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An unusual anatomical variant of the left phrenic nerve encircling the transverse cervical artery

Running head: Encircling of the left phrenic nerve around the transverse cervical artery

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Abstract

During educational dissection of cadavers, we encountered anatomical variability of the left phrenic nerve. In this cadaver, nerve fibers from C3 and C4 descended and crossed behind the transverse cervical artery (TCA), a branch of the thyrocervical trunk, at the level of the anterior scalene muscle. On the other hand, nerve fibers from C5 descended obliquely above the TCA and then joined the fibers from C3-4 on the medial side of the anterior scalene muscle to form the phrenic nerve. To our knowledge, the encircling of the TCA by the left phrenic nerve in the neck has not yet been reported and may pose as a potential risk for nerve compression during movement of the neck. We discuss several types of anatomical variants of the phrenic nerve and the associated risk during thorax and neck dissection procedures.

Key words: phrenic nerve, transverse cervical artery, variation

INTRODUCTION

The phrenic nerve is one of the most important nerves in the body, due to its role in respiration. The phrenic nerve mainly arises from the fourth cervical ventral ramus (C4) and receives contributions from the third (C3) and fifth (C5) cervical ventral rami in the posterior triangle of the neck. It descends obliquely along the surface of the anterior scalene muscle from the posterior margin to the anterior, then enters the thorax by passing in front of the subclavian artery (SCA). Phrenic nerve injury can lead to diaphragmatic paralysis, temporary dyspnea, and eventually worsen respiratory function due to the motor supply to the major respiratory muscles of the diaphragm; however, there is scarce literature on the anatomy of the nerve during neck dissection [1].

Unilateral diaphragmatic paralysis is frequently caused by an iatrogenic injury due to the anatomical variants of the phrenic nerve that are encountered during thorax and neck procedures, including surgical, anesthetic, or chiropractic complications [2,3]. There are several anatomical variants of the phrenic nerve that have been described; however, most are related to the duplication of the phrenic nerve, as well as medial and lateral deviations of the phrenic nerve [4]. Duplication of the phrenic nerve is associated with early developmental events of the nascent diaphragm [5,6], while aberrant origin and course of the thyrocervical trunk (TCT) arising in the SCA are thought to be the causes of deviations of the phrenic nerve [7]. In practice, branches of the SCA, as well as branches of the TCT, can compress the phrenic nerve and become potential sites of nerve impairment [7,8]. Injury to the phrenic nerve caused by anatomic variations of the accessory phrenic nerve have also been reported [9].

Recently, it has been suggested that the phrenic nerve might be pulled more laterally by the transverse cervical artery (TCA), a branch of the TCT, based on changes in posture and movement of the neck [8]. In addition, disruption in the normal quality of the prevertebral fascia between the TCA and the phrenic nerve on the anterior scalene muscle may result in adherence between the two structures and eventually lead to vascular compression of the nerve following surgical and interventional vascular procedures [10]. Thus, it is important to understand the anatomic relationship between anatomic variants of the phrenic nerve and the TCT itself, and/or the TCA in the neck region, in order to reduce postoperative complications. In this report, we present the potential risks of left phrenic nerve injury, which is caused by the TCA, one of the branches of the TCT, which we believe has not yet been reported.

CASE REPORT

During a routine educational dissection, a rare encircling of the left phrenic nerve around the TCA was found in an 83-year-old Korean male cadaver. The SCA and common carotid artery arose directly from the aortic arch. The vagus nerve entered the thorax between the common carotid artery and SCA. The first portion of the SCA divided into the vertebral artery, the internal thoracic artery, the TCT, the common trunk of TCA, the suprascapular artery, and the inferior thyroid artery. The common trunk, close to the medial edge of the left anterior scalene muscle, continued to extend approximately 3 cm from the SCA and then divided into the TCA and the inferior thyroid artery (the inferior thyroid artery had already been removed by the students) (Fig. 1). The left anterior scalene muscle crossed under the TCA before being inserted into the first rib.

The left phrenic nerve arose from ventral ramus of C3 to C5. The nerve fibers from C3 and C4 first descended passing the lateral side of the vagus nerve, and then crossed behind the TCA on the anterior scalene muscle. In contrast, the nerve fibers from C5 descended obliquely above the TCA toward the thorax. The fibers from the C3-C4 and C5 joined with each other, and then formed a loop around the TCA on the medial side of the anterior scalene muscle (Fig. 1). Therefore, the left phrenic nerve may be greatly affected by the movement of the neck and/or change in posture at the level of the anterior scalene muscle. In addition, TCA compressions can be one of the mechanisms of left phrenic nerve injury, due to altered conditions that lead to changes in the course and caliber of the TCA occur, such as inflammation. After encircling the TCA, the left phrenic nerve accompanied the internal thoracic artery and descended toward the thorax.

DISCUSSION

Diagnosis of phrenic nerve injury requires great discretion due to non-specific signs and symptoms, including unexplained shortness of breath with exertion and/or supine position, increased fatigue, loss of energy, gastrointestinal reflux, bloating (left sided paralysis), and insomnia [11]. In unilateral diaphragmatic paralysis, the patient is often asymptomatic at rest and has dyspnea only during exertion. In comparison, patients with bilateral paralysis always present shortness of breath [12]. However, mortality and morbidity associated with phrenic nerve injury, and subsequent diaphragmatic paralysis, depend on the underlying causes and status of pulmonary function [13]

The motor fibers of the phrenic nerve command the contraction of the diaphragmatic muscles, and is controlled mainly by the C3-C5 segments of the neural tube. The axons of the right and left phrenic nerves descend along the vertebrae and pericardium, enter the diaphragm, and subdivide into several branches that innervate the respiratory muscles [6]. In the posterior neck, the cervical phrenic nerve crosses obliquely to the anterior scalene muscle. It also traverses below the TCA and suprascapular artery, a branch of the TCT arising from the SCA [8].

Considerable variation of the standard anatomy of the phrenic nerve in the neck has not been extensively described in the literature. Interestingly, frequent phrenic nerve variation occur in patients with supraclavicular decompression surgery for neurogenic thoracic outlet syndrome; however, there are few reports based on cadaver research [4]. In this report, anatomic variations of the phrenic nerve were identified in 28 (28%) patients with duplicated phrenic nerves, accessory phrenic nerve, and medially or laterally displaced phrenic nerves. Duplicated phrenic nerve is defined as the same-sized medial and lateral contributions of the phrenic nerve, regardless of its relationship to the anterior scalene muscle. Phrenic nerve duplication may originate in early stages of ontogenesis, as a result of alternative developmental pathways, in which axons of the phrenic nerve, specific to a given domain of the diaphragm, running separately at a specific stage of development, instead of forming a single stem [5, 6]. In addition, accessory phrenic nerve arising from superior trunk of the brachial plexus, ansa cervicalis, or nerve to subclavius was reported [9]. The accessory phrenic nerve commonly lies lateral to the phrenic nerve and traverses the neck with a highly variable course [14]. This variable course of the accessory phrenic nerve increases the complexity of the surgical procedure performed in the neck. Displacement of the phrenic nerves have also been observed, specifically with a completely medial or lateral course relative to the belly of the anterior scalene muscle. Topographical studies of the relationship between the phrenic nerve and variation of the origin of the TCT demonstrate that lateral displacement of the phrenic nerve results from the unusual origin of the TCT, which arises from the third portion of the SCA [7, 8]. Lischka *et al.* [15] reported that the TCT arose from the third portion of the SCA in 2 among 166 possibilities (83 cases, 2 sides each). In general, the TCT is formed by the fusion of the suprascapular artery, TCA, and the inferior thyroid artery, which originate from the first portion of the SCA. The aberrant origin of the TCT can lead to potential impairment of the phrenic nerve. Hamada *et al.* [16] also reported that lateral displacement of the phrenic nerve could increase the risk of phrenic nerve injury during internal jugular or subclavian venous catheter placement and brachial plexus block. In addition, marked lateral deviation and subsequent strain of the phrenic nerve in the neck could increase the risk of nerve injury or nerve dysfunction [7]. Pretterklieber et al. [17] described that left phrenic nerve passed the diaphragm dorsal to the apex of the pericardium, though its passage is described as the esophageal hiatus in many textbooks. In present case, left phrenic nerve passed not the esophageal hiatus but the diaphragm. Anatomical study about the phrenic nerve was rare, therefore, its further study should be performed with larger cases.

Post-procedural and post-surgical nerve injuries may result from direct nerve transection, stretching, or may be secondary to the fibrosis and scarring that occurs after inflammation. Loss of normal tissue properties and adherence between normally separate anatomical structures can lead to compression and nerve dysfunction [8]. In this case, the nerve fibers from the C3 and C4 ventral rami transverse the anterior scalene muscle superiorly in the posterior neck, just under the prevertebral fascia, before joining the nerve fibers from C5. We postulated that trauma or manipulation in the neck, including neck surgery, may result in inflammation of the prevertebral fascia, scalene muscle induration, and, in association with an intramuscular hematoma, can sometimes cause adhesion and compression of the ventral rami of the left phrenic nerve where it is interposed between the muscles and the inflammatory semi-rigid prevertebral fascia.

This case also shows that nerve fibers from C3-4 and C5 separately cross the TCA posteriorly and superiorly on the anterior scalene muscle forming a loop around the TCA. Kaufman *et al.* [8] reported three patients with diaphragm paralysis caused by TCA compression of the phrenic nerve. They described that this artery normally originated from the TCT in the first portion of the SCA. They called this condition the ‘Red Cross Syndrome’ and reported that one in three patients suffered severe dyspnea when turning their head to the affected side. In our case, as in the report by Kaufman et al., the root of TCA arose from the TCT. We postulated that the potential risk of phrenic nerve compression by the TCA is based on the movement of the neck or change in posture. In addition, the left phrenic nerve and/or phrenic nerve loop might be pulled more laterally by the altered course and caliber of the ipsilateral TCA. Thus, a vascular nerve compression may result in either an ischemic or demyelinating neurapraxia. Vascular compression of a central and peripheral nerve has been well examined in various locations throughout the body. Examples of such events include the vertebral artery compression of a cervical root, cerebral arterial compression of the intracranial trigeminal nerve, vascular compression of the vestibulocochlear nerve, vascular compression of the occipital nerve causing migraine headaches, and radial nerve palsy secondary to a thickened recurrent radial artery [18-20]. In particular, the radial nerve palsy condition may occur in a similar manner to our case in that, prior trauma or inflammation may alter the caliber or course of the TCA and/or the spatial relationship between it and the involved phrenic nerve.

Iatrogenic damage to the phrenic nerve is most commonly due to cardiothoracic or neck surgery and is described after interscalene brachial plexus block and central vein catheterization [21]. Other studies have shown that carotid-subclavian bypass grafting (CSBG) procedures were associated with phrenic nerve injury, with levels of morbidity after iatrogenic injury varying across patient types [22]. Cohen *et al.* [23] showed that patients with chronic obstructive pulmonary disease (COPD) and phrenic nerve injury after CSBG had significantly worse survival rates than those of patients with only COPD or phrenic nerve injury undergoing the same procedures.

CONCLUSIONS

In the present article, we described a variant of the left phrenic nerve, which can be compressed by the TCA depending on the movement of the neck or even changes in posture. Additionally, variants of the phrenic nerve can increase the risk of iatrogenic injury during neck procedures, including surgery. Moreover, phrenic nerve injury can have a substantial negative impact on a patient’s quality of life compared to that in other groups. Based on the increasing use of invasive procedures, accurate knowledge of the anatomic variants of the phrenic nerve is of considerable importance for surgeries and interventional vascular procedures. Therefore, we believe that this case report will be helpful for clinicians who perform these procedures.

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Figure 1. The common carotid artery and subclavian artery arise directly from the aortic arch. The vagus nerve enters the thorax between the common carotid artery and subclavian artery. The first portion of the subclavian artery divided into the vertebral artery, the internal thoracic artery, and the common trunk of thyrocervical trunk. The common trunk is located close to the medial edge of the anterior scalene muscle. The nerve fibers from C3 and C4 (**) descend passing the lateral side of vagus nerve and then cross the transverse cervical artery posteriorly on the anterior scalene muscle. In contrast, the nerve fibers from C5 (*) descend obliquely above the transverse cervical artery toward the thorax. The fibers from C3-C4 and C5 join together and then form a loop around the transverse cervical artery. After encircling the transverse cervical artery, the phrenic nerve accompanies the internal thoracic artery descending toward the thorax. **– nerve fibers from C3-4, *– nerve fibers from C5, C5-ventral ramus of C5, CCA –common carotid artery, VN –vagus nerve, VA –vertebral artery, TCT –thyrocervical trunk, ITA –internal thoracic artery, PN –phrenic nerve, ASM –anterior scalene muscle, TCA –transverse cervical artery, SCA- subclavian artery, BP- brachial plexus.