46 Cervical Spine and Cervicothoracic Junction

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SUMMARY OF KEY POINTS

- Understanding the anatomy of the cervical spine and neck is of the utmost importance for the surgeon operating in this region.
- The anatomy of this region can be classified from superficial to deep and further analyzed by system, including muscle, bone, nerves, vasculature, and soft tissue.
- Regarding the nerves in the neck, more focused consideration is taken for surgical purposes when discussing the laryngeal nerve as a result of the potential morbidity associated with iatrogenic injury to this nerve.
- The vertebral artery is discussed in specific detail as well due to its clinical importance and proximity to many operative cases in the cervical spine.
- Each level of the cervical spine has unique bony anatomy and as a result the location of the surrounding anatomic structures vary from one region to another. The nuances of this anatomy influence the surgical approach at each level.

CERVICAL AND NUCHAL ANATOMY

An understanding of anatomy is the most basic tenet of surgery. Because both ventral and dorsal approaches are commonly used when operating on the cervical spine, it is essential that the spine surgeon be familiar with the anatomy of both the cervical and nuchal regions.[1]

Anatomic Overview of the Neck

Frick and associates have presented an overview of the anatomy of the neck with the cervical spine as the centerpiece.[2] Dorsal to the cervical spine lies the nuchal musculature, which is covered superficially by two large muscles: the trapezius and the levator scapulae. Just ventral to the vertebral bodies lies the visceral space, which contains elements of the alimentary, respiratory, and endocrine systems. The visceral space is surrounded by the cervical musculature and portions of the cervical fascia. Dorsolateral to the visceral space but separated from the visceral space, as well as the cervical musculature, lie the paired neurovascular conduction pathways. Thus, in this scheme, the neck may be divided into five distinct regions: cervical spine, nuchal musculature, visceral space, cervical musculature, and neurovascular conduction pathways.

Surface Anatomy of the Neck

Knowledge of the surface anatomy of the neck is essential when planning cervical spine surgery. These relationships help establish the site of the skin incision and dictate which vertebral level(s) may be approached. Classically, several superficial anterior neck structures have been used to identify the approximate cervical spinal levels for the purposes of the skin incision. These include the hyoid bone (C3), thyroid cartilage (C4-5), cricoid cartilage (C6), and carotid tubercle (C6). These landmarks, however, may not be universally reliable because, depending on a patient's body habitus, they may be difficult to palpate reliably; moreover, the relationships are only an estimate and variability exists.

The most prominent structure of the upper dorsal surface of the nuchal region is the inion, or occipital protuberance. This may be palpated in the midline and is a part of the occipital bone. The spinous processes of the cervical vertebrae may then be followed caudally to the vertebral prominence, variably corresponding to the spinous process of C6, C7 (most common), or T1.

The prominent surface structure of the ventral neck is the laryngeal prominence, which is produced by the underlying thyroid cartilage. The thyroid cartilage is composed of two broad plates that are readily palpable. This cartilage protects the vocal cords, which lie at the midpoint of the ventral surface. Rostral to the thyroid cartilage lies the horseshoe-shaped hyoid bone, which is easy to palpate with the neck extended. The hyoid bone lies in the mouth-cervical angle[3] and mediates the muscular attachments of the muscles of the floor of the mouth (middle pharyngeal, hyoglossus, and genioglossus muscles), as well as those of the six hyoid muscles (stylohyoid, thyrohyoid, geniohyoid, omohyoid, mylohyoid, and sternohyoid). The hyoid bone provides some movement during swallowing. This movement is limited caudally to the fourth cervical vertebral body by the stylohyoid ligament.[2] The transverse process of the atlas may be palpated at a point marked by a line between the angle of the mandible and a point 1 cm ventrocaudal to the tip of the mastoid process.[3]

Caudal to the thyroid cartilage lies the signet ring–shaped cricoid cartilage. The cricoid cartilage marks the laryngotracheal transition of the respiratory system and the pharyngoesophageal transition of the gastrointestinal system. Caudal to the cricoid cartilage lies the trachea. The isthmus of the thyroid gland overlies the first few rings of the trachea, which may make palpation of these rings difficult. The trachea may be followed caudally to the jugular notch, which is the rostral depression of the manubrium. The trachea may be palpated dorsally and the sternal heads of the sternocleidomastoid muscle may be palpated laterally. The sternocleidomastoid muscle is the key landmark of the ventral neck, with respect to the traditional division of the neck into triangles.

Triangles of the Neck

The sternocleidomastoid muscle divides the neck into two large triangles, posterior and anterior, which are then subdivided into two and four triangles, respectively. Knowledge of these triangles includes a definition of the borders and the contents of each triangle (Fig. 46-1).

Posterior (Dorsal) Triangle

The borders of the posterior (dorsal) triangle are the dorsal edge of the sternocleidomastoid muscle, the ventral edge of the trapezius muscle, and the middle third of the clavicle. The

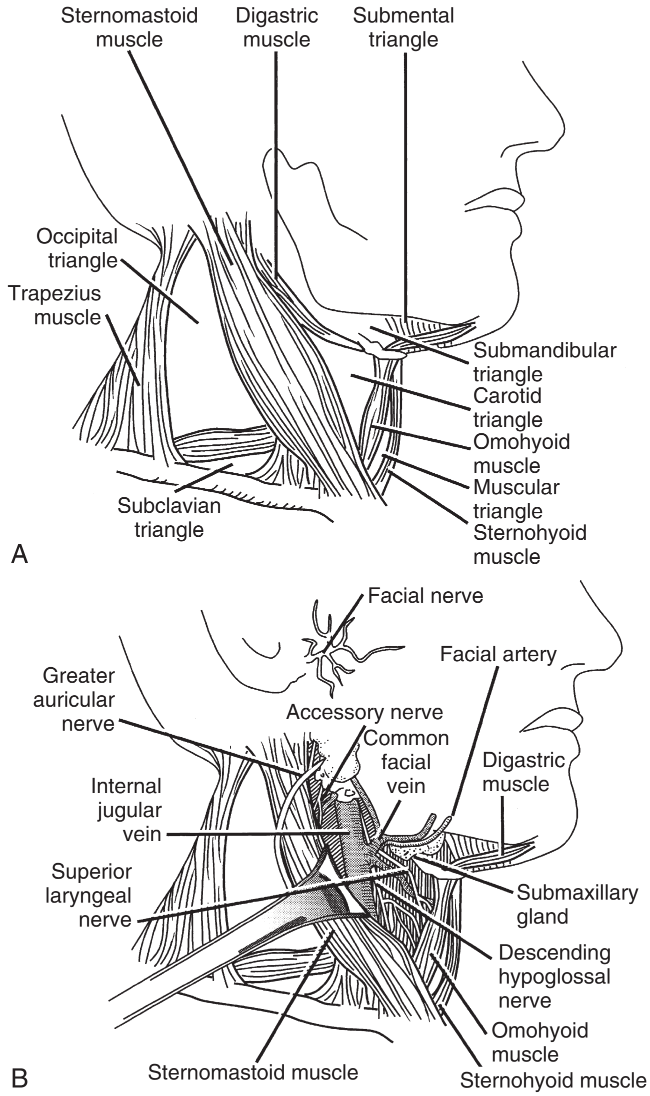

Figure 46-1. A, Cervical triangles. **B,** Carotid triangle and its contents. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

deep cervical fascia covers the dorsal cervical triangle, thus forming its roof. The floor of the dorsal cervical triangle is formed by the scalenus posterior, scalenus medius, levator scapulae, and splenius capitis muscles, as well as the lateral extension of the prevertebral fascia that overlies these muscles. The dorsal belly of the omohyoid muscle partitions the dorsal cervical triangle into a large rostral occipital triangle named for the occipital artery exiting at its apex and a small caudal subclavian triangle named for the subclavian artery, which lies deep to it.

The spinal accessory nerve leaves the deep surface of the sternocleidomastoid muscle to enter the dorsal triangle of the neck, which it crosses to innervate the trapezius muscle. The two important structures found in the dorsal cervical triangle, which arise above the spinal accessory nerve, are the occipital artery and the lesser occipital nerve. The occipital artery leaves the dorsal cervical triangle at its apex where the sternocleidomastoid and trapezius muscles approach one another on the superior nuchal line. This artery then ascends to supply the dorsal scalp. The lesser occipital nerve ascends along the dorsal surface of the sternocleidomastoid muscle before dividing into several superficial branches that supply the scalp dorsal to the ear.

Caudal to the spinal accessory nerve are many important anatomic structures. The external jugular vein, which is formed by the confluence of the posterior auricular and the posterior division of the retromandibular vein at the angle of the mandible, courses over the sternocleidomastoid muscle obliquely to enter the dorsal cervical triangle caudally, en route to joining the subclavian vein approximately 2 cm above the clavicle.[3] Two branches of the thyrocervical trunk cross the dorsal cervical triangle. The suprascapular artery runs rostral to the clavicle before passing deep to the clavicle to supply the periscapular muscles. The transverse cervical artery lies 2 to 3 cm rostral to the clavicle and also runs laterally across the dorsal cervical triangle to supply the periscapular muscles.

Three superficial nerves also exit the dorsal triangle below the spinal accessory nerve. In all cases, these nerves arise from the cervical plexus, which is formed by the ventral rami of the rostral four cervical spinal nerves. The plexus lies within the lateral neurovascular conduction pathways located between the internal jugular vein and the sternocleidomastoid muscle. The superficial nerves then arise along the middle portion of the dorsal border of the sternocleidomastoid muscle to supply the skin of the neck and scalp between the mastoid process and the inion. The great auricular nerve crosses the sternocleidomastoid muscle and ascends toward the parotid gland, branching into dorsal and ventral rami that supply the skin in an area stretching from the angle of the mandible to the mastoid process and the skin of the neck. The transverse cervical nerve also crosses the sternocleidomastoid muscle to supply the skin overlying the ventral cervical triangle. The supraclavicular nerves arise from a single trunk that trifurcates into lateral, intermediate, and medial branches that innervate the skin of the neck, ventral chest, ventral shoulder, sternoclavicular joint, and acromioclavicular joint. The phrenic nerve arises, in part, from the cervical plexus and, in part, from the brachial plexus. The brachial nerve arises near the scalenus anterior muscle, where it crosses ventromedially and deep to the transverse cervical and suprascapular arteries and the prevertebral fascia, to descend through the superior thoracic aperture near the origin of the internal mammary artery. The upper, middle, and lower trunks of the brachial plexus lie deep to the floor of the posterior cervical triangle. They emerge between the scalenus medius and scalenus anterior muscles and cross deep to the transverse cervical and suprascapular arteries to descend under the clavicle to enter the axilla.

Anterior (Ventral) Triangle

The borders of the anterior (ventral) cervical triangle are the ventral edge of the sternocleidomastoid muscle, the inferior border of the mandible, and the midline of the neck. The ventral cervical triangle may be subdivided into four smaller triangles: submental, submandibular, carotid, and muscular.

The submental triangle is bounded by the hyoid body and laterally by the ventral bellies of the right and left digastric muscles. This triangle has, as its floor, the two mylohyoid muscles that connect to each other in the midline by forming a median raphe. Within this triangle lie the submental lymph nodes that drain the ventral tongue, the floor of the oral cavity, the middle portion of the lower lip and the skin of the chin, and several small veins that ultimately converge to form the anterior jugular vein.

The boundaries of the submandibular triangle are the anterior and posterior bellies of the digastric muscle and the inferior border of the mandible. The floor of the submandibular triangle is formed by the mylohyoid, hyoglossus, and middle constrictor muscles. The submandibular gland fills a significant portion of this triangle, and its duct passes parallel to the tongue to open into the mouth. The hypoglossal nerve also passes into this triangle along with the nerve to the mylohyoid muscle, a branch of the inferior alveolar nerve, and portions of the facial artery and vein.

The carotid triangle is bounded by the ventral border of the sternocleidomastoid muscle, the rostral edge of the rostral belly of the omohyoid muscle, and the caudal edge of the dorsal belly of the digastric muscle. Within the carotid triangle lie the bifurcation of the common carotid artery, the internal jugular vein laterally, the vagus nerve dorsally, and the ansa cervicalis (see Fig. 46-1B).

The muscular triangle is bounded by the median plane of the neck, the caudal edge of the rostral belly of the omohyoid muscle, and the medial border of the sternocleidomastoid muscle. Within this triangle lie the infrahyoid muscles and neck viscera.

Cervical Fascia

An understanding of the cervical fascia aids the surgeon approaching a targeted cervical spine level by providing an avascular plane of dissection. There are three layers of the cervical fascia: investing, visceral, and prevertebral (Fig. 46-2). The investing fascia surrounds the entire neck, splitting to enclose the sternocleidomastoid and trapezius muscles and the submandibular and parotid glands. Rostrally, the investing fascia is connected to the hyoid bone, caudal border of the mandible, zygomatic arch, mastoid process, and superior nuchal line. Caudally, the investing fascia splits to attach to the ventral and dorsal surfaces of the sternum, thus forming the suprasternal space.[3] The investing fascia forms the roof of both the ventral and dorsal cervical triangles.

The visceral, or pretracheal, fascia courses deep to the infrahyoid muscles and surrounds the visceral space, including the thyroid gland, trachea, and esophagus. The visceral fascia is attached to the hyoid bone and the thyroid cartilage rostrally and extends caudally to the dorsal surface of the clavicles and sternum and into the mediastinum. Laterally, this layer blends into the carotid sheath. The thyroid vessels are located deep to this layer.

The prevertebral layer of cervical fascia surrounds the vertebral column and its musculature, including the scalene and longus groups of muscles. Ventral to the vertebral bodies, the prevertebral fascia splits into a ventral alar layer and a dorsal prevertebral layer, forming a potential space. This space is referred to as the "danger zone" because it extends from the skull base rostrally to the level of T12 caudally and communicates with the mediastinum. Within the prevertebral fascia, and in front of the longus colli muscle, lies the cervical portion of the sympathetic chain.

Cervical Sympathetic Chain

The cervical sympathetic chain (CSC) usually consists of three cervical ganglia that lie at the levels of the first rib, the transverse process of C6, and the atlantoaxial complex, respectively. The CSC lies directly over the longus colli muscles and beneath the prevertebral fascia.[4] The chain runs in a superior and lateral direction with an average angle of 10.4 ± 3.8 degrees relative to the midline.[4] The superior ganglion is typically located at C2-3[4] or C4[5] and lies more laterally on the splenius capitis. The average distance between the CSC and the medial border of the longus colli muscles at C6, however, is 10.6 ± 2.6 mm.[4] Therefore, the CSC is considerably more vulnerable to damage at lower levels due to its more medial location. Whereas the longus colli diverge laterally when descending down the cervical spine, the CSCs converge medially at C6.[4] The average diameter of the CSC at C6 is 2.7 ± 0.6 mm.[4] Potential damage to the CSC may result during longus colli dissection off the ventral vertebral bodies or during lateral retraction of the carotid sheath or longus colli.[4] Fibers from the superior cervical ganglia pass to the internal carotid artery to innervate the pupil. Interruption of the sympathetic trunk in the neck results in an ipsilateral Horner syndrome.

Cervical Musculature

The cervical musculature is divided into two layers: superficial and deep. The muscles of the superficial layer include the platysma, the sternocleidomastoid, and the infrahyoid group. The platysma lies just under the surface of the skin and is one of the muscles of facial expression, innervated by the cervical ramus of the seventh cranial nerve. It is draped like an apron from the mandible to the level of the second rib and laterally as far as the acromion processes. The sternocleidomastoid

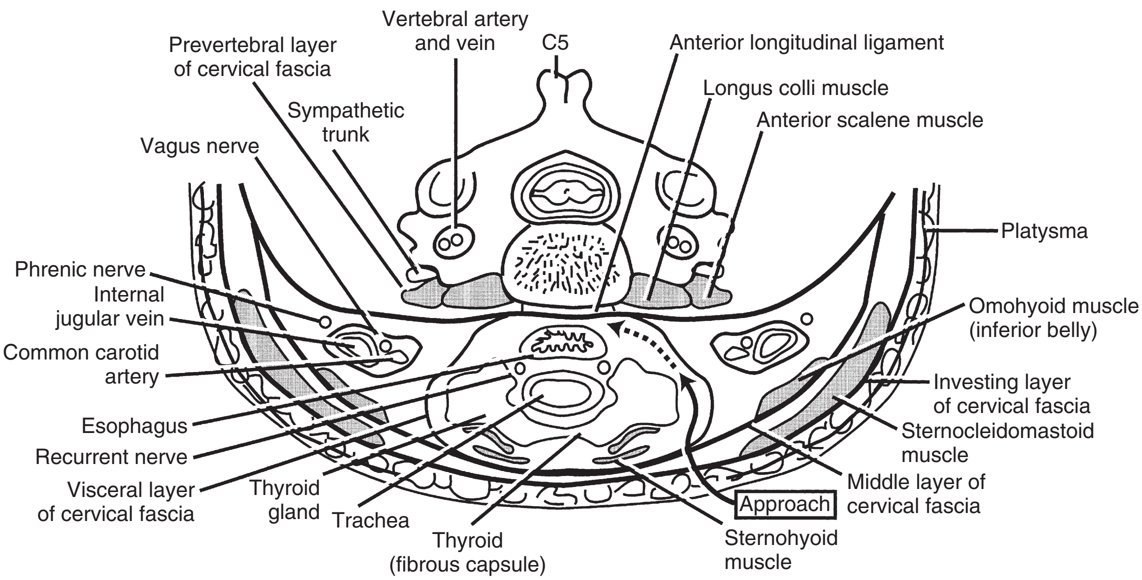

Figure 46-2. Cervical fascia. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

muscle arises from the region of the jugular notch and courses rostrolaterally to the mastoid process. It is dually innervated by the 11th cranial nerve and ventral branches of the C2-4 spinal nerves. The spinal accessory nerve enters the deep surface of the muscle at the border of the middle and rostral thirds. The two main actions of the sternocleidomastoid muscle are to turn the head to the contralateral side and to flex the head ipsilaterally. The infrahyoid group represents the rostral continuation of the rectus muscular system of the trunk.[2] This group contains four muscles: sternohyoid, sternothyroid, omohyoid, and thyrohyoid. The first three members of this group are innervated by the ansa cervicalis, and the thyrohyoid receives its innervation from the C1 spinal nerve via the hypoglossal nerve. The main actions of the infrahyoid group are to assist in swallowing and mastication. This group, together with the suprahyoid group, determines the rostrocaudal location of the larynx between the hyoid bone and the rostral thoracic aperture and can help flex the cervical spine and lower the head.

The deep layer of cervical musculature includes two groups: the scalene and longus groups. The scalene group includes three muscles: anterior, medius, and posterior. These muscles form a roof over the cupula of the lung. As a group, these muscles arise from the transverse processes of the subaxial cervical spine and project to the first and second ribs. The scalene muscles are innervated by the ventral rami of C4-8. They help to elevate the rib cage during respiration. The longus group also includes three muscles: rectus capitis anterior, longus capitis, and longus colli (Fig. 46-3). As a group, these muscles arise from the ventral vertebral body, transverse processes, and basilar portion of the occiput. They project caudally along the ventrolateral aspects of the cervical and upper thoracic vertebral bodies. These muscles are innervated by the ventral rami of C1-6, and their main action is to flex the head and the cervical spine.

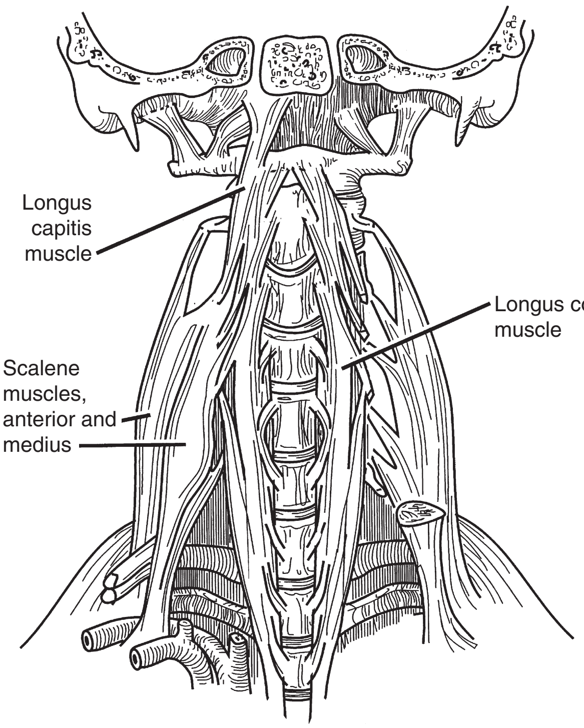

Figure 46-3. The scalene and longus muscles. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

Longus Colli

The longus colli attach to the anterior atlas, the vertebral bodies of C3-T3, and the transverse processes of C3-6.[6] The distance between the medial borders of the longus colli muscles increases in a rostral to caudal direction, measuring 7.9 ± 2.2 mm at C3, 10.1 ± 3.1 mm at C4, 12.3 ± 3.1 mm at C5, and 13.8 ± 2.2 mm at C6.[6] A great deal of variation exists in this musculature, so care should be taken in using it as a landmark for lateral dissection.

Cervical Viscera

The cervical viscera are arranged in three layers: a deep gastrointestinal layer, containing the pharynx and esophagus; a middle respiratory layer, containing the larynx and trachea; and a superficial endocrine layer, containing the thyroid and parathyroid glands. These structures are not covered in detail here, and much of the anatomy of the larynx and trachea has already been described in other sections of this chapter. As previously noted, these structures are contained within the visceral or pretracheal fascia.

The pharynx is a fibromuscular tube that projects from the pharyngeal tubercle of the clivus to its transition into the esophagus near the level of C6. The dorsal surface of the pharynx lies on the prevertebral fascia and must be mobilized during ventral approaches to the cervical spine. The muscles of the pharynx may be divided into two groups: constrictors and internal muscles of the pharynx. The constrictor group includes three muscles whose main action is to sequentially constrict the pharynx during swallowing, propelling food caudally. All of the constrictors are innervated by the pharyngeal plexus, which receives its branches from both the glossopharyngeal and vagus nerves. The constrictors do not form a continuous tube but are open at four points, allowing certain structures to pass into the pharynx. Rostral to the superior constrictor, the ascending palatine artery, the eustachian tube, and the levator veli palatini muscles pass to enter the pharynx. Between the superior and inferior constrictors pass the glossopharyngeal nerve, the stylohyoid ligament, and the stylopharyngeus muscle. In the gap between the middle and inferior constrictors pass the internal laryngeal nerve and the superior laryngeal artery and vein. Caudal to the inferior constrictor pass the recurrent laryngeal nerve and the inferior laryngeal artery. The internal muscle groups of the pharynx have a common function of elevating the larynx and pharynx during swallowing and a common innervation by the glossopharyngeal nerve. At the level of C6, the pharynx blends into the esophagus, which passes through the superior thoracic aperture to the stomach. In the root of the neck, the esophagus is in close approximation to the thoracic duct as it empties into the left subclavian vein.

Thoracic Duct

The thoracic duct is located on the left side within a triangle bounded medially by the longus colli muscles and the esophagus, laterally by the anterior scalene muscle, and inferiorly by the first rib.[7,8] Although it may ascend as high as C6, it is most often found between C7 and T1, before it descends to empty into a variable termination at the jugulosubclavian junction.[7,8] The rostral extension of the thoracic duct appears to vary by gender, as in patients who have a narrow thoracic inlet, as most women do, the duct may ascend as high as the level of the C6 vertebral body. Conversely, in patients who have a wide thoracic inlet, as most men do, the duct may ascend to the level of the C7-T1 disc, never truly leaving the mediastinum. Many have cited the increased possibility of injuring this structure in the left upper thorax as a reason for preferring a right-sided approach, especially to the upper thoracic vertebrae.[7]

The isthmus of the thyroid gland usually overlies the first two or three tracheal rings. The isthmus is the center bridge of glandular tissue that connects the right and left lobes. The entire gland is surrounded by a fibrous capsule, which should be differentiated from the pretracheal fascia. The thyroid gland is heavily vascularized and receives its blood supply from the superior and inferior thyroid arteries, which are branches of the external carotid and thyrocervical arteries, respectively. The recurrent laryngeal nerve is in close approximation to the inferior thyroid artery, and if this artery must be ligated, it is best ligated at a distance from the thyroid gland to avoid the nerve. A similar relationship exists between the superior thyroid artery and the external laryngeal nerve, again dictating arterial ligation distal from the substance of the gland. The thyroid gland is drained by the superior, middle, and inferior thyroid veins. The inferior thyroid veins may cover the ventral surface of the trachea and represent a potential source of bleeding during tracheotomy.

Laryngeal Nerves

The vagus nerve, or cranial nerve X, emerges from the brain stem, exits the intracranial space via the jugular foramen, and passes through the neck, chest, and abdomen, where it contributes to the innervation of the viscera. In the cervical region, both the right and left vagus nerves lie within the carotid sheath, lateral to the carotid artery. Near its passage through the thoracic inlet, the vagus nerve branches, giving rise to the recurrent laryngeal nerves (RLNs), which subsequently ascend toward the larynx. Before doing so, however, each RLN assumes a different course. The right RLN leaves the main trunk of the vagus and passes anterior to and then under the subclavian artery. This loop occurs at the T1-3 level. Meanwhile, the left RLN passes under and posterior to the aorta at the site of origin of the ligamentum arteriosum, a loop that is found at the T3-6 level.[9] The right RLN also courses rostrally in a more oblique fashion (in a superior and medial direction at an angle of 25 ± 4.7 degrees relative to the sagittal plane) than the left RLN (4.7 ± 3.7 degrees).[9] In the neck, the left RLN lies in the tracheoesophageal groove, entering at the midpoint of its course. The right RLN, however, lies 6.5 ± 1.2 mm anterior and 7.3 ± 0.8 mm lateral to the tracheoesophageal groove at C7, with high variability at this site and throughout its course.[9] The left RLN, therefore, is better protected from iatrogenic injury. Anatomic variations of the RLN such as nonrecurrence on either side or the nerves entering the larynx directly after their takeoff from the vagus are overall extremely rare.[9]

Nearing their entrance into the laryngeal structures at C5-7, the RLNs lie in close association with the inferior thyroid arteries (ITAs). The RLN length between the superior margin of the clavicle and the ITA is 23 ± 4.4 mm on the left and 22.8 ± 4.3 mm on the right.[9] The RLNs' relation to the ITA branches, however, is highly variable; on the right, the RLN is more commonly found anterior (26% to 33% of the time) or between the arterial branches, whereas on the left, the RLN is more commonly posterior (50% to 55%).[9]

Although unilateral RLN palsy is reported to be the most common nerve-related injury after ventral cervical surgery, the overall incidence of the resultant hoarseness is relatively low at 2% to 4%. This may be avoided by recognizing the sites at which the RLN is most vulnerable. The nerve is susceptible to injury if the dissection plane is not maintained entirely medial to the carotid sheath, if the longus colli dissection is not limited to the area between the muscle and the vertebrae, or if the dissection is carried superficial to the esophagus.[7] As mentioned earlier, the right RLN is vulnerable to injury if ligation of the inferior thyroid vessels is not performed as laterally as possible or with prolonged retraction without intermittent interruption.[9] The superior laryngeal nerve (SLN) originates from the inferior vagal ganglion at the C2 level and then descends medially toward the thyrohyoid membrane.[10] At the C3 level, the SLN branches into external and internal branches deep to the internal carotid artery.[10,11] The external branch of the SLN (EBSLN) travels with the cricothyroid artery and descends deep to the superior thyroid artery (STA) toward the cricothyroid muscle.[10] The internal branch travels with the superior laryngeal artery and passes deep to a loop of the STA before piercing the thyrohyoid membrane.[10,12] Both the external and internal branches of the SLN are within the fascia overlying the longus colli muscles.[11]

Conduction Pathways

The neck has two major neurovascular conduction pathways: cervicocranial and cervicobrachial (Fig. 46-4). The cervicocranial neurovascular bundle is outlined by the carotid sheath, which contains the common carotid artery medially, the internal jugular vein laterally, the vagus nerve dorsally, and the lymphatic plexus. As a whole, the cervicocranial neurovascular bundle lies laterally to the visceral space and ventrally to the prevertebral fascia. The bundle passes rostrally from the thorax and enters the carotid triangle, where the common carotid artery bifurcates into the internal carotid artery dorsolaterally and the external carotid artery ventromedially.

Within the carotid triangle, the external carotid artery provides a total of eight branches: three ventral, one medial, two dorsal, and two terminal. The ventral branches include the superior thyroid, lingual, and facial arteries. The superior thyroid artery descends from its origin caudal to the greater cornu of the hyoid to supply the thyroid gland. The lingual artery also arises at the level of the greater cornu of the hyoid bone and crosses under the hyoglossus muscle to supply the

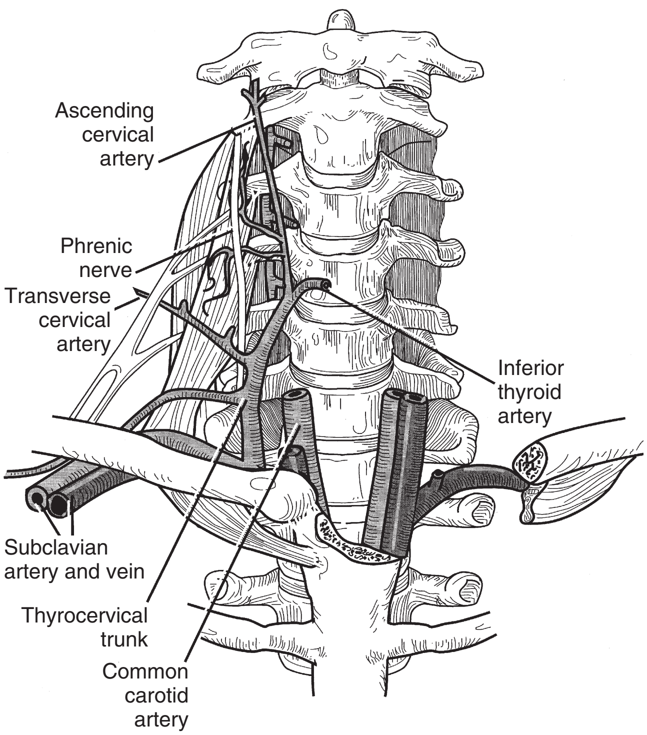

Figure 46-4. The conduction pathways. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

tongue. The facial artery is the final ventral branch of the external carotid artery. It runs under the submandibular gland before crossing the mandible and arriving to supply the face at the ventral surface of the masseter muscle. The sole medial branch is the ascending pharyngeal artery, which arises from the medial external carotid artery to supply the pharyngeal wall. The two dorsal branches are the posterior auricular and occipital arteries. The posterior auricular artery runs from underneath the parotid gland to the mastoid process. The occipital artery also reaches the mastoid but on its medial aspect in the groove named for the artery. The two terminal branches are the superficial temporal and maxillary arteries. The internal jugular vein originates in the jugular foramen as the superior bulb turns dorsolaterally to enter the carotid sheath lateral to the common carotid artery. It eventually drains into the subclavian vein.

Five of the cranial nerves—facial, glossopharyngeal, vagus, spinal accessory, and hypoglossal—traverse the neck. The facial nerve exits the skull at the stylomastoid foramen and ramifies into five branches within the parotid gland. The most caudal branch, the marginal mandibular, courses under the mandible and may be encountered in retropharyngeal approaches. Damage to this ramus results in drooping of the ipsilateral lip. Arising from the jugular foramen are the vagus, glossopharyngeal, and spinal accessory nerves. The vagus travels dorsally in the carotid sheath and gives off two important branches that run in the neck to supply the larynx.

The superior laryngeal nerve exits just below the inferior vagal ganglion and bifurcates into a small external laryngeal nerve that supplies the motor innervation to the inferior pharyngeal constrictor and cricothyroid muscles. This nerve also bifurcates into a large internal laryngeal branch that receives the sensory input of the laryngeal mucosa above the glottis. Damage to the superior laryngeal nerve results in early fatigue of voice, difficulty in producing high notes, and decreased gag reflex, resulting in a risk of aspiration. Both inferior laryngeal nerves ascend from the thorax in the tracheoesophageal groove, enter the inferior pharyngeal constrictor to supply motor innervation to the intrinsic laryngeal muscles, and receive all sensory innervation below the glottis. Damage to the inferior laryngeal nerve results in hoarseness.

The glossopharyngeal nerve exits the skull from the jugular foramen in close approximation to the vagus nerve and courses between the internal carotid artery and the internal jugular vein before passing between the stylopharyngeus and styloglossus muscles to enter the base of the tongue. The caudal ganglion of the glossopharyngeal nerve has two branches. The tympanic nerve, which supplies sensory innervation to the tympanic mucosa, divides into the tympanic plexus, from which the lesser petrosal parasympathetic fibers form to supply the otic ganglion. The communicating rami join the auricular ramus of the vagus. Below the inferior ganglion, the glossopharyngeal nerve divides into the following branches: stylopharyngeal ramus, carotid sinus ramus, tonsillar ramus, lingual ramus, and pharyngeal ramus. Both the vagus nerve and the glossopharyngeal nerve contribute to the pharyngeal plexus, which mediates motor and sensory innervation of the pharynx.

The spinal accessory nerve traverses the rostrodorsal corner of the carotid triangle to reach the deep surface of the sternocleidomastoid muscle one third of the distance from the mastoid to the clavicle and then continues through the occipital triangle to supply the trapezius muscle. The hypoglossal nerve exits the skull from the hypoglossal canal, enters the carotid triangle deep to the dorsal belly of the digastric, and courses between the carotid artery and the internal jugular vein before turning medially to enter the substance of the tongue. The hypoglossal nerve gives off the superior branch to the ansa cervicalis, which innervates the strap muscles and may be divided at the time of surgery.

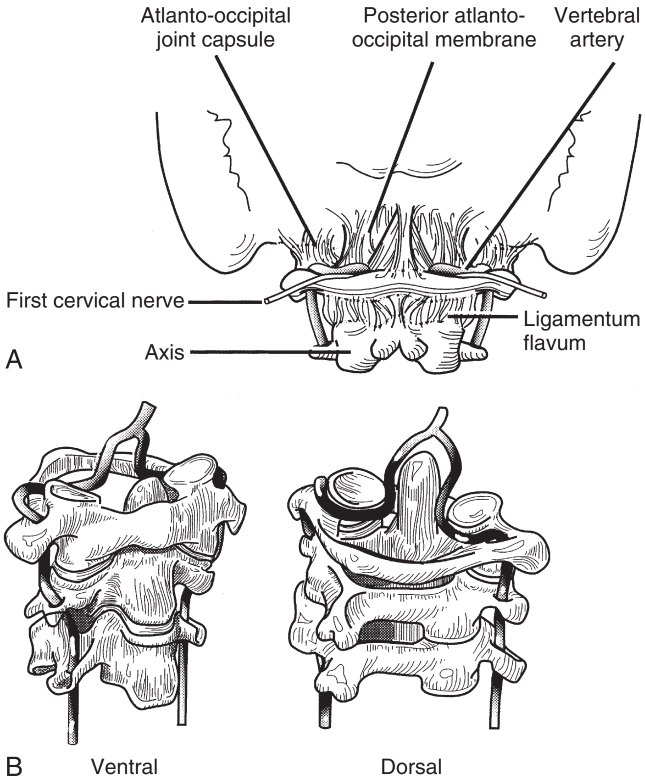

Figure 46-5. The cervicocranium and the vertebral artery relationships. **A,** Dorsal soft tissue and bony relationships of the vertebral artery. **B,** Ventral *(left)*, dorsal *(right)*, and bony relationships of the vertebral artery. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

The other major neurovascular conduction pathway is the cervicobrachial pathway, which supplies the upper extremities. The subclavian artery and the components of the brachial plexus exit the neck over the first rib and between the anterior and middle scalene muscles and then proceed through the posterior triangle of the neck to enter the axilla. The subclavian artery gives off the following arteries: vertebral, thyrocervical, internal thoracic, costocervical, and dorsal scapular. The vertebral artery is the vessel of most interest to the spine surgeon (Fig. 46-5). It arises from the dorsal aspect of the subclavian artery and courses medial to the anterior scalenus to enter the foramen transversarium of the sixth cervical vertebra. It then ascends in the foramen transversarium until the level of the axis, where it courses medially in a groove bearing its name and through the atlanto-occipital membrane to enter the cranial cavity. The subclavian vein runs ventral to the artery and to the scalenus anterior muscle just under the clavicle.

Vertebral Artery

The vertebral artery (VA) usually originates from the subclavian, or innominate, artery on the right and the aortic arch on the left. The artery is typically divided into four anatomic segments: the first segment, V1, consists of the artery's origin to the C6 transverse foramen; the second segment, V2, passes cranially from the C6 to the C2 transverse foramen; the third segment, V3, exits C2 and extends to the level of the foramen magnum; and the final portion, V4, passes through the foramen magnum and reaches to the vertebrobasilar junction.[13]

Due to the frequency of operative procedures in the subaxial spine, the anatomy of the V2 segment has been thoroughly reviewed. After ascending cranially, V1 passes by the transverse process of C7 anteriorly and laterally before entering the transverse foramen of C6.[14] V2 then extends from the artery's entry into the C6 foramen to the transverse foramen of C2.[15] In 94.9% of specimens, C6 is the first transverse foramen entered, but variations do exist (C4 in 1.6%, C5 in 3.3%, and C7 in 0.3%).[13] Within the intertransverse space, the vertebral artery and nerve root are encased in a fibroligamentous band. This band is attached to the lateral aspect of the uncinate process and the uncovertebral (UV) joint, combining the artery, nerve root, and uncinate process as a unit.[16] Before resection of the uncinate process or UV joint (i.e., uncoforaminotomy), it is necessary to dissect this fibroligamentous tissue off of the uncinate process.[16] In addition, it must be noted that the posterior and medial portion of the VA gives rise to numerous spinal and muscular branches in the intertransverse space.[15,17]

For a number of reasons, the V2 segment of the vertebral artery is more at risk during decompression of more cephalad vertebrae.[14,16,17] First, the diameter of the artery decreases from C2-3 to C6-7 (4.88 ± 0.63 mm at C2-3 to 4.27 ± 0.63 mm at C6-7),[17] and the anteroposterior diameters of the transverse foramina decrease from C6 to C3 (5.4 ± 1.1 mm at C6 to 4.7 ± 0.7 mm at C3).[14] The amount of the intertransverse space occupied by the artery, therefore, increases at more rostral levels.[17] Second, the artery ascends medially from C6-3 at an angle of approximately 4 degrees relative to midline, making it more likely to be encountered in the surgical field at higher cervical levels.[18] Finally, a series of other relationships places the VA at greater risk of iatrogenic injury at more cephalad levels. These include decreased interforaminal distance (27.4 mm ± 2.3 mm at C6 to 22.6 ± 1.8 mm at C3), width of the vertebrae (25.6 ± 2 mm at C7 to 19.2 ± 1.8 mm at C3), interuncinate distance (24.6 ± 2.1 mm at C7 to 19.2 ± 1.5 mm at C3), and distance from the lateral tip of the uncinate process to the medial border of the transverse foramen (3.3 ± 1 mm at C6 to 1.7 ± 0.8 mm at C4) at higher levels.[14] In addition, it should also be noted that because the vertebral artery is more anterior at C6 and becomes more posterior as it travels toward C3, there is greater risk with anterolateral uncinate resection in more caudad levels and with posterolateral decompression in more cephalad levels.[19]

Three possible risk factors have been identified for vertebral artery injury: motorized dissection with a high-speed diamond bur used off midline, excessive lateral dissection of bone and disc, and the bone of the lateral part of the spinal canal being pathologically softened by infection or tumor.[20] Intraoperative VA injury can be largely avoided by following a number of guidelines. If far lateral decompression is necessary, the anterior wall of the transverse foramina should be removed, the vertebral artery retracted laterally, and small rongeurs and curettes used, rather than a high-speed drill.[14,16] In performing foraminotomies, lateral dissection can generally be carried safely to the medial margin of the UV joint in most patients. Care should be taken, however, when extending farther laterally and should likely not exceed 5 to 6 mm beyond the nerve root's emergence from the thecal sac.[19] This is because the posterior surface of V2 rests on the anteromedial aspect of the cervical nerve roots at each level of the intertransverse space, and the mean length of the nerve root between the dural sac and the VA is 6.3 ± 1.06 mm.[15]

In posterior approaches, injury to the vertebral artery is more common than in ventral surgery. Whereas in anterior cervical procedures, the artery is most at risk during osseous decompression, the placement of posterior instrumentation is the portion of that procedure during which there is greatest risk for VA injury. It is, therefore, important to recognize the artery's relationship to the osseous structures of the posterior column. The shortest distance from the artery to the cervical pedicle increases from C3 to C5 (0.5 ± 0.2 mm at C3, 1.1 ± 0.4 mm at C4, 1.4 ± 0.8 mm at C5), decreases at C6 (0.9 ± 0.5 mm), and then dramatically increases at C7 (7.3 ± 2.7 mm).[21] As the VA emerges from the C2 transverse foramen, it travels in a groove extending horizontally from the medial border of the transverse foramen to the medial edge of the posterior ring.[19] To avoid injury, exposure of the posterior ring of the atlas should remain medial to that groove.[19] In about 80% of patients, the VA makes an acute lateral bend in the C2 lateral mass just under the superior articular facet.[19] If the trajectory of a C1-2 transarticular screw is aimed too low, the VA may be injured here.[19] In C2 pedicle screws, lateral perforation of the pedicle puts the VA at risk, and in C1 lateral mass screws, the VA is vulnerable near its exit from the C2 transverse foramen where it lies in close proximity to the C1 lateral mass.[19]

Nuchal Musculature

The intrinsic musculature of the dorsal neck may be divided into three layers: superficial, intermediate, and deep (Fig. 46-6). All of these muscles are innervated by the dorsal rami of several consecutive spinal nerves. The superficial layer contains the splenius capitis and the splenius cervicalis, which take their origin from the ligamentum nuchae and the spinous processes of C6-T1. The splenius capitis inserts along the lateral third of the superior nuchal line and on the mastoid process. The splenius cervicalis muscle inserts into the posterior tubercles of the transverse processes of C1-4. These muscles produce extension, lateral bending, and rotation of the head or neck.

The intermediate layer is composed of the massive erector spinae group, of which there are three columns: spinalis medially, iliocostalis laterally, and longissimus muscle between. All three columns share a common origin from the iliac crest, sacrum, and caudal lumbar spinous processes. The spinalis group inserts along the spinous processes of the cervical spine. The longissimus group inserts onto the mastoid process, and the iliocostalis group inserts into the posterior tubercles of the transverse processes of C4-6. As a group, the erector spinae muscles act to extend or laterally bend the head or neck.

The deep layer of the spinal musculature is also termed the *transversospinalis group* because it lies in the angle of the spinous

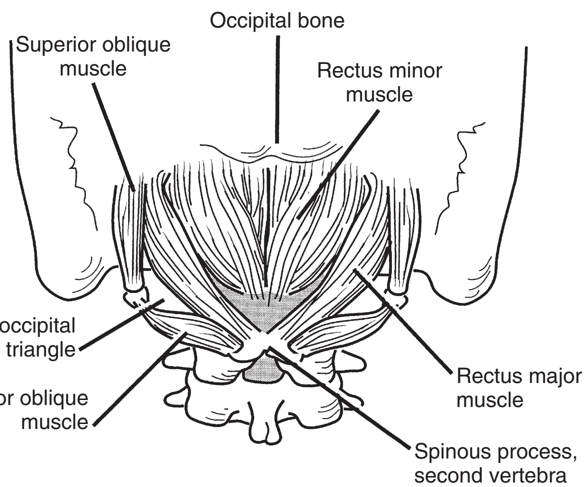

Figure 46-6. The suboccipital region. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

and transverse processes. This layer is divided into three groups. The semispinalis group lies most superficially and has both capitis and cervicalis divisions. The semispinalis capitis muscle arises from the transverse processes of T1-6 and inserts medially between the superior and inferior nuchal lines. The semispinalis cervicalis muscle originates from the transverse processes of the lower cervical and upper thoracic spine and inserts on the cervical spinous processes. Beneath the semispinalis division lies the multifidus division, which comprises short muscles that span only one to three spinal segments. These muscles pass from the lamina caudally to the spinous process of the adjacent level. The deepest divisions of the transversospinalis group are the rotators that arise from the transverse process of one vertebral level and insert on the base of the spinous process at the adjacent rostral level. As a group, the transversospinalis muscles produce rotation and extension of the head or neck.

Spinal Anatomy

The upper cervical spine is characterized by the axis and its "anatomic neighbors" (Fig. 46-7). The subaxial cervical spine varies minimally from level to level and is discussed as a single unit (Fig. 46-8). The components of the subaxial vertebrae include the body, upper and lower articular processes, pedicles, lamina, and spinous process. The vertebral bodies are the axial load-bearing elements of the spine. In the subaxial cervical spine the vertebral body height increases as the spine is descended with a slight reversal of this relationship at C6, which is usually shorter than either C5 or C7. Each body has a dorsally directed concavity that forms the ventral spinal canal. From each body arise three body projections: rostrally the uncus, laterally the ventral ramus of the transverse process, and dorsolaterally the pedicle.

The rostral aspect of each of the lower cervical vertebral bodies contains the uncus, a dorsolateral bony projection. The uncus gives the body a rostrally concave shape in the coronal plane and enables the vertebral body to receive the rounded caudal aspect of the immediately adjacent vertebral body, sometimes overlapping the next level by a third of the vertebral body height. The uncovertebral joints limit lateral translation and contribute to the coupling of lateral bending and rotation of the cervical spine.

The anterior tubercle arises from the rostral vertebral body and projects laterally while the posterior tubercle arises from the midportion of the lateral mass and projects ventromedially to join the anterior tubercle. The lateral surface of the pedicle, the dorsal surface of the anterior tubercle, and the ventral surface of the posterior tubercle form the foramen transversarium, which transmits the vertebral artery from C6 to the atlas. The anterior scalene, longus colli capitis, longus colli cervicalis, and ventral intertransversus muscles take their origin from the anterior tubercles. The splenius cervicalis, longissimus, levator scapulae, middle scalene, posterior scalene, and iliocostalis take their origin from the posterior tubercle. On the rostral surface of each transverse process there is a prominent groove carrying the exiting nerve root.

The pedicles of the subaxial cervical spine connect the vertebral bodies with the lateral masses and are small and medially oriented. The lateral masses of the subaxial cervical spine consist of superior and inferior articulating surfaces that form the facet joint. The facet joint is a coronally oriented synovial joint that is protected by a thin capsule. The vascular supply to the joint capsule arises from the vertebral, ascending

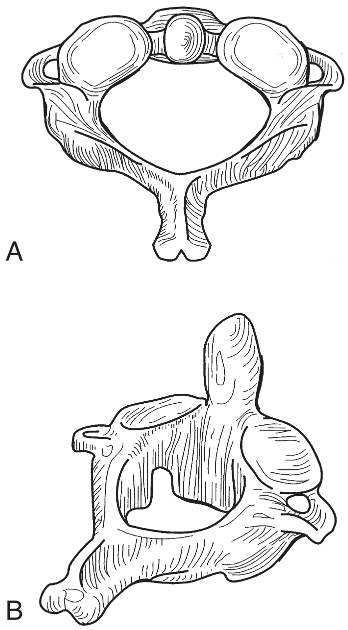

Figure 46-7. The axis. **A,** Axial view from above. Note that the articular facets and odontoid are anterior to the spinal canal. **B,** Posterior view. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

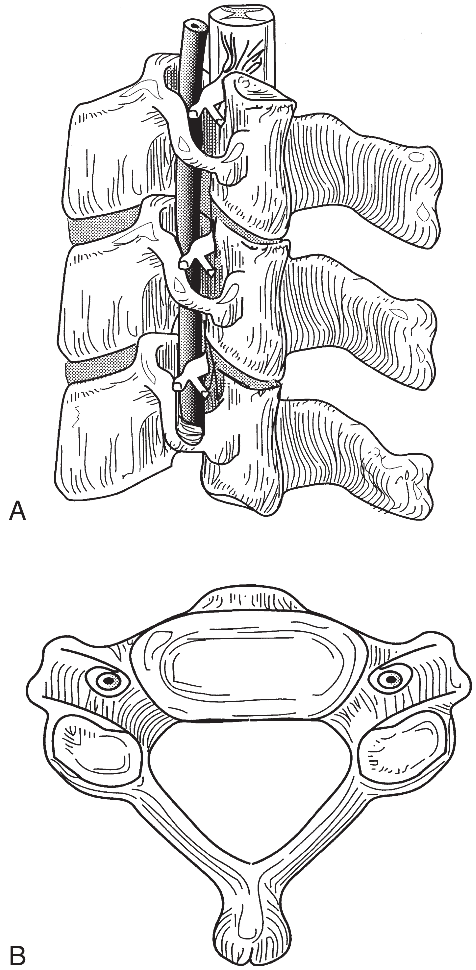

Figure 46-8. The subaxial spine. **A,** Lateral view. **B,** Axial view. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

pharyngeal, deep transverse cervical, supreme intercostal, and occipital arteries. The facet joints are innervated by the dorsal branches of the spinal nerves, which enter the joint at the center of the dorsal capsule. The laminae are thin, and the spinous processes of the midcervical spine are small and often bifid.

Discs

The intervertebral discs adjoin each of the subaxial vertebral bodies and contribute significantly to the flexibility of the spine. The cartilaginous end plates of the bordering vertebral bodies are the rostral and caudal boundaries of the disc space, and the anterior and posterior longitudinal ligaments overlie, respectively, the ventral and dorsal surfaces of the intervertebral disc space. Laterally, the disc space is limited by the uncal process. The end plate is more substantial on its periphery than centrally and is composed of hyaline cartilage. The disc itself is composed of the gelatinous nucleus pulposus surrounded by a fibrous ring. The fibrous ring contains intersecting layers of predominantly collagen and, to a lesser extent, elastin fibers.

Ligaments

The ligaments of the cervical spine are essential for the maintenance of alignment and stability. The ligaments of the subaxial spine include the anterior longitudinal ligament, the posterior longitudinal ligament, the interspinous ligament, the supraspinous ligament, the capsular ligaments, the ligamentum flavum, and the intertransverse ligaments (Figs. 46-9 and 46-10). The anterior longitudinal ligament is attached to the ventral surfaces of the vertebral bodies and the intervening discs. It spans the entire length of the spine from the skull base to the sacrum. The main biomechanical feature of the anterior longitudinal ligament is resistance of hyperextension. The superficial fibers extend for four or five vertebral bodies, and the deep fibers span two vertebral bodies.

The posterior longitudinal ligament is attached to the discs on the dorsal surface of the vertebral bodies and rostrally fans out to become continuous with the tectorial membrane. The main biomechanical effect of the posterior longitudinal ligament is resistance of hyperflexion. The interspinous and supraspinous ligaments attach adjacent spinous processes and are represented in the cervical region as the ligamentum nuchae,

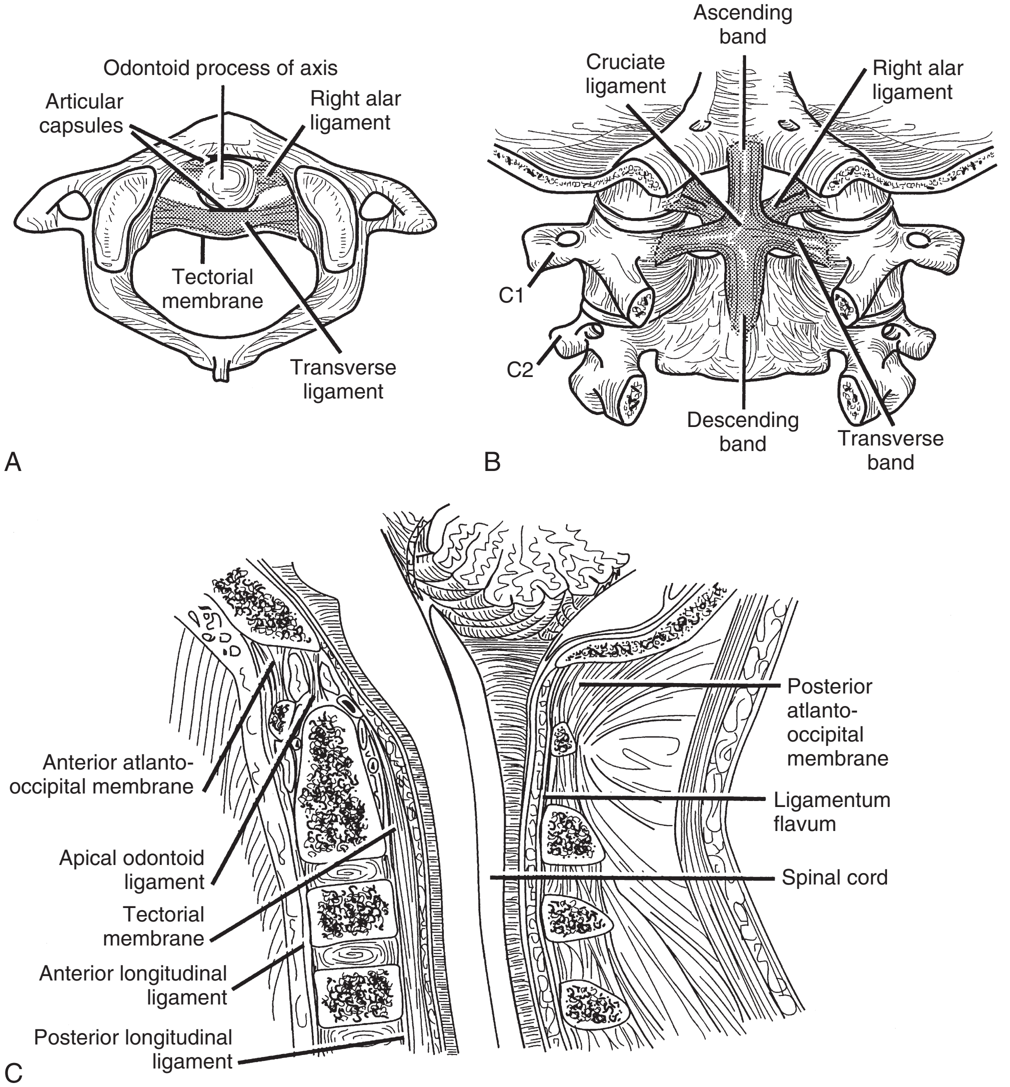

Figure 46-9. Ligaments of the cervical spine: axial (**A**), dorsal (after laminectomy) (**B**), and midsagittal (**C**) views. *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

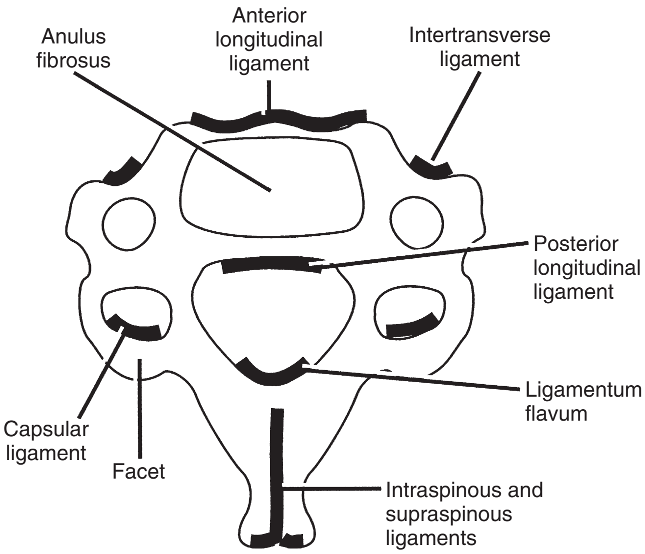

Figure 46-10. Ligaments of the subaxial cervical spine (axial view). *(Copyright University of New Mexico, Division of Neurosurgery, Albuquerque, with permission.)*

which runs from the inion to the spinous process of C7. This fibromuscular septum divides the paraspinal muscles and serves as an attachment site for the nuchal musculature. This represents the midline avascular plane, which may be transversed when exposing the dorsal cervical spine. These ligaments can limit flexion to a significant degree because of their long lever arm, with respect to the instantaneous axis of rotation. The capsular ligaments are loose under normal cervical spine movement and become taut with movement, thus limiting excessive flexion and rotation. The ligamentum flavum is an elastic ligament that traverses adjacent laminae in a shingle-like fashion, arising from a ridge on the inner surface of the lamina and projecting to the inner surface of the next rostral lamina. The intertransverse ligaments connect adjacent transverse processes, which have little biomechanical effect in the cervical spine.

Ligamentum Nuchae

The ligamentum nuchae (LN) is a triangle-shaped intervertebral syndesmosis, a bilateral fibroelastic intermuscular septum interposed between paired groups of paravertebral muscles of the cerviconuchal region.[22] It is formed by the aponeurotic fibers of the trapezius, splenius capitis, rhomboideus minor, and serratus posterior superior muscles.[23] Functionally, the LN serves to maintain lordotic alignment and stabilize the head during rotation of the cervical region.[22] Extending from the external occipital protuberance, or inion, to the spinous process of C7, it is covered by layers of cervical fascia and the aponeurosis of the trapezius muscle.[22] During posterior exposure of the cervical spine and suboccipital region, it is important to identify and maintain the dissection plane within the LN in order to minimize tissue damage, blood loss, and the possibility of injury to lateral structures such as the vertebral arteries.

The LN consists of two components: the lamellar portion ventrally and the funicular portion dorsally. The latter is a fibrous raphe that corresponds to the fusion of the underlying layers of the lamellar portion. The dorsal component is attached to the inion and the C7 spinous process and is freely mobile between these two structures.[24] The lamellar portion is a double-layered midline septum with fatty areolar tissue interposed between its layers. It inserts into the medial side of the cervical vertebra's bifid spinous processes.[22] Attached rostrally at the inion and external occipital crest, the lamellar portion is superficial at C6-7 and deepest at C1.[22,24] Anteriorly, it seems to be continuous with the interspinous ligament, suboccipitally with the atlanto-occipital and the atlantoaxial membranes, as well as the posterior spinal dura, and rostrally with the periosteum of the occipital bone.[22,25] Although it is laterally continuous with the deep fascia of the semispinalis capitis and the splenius capitis, a cleavage plane separates the adjacent semispinalis capitis, allowing for a relatively easy intraoperative division.[24]

To ensure that the midline plane is respected with a posterior dissection, three strategies should be used: (1) dissection should be maintained within the fatty areolar tissue of the LN's lamellar portion, (2) isolation and incision of the funicular portion should be carried from inside to outside, and (3) retrograde dissection of the cerviconuchal muscles attached to the occipital bone should be performed in a subperiosteal plane.[22]

Intervertebral Foramen

The cervical spinal nerves exit from the spinal canal through the intervertebral foramen. True foramina, with four distinct walls, are found in the subaxial cervical spine, and partial foramina are present at the atlanto-occipital and atlantoaxial levels.

The pedicles form the rostral and caudal boundaries of each foramen. The cervical spinal nerves exit above the like-numbered pedicle in close proximity to both the cervical disc and the uncovertebral joint at that level. The ventral wall of the intervertebral foramen is formed rostrally by the vertebral body and caudally by the uncovertebral joint that overlies the disc space. The dorsal wall is formed by the capsule of the facet joint, which covers the underlying superior articular process. The superior articular process often projects above the uncal process of the same intervertebral foramen. Degeneration of either the uncovertebral joint or the facet joint can cause stenosis of the intervertebral foramen, resulting in radiculopathy. The spinal nerve crosses dorsally to the vertebral artery as it ascends in the foramen transversarium.

Blood Supply

The blood supply of the subaxial cervical spine is derived mainly from the vertebral artery with additional and variable contributions from the ascending pharyngeal, occipital, and deep cervical arteries.

The vertebral artery branches segmentally to supply the cervical spine through two main branches: ventral branch and dorsal branch. The ventral branch is transmitted across the midportion of the lateral surface of the vertebral bodies below the transverse process and below the longus colli muscles. It contributes to the blood supply of the ventral vertebral body through the accompanying ventral vertebral body arterial plexus.

The dorsal branch enters the intervertebral foramen and, in turn, gives off three branches. The first is transmitted along the nerve roots and supplies the spinal cord itself, anastomosing with the anterior and posterior spinal arteries. The second branch supplies the inner surface of the lamina and the ligamentum flavum. The third branch contributes to the blood supply of the dorsal vertebral body through the accompanying dorsal vertebral body arterial plexus, which passes underneath the posterior longitudinal ligament.

The venous drainage of the cervical spine includes an internal and external system. The internal vertebral venous plexus

(Batson plexus) extends from the coccyx to the occiput. It consists of numerous small valveless veins that run ventral and dorsal to the thecal sac and merge at the intervertebral foramen. The internal system then exits the spinal canal along the nerve roots and flows into the external vertebral plexus, which is represented in the cervical region by the vertebral veins. The vertebral veins form a peripheral veil around the vertebral artery and, subsequently, anastomose with the condylar, mastoid, occipital, and posterior jugular veins.

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