2 to 3 years later because cord atrophy has resulted in an increased glottic gap. Laryngeal reinnervation maintains the bulk of the paralyzed fold. Currently it is not known as to the optimal time to perform reinnervation surgery and which patients it will benefit. It has been proposed that intraoperative EMG can distinguish those patients with no spontaneous reinnervation from those with inappropriate reinnervation (synkinesis). Those patients with no spontaneous reinnervation would be more likely to benefit from operative reinnervation.

A universal criticism of reinnervation is the 4 to 6 month period required for the procedure to be effective. Many authors advocate the concurrent use of a medialization procedure, either Gelfoam injection or thyroplasty. Tucker has described removing the posterior inferior aspect of the implant in order to allow room for the muscle-pedicle implant to be placed.

When comparing the two methods of reinnervation, it is currently unclear which procedure produces the best results. Preliminary work by Hall et al. indicates that the muscle pedicle allows for more rapid innervation and stronger contractile force. Current research is directed toward understanding the role of cell adhesion markers in the role of nerve regrowth. This research will likely have a significant impact on the methods of reinnervation surgery.

Recently a modification has been proposed to the recurrent laryngeal nerve – ansa recurrent laryngeal anastomosis procedure. Paniello (16) has proposed a recurrent laryngeal – hypoglossal nerve anastomosis. The theoretical advantage is that these are the only two nerves involved in swallowing and phonation. Other advantages are an abundance of axons in the hypoglossal nerve, use in patients in which ansa is unavailable, and low donor site morbidity. Initial work with the procedure suggests that it results in a stronger reinnervation and sphincter-like action on swallowing. Though there is denervation of the ipsilateral tongue, no increase in aspiration has been shown.
References:


7. Isshiki N. Vocal mechanics as the basis for phonosurgery. Laryngoscope December 1998; 108: 1761 – 1766


