

EDITORIAL

What Happens in (the) Vagus, Stays in (the) Vagus

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INTRODUCTION

... [I]n a given year, 7.4% of doctors (on average) get sued by patients. ...

... Neurosurgeons topped the list, with 19.1% of them facing a claim each year. They were followed by thoracic-cardiovascular surgeons (18.9%), and general surgeons (15.3%). —*Los Angeles Times* [Kaplan 2011]

Many cardiothoracic operations put the nerves of the thorax at risk. In fact, nerve injuries are one of the most common reasons cited in malpractice cases brought against cardiothoracic surgeons. While all physicians learn about the nerves of the thorax during anatomy courses in medical school, little is written about avoiding injury to these important nerves in the cardiothoracic surgical literature. We have, therefore, embarked on an effort to collate information on the anatomy, function, and protection of these nerves, with which every cardiothoracic surgeon should be familiar. We will call this effort “The Nerve Protection Project.” Acknowledging that the material to be covered is considerable, we will break the project into a series of editorials. The first installment in this series will address the anatomy and function of the vagus nerve and the protection of this nerve and its branches during cardiothoracic surgical operations, as they are in harm’s way during many of these procedures.

The vagus, the 10th cranial nerve, is the longest and most complex of the 12 cranial nerves. The vagus nerves are paired, but, by convention, they are usually referred to in the singular. The word vagus means “wandering” in Latin, and the vagus nerve certainly does wander “all along its southbound odyssey (with acknowledgment to Steve Goodman),” as it supplies motor (efferent) and sensory (afferent) innervation to structures in the neck, thorax, and abdomen. The vagus nerve has sometimes been called “the pneumogastric nerve” in recognition of its providing parasympathetic innervation to the heart and lungs, as well as to the upper gastrointestinal tract and other abdominal organs. The vagus and its branches provide not only

parasympathetic autonomic innervation but also have both motor and sensory functions. The vagus nerve supplies sensory innervation to the external auditory meatus, as well as the internal surfaces of the larynx and pharynx. The vagus also supplies motor innervation to the majority of the muscles of the pharynx and larynx, and it supplies parasympathetic innervation to the heart, as well as to the smooth muscles of the trachea, bronchi, and gastrointestinal tract.

It is noteworthy that the vagus nerve seems to have taken on an almost mythical status in the lay literature, with one author noting that “when we talk about the gut-brain connection, we’re talking about the bidirectional superhighway of neurotransmitters and other chemicals that race all day from your digestive system to your brain and back, under the direction of the vagus nerve” [Weinreb 2019]. It is interesting to note that the vagus nerves have also been implicated, in recent years, as a possible pathway for pathogens or pathological chemicals to make their way from the gut to the brain in Parkinson disease, as patients who have had a full truncal vagotomy appear to have a decreased risk for subsequent Parkinson disease, suggesting that the vagal nerve may be critically involved in its pathogenesis [Svensson 2015].

GENERAL PRINCIPLES OF INJURY TO NERVES AND THE PREVENTION OF THESE INJURIES

Mechanisms of Injury to Nerves

Injuries to nerves include physical injury (transection, stretch, or pressure injury), thermal injury (heat or cold injury), electrical injury, ischemic injury, toxic injury (chemical or pharmacological), and “double crush injury.” These injuries can be classified as neurapraxia (caused by compression), involving local myelin damage with the nerve still intact, axonotmesis (resulting from a crush injury) with loss of continuity of axons, resulting in Wallerian degeneration due to disruption of axoplasmic flow, and neurotmesis (the result of transection), which is the result of complete disruption of the entire nerve trunk [Sharma 2000].

Types of Injuries to Nerves

Injuries to nerves can occur to varying degrees. Complete transection of a nerve, which occurs relatively rarely in surgical operations, is called neurotmesis. Nerves are more commonly

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affected during surgical operations by stretch, compression, or thermal insults. Electrical injury can also occur with the use of electrocautery, as nerves conduct electrical current more readily than other tissues [Nichter 1984]. These nerve injuries can include damage to the Schwann cells of the myelin nerve sheaths, resulting in neurapraxia (the mildest form of injury to a nerve), or injuries to the nerve axons themselves, which are defined as axonotmesis (a more severe form of nerve injury). Injuries to the nerve sheaths can result in impaired nerve conduction, which tends to resolve over 8 to 12 weeks. On the other hand, injuries to the axonal fibers tend to be more permanent, with significant recovery being much less likely [Jellish 2018].

Prevention of Injury to Nerves

Physical injury can be inflicted on nerves by transection, pressure or tension, thermal injury (both heat and cold), and electrical injury.

Avoiding this type of injury to the vagus nerves starts with a thorough knowledge of the anatomy of the nerves and their branches, as noted above. One specific strategy to avoid neural injury, when working near the nerves, is to use nearby tissue as a “handle” to move the nerves slightly to expose structures. For example, the parietal pleura in the left chest can be incised a few centimeters from the vagus (or a branch), and this tissue can be used to apply gentle traction when working around the vagus or a branch (especially the RLN in the area of the ligamentum arteriosum).

Another strategy to avoid thermal injury to the vagus nerves is to ensure that any cold solutions or ice used during an operation are kept away from the nerves. This strategy is particularly pertinent when using topical cooling to aid in cardiac protection. Heat generated by the use of electrocautery can be absorbed by utilizing a metallic instrument as a “heat sink” between the site being cauterized and a nearby nerve.

Avoiding electrical injury to nerves can be a bit more challenging, given that electrical current tends to be carried preferentially through nerves, compared to most other tissues. The grounding pads for electrocautery grounding should be placed in a manner that will direct the current away from vulnerable nerves. Bipolar cautery can be used when working in close proximity to the nerves. Expedient use of hemostatic clips instead of cautery should also be considered when working in close proximity to nerves.

PROTECTING THE VAGUS AND ITS BRANCHES IN THE NECK

Course of the Vagus Nerve through the Cervical Region

The vagus nerves arise from the medulla oblongata and travel through the jugular foramen, passing inferiorly in the carotid sheath, posterior to the vascular structures 90% of the time, while 10% of the time, the vagus lies anterior to the carotid artery. Of note, when the vagus is anterior to the carotid artery, it must be mobilized for operations involving the carotid artery, particularly carotid endarterectomy or vascular access (such as cannulation for cardiopulmonary bypass

or for access for transarterial aortic valve replacement). When this mobilization is necessary, some degree of vocal cord paresis usually results, which is almost always transient.

The first 2 branches of the vagus nerve are the pharyngeal nerve and the superior laryngeal nerve, both of which are only rarely encountered during operations that involve one of the carotid arteries. The pharyngeal nerve supplies the majority of the motor innervation of the muscles of the pharynx. The superior laryngeal nerve, which branches from the vagus about 4 cm above the carotid bifurcation, innervates the cricopharyngeus muscle. These nerves are rarely identified in operations on the carotid artery, though attempts to protect them are made during operations on the thyroid.

The Recurrent Laryngeal Nerves

The recurrent laryngeal nerves (RLNs) are, arguably, the most important branches of the vagus nerves from a surgical perspective (see Figure 1). Most of the innervation of the muscles of the larynx is supplied by the RLNs. A rare variant of the RLN is the non-RLN, which may be found in patients with an abnormal right subclavian artery or other abnormal aortic arch branching patterns.

The long, circuitous routes of the RLNs add to the challenge of protecting them during surgical operations. The route to the larynx of the left RLN is said to be 7 times longer than would be the case if the nerve traveled directly from the vagus to the larynx in the neck. Injury to the RLNs can result in difficulty speaking and can even result in airway compromise.

The right and left RLNs differ in length and trajectory. These nerves are generally between 1 and 4 millimeters in diameter, which is slightly less than half the size of the vagus nerves themselves. The RLNs may separate from the main vagus nerve at variable points within the carotid sheath. Again, it is important to

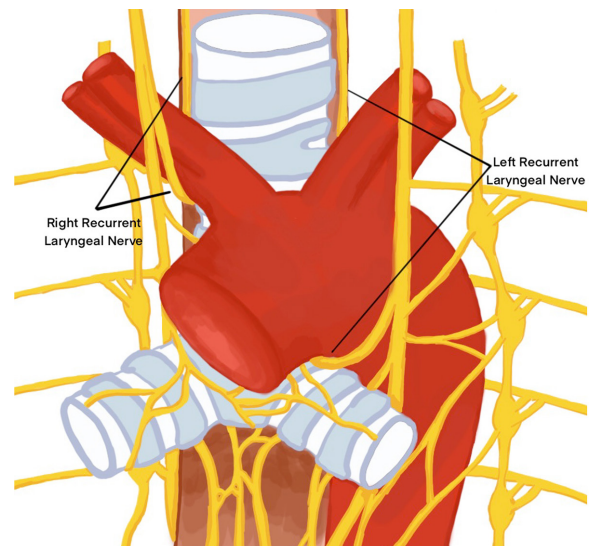


Figure 1. The recurrent laryngeal nerves (RLNs). The right RLN loops under the innominate artery, and the left RLN loops under the aortic arch. Both RLNs travel superiorly in the tracheoesophageal groove.

note that these nerves carry sensory, motor, and autonomic fibers to the subglottic area, the trachea, and the esophagus.

The RLNs contain motor neurons that innervate 4 of the 5 intrinsic muscles of the larynx, with the exception of the cricothyroid muscle, which is innervated by the external branch of the superior laryngeal nerve. This branch arises from the vagus high in the cervical region and is, therefore, rarely encountered in operations involving the carotid artery. These 4 laryngeal muscles work together to open and close the vocal cords to produce and modulate speech. Adduction of these muscles also plays an important role in swallowing, as they close the glottis as a bolus of food or liquid passes from the pharynx into the esophagus. Adduction of these muscles also closes the glottis at the inception of a cough, and impairment of these muscles interferes with the ability to create an effective cough. It is important to note that the motor fibers of the RLNs are located in the periphery of the nerves, which makes them particularly susceptible to injury.

Injury to both RLNs results in near complete loss of one's ability to speak and can also result in stridor, difficulty breathing, and an ineffective cough. In contrast, many patients may not have much impairment of these functions if only one RLN is injured.

Although the right RLN may separate from the vagus within the carotid sheath, it will usually remain near the right carotid artery all the way to the origin of that artery from the innominate artery. In a very small percentage of patients this nerve will be "nonrecurrent" and exit the carotid sheath in the neck to directly innervate the larynx. Therefore, the right RLN will exit the carotid sheath at the base of the neck and descend anteriorly to the right carotid, generally lying laterally and looping over the anterior aspect of the proximal portion of the right subclavian artery, moving posteriorly prior to ascending superiorly and medially into the neck in the tracheoesophageal groove. In a minority of people, the right RLN will ascend closer to the lateral side of the trachea, which puts it in a somewhat more vulnerable position during operations in this area. As it ascends, the right RLN will pass posterior and medial to the inferior thyroid artery and the posterior suspensory ligament of the thyroid. Near its termination in the larynx, the right RLN passes posterior to the right lobe of the thyroid gland. It then enters the larynx posterior to the cricothyroid joint as the inferior laryngeal nerve. In a minority of patients, the right RLN splits into anterior and posterior segments prior to entering the larynx.

The left RLN begins to separate from the left vagus nerve near the inferior portion of the carotid sheath. It continues to descend with the vagus, traveling along the anterior surface of the left common carotid artery and in relatively close proximity to the left subclavian artery. At the superior aspect of the aortic arch, the left RLN moves away from the left vagus nerve, which deviates to a more inferolateral position. The left RLN is, of course, smaller than the vagus nerve, allowing identification of these 2 structures in this area. The left RLN then loops under the aortic arch lateral to the ligamentum arteriosum. As does the right RLN, the left RLN supplies small branches to the cardiac, pulmonary, and esophageal

plexuses in this area. After passing under the aortic arch, the left RLN travels superiorly in the tracheoesophageal groove. In about a quarter of specimens, the left RLN may ascend outside of this groove in a slightly more anterior or lateral position. At this point, the trajectory of the left RLN mirrors that of the right RLN.

Protecting the Recurrent Laryngeal Nerves when Operating in the Neck

The main vagus nerve usually runs lateral or posterior to the carotid artery in the neck. However, the vagus nerve runs anterior to the carotid in 5% to 10% of patients. In these patients, exposure of the carotid during procedures such as transcatheter aortic valve replacement or cannulation for cardiopulmonary bypass may result in transient dysfunction of the vocal cords. There is likely no way to avoid this dysfunction in these circumstances.

The recurrent laryngeal nerves may be injured during esophageal surgery that involves an anastomosis in the neck, such as a transhiatal or a McKeown (tri-incisional) esophagectomy. Most surgeons believe that the risk to one of the recurrent laryngeal nerves is slightly lower when the cervical exposure is obtained on the left, using sharp dissection as close to the esophagus as is feasible. Other strategies suggested for avoiding RLN injury during these operations include making the anastomosis as low in the neck as feasible and explicitly identifying the ipsilateral nerve [Liebermann-Meffert 1999]. Most authors recommend the avoidance of electrocautery when exposing the cervical esophagus at this level, recognizing that temperatures higher than 100 C are often reached locally with the use of electrocautery [Scholtemeijer 2017]. Most authors also recommend direct surgical exposure of the RLN on the side of the dissection early in the operation [Amer 2017]. It is important to understand that the RLNs in this area are commonly more than 1 mm in diameter and are usually palpable. Some authors also point out that optical magnification will allow the surgeon to see the striations in the nerves that distinguish them from blood vessels [Liebermann-Meffert 1999]. While most thoracic surgeons will not take a primary role in thyroidectomies, they will occasionally assist a thyroid surgeon when an enlarged thyroid gland has an intrathoracic component. Some of the principles of avoiding RLN injury during thyroidectomy include direct visualization of the nerves and, in some cases, intraoperative monitoring of RLN function as a protective strategy [Jiang 2014; Hung 2017].

PROTECTING THE VAGUS AND ITS BRANCHES IN THE UPPER THORAX

Entrance of the Vagus Nerve into the Thorax

The right vagus nerve follows the trajectory of the right carotid artery to its origin from the innominate artery, where the recurrent laryngeal nerve leaves the vagus nerve and loops beneath the right subclavian artery and ascends back into the neck in the tracheoesophageal groove. After crossing the bifurcation of the innominate artery, the right vagus nerve

tracks medially and posteriorly to enter the mediastinum posterior to the innominate vein.

The Trajectory of the Vagus Nerves in the Thorax

As noted above, the vagus nerve enters the chest behind the innominate artery on the right and behind the carotid on the left, posterior to the sternoclavicular joint on both sides. The main vagus nerves run just laterally to the innominate artery on the right and to the left subclavian artery on the left. Branches of these nerves supply innervation to bronchi and to the heart. The branches that supply the heart enter mostly through the epicardial fat between the ascending aorta and the pulmonary artery. Many intercommunicating branches arborize around the esophagus, as the 2 vagus nerves travel inferiorly in the chest. One can feel these branches when doing a transhiatal esophagectomy, which can help define the appropriate plane of dissection for that procedure. (See Figure 2.)

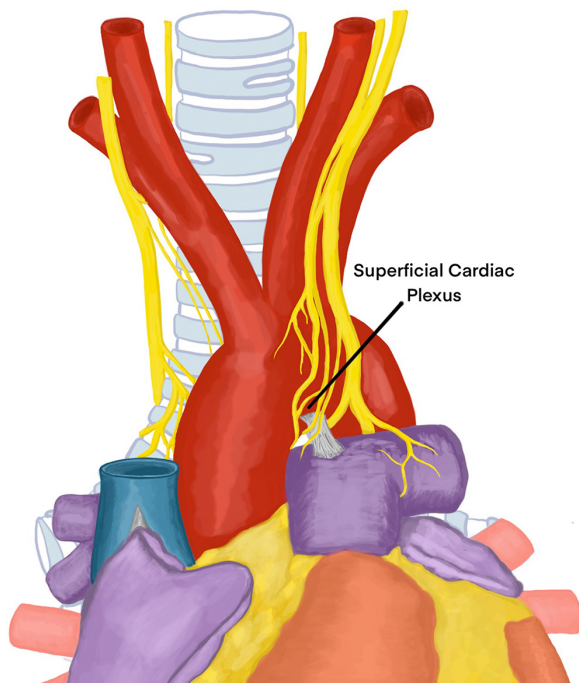


Figure 2. The paths of the vagus nerves in the upper mediastinum (demonstrating the branches supplying the cardiac plexus).

The superior and inferior cardiac branches of the vagus nerves separate from the main vagus nerves and travel medially toward the heart. These branches converge with branches from the sympathetic chains to form the thoracic cardiopulmonary nerves, which contribute fibers to the deep cardiac plexus.

The right vagus nerve continues its descent in the mediastinum behind the superior vena cava and near the lateral edge of the trachea, passing medial to the azygous vein. Both nerves pass posterior to the mainstem bronchi and give off branches that form the pulmonary neural plexus for each lung. The vagus nerves continue their descent in the mediastinum,

running in close proximity to the esophagus. At the level of the lower third of the thoracic esophagus, both vagus nerves contribute to a dense web of nerve fibers that encircle the esophagus. Just prior to passing through the esophageal hiatus into the abdomen, the right vagus nerve moves onto the posterior surface of the esophagus.

The left vagus nerve enters the thorax, passing between the left carotid and subclavian arteries, posterior to the innominate vein and the superior (or first) intercostal vein, and then passing anterior to the distal aortic arch.

The majority of the branches of the left vagus nerve that contribute to the deep cardiac plexus run behind the aortic arch, joining sympathetic branches of the cervicothoracic sympathetic ganglia. The left recurrent laryngeal nerve separates from the main trunk of the vagus nerve and loops below the ligamentum arteriosum and then passes superiorly within the tracheoesophageal groove to supply the larynx.

The left vagus nerve continues its descent posterior to the left pulmonary hilum and anterior to the descending aorta, providing branches to the left bronchus and the posterior pulmonary plexus. In the region of the inferior pulmonary ligament, the left vagus nerve runs along the left side of the esophagus, eventually lying anterior to it, providing branches to the lower esophageal plexus. The left vagus nerve passes into the abdomen as the anterior vagal trunk. Both vagus nerves lie beneath (medial to) the mediastinal pleura. The blood supply to both nerves is redundant and plentiful. However, theoretically, the nerves could be devascularized by extensive dissection around them.

Impingement on the left RLN by intrathoracic structures, most commonly an aortic aneurysm, can result in impairment of its function. When a thoracic aortic aneurysm causes impairment of the left RLN, the clinical condition has been called Ortner syndrome. However, impairment of the function of the left RLN is most commonly caused by iatrogenic injury. To avoid injury to the RLNs during operations in the apices of the thorax, it has been recommended that the nerves be actively identified and protected. The blood supply of the RLNs is also vulnerable during operations in the regions in which they lie. It is thought that dividing the small vessels supplying the RLNs can lead to ischemic dysfunction or injury.

Vulnerability of the RLNs during Nodal Dissection and during Pulmonary Resections

Nodal biopsy or resection in the setting of operations performed for mediastinal or pulmonary malignancies can put the RLNs in harm's way. While an RLN may need to be intentionally resected as part of a proper R0 resection, we will focus on inadvertent injury to the RLNs during these types of operations. The incidence of vocal cord dysfunction after pulmonary resection may be as high as 30%, occurring most frequently in patients undergoing pneumonectomies or patients having had preoperative radiation therapy. Even transient dysfunction of a vocal cord can interfere with airway protection from aspiration and with the ability of the patient to generate a robust cough [Filaire 2001].

One strategy to avoid RLN injury during these operations is to use clips instead of electrocautery during dissection in the area

of the RLNs. Other mechanisms of injury to the RLNs include stretch injury to the nerves. Avoiding injury during nodal dissection requires both an attempt to visualize the RLNs and an awareness of when they are likely in the area of dissection but not yet visualized. In addition to the use of clips, some surgeons use bipolar cautery, which can minimize the risk of injury to nerves that are near the field of dissection but remain unseen.

Injury to the RLNs must also be considered during mediastinoscopy. Some reports suggest that injury to one of the RLNs during this procedure occurs in as many as 5% of these procedures. The left RLN, ascending in the paratracheal groove may be the more vulnerable of the 2 RLNs. It is thought that the mechanism of injury, when it occurs, is more likely due to electrical current than to direct physical trauma. However, some reports have indicated that injury may actually occur most frequently during the initial blunt dissection on the anterior surface of the trachea, likely due to stretch injury. It is thought that the left RLN is slightly more vulnerable to this type of injury than is the right RLN. Some additional advice from experienced thoracic surgeons to avoid RLN injury during mediastinoscopy is to avoid excessive traction on nodes, as this force can end up affecting an RLN, and to treat minor oozing with packing and topical hemostatic agents [Roberts 2007].

Vulnerability of the RLNs during Aortic Surgery

Both RLNs are particularly vulnerable during open repairs of the thoracic aortic arch, given their proximity to the aorta and its branches. Injury to the RLNs during aortic arch surgery may be seen in as many as 30% of cases, though current literature suggests that this incidence may be lower, particularly in cases that do not involve total arch reconstruction or concomitant repair of the proximal descending thoracic aorta. The left RLN is generally more likely to be injured during these operations than is the right RLN. In general, one must be aware of the general location of the left RLN, which is often more proximal on the lesser curve than one might think. It is often possible to dissect the left RLN off of the aorta during a total aortic arch replacement, which can allow a distal anastomosis that does not threaten that nerve. In recent years, the distal anastomosis done to allow an elephant trunk extension can be performed at a more proximal location, between the left carotid and the left subclavian arteries, which is likely to lessen the chance of injuring the left RLN during these operations. These injuries seem to have become less common in the era of thoracic aortic endografting, particularly in cases such as when a frozen elephant trunk technique is used as part of an aortic arch procedure [Gable 2018]. However, there are times when it is not possible to protect the left RLN, which will require postoperative treatment of the paralyzed left vocal cord. (See Figure 3.)

Aortic reconstruction done for congenital anomalies also puts the RLNs at risk, especially the left RLN. For instance, one study of patients who had undergone a Norwood procedure reported that nearly 50% of the patients had vocal cord dysfunction postoperatively [Pourmoghadam 2017]. Another review, a meta-analysis of nearly 5,000 reports of patent ductus arteriosus operations, reported that vocal cord dysfunction was present in nearly 8% of the patients [Henry 2019]. This review

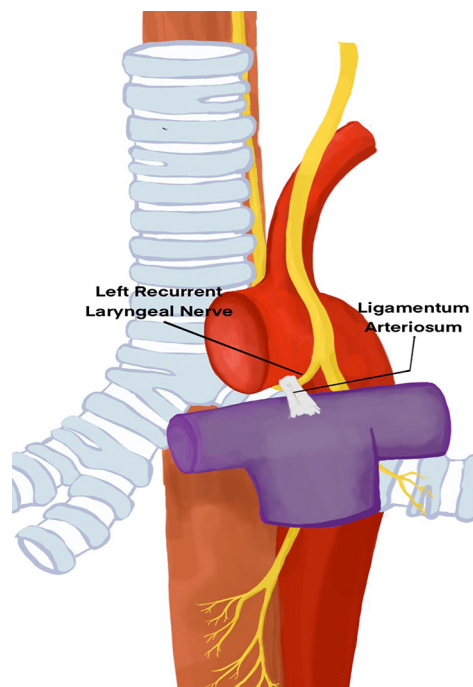


Figure 3. The left recurrent laryngeal nerve (RLN) passing under the aortic arch (demonstrating the proximity of the RLN to the ligamentum arteriosum).

also noted that vocal cord dysfunction was less common when the patent ductus was clipped rather than divided between vascular clamps and oversewn.

ADDRESSING INJURIES TO THE RLNS

If an RLN injury is recognized intraoperatively, attempts to repair the nerve can be made, such as direct reanastomosis of the 2 ends of the transected nerve. Adjuncts to such a repair have been described, such as surrounding the injured nerve with a segment of vein. Interposition nerve grafts have also been described. Relatively recent reports have suggested that repair of an injured RLN offers some reasonable possibility of functional recovery with minimal “downside” when compared to no attempt at repair [Isseroff 2013]. Utilizing a segment of the ansa cervicalis to restore some of the function of the injured RLN has been described [Aynehchi 2010]. Outcomes utilizing this approach are reported to be better in children than in adults. There are also reports of successful repairs of injured RLNs in adults [Li 2018].

Early postoperative recognition of vocal cord paresis or paralysis is important, as the risk of aspiration and pneumonia is significant. In patients with unilateral vocal cord dysfunction, medialization procedures, either via surgical intervention or injection procedures, will improve swallowing, phonation, and airway protection [Laccourreye 2010]. Injection techniques utilize various substances, including fat or collagen, and are quite safe as well as being relatively helpful in restoring a

reasonable degree of laryngeal function. It has been postulated that medializing the paralyzed cord so that apposition to the other cord occurs may increase afferent stimulation of the sensory nerves, which may enhance subsequent reinnervation. It is generally agreed that these medialization procedures should be considered early after recognition of laryngeal dysfunction to minimize pulmonary complications.

PROTECTING THE VAGUS AND ITS BRANCHES IN THE MIDDLE AND LOWER PORTIONS OF THE THORAX

The Contribution of the Vagus Nerve to the Extrinsic Cardiac Nerves

Nerve fibers that contribute to the innervation of the heart include preganglionic parasympathetic fibers from the vagus nerves and postganglionic sympathetic fibers arising from the cervical sympathetic trunks. These nerves are collectively called the extrinsic cardiac nerves. These nerves transmit signals from the brain and from the viscera. The parasympathetic fibers form ganglia prior to innervation of the heart. These ganglia reside in epicardial fat pads and synthesize all neural signals to the heart, which enable local regulation of heart rate, on a beat-to-beat basis. Some of these neural fibers enter the heart to innervate the cardiac conduction system, which is formed by specialized myocytes rather than neurons.

These extrinsic autonomic axons that contribute to the cardiac plexus begin to converge medially at the thoracic inlet and descend around the aortic arch. In this region, the sympathetic and parasympathetic nerves begin to intermingle as they approach the heart. The nerves from the right and left sides of the thorax coalesce in the epicardial fat pad at the base of the roots of the aorta and pulmonary arteries. Extensions of the fibers arising from the ganglia in this area travel with the coronary arteries to directly innervate the myocardium. Other fibers in this complex travel to the atria, the sinoatrial node, the aorta, the pulmonary arteries, the pulmonary veins, and the trachea. Some of these neurons are thought to innervate the atrioventricular node. Injury to these fibers has been associated with cardiac arrhythmias, such as postoperative atrial fibrillation [Davis 2000].

Pulmonary Branches of the Vagus Nerve

The main right vagus nerve descends through the chest, lying posterior to the right main bronchus. The left main vagus nerve, likewise, continues its inferior course, lying behind the left main bronchus. Fibers from the vagus nerve combine with branches from the sympathetic trunks to form the pulmonary neural plexus. These branches innervate both the pleura and the bronchi, transmitting sensory signals and providing innervation to the smooth muscle of the airways and to the pulmonary arterial branches. Disruption to the vagal innervation of the pulmonary vasculature and airways can alter vessel permeability, attenuate the cough reflex, and cause dysregulation of mucus production. These nerve branches can be disrupted during operations involving the bronchi such as pulmonary

resections and, especially, lung transplantations. However, disruption of these nerve fibers is generally unavoidable in these operations.

The Vagal Innervation of the Esophagus

The pharynx and proximal portions of the esophagus are innervated by the pharyngeal branches of the vagus nerve. The proximal intrathoracic esophagus receives both motor and sensory innervation from the vagus nerves, with motor and sensory innervation from both main vagus nerves and the recurrent laryngeal nerves. In the lower portion of the intrathoracic esophagus, the vagus nerves form the esophageal neural plexus, with contributions from the sympathetic trunks. The vagus nerves then continue inferiorly to pass through the esophageal hiatus to innervate the abdominal viscera.

While the vagus nerves and their branches have some efferent (motor) fibers, they are composed primarily of afferent (sensory) fibers. These fibers transmit sensation of mechanical distention, as well as sensation from a variety of chemical and thermal stimuli. These potentially nociceptive signals travel along pathways that are shared by afferent neurons arising from the cardiac plexus, which may help explain the overlap of symptoms arising from both the heart and the digestive tract.

The left vagal branches concentrate on the anterior surface of the esophagus in the midthorax, while the right vagal branches concentrate posteriorly. These neurons ultimately unify to form the anterior and posterior vagal trunks as they pass through the diaphragm.

Protecting the Vagus Nerves during Esophageal Surgery

While the vagal innervation of the esophagus and abdominal viscera are not essential for survival, disrupting these nerves can lead to the postvagotomy syndrome. Furthermore, injury or compression of the vagal trunks during operations in and around the esophageal hiatus can lead to gastric motility or gastric emptying issues. When the vagus nerves are injured during these operations, the patients may suffer from the postvagotomy syndrome, characterized by postprandial gastrointestinal distress, including the “dumping syndrome” [Engel 1978]. Impairment of gastric emptying can also result from loss of vagal innervation of the stomach and pylorus.

Risk of injury to the vagus nerves when operating in this area can be minimized by careful identification and by avoiding injury from compression or electrocautery. One specific strategy that is recommended to avoid injury to the vagus nerves during dissection in this area is to mobilize the nerves off of the esophagus and to encircle the esophagus with vascular loops or Penrose drains. If the operation being done includes a gastric wrap around the esophagus, the vagus nerves should not be compressed by the wrap, nor should the anchoring sutures contact or injure the nerves. These nerves should be dissected carefully and protected during esophageal resections.

Techniques have been developed for resection of the esophagus while preserving the vagus nerves. The outcomes of operations performed with these strategies have been reported to include a lower incidence of respiratory complications.

However, the main vagus nerves and their interconnecting branches are always in some degree of jeopardy during esophageal resections and other esophageal procedures. Obviously, consideration must be given in operations on the esophagus for cancer to the need to accomplish an adequate lymph node resection while trying to preserve vagal fibers [Banki 2002].

Protecting the Vagus Nerves during Ablations for Atrial Arrhythmias

The vagus nerves and their branches can also be injured during radiofrequency ablations in the left atrium done in the treatment of atrial arrhythmias. Given that the operators of such ablation catheters cannot visualize the vagus nerves, knowing of their vulnerability can be taken into account if gastrointestinal symptoms are present after procedures of this sort. Some practitioners involved in catheter ablations monitor the temperature in the esophagus during ablations in hopes of minimizing injury both to the vagus nerves and to the esophagus.

PROTECTING THE VAGUS AND ITS BRANCHES TO THE ABDOMINAL VISCERA

The Vagus Nerve in the Abdomen

The anterior and posterior vagal trunks traverse the esophageal hiatus to provide parasympathetic innervation of the abdominal viscera. Through a myriad of small branches, these vagal fibers innervate the liver, gallbladder, pancreas, the proximal ureters, and the alimentary tract to the splenic flexure of the colon. The primary roles of these afferent and efferent branches include coordination of peristalsis, regulation of intraluminal pH, promotion of secretory activity, and transmission of visceral sensation to the brain.

At the level of the esophageal hiatus, the anterior trunk branches into a hepatic branch and the anterior nerve of Latarjet that travels along the lesser curvature of the stomach, emitting numerous gastric branches that envelop the anterior body of the stomach and the fundus. Similarly, the posterior vagal trunk divides into a celiac branch and the posterior nerve of Latarjet at approximately the same level. The posterior nerve of Latarjet descends along the posterior portion of the lesser curve of the stomach, projecting nerve fibers onto the posterior surface of the stomach. The first branch innervating the posterior fundus has been called “The Criminal Nerve of Grassi.” Both the anterior and posterior nerves of Latarjet ultimately terminate at the angular incisure, near the pylorus, supplying the antrum and the pylorus. Vagal innervation of the gastrointestinal tract ends near the splenic flexure of the colon, with the lower portion of the large intestine and rectum being supplied by parasympathetic fibers arising from the sacral plexus.

The function of the vagus nerves in the abdomen serves both efferent (motor) functions, including stimulating smooth muscle contraction and glandular secretions, such as gastric acid, and afferent (sensory) functions, transmitting neural information regarding the mechanical, chemical, and immunological milieu of the gastrointestinal tract to the brain. Injury to the vagus nerves in the upper abdomen can result in nausea, dumping syndrome, and diarrhea [Stakenborg 2013].

Protecting the Vagus Nerves and Their Branches in the Abdomen

I've never done a vagotomy that I liked. —David E. Tribble, MD

Strategies to retain optimal gastric emptying, pyloric function, and the motility of the more distal gastrointestinal track during upper abdominal operations have been commonly described. Some authors describe identifying and preserving, when possible, the celiac, hepatic, and pyloric branches of the vagus nerve [Ikeguchi 2011].

Surgeons performing antireflux procedures have also focused on avoiding vagus nerve injury during these operations, as unintended injury to the vagus nerves has been reported to occur in at least 10% of patients undergoing these procedures [van Rijn 2016]. Most authors recommend that both vagal trunks be dissected from the esophagus in the area of the esophageal hiatus prior to dissecting the esophagus itself for operations involving the distal esophagus. Bipolar cautery or the harmonic scalpel is thought to minimize injury to the nerves while maintaining hemostasis [Crema 2018].

SUMMARY

The vagus nerve is one of the longest and most complex nerves of the body. The vagus and its branches, especially the recurrent laryngeal nerves, are at risk in many procedures performed by cardiothoracic surgeons. It is essential that they have a thorough understanding of the anatomy and the potential sites and mechanisms of injury to the vagus and its branches.

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