Anatomy and Blood Supply of the Lower Four Cranial and Cervical Nerves: Relevance to Surgical Neck Dissection

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Abstract. **This study is a continuation of previous work searching for possible anatomic reasons to explain variable and usually unpredictable postoperative pain and dysfunction after the same nerve losses with similar neck dissection operations. The study consisted of dissections of 19 deceased unpreserved elderly subjects arterially injected with dyed latex. Of the 19 subjects, 14 had brain stem and cervical spinal cord dissections, and all had neck dissections. The findings suggested two possible anatomic reasons for the pain and dysfunction: (i) The intracranial anatomy of the lower four cranial nerves, the glossopharyngeal (IX), the vagus (X), the spinal accessory (XI), and the hypoglossal (XII), was just as variable as the previously reported peripheral spinal accessory nerve plexus; and (ii) Both the intracranial and neck dissections indicated that the blood supply to the lower four cranial and cervical nerves, particularly to the brachial plexus, could be impaired by atherosclerosis and/or neuroforaminal impingement or operative loss. This loss of blood supply theoretically could result in ischemia as another possible cause of postoperative pain and dysfunction. It is concluded that because of the potential importance of each nerve and vessel, often unknown at operation, it is very important to spare as many of them as possible to avoid subsequent painful impairment.** [P.S.E.B.M. 2000, Vol 223:352–361]

The dissection of the nerves is a toilsome and difficult matter for many reasons.—Consequently, I believe that in regard to the very small nerves, a number of anatomists simply follow what they find to be the likeliest and most reasonable course, that of adopting what others have said without having seen the nerves with their own eyes. Many of them have made unsatisfactory statements about them.
–*Galen* (1).

Motor and sensory deficits after head and neck surgery are serious drawbacks to otherwise often successful outcomes (2, 3, 4). One of the most disabling events is loss from the spinal accessory plexus when accompanied by functional loss of the trapezius muscle.

In an earlier report, observed variability in impairment was explained in part because of differences in peripheral connections of the spinal accessory nerve to other cervical and cranial nerves. These connections were found to form a plexus termed the spinal accessory nerve plexus (2). The present study was a continuation of that work to look for further possible anatomic reasons. This study was of: (i) the intracranial anatomy of the lower four cranial nerves, the glossopharyngeal (IX), the vagus (X), the spinal accessory (XI), and the hypoglossal (XII); and (ii) the blood supply to those nerves and the cervical nerves.

The findings in both of the additional anatomic areas studied, to be presented in the order numbered above, suggested other possible anatomic causes for variable postoperative painful impairment.

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The black and white photographs lose the contrast of color photography, especially between blood vessels and nerves. For persons interested in this contrast, please contact the first author for similar color photographs.

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Figure 1. In this dorsal view after removing the occipital bone and vertebral laminae with their spinous processes the cerebellum obscures the lower four cranial nerves. (1a,1b) Left and right cerebellar hemispheres. (2a,2b) Left and right cerebellar peduncles. (3) Medulla and cervical spinal cord.

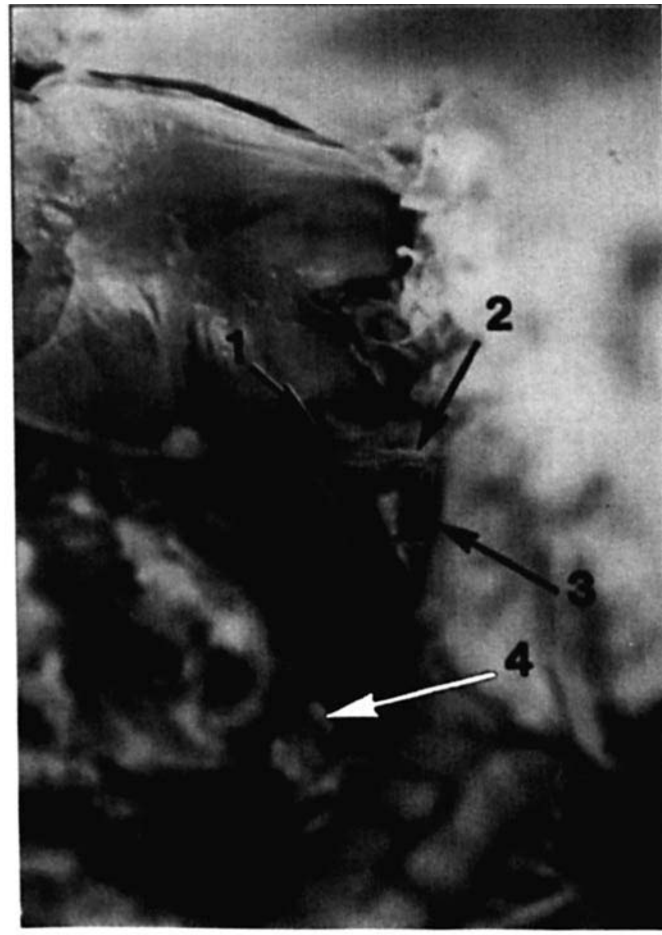

Figure 2. A dorsal view of the left posterior fossa and brain stem. (1) With removal of the cerebellum from its peduncles, the glossopharyngeal, vagus and cranial part of the spinal accessory nerve are seen in a bundle (2) having arisen in a continuous line from the inferior border of the olivary body and accompanied by the artery of Bichat. (3) The hypoglossal nerve is ventral to the other three nerves. (4) The spinal portion of the spinal accessory nerve joins the cranial part at the jugular foramen (1).

Materials and Methods

Gross dissection of deceased subjects using three-power loupe magnification was followed by five- to ten-power dissection microscopy.

Arterial Injection Studies. To identify arteries more accurately and to differentiate them from nerves, head and neck arteries were injected with dye-colored latex in 19 unpreserved, deceased subjects, ages 76 to 95 with an average of 89 years. The brain stem and cervical spinal cord were dissected in 14 subjects, and the neck was dissected in all 19.

The arteries to the lower four cranial and cervical nerves at first glance appeared to be so interrelated as to describe them as a single unit. Studies showed, however, that these arteries at times may become divided physiologically into four individual territories by constriction of vessels (called choke vessels) connecting them (5). Loss or deviation of the arterial supply to any nerve in the living as a result may affect other nerves in another territory at a distance depending on the hemodynamic balance between the territories that in turn determines direction of blood flow, as pointed out by Lasjaunias (6). These physiologically divided territories are: (i) the external carotid territory to cervical and cranial nerves outside the skull in the upper neck and face; (ii) the internal carotid territory to nerves within the skull; (iii) the vertebral arterial territory to the brain stem, including the lower four cranial nerves, the cervical spinal cord, and the first one or two thoracic segments; and (iv) the subclavian arterial territory to the peripheral parts of the lower four cervical nerves, the first and second thoracic, and the cranial nerves in the lower part of the neck.

In deceased subjects, the four territories really do form only one interrelated network since separation by physiologic arterial constriction, of course, does not occur.

Prior to injection subjects had been refrigerated, but were placed in the laboratory for several hours to equilibrate to room temperature. The artery or arteries to be injected were cannulated and gently irrigated with warm detergent solution with a 50-ml syringe until the effluent was clear or until no more would be accepted. Effluent usually was from

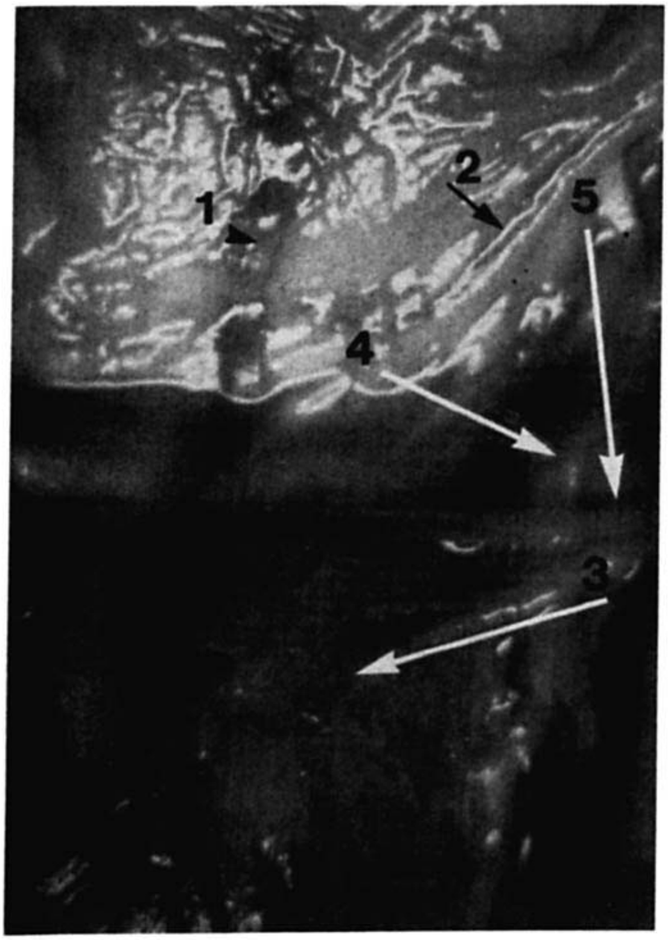

Figure 3. (1) A photomicrograph of this part of the spinal cord shows a latex injected dorsal longitudinal artery; (2, 3) C1 and C2 dorsal roots arising to the reader's right of that artery, each dorsal root having a fine injected dorsal artery accompanying it. (4) At the left border of the photograph is the spinal part of the spinal accessory nerve (5) lying on the dentate ligament between the dorsal and ventral (latter not seen) roots. The trunk of the spinal part of the spinal accessory nerve is substantial here; but it becomes attenuated, thread-like, and adherent to the cord before terminating about C4 or C5 in these subjects. Original magnification: ×5.

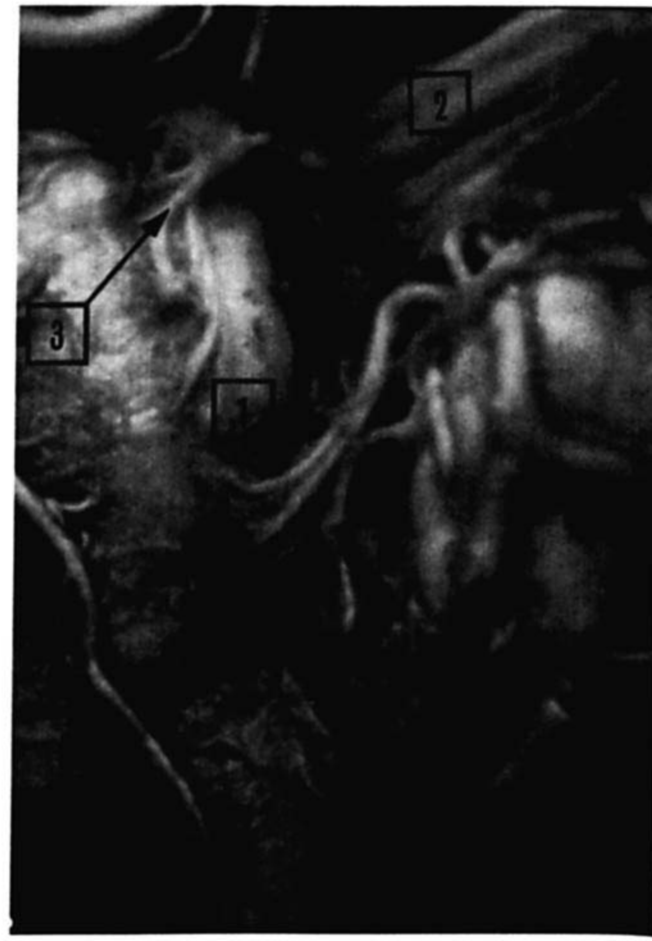

Figure 4. This photomicrograph shows (1) the relation of the olivary body to (2) the superficial origins of the glossopharyngeal, vagus, and cranial portion of the spinal accessory nerves at its dorsal border; and to (3) the hypoglossal nerve at its ventral border. Original magnification: ×5.

a corresponding artery on the opposite side. The dyed latex was filtered through several layers of fine mesh gauze to remove particulate matter, and the filtrate was injected gently again with a 50-ml syringe until the system would accept no more, usually 100 to 500 ml. The smaller amounts were associated with an atheromatous block found in one or more territorial arteries in most of these elderly subjects.

Since all territories are connected, it would be preferable, to inject them all simultaneously *via* only one artery through a catheter tied in place. With this minimal dissection, filling is usually both more efficient and complete because with minimal dissection, less leaking of latex occurs from cut arterial branches. With this principle in mind, for the 14 subjects having both brain stem and neck dissections, four subjects had latex-injected cephalad only through the right common carotid artery and a fifth *via* the left common carotid artery. Such an injection usually filled the external and internal carotid territories well ipsilaterally unless obstructed by atherosclerosis. The ipsilateral vertebral and subclavian arterial territories filled retrograde to varying degrees as did the head and neck arteries on the opposite side, the amounts again being dependent partly on the extent of atherosclerosis. Filling of superficial small skin arteries high on the face such as in the eyelids and forehead was one sign often indicating good arterial filling of the head, but not necessarily of the neck.

Because of the widespread atherosclerosis, two other subjects were injected *via* both common carotid arteries to try to fill head and neck arteries more completely. Two additional subjects had injections *via* both common carotid as well as brachial or subclavian arteries, the latter being tied distally. One subject was injected through both the right common carotid and the right brachial arteries. Another was injected only through the right subclavian artery near its origin peripherally with the right brachial, left subclavian, and common carotid arteries tied. The rationale was to try to induce better latex perfusion through the right vertebral artery into the vessels of the cervical nerves and brachial plexus. In two of the three final subjects, the arch of the aorta was opened, and the injection was made directly into

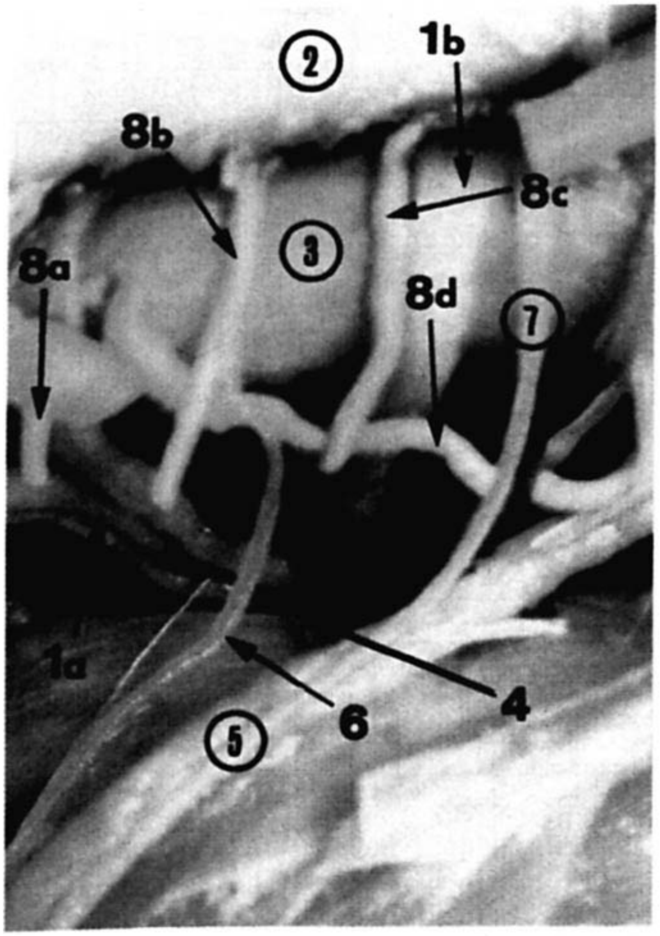

Figure 5. This photomicrograph shows (1a,1b) the rootlets of the hypoglossal nerve arising from beneath (2) the dura and their superficial brain stem origins then winding about (3) the vertebral artery before leaving the skull base through (4) the hypoglossal foramen. (5) The spinal portion of the spinal accessory nerve is joined by (6, 7) rootlets from the hypoglossal nerve. (8a, 8b, 8c, 8d) Note the plexus of small arteries that richly supplies the lower four cranial nerves. Original magnification: ×5.

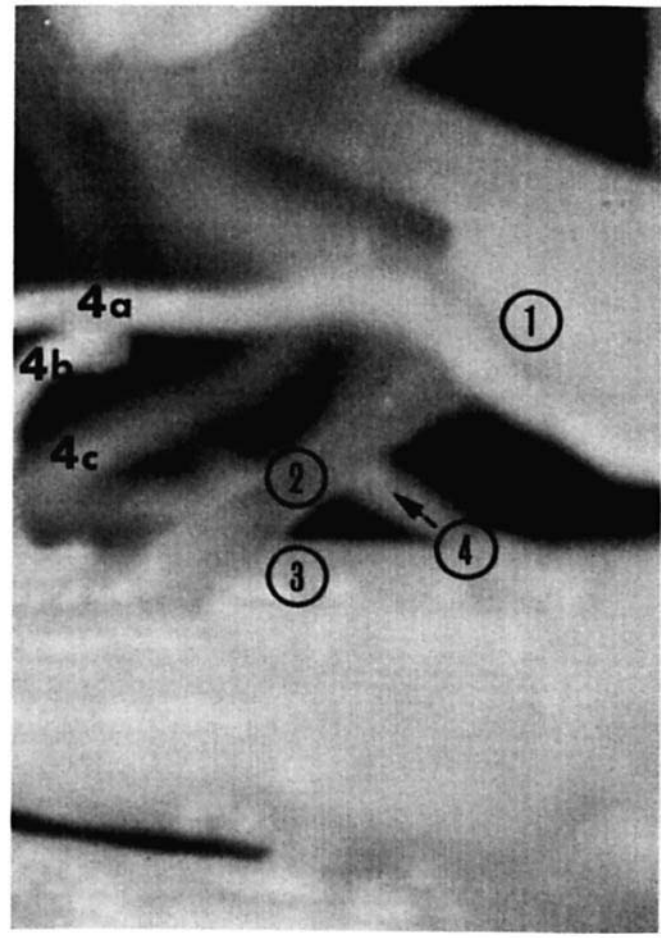

Figure 6. The glossopharyngeal and vagus nerves have been teased apart from their position in a bundle arising from the dorsal border of the olivary body (See Figs. 2 & 4). (1) The glossopharyngeal has (2) a rootlet here connecting with (3) the vagus. (4a) The artery of Bichat has (4, 4b, 4c) several branches including (4) one passing under (2) the connecting rootlet branch between the nerves. Original magnification: ×5.

the (right) brachiocephalic and left common carotid and subclavian arteries, with one having the carotid arteries tied for the same reason as above. In the last subject, the right and left brachial arteries were injected whereas, the brachiocephalic, left carotid, and left subclavian were injected intrathoracically without opening the aorta.

For the final five subjects, who had only neck dissections, three were injected *via* the left carotid; one *via* both carotid and both subclavian; and one *via* both carotids, the left axillary, and the left subclavian arteries.

By injecting latex *via* these various routes outlined, good filling occurred in each of the four arterial territories in one or another of these subjects (see Results section). About 0.1 mm was the smallest diameter of any artery filling with latex. Latex generally filled fine intrinsic arteries well intracranially but less so peripherally.

Usually it was not possible to complete dissections of fresh materials in a timely fashion because of tissue decomposition. For that reason most of the material was placed in formalin as the dissection progressed. Partial clearing of tissues was done before fixation for dissection microscopy in three subjects. The material was immersed in glycerol, phenol, and gelatin solution at 37°C to clear for days to weeks depending on tissue density according to the method of Hidden and dos Santos as modified from Spalteholtz (7, 8).

Results

The lower four cranial nerves were not seen on opening the occiput and cervical vertebrae (Fig. 1) until the cerebellum covering and lying in very close proximity had been removed (Figs. 2 & 8). For orientation some details of the anatomy of the origins of the spinal portion of the spinal accessory nerve are also shown in Figures 3 and 8.

Superficial Brain Stem Origins for the Lower Four Cranial Nerves and Their Emergence into the Neck. Cranial nerves by custom have two central origins: (i) a superficial origin; and (ii) a deep origin (9). The superficial origin is the point at which the nerve is attached to the surface of the brain. This origin as a rule is identified

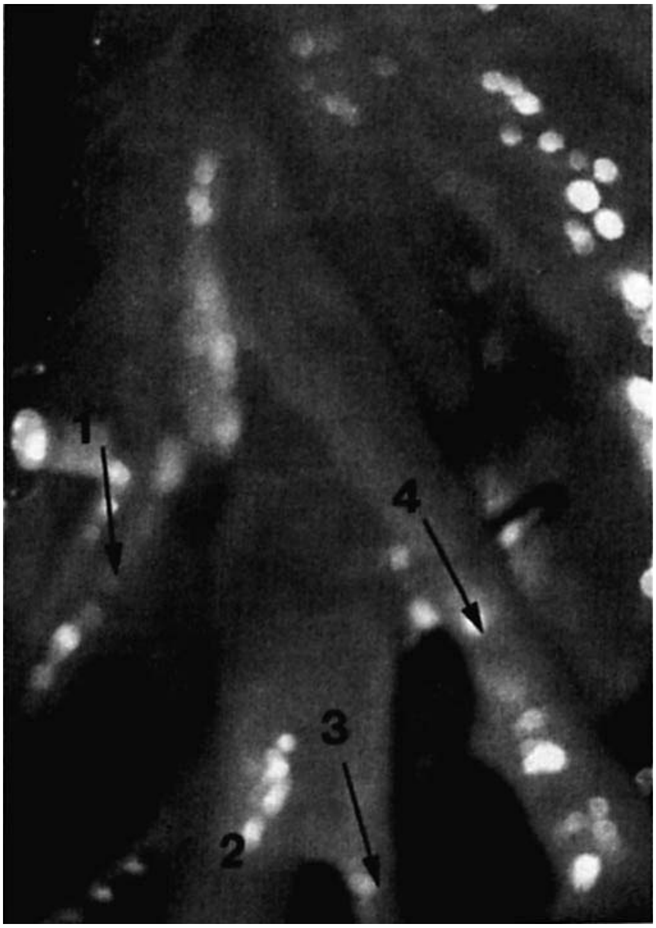

Figure 7. This figure shows the lower four cranial nerves emerging from the right skull base just a little below and posterior to the pinna of the ear. The individual nerves are encased in fatty areolar tissue as well as their own epineurium making distinct separation into individual trunks difficult, as Galen (1) observed. Further distally they separate to become (1) the spinal accessory, (2) the vagus, (3) the glossopharyngeal, and (4) the hypoglossal nerves. Original magnification: ×5.

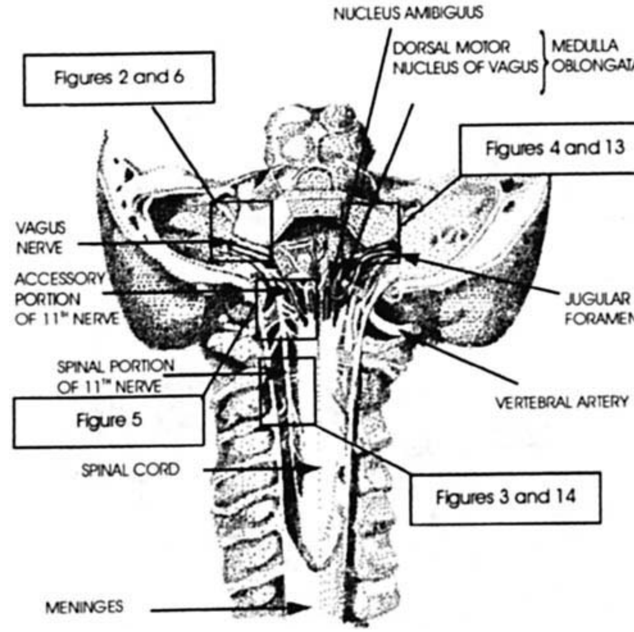

Figure 8. This schematic drawing is of the interior of the posterior cranial fossa and cervical vertebral column. The cerebellum has been removed exposing the brain stem in continuity with the spinal cord. Anatomic location of some of the figures mentioned in the text has been indicated for better orientation. (Reproduced by permission as modified from figure 1 (2).)

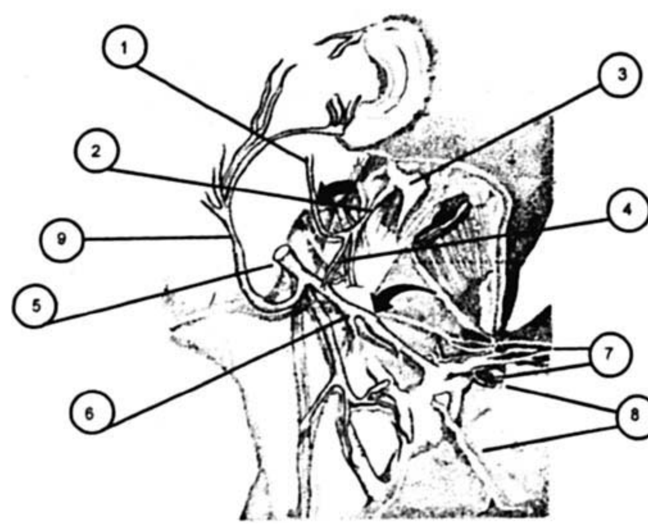

Figure 9. Dissection of a preserved middle aged male subject indicates that a large acromial branch of the cervical plexus is the principle innervation to the trapezius muscle. (1, 2) (upper, heavy, short black arrow) The spinal accessory nerve terminates mainly in (3) the substance of the sternomastoid muscle, here transected and reflected upward. (4) A small spinal accessory nerve branch connects to (5, 6) (lower black arrow) the large acromial branch of (7) the cervical plexus that arborizes in the substance of (8) the trapezius muscle. The nerves are drawn in their relative size and calibre, but are larger than actual size to emphasize their location.

macroscopically. The deep origin is the more or less deeply situated collection of cells termed nuclei with which the cranial nerve fibers are directly related. The deep origin is usually identified microscopically. This study was principally concerned with the superficial origins.

Rootlets of the cranial part of the spinal accessory as well as rootlets of the vagus and glossopharyngeal nerves arose from the brain stem in a flat bundle at the dorsal border of the olivary body (Figs. 2, 4, & 8). This arrangement may reflect the deep origin of all three nerves from common brain stem nuclei, a large part being the nucleus ambiguous of the vagus nerve (Fig. 8). Rootlets and their branches were very difficult to count accurately even after formalin fixation as they were very fragile and tightly packed in small areas among other very fragile structures. It was equally difficult to know precisely where one group of a particular nerve ended and rootlets for another nerve began. Also, each of the larger-diameter rootlets counted may have been a bundle of more than one. Consequently, the numbers of rootlets counted in this study were only approximations ranging from 18–28 total for the three nerves. Examples of numbers of rootlets for each of the glossopharyngeal, vagus, and spinal accessory nerves were 3, 17, and 3, respectively, in one subject; and 3, 11, and 6 in another. Both examples were similar to ranges reported in the literature (10, 11). Rootlets of the hypoglossal nerve arising from

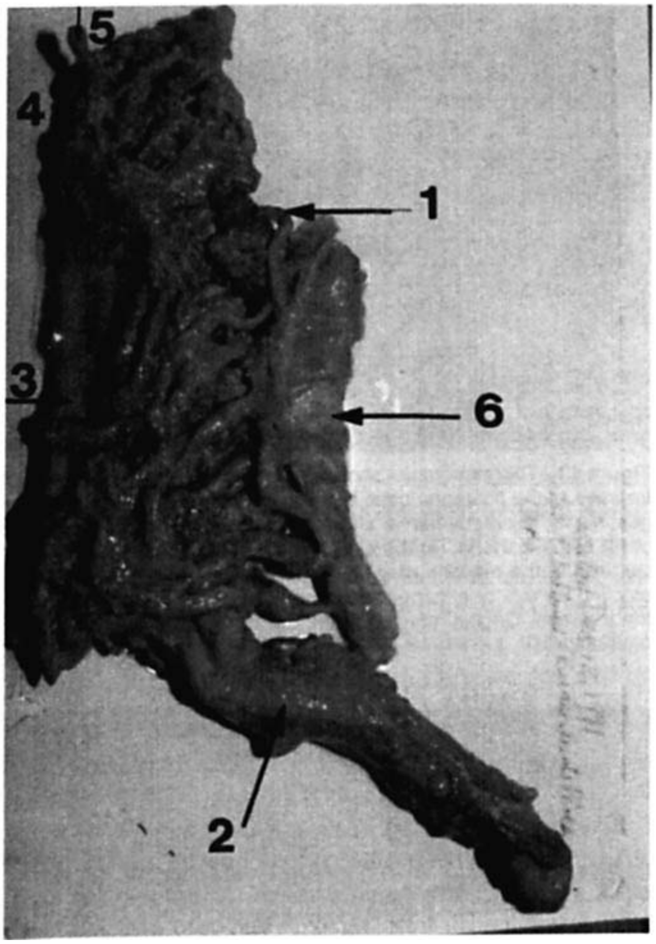

Figure 10. This red latex-injected composite dissection from the left neck includes the four arterial territories supplying the cervical portion of the lower four cranial and cervical nerves: (1) The vertebral; (2) the subclavian; (3) the common carotid artery; (4) the external carotid; and (5) the internal carotid. Also labeled is (6) the cervical spinal cord with cervical nerves arising from it.

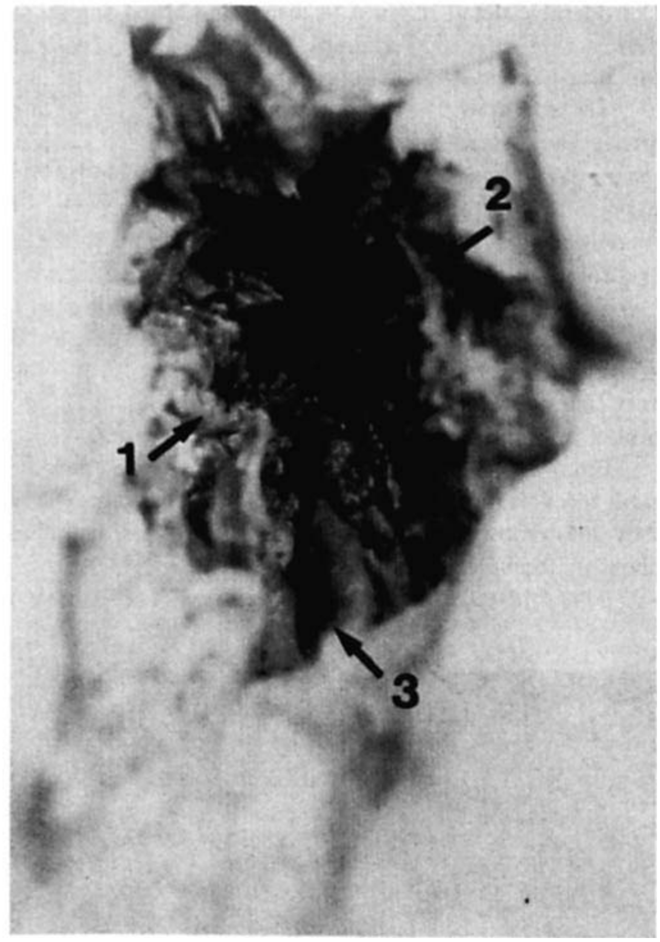

Figure 11. In this view the left angle of the mandible has been removed. The arteries beneath have been exposed by dissecting away much neck tissue. (1) The latex-injected superior thyroid and (2) external maxillary arteries are two of the large branches of (3) the external carotid artery from which many small branches supply the lower four cranial nerves between the skull base and the common carotid artery bifurcation. Most of the small branches have been cut away to expose the large arteries.

the ventral border of the olivary body had equally variable numbers ranging from 6–13 (Figs. 4 & 8). The course of the hypoglossal nerve differs from the glossopharyngeal, the vagus, and the spinal accessory nerves in that the hypoglossal winds about the vertebral artery circumference as it leaves its superficial origins at the ventral border of the olivary body *en route* to the hypoglossal foramen (Figs. 5 & 8).

Two further observations were made from the dissections concerning rootlet branching and how the four nerves emerged from the skull. Rootlets within a given area may branch and join adjacent rootlets of the same or other nerves. These interconnections are detailed here because they are not commonly found in anatomy texts, even though they undoubtedly have been recorded many times over the centuries of anatomic studies. In one subject, for example, a branch from the glossopharyngeal joined the vagus nerve before they separated into their individual trunks (Figs. 6 & 8). In another subject rootlets of the glossopharyngeal, vagus, and spinal accessory nerves connected with each other at the level of the jugular foramen, the glossopharyngeal, and the vagus just rostrally and the vagus and spinal accessory just caudally to the foramen. Great care must be taken during dissection to avoid tearing and hence not seeing these very fragile connecting branches. Thus, the composition of the intracranial part of the lower four cranial nerves in these 14 subjects was variable, just as was the previously reported peripheral spinal accessory nerve plexus (Fig. 9) (2). This intracranial variability suggests another possible anatomic reason for unpredictability of impairment from spinal accessory nerve injury.

These rootlets usually form four nerve trunks that leave the skull from the jugular and hypoglossal foramina close together. Immediately below the skull base they are in a common connective tissue sheath that could be mistaken for a single nerve trunk, or at least could make individual nerves difficult to identify (Fig. 7). This configuration is another place for anatomic confusion, as Galen pointed out two millennia ago (1).

Patterns of Blood Supply to the Lower Four Cranial and Cervical Nerves. Figure 10 illustrates a composite dissection of the arteries supplying these nerves.

Considerable detail is given in discussing blood supply to these nerves since most anatomy and surgical texts speak of this blood supply only in general terms.

The external carotid territory. A rich network of fine arterial twigs surrounds the lower four cranial nerves below their exit foramina from the skull base (i.e., the jugular and hypoglossal) to the level of the common carotid artery bifurcation. This network is chiefly from the relatively large branches of the external carotid as, for example, the superior thyroid, the external maxillary, and the occipital (Fig. 11). The ascending pharyngeal artery, the first external carotid branch, accompanies these nerves in this network; but being very fine, the artery probably contributes only a small fraction of arterial blood to them.

From this plexus small arterial branches also enter the skull through the jugular and hypoglossal foramina where they anastomosed with another network of small branches about the brain stem (Fig. 12).

The internal carotid artery territory. The right and left internal carotid arteries form the anterior part of the circle of Willis (circulus arteriosus). Posteriorly their right and left communicating branches join to form the basilar artery. The latter distally separates again into the right and left vertebral arteries. Collectively all of these arteries supply most of the intracranial structures. Hence, loss of even part of an internal carotid territory may lead to weakness or total loss of function of a considerable part of the brain. As a rule, in subjects dissected for this study, the circle of Willis itself filled well with latex, but this was not always true for the plexus of small arteries supplying the lower four cranial nerves. One reason was believed to be due to stenosis of their exit foramina. For example, heaped up bony hard fatty gritty material encroached on and stenosed the lumina of the jugular foramina in two subjects. No latex

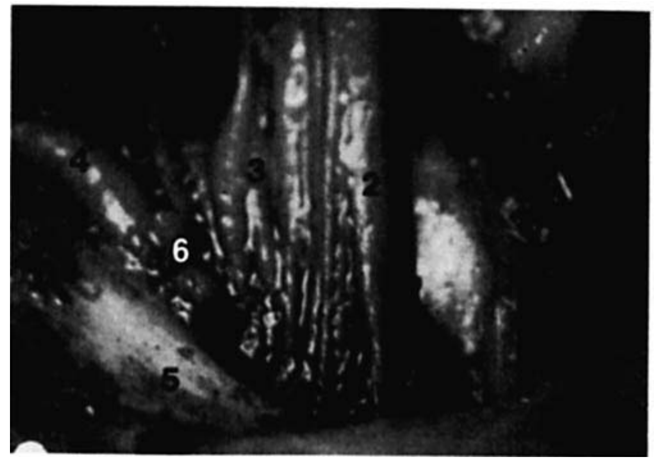

Figure 13. This intracranial photomicrograph shows the right jugular foramen of the posterior fossa in a subject whose (1) glossopharyngeal nerve, (2) vagus nerve, and spinal accessory nerve, (3) cranial or (4) spinal parts, at (5) the jugular foramen have no injected arteries. In part the reasons may be atherosclerosis as well as (6) constricting hard fatty mineralized concretions about the nerves within the foramen. Original magnification: ×5. See Figure 8 for anatomic orientation.

Figure 12. This photomicrograph shows how arteries accompanying nerves intracranially as seen in Figures 2 and 6 may continue with those nerves extracranially joining intracranial with extracranial networks. (1) The left internal carotid artery entering the skull *via* (2) the carotid foramen has (3) the vagus nerve with (4) the artery of Bichat adherent to it. Both (3) and (4) emerge from the cranium through the jugular foramen, lying very close, ventral, and medial to the artery. Original magnification: ×5.

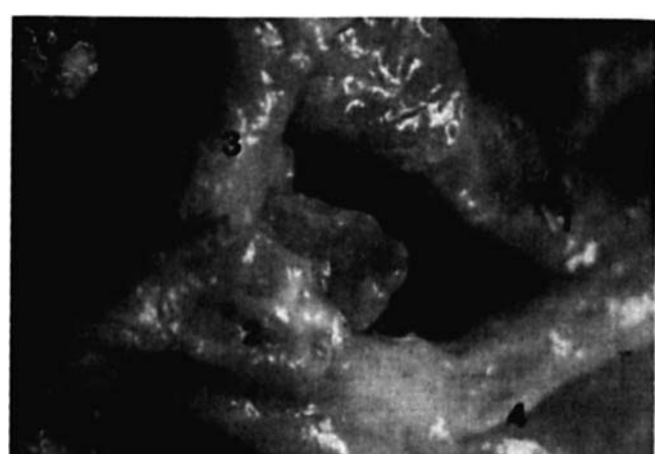

Figure 14. This photomicrograph is of (1) the left dorsal roots of C3 and C4 (2) with injected arteries arising from (3) the vertebral artery and the cervical spinal cord, (4) here covered by meninges. Original magnification: ×5. See Figure 8 for anatomic orientation.

injected arteries were found accompanying these nerves as they traversed these foramina (Fig. 13). As with spinal nerves, foraminal stenosis here would also be expected to impair by nerve and vessel constriction.

The vertebral artery territory. The vertebral artery is the first branch of the subclavian artery. Many of the rootlets comprising superficial spinal cord origins of cervical nerves had small accompanying arteries joining a well-injected vertebral artery to the longitudinal, dorsal, or ventral spinal cord arteries (Figs. 3 & 14). Not every spinal root had an accompanying extrinsic artery.

C5-8 and T1 brachial plexus roots, lying below the deep cervical fascia had varying numbers of latex-containing arteries. They usually filled retrograde just from a common carotid artery injection alone, as did the arteries in the posterior cervical triangle superficial to the deep fascia. More peripherally, filling, almost entirely *via* the subclavian arterial branches, was much less constant (Figs. 15–19). The least latex perfusion of structures studied in these elderly subjects occurred in about 10 cm of the brachial plexus in the neck between the trunks and acromial artery (Fig. 19). Here, the poor latex perfusion was attributed largely to extensive atherosclerosis. This paucity of vessels suggested ischemia as a cause for pain and other sensory and motor dysfunction in the brachial plexus distribution either from atherosclerosis and/or operative loss or foraminal stenosis. This now theoretical assumption would agree with a much earlier report of intermittent upper extremity motor and sensory impairment associated with an atheromatous block of the vertebral arteries, the right carotid sinus, and spondylosis for two years prior to fatal cerebral infraction (12). As injectable image-enhancing polymers for magnetic resonance imaging (MRI) with half-lives of hours, now used to study fine vessels only in animals (13), become available for human use, clinical studies with them may also corroborate and extend our present laboratory-based assumption.

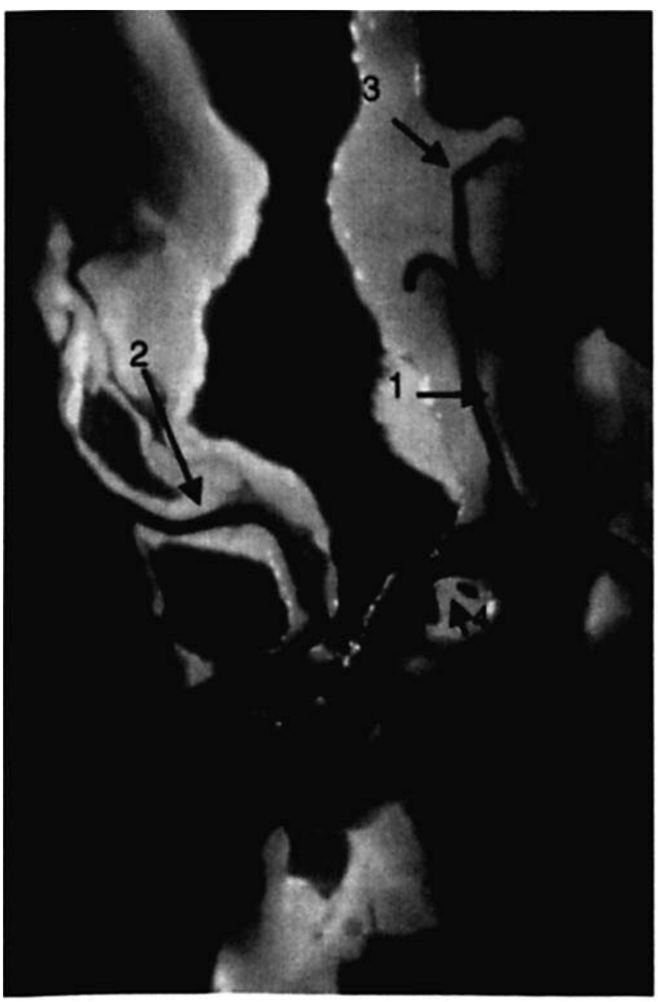

Figure 15. This photomicrograph of a partially cleared specimen taken with reflected light shows (1) the spinal accessory nerve with (2, 3, 4) accompanying arteries. A large number of branches of the surrounding arterial network were cut away to show the nerve. Original magnification: ×10.

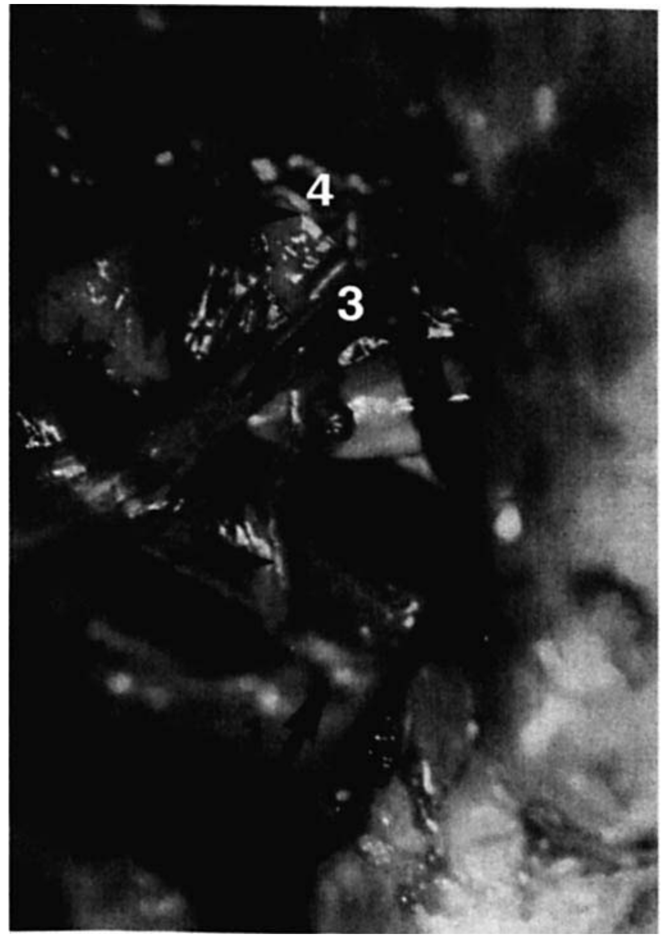

Figure 16. In this left neck dissection, extrinsic arteries to the brachial plexus trunks are shown. (1, 2, 4) Lower, middle, and upper trunks are overlain by (3) the omohyoid muscle. Original magnification: ×5.

The subclavian artery territory. Cervical nerves were supplied directly from the subclavian artery as well as indirectly through its branches as the transverse cervical, thyrocervical, and ascending cervical. These branches also richly supplied the superficial nerves (i.e., those above the deep cervical fascia of the posterior cervical triangle includ-

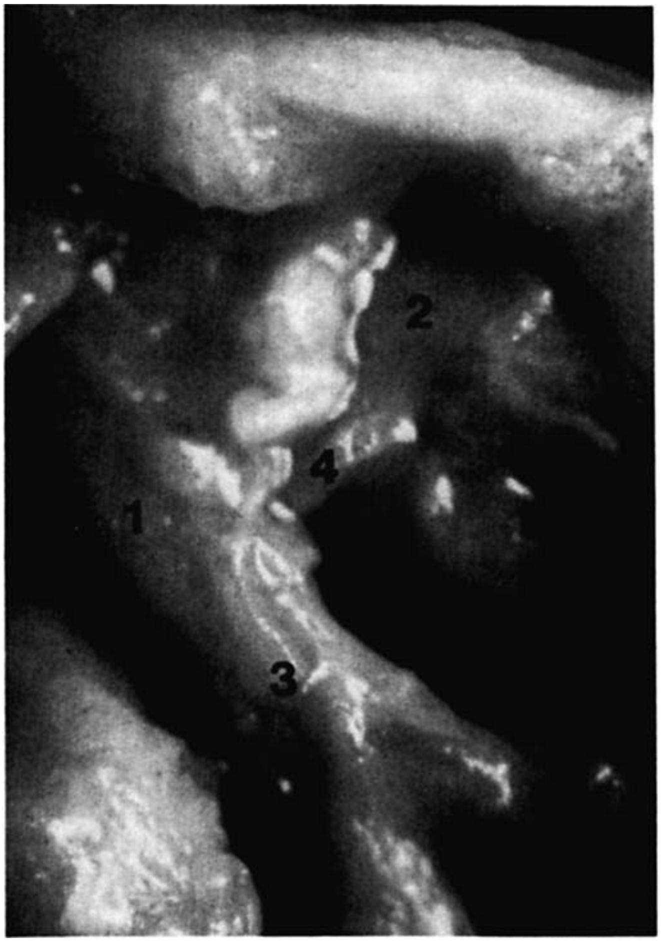

Figure 17. In this photomicrograph of a left neck dissection (1) the upper and (2) middle brachial plexus trunks are shown with (just distal to 3) injected extrinsic and (4) intrinsic arteries. Original magnification: ×5.

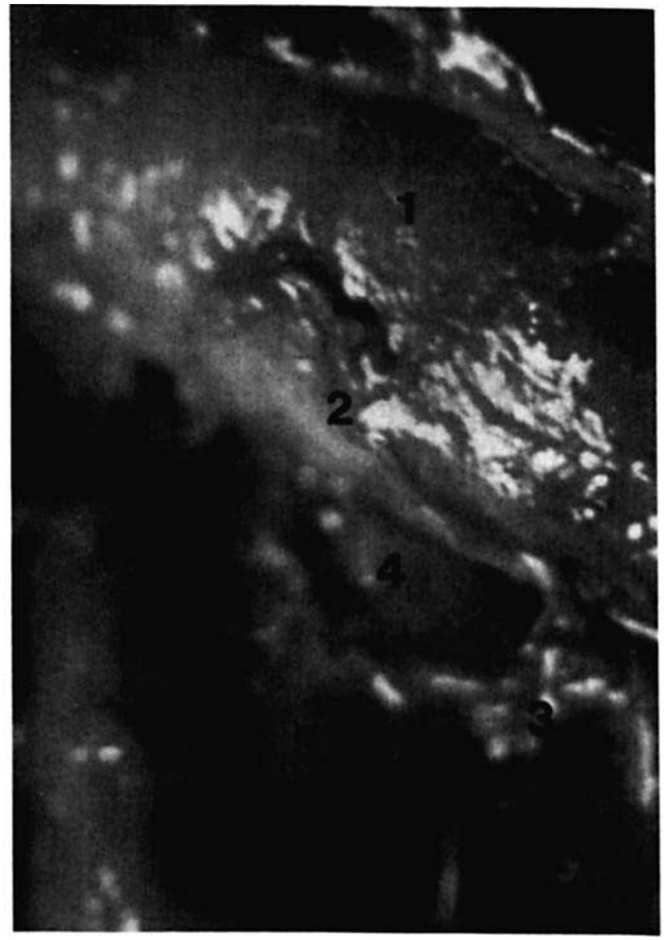

Figure 18. This photomicrograph shows that (1) the subclavian artery has (2) a small latex-injected branch (3) proceeding (4) into the surrounding fat (5) and middle trunk of the brachial plexus. Original magnification: ×5.

ing the cervical plexus (C2-4)) and the spinal accessory nerve plexus (Fig. 15). When the subclavian arterial territory was open, latex also flowed *via* one or more of its larger-named branches to the brachial plexus. With an atherosclerotic block of these larger vessels, some latex either perfused in small amounts through smaller unnamed vessels, or with complete block, did not perfuse at all (Fig. 19).

Discussion

Anatomy texts illustrate that body systems follow general principles of structure and function. This study confirms one such principle, namely that even though the lower four cranial and cervical nerves arise and interconnect in many different ways, we know from clinical experience that they nearly always and predictably have, as a group, the same overall function.

As others have formerly noted (14), relatively few references to the blood supply of the brachial plexus are found in the literature. A rich vasculature to the plexus, however, was reported in 1892 (15). More recently Klaus *et al.* (16) showed a rich extrinsic and intrinsic blood supply in the older fetal brachial plexus confirming the 1967 studies of

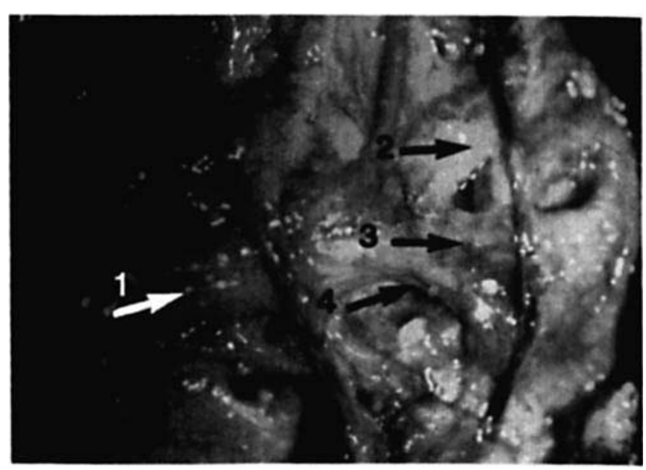

Figure 19. Few blood-filled, but no latex-filled arteries are seen in this segment of (1) the brachial plexus between the level of the acromial artery laterally and (2) the upper, (3) middle, and (4) lower brachial plexus trunks medially.

Bowden, Abdullah, and Gooding in both the fetus and adult (17). The staining and injection methods of these investigators may have permitted demonstration of finer vessels than using latex alone. In preliminary experiments we, too, were able to fill some of these very fine intrinsic and extrinsic vessels in brachial plexus roots by injecting dilute blue-dyed polystyrene in acetone or polyvinyl acetate in ethanol and acetone directly into the subclavian or vertebral arteries, but no filling occurred if these vessels were blocked by atheromata, as was common in our subjects.

The dissections identifying arteries supplying nerves in the neck also reaffirmed previous anatomical findings (2) (i.e., those suggesting that cutting cervical nerves may be correlated with extensive motor impairment of the trapezius muscle without the spinal accessory nerve being damaged as Figure 9 exemplifies). In that dissection the cervical plexus *via* its acromial branch mainly supplies the trapezius.

As already pointed out, it is probable that the head and neck neural and arterial anatomy reported here were well known to former classical anatomists, but were omitted from standard texts both due to space limitations and their clinical irrelevance and unimportance at the time. However, knowledge of these impairments is needed now to predict outcomes following head and neck operations, trauma, and disease. Unfortunately, which functions might be affected by deletion of specific arteries and nerves in the individual patient remains only speculative because of individual variability. Physiologic functional nerve testing before deletion for each patient at operation, as well as testing head, neck, and upper extremity function postoperatively, may be helpful in giving answers.

In view of the potential and often unknown importance of each nerve and vessel, every effort should be made during surgical neck dissection to spare these structures to avoid postoperative impairment.

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