

**TITLE: Vocal Cord Paralysis and Vocal Cord Medialization**

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## **Anatomy**

The cartilages of the larynx consist of the thyroid cartilage, the epiglottis, the cricoid cartilage, and the arytenoid cartilages. The corniculate and cuneiform cartilages stiffen the aryepiglottic folds. The arytenoid cartilages articulate with the cricoid by means of a true synovial joint. This joint allows two movements of the arytenoid cartilages – rotation and lateral gliding.

There are three groups of intrinsic laryngeal musculature – the abductors, adductors, and tensors. The only abductor of the larynx is the posterior cricoarytenoid muscle and it is innervated by the recurrent laryngeal nerve. The adductors are composed of the lateral cricoarytenoid muscle, interarytenoid muscle, oblique arytenoid muscles, and thyroarytenoid muscles. Innervation of the adductors is again supplied by the recurrent laryngeal nerve. The tensors are composed of mainly the cricothyroid muscle, which is innervated by the external branch of the superior laryngeal nerve, and to a lesser extent by the thyroarytenoid muscles.

The true vocal folds have an epithelial lining that is composed of respiratory epithelium (pseudostratified squamous) on the superior and inferior aspects of the fold and nonkeratinizing squamous epithelium on the medial contact surface. The subepithelial tissues are composed of a three-layered lamina propria based on the amount of elastin and collagen fibers. The superficial layer is composed of mostly amorphous ground substance and contains a scant amount of elastin with few fibroblasts – this layer is termed Reinke's space. The intermediate layer has an increased elastin content. The deep layer has less elastin but a greater amount of collagen fibers. The intermediate and deep layers have a higher concentration of collagen fibers and are termed the vocal ligament. Deep to the lamina propria is the thyroarytenoid (or vocalis) muscle. Reinke's space and the epithelial covering are responsible for the vocal fold vibration.

## **The Vagus:**

Understanding the anatomy of the vagus nerve is important because branches of the

vagus nerve are responsible for innervation of the larynx. The vagus nerve has three nuclei located within the medulla:

- 1) the nucleus ambiguus
- 2) the dorsal nucleus
- 3) the nucleus of the tract of solitarius

The nucleus ambiguus is the motor nucleus of the vagus nerve. The efferent fibers of the dorsal (parasympathetic) nucleus innervate the involuntary muscles of the bronchi, esophagus, heart, stomach, small intestine, and part of the large intestine. The efferent fibers of the nucleus of the tract of solitarius carry sensory fibers from the pharynx, larynx, and esophagus.

Vagus means "wanderer" which is appropriate for the path this nerve takes after emerging from the jugular foramen. It has two ganglia, the smaller superior ganglion and the larger inferior, or nodose, ganglion. The vagus sends small meningeal branches to the dura of the posterior fossa and an auricular branch, which innervates part of the external auditory canal, the tympanic membrane, and skin behind the ear. In the neck, the vagus runs behind the jugular vein and carotid artery to send pharyngeal branches to the muscles of the pharynx and most of the muscles of the soft palate. The superior laryngeal nerve separates from the main trunk of the vagus just outside the jugular foramen. It passes anteromedially on the thyrohyoid membrane where it is joined by the superior thyroid artery and vein (see vasculature). At approximately this level, the external laryngeal nerve leaves the main trunk. The main internal laryngeal nerve enters the thyrohyoid membrane through a hiatus. It then divides into three set of branches (ascending, transverse and descending), which communicate with the recurrent laryngeal nerve posterior to the cricoid cartilage; this is referred to as the ansa galeni. The internal superior laryngeal nerve penetrates the thyrohyoid membrane to supply sensation to the larynx above the glottis. The external superior laryngeal nerve runs over the inferior constrictor muscle to innervate the one muscle of the larynx not innervated by the recurrent laryngeal nerve, the cricothyroid muscle.

The right vagus nerve passes anterior to the subclavian artery and gives off the right recurrent laryngeal nerve. This loops around the subclavian and ascends in the tracheo-esophageal groove. It tends to run with the inferior thyroid artery for part of its course before it enters the larynx just behind the cricothyroid joint. It may branch prior to this with sensory fibers supplying sensation to the glottis and subglottis. The left vagus does not give off its recurrent laryngeal nerve until it is in the thorax, where the left recurrent laryngeal nerve wraps around the aorta just posterior to the ligamentum arteriosum. It then ascends back toward the larynx in the TE groove. The vagus then continues on into the thorax and abdomen contributing fibers to the heart, lung, esophagus, stomach, and intestines as far as the descending colon.

## **Normal function/movement/physiology**

The larynx has a variety of functions. It acts as a sphincter to close the airway during swallowing, preventing aspiration of food and liquids. This is phylogenetically the oldest and perhaps most important function of the larynx. Its function is also essential for respiration. Since the larynx is the gateway to the airway, laryngeal disease may result in obstruction of the airway. It functions during communication of both intellectual and emotional expression. Thus,

voice deterioration is only one symptom of laryngeal dysfunction. It also stabilizes the thorax by preventing exhalation, this helps stabilize the arms during lifting. During coughing, lifting, and straining it compresses the abdominal cavity. Aspiration on swallowing, ineffective cough, and breathy voice are symptoms caused by the loss of sphincteric function, and can occur in addition to hoarseness in patients with true vocal fold paralysis.

Phonation is defined as the physical act of sound production by means of passive vocal fold interaction with the exhaled airstream. Basically, this sound production arises from a passive movement of the true vocal cords (TVC)s modified in terms of pitch, quality, and volume by complicated interaction of thoracic and abdominal muscles, intrinsic and extrinsic muscles of larynx, and the shaping and resonance of the upper airway and nasal passages. Contraction of the expiratory muscles produces a rise in subglottic air pressure causing rapid escape of air between the nearly apposed TVCs. Bernoulli's effect and the elasticity of the cords causes medial displacement of the medial edges of cords and airflow is stopped. A rapid rise again in subglottic pressure causes the cords to part and the cycle is repeated. It is the escape of small puffs of air that produces the vibratory phenomenon interpreted as sound.

During phonation the lower margins of the true vocal folds separate first with formation of a volume of subglottic air. As the upper margins of the vocal folds separate a burst of air is released – the *glottal puff*. The lower fold then returns to midline, followed by the upper margin. This delay between closure of the lower and upper margins of the fold is termed the *phase delay*. The *mucosal wave* consists of both a horizontal movement of the folds and a vertical undulation.

The body-cover theory helps explain this mucosal wave. It states that there are two layers of the vocal folds with different structural properties. The cover is composed of stratified squamous epithelium and the superficial layer of the lamina propria (Reinke's space). The body of the fold is composed of the intermediate and deep layers of the lamina propria (which is more fibrous than the superficial layer – the “vocal ligament”) and the thyroarytenoid (vocalis) muscle. The cover is pliable, elastic, and nonmuscular, whereas the body is more stiff and has active contractile properties that allows adjustment of stiffness and concentration of the mass. The mucosal wave occurs primarily in this loose cover of the fold. Changes in stiffness or tension in the fold alters the mucosal wave. As the stiffness in the fold increases – as by contraction of the cricothyroid muscle – the velocity of the wave increases and the pitch rises. Mucosal wave velocity also increases with greater airflow and greater subglottal pressure.

The pitch of voice is related to the fundamental frequency of vocal fold vibration (measured in hertz). The fundamental frequency of vocal fold vibration correlates with changes in vocal fold tension and subglottic pressure. Contraction of the cricothyroid muscles, which correlates positively with vocal fold tension, is the main predictor of fundamental frequency, especially at high frequency. Contraction of the thyroarytenoid may change the tension of the vocal fold cover and body and affect the fundamental frequency also. Three physical properties of the vocal folds determine frequency of vibration – mass, stiffness, and viscosity

*Mass* – the fundamental frequency of vocal fold vibration is inversely proportional to its mass. Decreasing the mass – thinning of the fold by longitudinal stretching (contraction of the cricothyroid muscle with elongation of the vocal folds) – increases the frequency of vibration. Increasing the mass – contraction of the thyroarytenoid muscle with increased concentration of

the fold – will decrease the fundamental frequency.

*Stiffness* – vocal fold tension is an important variable in the control of fundamental frequency at the mechanical level. Vocal fold tension is affected by the contractile forces of the vocal fold musculature and the tissue characteristics of the vocal fold body, cover, and the connecting fiber structure of the vocal folds.

*Viscosity* – Viscosity is inversely related to ease with which the tissue layers slip over one another in response to a shear force. Increased viscosity of the vocal folds would require greater subglottal pressure to maintain the same vibratory characteristics. Therefore, hydration of the vocal folds has effect on the voice quality and ease of voice production.

## **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, dyspnea, 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 as 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 (9). 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.

## ***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 collagen may be

precipitated by an upper respiratory infection. There have been reports of hypersensitivity reactions with rare cases of airway compromise with the use of Bovine collagen, Zyderm. 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 use of Cymetra, a form of collagen composed of micronized homologous alloderm, has decreased the incidence of allergic reactions and lengthened the period of benefit.

### *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 antero- 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.

### ***Synthetic Injectables:***

Calcium Hydroxyapatite (Radiance FN; BioForm) is an injectable material made of small spherules of CaHydroxyapatite. No granuloma formation occurs with this agent. Long term efficacy is currently under study.

Polydimethylsiloxane gel (Bioplastique; Bioplasty) is widely used in Europe for vocal fold medialization, but is not approved for use in the U.S. Sustained phonatory improvement up to 7 years has been shown in some European studies.

## **--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 aspirations.

- **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. Nettekville 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 nasopharyngoscope, 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 if 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 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 is 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

## **Bilateral Vocal Cord Paralysis:**

In contrast to unilateral vocal cord paralysis, voice quality is not the primary concern in patients with bilateral vocal cord paralysis. The significant problem is airway compromise. This can range from unnoticeable to, more commonly, dyspnea and stridor. The patient's voice quality is usually only mildly affected (if just the recurrent laryngeal nerves are involved) because the paralyzed cords tend to assume the natural position for phonation.

There are three basic ways that bilateral vocal cord paralysis is managed:

- 1) tracheotomy
- 2) vocal cord lateralization
- 3) reinnervation

## **Tracheotomy:**

Tracheotomy has the advantages of providing immediate relief of airway restriction. It can be performed under local anesthesia, and has relatively little reduction in voice quality. Disadvantages include the creation of a stoma that has both cosmetic and long-term care problems, and the need to occlude the tube or wear a speaking valve to phonate. This may be the best option for many patients because it controls the airway while preserving voice quality. In many patients, the tracheotomy can be occluded the majority of the time. In times of exertion, while sleeping, or when the patient has a cold or other respiratory condition, the tracheotomy can simply be unplugged.

## **Vocal Cord Lateralization:**

This involves several techniques that surgically widen the glottic opening. While this improves the airway, the patient's voice quality suffers. The three most commonly utilized techniques are arytenoidectomy, arytenoidopexy, and cordectomy/cordotomy.

## **Arytenoidectomy:**

Classic arytenoidectomy involves removal of some or all of the arytenoid cartilage. This procedure can be performed in a variety of ways, from endoscopically by microsurgical or laser technique to an external, lateral neck approach (Woodman). The Woodman procedure involves a lateral neck incision, exposure of the arytenoid cartilage posteriorly with removal of the majority of the cartilage, sparing the vocal process. A suture is then placed into the remnant of vocal process and fixed to the lateral thyroid ala. This technique seems to cause less voice deficit than other approaches.

## **Arytenoidopexy:**

Arytenoidopexy displaces the vocal fold and arytenoid without surgical removal of any tissue. It can be done endoscopically with a suture passed around the vocal process of the arytenoid and secured laterally. This procedure, however, has a relatively high failure rate and is technically difficult.

## **Corpectomy:**

Dennis and Kashima (1989) introduced the posterior partial corpectomy procedure using the carbon dioxide laser. This involves excising a C-shaped wedge from the posterior edge of one vocal cord. If this posterior opening is not adequate after 6-8 weeks, the procedure can be repeated or a small corpectomy can be performed on the other vocal cord. Laser cordotomy removes a smaller posterior portion of the true vocal cord and better preserves voice.

## **Reinnervation:**

Tucker proposed a nerve-muscle transfer to the posterior cricoarytenoid muscle for the treatment of bilateral vocal cord paralysis. The technique is similar to the one used for unilateral vocal cord paralysis. Prerequisites are that the cricothyroid joint not be fixed and that the necessary nerve for the graft not have been affected by the process that caused the paralysis. Tucker reports a high success rate.

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