MINIREVIEW

Anatomy of the Spinal Accessory Nerve Plexus: Relevance to Head and Neck Cancer and Atherosclerosis[1]

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The term spinal accessory nerve plexus may be defined as the spinal accessory nerve with all its intra- and extracranial connections to other nerves, principally cranial, cervical, and sympathetic. The term is not new. This review examines its applied anatomy in head and neck cancer and atherosclerosis. Over the centuries, general studies of neural and vascular anatomy and embryology formed a basis for the understanding upon which the plexus is described. During the past century, its anatomy and blood supply have come to be better understood. The importance of almost all of the plexus to head, neck, and upper extremity motor and sensory functions has come to be realized. Because of this understanding, surgical neck dissection has become progressively more conservative. This historical progression is traced. Even the most recent anatomic studies of the spinal accessory nerve plexus reveal configurations, new to many of us. They were probably known to classical anatomists, and not recorded in readily available literature, or not recorded at all. Human and comparative anatomic studies indicate that the composition of this plexus and its blood supply vary widely, even though within the same species their overall function is very nearly the same. Loss of any of these structures, then, may have very different consequences in different individuals. As a corollary to this statement, data are presented that the spinal accessory nerve itself need not be cut during surgical neck dissections for severe impairment to occur. In addition, data are presented supporting the theory that atherosclerosis by obstructing vessels to this plexus and its closely connected brachial plexus will very likely result in their ischemic dysfunction, often painful. Finally evidence, as well as theory, is stated concerning anatomic issues, methodology, outcome, and possible improvements in surgical procedures emphasizing conservatism. [Exp Biol Med Vol. 227(8):570–578, 2002]

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The term spinal accessory nerve plexus may be defined as the spinal accessory nerve with all of its intra- and extracranial connections to other nerves, principally cranial, cervical, and sympathetic. The term, however, is not new (1). This review discusses its anatomy and blood supply in head and neck cancer and atherosclerosis. For many centuries, the knowledge gleaned from studies of neural and vascular systems in general and their embryology has given us the tools to describe this plexus. For example, early descriptions of cranial nerves were incomplete (2, 3) until 1778 when von Soemmering established the now accepted number of cranial nerves as 12 (4). This knowledge helped to enable scholars to understand the anatomy of the spinal accessory nerve.

In parallel, understanding the circulatory system was already evolving at the time Herophilus of Chalcedon described the confluence of veins at the cerebral occiput, the "torcular Herophili," in the fourth century B.C. (5). Much later, Andreas Vesalius (1514-1564) in the first known systematic anatomy text of the western world (6) vehemently

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corrected some of Galen's misstatements concerning the nervous and circulatory systems, which had been accepted as dogma for the previous thousand years (7). Vasculature of the nervous system has continued to intrigue anatomists from then to the present (8–15). Rather recently, Lasjaunias and others (16) added concepts of arterial territories and directional blood flow, and Taylor *et al.* (17) described three-dimensional independent vascular territories called angiosomes. Collectively, these studies, too, have emphasized the critical importance of the blood supply to the plexus.

During the past century, the importance of almost all of the plexus to head, neck, and upper extremity function has come to be understood. As a consequence, surgery has become more conservative. Now, both as little of the plexus and as few of its closely related structures are removed as is possible during neck dissections to prevent iatrogenic injury to the plexus. This progression of conservatism is traced historically. Earlier work will also be mentioned later in the review in connection with modern surgery involving the spinal accessory nerve plexus because of the relevance of the two in the modern context.

Most of the studies done in the past half century, however, rather than systematically describing the entire plexus and its vasculature, have been more narrowly focused on specific clinical problems. One such recent instance is the work of Katsuka *et al.* (18) on the anatomy of the jugular foramen. Regarding embryology, Padget's 1948 embryologic work (19), the most complete studies of which the author is aware, suggested that developmental variations might cause clinically significant aberrations or anomalies, as aneurysms, a theory now being confirmed by imaging studies (20). A much more recent embryologic review is far less complete than Padget's (21).

Other topics relating to the circulatory and neural anatomy of the spinal accessory nerve plexus, i.e., the lymphatic circulation and the sympathetic nerves, reviewed by Hidden (22) and Collins (23), respectively, will be discussed later in relation to surgery involving the plexus.

Studies Involving Surgery of the Spinal Accessory Nerve Plexus and Related Structures in the 20th Century Leading to the Present Conservative Approach

The best surgical minds of the 20th century were divided on the need to leave the spinal accessory nerve undamaged in surgical neck dissections for cancer. Perhaps some of the divergence of opinion was due to a spectrum of impairments seen by different observers from loss of that nerve. These impairments vary from minor to severe, depending on the composition of the spinal accessory nerve excised. In 1900, little had been published in the surgical literature about this varying composition, now known to be an important determinant of impairment (1).

Early on, however, Crile in 1906 advocated leaving the nerve (24). Later, in 1944 Brown and McDowell (25) published their view that that nerve may need excision, but often it was unnecessary in an area not expected to be involved in cancer. Unfortunately, they did not state criteria for determining whether an area could be expected to be involved in cancer. They did add that the mandibular branch of the facial nerve should be removed in lip and tongue cancers. This latter procedure unhappily is not only disfiguring because it causes the corner of the mouth to droop, but also it is socially unacceptable because of constant drooling from inability to close the lips abetted by sensory loss. By 1951, Martin *et al.* (26) had again reversed course, writing that removal of the mandibular branch of the facial nerve need not be done, but that it was essential to remove the spinal accessory nerve. In 1976, Beahrs (27) did not advocate removal of the spinal accessory nerve without very good cause, but he also stated words to the effect that removal of the spinal accessory nerve was a small price to pay for a curative cancer operation. Patients losing that nerve, however, know the pain and disability that may accompany that loss, so that in their minds, its loss may not be a small price particularly because it may not be necessary to pay that price at all. Evidence published from a study of 967 patients (28) and confirmed a few years later (29) strongly suggested that removal of the spinal accessory nerve need not be done. Leaving it apparently had no adverse effect on outcome even if the nerve were involved with the cancer. The studies of Byers *et al.* (28) also gave good indication that in doing neck dissections, structures as the internal jugular vein, the sternocleidomastoid muscle and some of the lymph nodes very often could be left intact without influencing outcome.

Gross Anatomy and Dissection Microscopy Intracranially and Extracranially of the Spinal Accessory Nerve Plexus and Its Blood Supply With Some Practical and Theoretic Observations

Two central nervous system origins are customarily ascribed to each cranial nerve: 1.) Superficial origins are from the surface of the central nervous system, while 2.) Deep origins are from cell bodies and nuclei within the central nervous system (30). The general location and approximate number of rootlets of origin for cranial nerves have been well described in standard anatomy texts (31). Contrariwise, descriptions of the interconnections of these rootlets are not readily found. Bischoff published such a study in 1865 (32). Fragmentary descriptions of individual nerve connections often have been found only scattered throughout the literature. For example, Hovelaque (33) quotes earlier authors Hirshfield and Sappy in their descriptions of variations in interconnections of the ansa of von Haller, also called the nerve of Jacobson, lying between the hypoglossal and facial nerves. As another example of a variable interconnection observed in our laboratory, in one subject, the rootlets of the glossopharyngeal were connected to the vestibulocochlear as well as the facial nerve. The latter interconnection was other than the inconstant but well-known branch of the facial nerve to the tympanic cavity just described, i.e., the nerve of Jacobson or the Ansa of von Haller (33, 34). In this regard, it would be useful to know the topographical anatomy of the cranial nerves as discussed in 1980 by Lang (35) and Sunderland (36). Many descriptions of cranial nerve rootlet interconnections are found only in comparative anatomic studies (37, 38). Variable connections intracranially between cranial nerve rootlets involving the spinal accessory nerve plexus and extracranially between the nerves themselves may give very different composition to nerves in the same location in different patients. Thus, very different impairments may occur when nerves in the same location are cut in these different patients. These variations in connections also explain in part why the spinal accessory nerve itself need not be cut for severe head, neck, and shoulder impairment to occur when there is loss of other cervical nerves in the plexus (1, 39).

Cranial nerves, unlike peripheral nerves, lack an epineurium, do not stretch, and have less collagen, and so are more subject to injury than peripheral nerves (36, 40). Because of the unpredictability of what may be serious impairment from cutting a rootlet or one of its branches to any of these important nerves, much clinical and anatomic study has gone into efforts to protect them during operations, as for example, coating them with fibrin (40). Also, to avoid iatrogenic injury, before operating or radiation therapy, it becomes important to know whether dural, perineural areas, or venous sinuses close to these nerves are invaded by skull-based tumors. Assistance is given by magnetic resonance imaging (MRI) alone or together with pial enhancement, preoperatively (41). The radiation vulnerability intracranially of all four of the lower cranial nerves is illustrated by what was believed to be radiation induced bulbar palsy 14 years after a 41-year-old man had irradiation arrest of a nasopharyngeal carcinoma. The mechanism was theorized to be either from radiation-induced nerve damage or to vascular endothelial damage with resulting ischemia, fibrosis, and neural tissue compromise (42). Partly for the above reasons, our laboratory has recently restudied not only the numbers of rootlets of the lower four cranial nerves, but also their interconnections that are very probably important clinically. In addition, because of possible nerve ischemic dysfunction from atherosclerosis or radiation or operative loss, we have also restudied the blood supply to the lower four cranial nerves (39).

The Spinal Accessory Nerve Plexus in Head and Neck Cancer Surgery: Clinical and Theoretical Importance of Its Vasculature and Connections to the Lower Cranial and Cervical Nerves

Effects from vascular changes and tumors on cerebral function, and specifically for this review, on the cranial and cervical nerves comprising the spinal accessory nerve plexus, have been extensively discussed in neurology texts (43). In addition, the voluminous neurosurgical literature is a rich source of clinical experience recorded to identify nerves making up the spinal accessory nerve plexus both intra- and extracranially. It contains many reports of anatomic studies, only a few being cited here, which are meant to be helpful in getting into the much wider literature. As already stated, they are usually focused on a clinical problem in a specific area. For example, the vagal nuclei have been investigated as part of a study of brain stem dysfunction and malformation (44). Also, in general, most of these papers say little of the intracranial connections of individual nerves to each other or of the specific blood supply to each individual nerve. Rather, they address, for example, the blood supply to an entire area or a group of nerves as a whole with an occasional exception (14, 45, 46).

Normal neural anatomy and vascular anatomy, both arterial and venous in relation to brain and cord structures of the entire posterior fossa, however, are described and shown in elegant colored photographs of dissections painstakingly done by Rhoton and collaborators (47). The emphasis in these writings is on the safest surgical approaches to the posterior fossa structures, accomplished by combining anatomic relationships to incisions.

Studies of vessels such as the above when injected with latex into deceased subjects have the advantage of retracting little on solidification. That property, along with the ability to color latex, makes it relatively easy to identify and measure the actual caliber of the injected vessels. This advantage has been noted previously by others (48). Also, the caliber of vessels relative to each other may be measured on x-ray film after injection of radio opaque substances (48). In clinical practice, radiologists commonly measure the size of such injected vessels on film, the caliber often being very close to the true size.

The intracranial region of the brainstem is very compactly arranged, with important neural and vascular structures that may be described in levels, but which in reality are very close to each other. As examples of writings about the brain stem at three levels dorsally to ventrally, one study detailed the bridging veins on the tentorial surface of the cerebellum in close proximity dorsally to the lower four cranial nerves. The writing points out the serious risks to those veins and the cerebellum from traction on them when operating in this area (49). At a level a bit more ventrally, Person *et al.* (45) did 59 microdissections of the medullo-spinal junction, noting the great variability of the posterior inferior cerebellar artery in relation to the lower four cranial nerves. They held that the lack of landmarks necessitated complete angiographic studies for each patient to avoid iatrogenic operative injury to these vessels and nerves (45). Work in the dissecting laboratory also illustrates the vagaries of anatomic landmarks (39), reemphasizing the need clinically to be circumspect in identifying as many anatomic relationships as possible for more certain identity. Katsuka *et al.* (18), studying more ventrally at the skull base, described microsurgical anatomy and surgical approaches to the jugular foramen, the exit for the glossopharyngeal, vagus, and spinal accessory nerves. This report complements an earlier detailed study by Lang *et al.* (50).

Vascular or direct nerve compression of the glossopharyngeal in this area with attendant glossopharyngeal neuralgia, attributed to atherosclerosis and architectural changes, may be amenable to surgical relief by decompression (51, 52). Bejjani *et al.* (53), studying still more ventrally, reported on the extradural foraminal exit from the skull base of cranial nerves, among them the lower four and the facial nerve, into the infratemporal fossa. The latter, in their terminology, was the area under the middle fossa of the skull base. They point out that cranial nerves are at risk when exposing neoplasia in this confined and difficult area. As a result, they too point out that important landmarks must be observed to identify relationships of nerves both to each other and to major cerebral vessels before proceeding (53). Another study investigated the relationship of the vertebral artery to the foramen magnum and the upper cervical vertebrae for suboccipital craniectomy (54). In still another study, this one concerning more actual deficiency in cerebral blood supply, Koboyashi *et al.* (55) point out their use of the transverse cervical artery to revascularize the internal carotid artery in two patients.

At the end of the nineteenth century, Quenu and Lejars (56) changed the thinking of the time by stating that "the arterial circulation of nerves is at the same time very rich and very regular". They also described the rich blood supply of the brachial plexus (56). Without specifically mentioning that plexus, they implicated circulatory disturbances, including those from atheromata, as causes of neuralgia, functional disorders, and many vascular accidents of peripheral nerves. A clinico-pathological study nearly a half century ago (57) and a recent study in the anatomical laboratory (39) confirm that the blood supply to the lower four cranial and the cervical nerves, although usually very rich, is not constant. The recent laboratory study also suggested that the deprived blood supply might be the cause of dysfunction, often painful. Parenthetically, the brachial plexus, formed from cervical nerves, is intimately connected with the spinal accessory nerve plexus and its blood supply (1). In the dissecting room, the blood supply to the brachial plexus was observed to be deficient, particularly in older people, mostly from atherosclerotic vessel narrowing or occlusion. This relative ischemia is theorized to be the cause of otherwise unexplained shoulder pain that has been commonly observed in the author's clinical experience. In the laboratory, this ischemia was observed not only in the brachial plexus, but in the lower four cranial nerves as well. In the case of the lower four cranial nerves, neuroforaminal occlusion obstructing blood flow was believed to be the cause of ischemia. In addition, severance of blood vessels at operation may be an iatrogenic cause for ischemia. Logically, ischemia would result in dysfunction. The mechanism may be similar to the generally accepted view that atherosclerosis usually is the cause of a painful ischemic dysfunction in the lower extremity, i.e., intermittent claudication. In the same way, ischemia of the lower four cranial nerves from these causes as suggested by the same anatomic studies (39) theoretically could cause some otherwise unexplained swallowing dysfunction in elderly patients. The mechanism could be by impairing the highly coordinated swallowing mechanism which is dependent on these nerves at the pharyngo-esophageal sphincter (43). These theoretical considerations would be in agreement with observations of others (41, 56, 57). More evidence is needed, however, to conclusively show a clinical correlation between painful ischemic dysfunction of the brachial plexus or of the lower four cranial nerves or swallowing dysfunction and the deficient blood supply observed in our laboratory (39).

Beside the above disadvantage of atherosclerosis, Robbins *et al.* (58) in a recent review article pointed out another hazard from significant carotid artery atherosclerosis, namely, that it increases the chance of stroke with head and neck cancer surgery. Vascular imaging procedures, especially duplex ultrasonography, usually a reliable screening technique to detect such problems preoperatively, may miss a high-grade (80%) internal carotid artery stenosis. This error may occur with a densely calcified carotid bifurcation. Wixon *et al.* (59) term this error the "Gibraltar Sign". In these circumstances, magnetic resonance angiography or selective cerebroangiography are needed to assist in diagnosis (59). Parenthetically, these laboratory and clinical observations give some of the reasons why studies on more ways to impede atherosclerosis are urgently needed.

Interruption of the essential blood supply to the spinal accessory nerve may occur from other causes. Vessels must change caliber to maintain cerebral blood flow with the rise and fall of cerebrospinal fluid pressure because the rigid skull requires the intracranial content to remain constant, i.e., the Monro (1783) Kellie (1824) law (60). In this light, additional study is required of an intriguing but undocumented theory. This theory is based on the fact that vessels in the brain may differ structurally from each other, as for example when they are abnormally large, tortuous, or pulsating or have atheromatous changes (14). These structural differences might account in part for variations in blood supply under changing conditions in the brain. This thesis may well have been part of what Hofmökl had in mind when in 1875 he wrote on the subject of the ratio of blood vessel pressure in the large and small circulations (61). Similarly, it is worth considering the theory that both cellular factors of blood vessels as well as blood flow in the vessels themselves may be important in nerve healing. The evidence that vascular endothelial cells supply trophic and mitogenic factors to injured nerves (62) is one instance illustrating this idea. In fact, recovery of nerve and vessel function in peripheral nerves may be mutually dependent on one another. For example, the nerve's microarteriolar smooth muscle altered reactivity might contribute to vascular disturbances *in vivo* after nerve damage or surgical denervation (63). Specifically, in this review regarding the spinal accessory nerve plexus, the degree of plasticity of the injured central nervous system is probably of critical importance, along with circulation, for its recovery. Plasticity here has the connotation of the capacity of the central nervous system to alter sensory and motor representation. Without this plasticity, the ability to relearn sensibility may be impaired because the central nervous system representation of a recovered injured nerve may differ from that prior to injury (64, 65).

The anatomy of the cervical sympathetic plexus and the operative risks to it (in this review, in surgery involving the spinal accessory nerve plexus) were well documented by Collins in 1991 (23). She pointed out that most of the major risks as, for example, causing a Horner's syndrome from stellate ganglion injury come when operating beneath the deep cervical fascia. In the author's clinical experience, this has seldom been the case in head and neck cancer surgery; but he agrees that exceptions may occur as when deep structures as the carotid artery have been invaded by tumor. It is unclear whether the numbness, pain, and dysesthesia sometimes following surgical neck dissection are also due in part to severance or injury to the cervical sympathetic branches penetrating the deep cervical fascia and connected to the spinal accessory nerve plexus. This question requires further study.

According to Brierley and Field (66), connection of cerebrospinal fluid to cervical lymphatics was first shown by Schwalbe in 1869 (67). Brierley and Field traced researches done in this area up to 1948, including their own work. Even though incompletely understood, the connection of the spinal subarachnoid space to the cervical lymphatics at that time was generally accepted, as was the idea that cervical lymph nodes may be filled with cerebrospinal fluid under physiological conditions (66). The possible routes of metastatic spread of cancer to peripheral nerves from the central nervous system and *vice versa* via the cerebrospinal fluid, as well as the role of cerebrospinal fluid in normal nutrition of nerves, are important topics, but are beyond the scope of this review. Similarly, the entire feedback mechanism involved in cerebrospinal fluid pressure, arterial pressure, baroreceptors, and chemoreceptors discussed by others (68) also are beyond the scope of this review. These latter mechanisms may also have clinical significance, with cerebrospinal fluid pressure changes affecting head and neck lymphatic metastases.

Several papers quoted here, nevertheless, review the literature on the importance of cervical lymphatics in head and neck cancer (69–73). They omit reference to the possible role of cerebrospinal fluid pressures in cervical metastases. These clinical papers also usually do not add appreciably to knowledge of the normal gross anatomy of cervical lymphatics. Perhaps part of the reason for this relative paucity of research is the difficult and painstaking laboratory techniques involved in laboratory dissections (74).

From a clinical perspective, Kraus (69) retrospectively reviewed the incidence of supraspinal accessory lymph node metastases in 47 supraomohyoid neck dissections. He concluded that; 1.) Dissection of these nodes exposed the patient to trapezius muscle paralysis from spinal accessory nerve injury, which could be avoided since 2.) Dissections of those nodes could be safely omitted without changing prognosis since metastatic spread to those nodes is very uncommon. This statement is another indication of the trend toward more conservative surgery when the spinal accessory nerve plexus is involved. Neck dissections other than for cancer, as for example, carotid endarterectomy for atherosclerotic stenosis, also expose the spinal accessory nerve plexus to injury. Fortunately, many injuries to these nerves from stretching or scarring are only temporary (75, 76). Restenosis of the carotid artery also might expose the spinal accessory nerve plexus again to ischemic injury. In this regard, Archie (77) pointed out that applying proper geometric dimensions in reconstruction after carotid endarterectomy is important in preventing restenosis. Also, stretching of the spinal accessory nerve from heavy lifting may injure that nerve. For one patient with a partially torn nerve from such an injury, a cable graft replacing only the torn part of the nerve was reported to give good results (78). Conversely, mixed results have been reported for surgical repair following complete transection of the spinal accessory nerve. Generally, in those circumstances, the repaired nerve either by direct suture or nerve cable graft gives less satisfactory function, often much less, than the nerve gave prior to injury (79–81). The same may be said for shoulder and arm function after muscle transfer performed for patients where nerve repair could not be done or when earlier nerve repair gave unsatisfactory results (82, 83). When the spinal accessory nerve has been transected at the base of the skull, others suggest reinnervation of the trapezius muscle with cervical and thoracic nerves (84). Still others suggest reinnervation of the trapezius muscle with the entire cervical plexus following transection and removal of the spinal accessory nerve (85). When so many different methods for repair are offered, it suggests to the author that no method is completely satisfactory. From the viewpoint of a neurobiologist, a discussion of the few known factors favoring nerve regeneration after repair and the many daunting factors against nerve regeneration may also help to explain these mixed results (86). A recent review of the immunologic response to injury may also give pertinent insights here as to why so many failures occur with nerve repair (87).

The same line of reasoning may be applied to injury and recovery in the central nervous system from the effects of endocrine, systemic, inflammatory, and infectious stimuli on blood-brain communication. Studies of these factors suggest that proinflammatory cytokines released from the myeloid cell lineage on presentation of an antigen set off a cascade of events involving mitogen-activating factor protein, janus kinase/signal transducer, and signaling molecules of vascular-associated cells of the central nervous system. These cells in turn induce fever and autonomic functions to restore homeostasis (88). Experimental evidence for this hypothesis is strong in animals, but more work is needed to establish its exact role clinically.

The Spinal Accessory Nerve Plexus in the Neck With Further Anatomic, Operative and Theoretic Considerations of Its Innervation of the Trapezius and Sternocleidomastoid Muscles

This part of the review will discuss not only anatomic issues, but also methodology, outcome, and possible improvements in cancer operations involving these structures. Many texts also address operative issues with divergent opinions (70, 71, 89).

Animal work as to motor innervation of the trapezius muscle has yielded divided opinions, perhaps due in some measure to species differences. The studies of Ueyama *et al.* (90) in the Japanese monkey, *Macaca fuscata*, and investigations in the cat by Reighard and Jennings (91) and later by Rose *et al.* (92) all indicate that only motoneurons of the spinal accessory nerve innervate the trapezius muscle. Contrary to this, Gurushanthiah's (93) observations would indicate motor innervation both from the spinal accessory and cervical nerves in the Bonnet monkey, *Macaca radiata*.

In humans, the two muscles innervated by the spinal accessory nerve have different embryologic origin. The sternocleidomastoid muscle is branchiomeric, i.e., of branchial arch origin, whereas the trapezius muscle is telomeric, i.e., of somatic origin. A teleological theory states that innervation to the sternocleidomastoid muscle is cranial, and almost always by the spinal accessory nerve. The sternocleidomastoid functions to turn the head, essential to being alerted to danger not coming from directly ahead. The trapezius, on the other hand, does not serve this essential function so that it may be innervated occasionally by a cranial nerve alone (i.e., the spinal accessory nerve), or more commonly by a spectrum of combinations of cranial and cervical nerves, or rarely, by cervical nerves alone. It appears most reasonable anatomically and clinically that this explanation is the correct view of innervation of those two muscles (1, 94).

The anterior rami of the second through fourth cervical nerves of the cervical plexus, in addition to frequently connecting to the branches or trunk of the spinal accessory nerve, may also interconnect with: 1.) Peripheral branches of the trigeminal, facial, glossopharyngeal and hypoglossal nerves. 2.) The brachial plexus; and sensory nerves of the scalp as the great auricular and the greater and lesser occipital nerves. The sensory connections may carry over from this plexus beyond the mid-line of the face and head and also may interconnect with all other cervical nerves. A listing of many of these peripheral connections observed in the anatomy laboratory has been published (1). Cruvielhier in 1871 described a spinal accessory nerve plexus within the trapezius muscle with connections to the posterior divisions of the second through fourth cervical nerves (95). Possibly, fibers from the posterior divisions, which are largely motor, also randomly supply motor fibers to the trapezius muscle, which might be a further anatomic reason for different motor and sensory responses in patients having the same cervical nerves cut in surgical neck dissections.

Identification of the spinal accessory nerve, nevertheless, is not always easy (1, 39). Confirming this view, the late Dr. Narakas, with an extensive experience in reconstruction of brachial plexus injuries (96), told the writer anecdotally that the spinal accessory nerve, even in the correct anatomical position, was not always a reliable source for use as motor reinnervation for the damaged brachial plexus. Regarding this statement, the position of the spinal accessory nerve as it left the posterior border of nine sternocleidomastoid muscles has also been recorded (1). The nerve exited at approximately the mid-point in five, but between the junction of the upper and middle third in four. Absence of the spinal accessory nerve was reported in three subjects dissected in Piersol's experience at the University of Pennsylvania (97). Relatively more commonly in the author's experience as previously stated, the sternocleidomastoid muscle nearly always has solely spinal accessory innervation, but the trapezius muscle may have a wide spectrum from almost all to very little innervation from that nerve (1). Likewise, Soo *et al.* (98) in 1990 wrote that their anatomical, clinical and electrophysiological studies 1–156 months after neck dissections suggested a motor input from the cervical plexus by way of the spinal accessory nerve. In view of these lines of evidence, it is difficult to accept the thesis that motor fibers from the cervical plexus to the trapezius muscle are purely proprioceptive (99). Miyata *et al.* (100) in 1997 again reviewed the controversy in the literature as to whether cervical plexus innervation of the trapezius muscle is purely proprioceptive.

More recently Terzis *et al.* (101) have reported the results of surgical reconstruction of 204 patients with brachial plexus injury and paralysis with overall good to excellent results in 75% using their evaluation system. Sixty-nine of 204 patients had the spinal accessory nerve used as a motor source, so that it was undoubtedly successful in some patients; but the exact number of successful outcomes for this specific nerve is not stated (101). Samardzic *et al.* (102), one year later, reported their use of the spinal accessory nerve to reinnervate the musculocutaneous nerve in 20 patients with brachial plexus avulsion injuries. With their evaluation scale, 13 of 20 patients (65%) had a good functional recovery (102). In this light, one might theorize that failure of a spinal accessory nerve repair after neck dissection injury occurred in some instances because the wrong nerve, a sensory nerve, was repaired; or that more than one injured motor nerve in the spinal accessory nerve plexus should have been repaired.

In using the spinal accessory nerve for reinnervation procedures, some investigators believe that the upper part of the trapezius muscle function may be preserved. To accomplish this end, they recommend severing the spinal accessory nerve distal to where branches innervating the upper trapezius muscle are given off (103). This writer would urge caution in trusting anatomic observation alone in using this technique for preserving upper trapezius muscle function at operation. Intraoperative use of nerve and muscle stimulators has been suggested to help to identify nerves to avoid impairment (71, 104). Even these measurements have not always given results, which are in agreement with each other (100, 104), possibly due to differences in methodology. In support of this latter statement are the electromyographic (EMG) studies of Wiedenbauer and Mortensen done 50 years ago (105). Their studies over separate regions of the trapezius muscle during voluntary movements showed even minor changes in experimental conditions to be associated with considerable variation of activity patterns of individual subjects (105).

Finally, many more factors are known to affect operative outcome and its predictability, only three of which will be cited here. 1.) A recent review of head and neck surgery points out that comorbidity is an important factor in cancer severity staging (73). This information is useful in both planning an operation and in predicting its outcome. 2.) The same review points out that the immune system, with T lymphocyte and monocyte function in particular, is similarly useful (73). 3.) Medical imaging is becoming more and more important in improving operative outcome. For example, by showing precisely where neck masses are located, these studies help to prevent iatrogenic injury to the spinal accessory nerve plexus at operation. These imaging methods include computerized tomography (CT), positron emission tomography with fluorodeoxyglucose (EDG-PET), magnetic resonance imaging (MRI), and ultrasonography. Color flow duplex ultrasonography might be added to this list (73). In some instances, only one imaging method may be used successfully. An example is a report that a 3 × 3 cm paraganglioma at the left carotid artery bifurcation could only be successfully delineated by "color-coded Doppler ultrasonography with power Doppler" (106).

Conclusions

1.) The foregoing review leads to the conclusion that in doing surgical neck dissection, one should avoid removing any nerve, including cervical plexus nerves, each of which may have important sensory as well as motor functions. Especially, the spinal accessory nerve and the mandibular branch of the facial nerve should not be cut because their loss almost always increases morbidity such as functional loss and pain; and, in the case of the facial nerve, unacceptable disfigurement and drooling as well. Furthermore, removal of those two nerves is nearly always unnecessary since, as a rule, their loss does not influence outcome.

2.) The same may be said for leaving structures which had been commonly removed in radical neck dissections in the past, since their removal, too, rarely affects outcome. Those structures no longer commonly removed include the sternocleidomastoid muscle, the internal jugular vein, and even some lymph nodes. Another compelling reason for leaving these structures is that their dissection and removal also increases the risk of iatrogenic injury to the spinal accessory nerve plexus.

3.) Great variability of interconnections within the spinal accessory nerve plexus occurs both intracranially and extracranially. These anatomic findings probably explain at least in part why in different patients functional loss also may be very different when the same parts of the plexus have been removed. Hence, cutting those parts of the plexus in the same location in different patients may give a whole spectrum of impairments from almost none to very severe.

4.) It follows then that the spinal accessory nerve itself need not be cut in some patients for severe impairment to follow. This impairment may occur in the head, neck, shoulder and upper extremity.

5.) Laboratory dissections also strongly suggest that loss of blood vessels to any of the plexus could lead to both sensory and motor impairment such as pain or swallowing dysfunction. Laboratory dissections also suggest that ischemia of the brachial plexus may be one reason for otherwise unexplained shoulder pain in elderly patients which has been commonly observed in the author's personal clinical experience. Even though some clinical evidence would corroborate these theories, more clinical evidence is required for a clinical correlation to be firmly established.

6.) From all of the above, the trend toward more and more conservative surgical neck dissection is indicated in head and neck cancer. Historically, this viewpoint has been confirmed. Over the past century, the more radical dissections not only have made little difference in outcome, but have been shown to increase morbidity greatly.

It is evident that gross and microscopic study continues to be needed to know the anatomy and blood supply of the spinal accessory nerve plexus. Despite centuries of intensive study by learned and capable scholars, many aspects of the anatomy of this structure still remain unknown. More knowledge in this area will assist us in better planning surgical head and neck dissections to improve outcomes; and, even more importantly, to improve our patients' well being and quality of life.

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