muscle is the only portion of the true vocal fold that can contract and relax in response to neurologic control. Therefore, vibration of the vocalis is both active and passive.

BLOOD SUPPLY AND SECRETIONS

The internal fluid balance of the larynx is controlled by the blood supply, whereas external secretions control the external "hydration" of the vocal folds. The blood supply arises from the superior thyroid, superior laryngeal, and inferior laryngeal arteries. These arteries branch from the external carotid artery in the neck. Venous return is transmitted through the jugular vein.[1,2,9] The predominant blood supply is found in the intermediate and deep layers of the lamina propria and the vocalis muscle. Those small blood vessels, arterioles, and capillaries that lie closest to the free vibrating edge run parallel to the vocal fold. In general, the blood supply to the vocal fold is arranged similarly to the histologic layer organization, in that larger arterial supply is found in the deeper layers, whereas smaller capillaries are seen in the lamina propria. There is limited blood supply to the superficial layers and epithelium of the vocal fold, which likely offers some protection from injury to the superficial surface of the vocal fold. When hemorrhage does occur, it creates an extra mass that inhibits vibration, due to the stiffness formed by the subepithelial clot (varix).[1,2,9,10]

Serous and mucous glands are located in the tissues lateral, superior (in the ventricle), and inferior to the vocal folds, again avoiding the medial edge.[45,46] Mucus propagation along the margin of the fold is assisted by the texture of the epithelial layer, which has microscopic irregularities (microvilli and microridges). These microstructures serve two purposes: increasing the surface tension of the outer membrane to adhere fluids to the vocal fold surface and channeling them to distribute a thin film of liquid along the vocal fold.[32,33,46] This thin, watery, and healthy mucus contributes the characteristic "shine" seen on normal vocal folds. However, in dehydrated or pathologic conditions, the vocal folds may appear dry and dull, and thick clumps of white tacky mucus can appear, especially over lesion sites.

NEUROLOGIC SUPPLY

Central Nervous System Control

Central nervous system (CNS) mechanisms relay afferent (sensory) information from the larynx to the brain and send efferent (motor) commands from the brain to the body. In the larynx, these central nervous system relays and commands are not entirely understood, because of the difficulty in studying relevant respiratory and phonatory function in vivo, and the complex range of vegetative and communicative laryngeal activities required for respiration, phonation, and deglutition. Consider that respiration alone involves very carefully timed acts both of glottal opening for respiration and airway preservation, and glottal closing for swallowing and thoracic stabilization (eg, grunting) as well as coughing, throat clearing, and other airway protective gestures. Similarly, CNS control of phonation requires modulation of many vocalizations, from vegetative sounds produced in nonspeech sounds, (eg, laughter, crying), to complex communicative demands of speech and voice, as well as skilled vocalizations for acting and singing performance.

The sensory receptors in laryngeal mucosa and respiratory passages send information from the larynx to the CNS, transmitted along the afferent pathway by the internal branch of the superior laryngeal nerve, through the vagus, to terminate in a region of the medulla called the nucleus tractus solitarius (NTS). This region contains areas that are involved in the control of respiration, laryngeal maneuvers, and swallowing. In anesthetized animal studies, NTS fiber activity has been shown to occur in phase with the timing of evoked swallowing or respiratory events. Other sensory fibers do not terminate in NTS, but continue to another section of the midbrain called the periaqueductal gray area (PAG).[47,48] There is also some limited evidence of sensory projection from the larynx to even higher order centers (above the midbrain) in the cortex, including projections to the thalamus (a major sensory relay center), superiorly through the corona radiata, and finally to the postcentral gyrus of the cortex.[49–51]

Efferent (motor) commands for voice production originate in the precentral gyrus of the cerebral cortex, which communicates with motor nuclei in the brainstem and spinal cord, before transmitting commands to the peripheral nervous system to trigger muscle contractions. Both pyramidal and extrapyramidal motor pathways are involved in laryngeal control for phonation. Conclusions from experimental work suggest the PAG is a crucial center for voluntary control over vocalizations by projecting motor commands through the nucleus retroambiguus (NRA) located in the medulla, which in turn projects to the motor nucleus ambiguus, located in the reticular formation. It has been suggested that this PAG-NRA projection may serve as a final common pathway for vocalization.[47,48] The nucleus ambiguus contains the central origins of the laryngeal motoneurons for all of the intrinsic laryngeal muscles. The localized site of cricothyroid motoneurons is more distinct than the motoneuron groupings of the other intrinsic muscles, which appear to converge in a general area. Motoneurons for esophageal and respiratory control are also located in the nucleus ambiguus. Studies that examine laryngeal motoneuron activity have found that units may be task-specific for vocalization, inspiration, or a combination of expiration and vocalization.[47,48] Thus, the interaction between phonation, deglutition, and respiration is inherent to understanding the central pathways of laryngeal control, reflexive activity, and voluntary laryngeal maneuvers for nonspeech gestures and speech production.[2,9,10,47,48]

Peripheral Innervation

The 10th cranial nerve (X), the vagus, innervates the larynx peripherally (Figure 2–19). Vagus means, "wandering" and the name appropriately describes its circuitous and far-reaching route through the body to innervate sites from the skull to the abdomen. The vagus innervates the larynx via two important branches, the recurrent and superior laryngeal nerves, which contain all the sensory and motor fibers that supply the

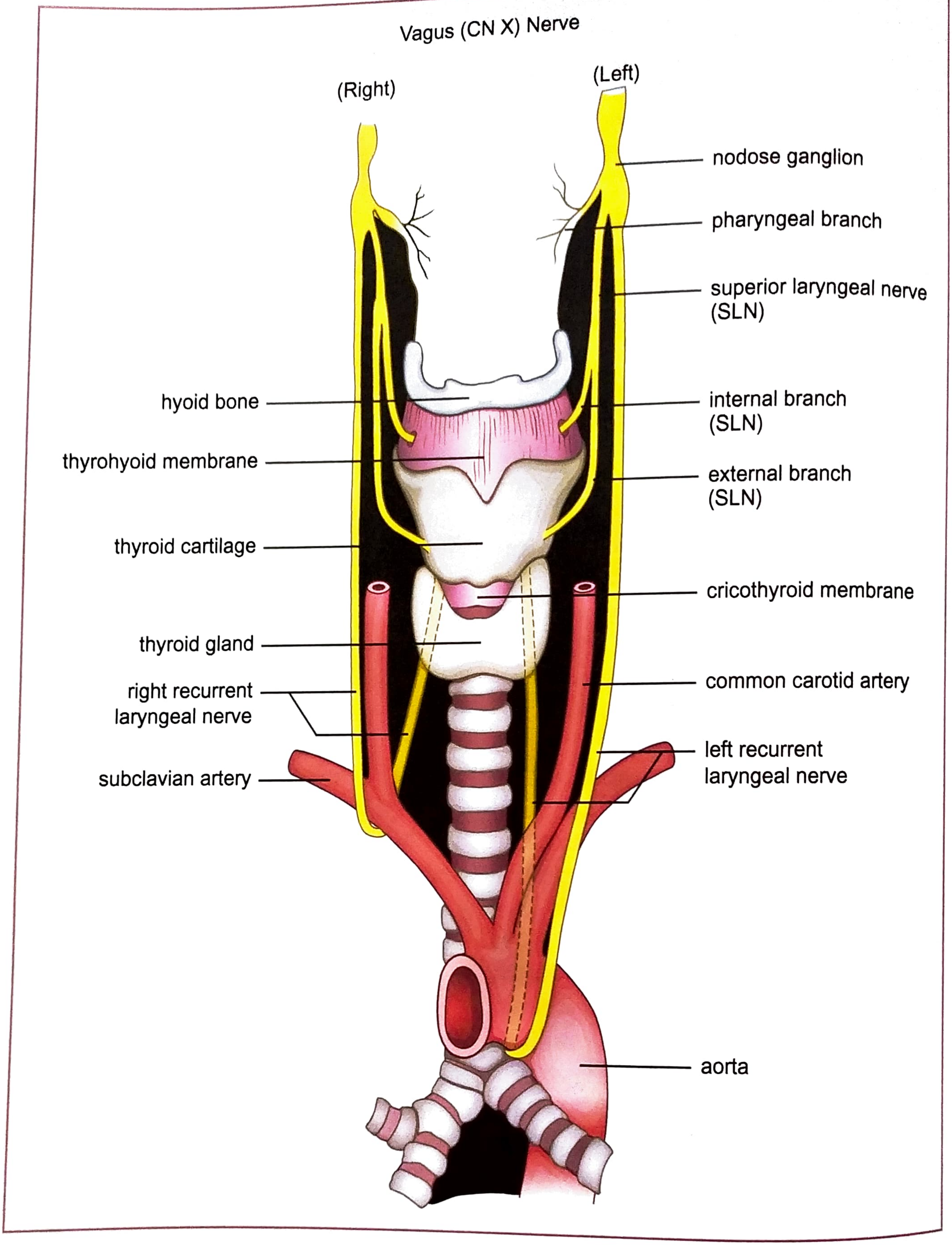

FIGURE 2–19. Vagus (cranial nerve X) innervation of the larynx.

larynx. The first portion is the superior laryngeal nerve (SLN), which branches off the vagus near the nodose ganglia in the neck. After coursing alongside the carotid artery, the SLN forms internal and external branches. The internal branch inserts through the thyrohyoid membrane, superior to the vocal folds, and provides most of the sensory information to the larynx. The external branch is primarily a motor nerve that has been regarded historically as innervating the cricothyroid muscle only.[1,2,9,10] However, recent studies have suggested that the external branch of the SLN can also innervate the ipsilateral thyroarytenoid muscle, inferior pharyngeal constrictor (and upper esophageal sphincter), as well as connect with the recurrent laryngeal nerve in some cases.[52]

The second branch off the vagus is the recurrent laryngeal nerve (RLN), which extends to the thorax, where it forms long loops through the heart before coursing superiorly back up under the thyroid gland and on to the larynx. The pattern of "recurrence" is different on the right and left sides of the body. The right RLN courses under the subclavian artery, and the left RLN courses under the aortic arch before it reaches the larynx.[1,2,9,10] Consequently, these nerves (especially on the left) are susceptible to injury, and a patient with an unexplained idiopathic vocal fold paralysis should always be evaluated to rule out possible cardiac, lung, or thyroid compromise.

The RLN supplies all sensory information below the vocal folds and all motor innervation to the posterior cricoarytenoid, thyroarytenoid, lateral cricoarytenoid, and interarytenoid muscles. Two characteristics of the SLN and RLN ensure the ability of the intrinsic laryngeal muscles to move quickly and with fine motor control. First, the laryngeal nerves have a high conduction velocity (second only to the eye), which allows rapid contractions. Second, the innervation ratio is low, meaning that only a few muscle fibers are innervated by a single motor unit, allowing very specific motor control and tuning.[47,48]

Peripheral muscle receptors are present in all intrinsic laryngeal muscles, to control vocal fold tone and movement. Part of this specialized control arises from the discrete nerve innervation to separate muscle compartments in three of the muscles: the posterior cricoarytenoid, the cricothyroid, and the thyroarytenoid (thryomuscularis and thyrovocalis). Muscle spindles are special proprioceptive receptors common in skeletal muscles that must control dynamic changes in muscle length to adjust for fluctuating structural posture, weight bearing, or position, by creating graduated changes in muscle length under variable stimuli. These receptors occasionally have been identified in the intrinsic laryngeal muscles, most prominently in the thyromuscularis compartment of the thyroarytenoid.[27] However, a later investigation failed to identify the presence of any muscle spindles in the thyroarytenoid muscle, which reinforces the need for additional study confirming the presence and function of muscle spindles in the larynx.[51]

LARYNGEAL REFLEXES

A complex system of laryngeal reflexes preserves the airway through a series of sensory receptors located in mucosal tissue, articular joints, and muscle. These receptors have the ability to elicit tight sphincteric closure, also known as a laryngeal adductor response, to close off the trachea and lungs to protect the airway from foreign materials or aspiration. Mucosal tissue receptors respond to touch, vibration, changes in air pressure, and liquid stimuli; mechanoreceptors respond to stimuli in articular joints