HORACIC outlet syndrome is perhaps the most controversial and therapeutically challenging compression neuropathy encountered by the neurosurgeon. Although it is generally accepted that TOS is caused by compression of either the subclavian vessels or the brachial plexus as they pass from the root of the neck toward the axilla, there is considerable disagreement among clinicians regarding its diagnostic criteria and optimal treatment.

In considering the various causes of TOS, it is important to visualize the regional anatomy. The neurovascular bundle, which contains the brachial plexus trunks and the subclavian vessels, courses through 3 narrow passageways from the root of the neck toward the axilla: the most proximal, the interscalene triangle, which is bordered by the anterior scalene muscle anteriorly, the middle scalene muscle posteriorly, and the medial surface of the first rib inferiorly. This triangle contains the trunks of the brachial plexus and the subclavian artery. This already confined passageway may become further constricted by anomalous structures such as fibrous bands, variable muscles, and cervical...
ribs. Although cervical ribs are rare, occurring in only 0.5–1% of the population, they have been shown to have a role in the pathogenesis of some cases of TOS, particularly neurogenic TOS.14 Although this association has been established, to the best of our knowledge, no report exists in which authors have demonstrated the histopathological changes in the neural elements of the brachial plexus as a result of cervical rib compression (Fig. 1). The aim of our study was to explore the histological changes of the lower trunk of the brachial plexus in cadavers identified as harboring cervical ribs and to discuss their possible relationship to neurogenic TOS.

Materials and Methods

Four hundred seventy-five consecutive human cadavers (230 male and 245 females, age range 49–104 years, mean 77 years) were evaluated for the presence of cervical ribs. From this cohort, 2 male specimens (0.42%) were identified that harbored cervical ribs. One of the cadavers (that of a man 69 years of age at the time of death) was found to harbor bilateral cervical ribs and the other (that of a man 58 years of age at the time of death) a single right cervical rib (Figs. 2 and 3). One of these individuals had died of myocardial infarction and the other of colon cancer. There was no known history of brachial plexopathy. Following gross observations of the brachial plexus and, specifically, the lower trunk and its relationship to the cervical rib, the lower trunks were submitted for immunohistochemical analysis. The specimens were compared with 2 age-matched control male cadavers without cervical ribs. Tissue samples were routinely processed and embedded in paraffin. Sections 5 μm in thickness were stained with H & E, trichrome, Sevier–Munger silver stain, Luxol fast blue, and neurofilament immunohistochemistry.

Results

Grossly, in both specimens with a cervical rib (but not the control specimens), there was mild flattening and deflection of the lower trunk beginning ~ 0.5 cm from the point of merger of the C-8 and T-1 spinal nerves and extending distally for ~ 1 cm over the cervical rib. No atrophy was noted in the muscles supplied by the lower trunk (for example, the ulnarly innervated muscles such as those of the hypothenar eminence).

Histologically, brachial plexus specimens from C-8 and T-1 and the lower trunk areas obtained proximal to the nerve compression caused by the cervical rib and at a similar anatomical location in the control patients were unremarkable (Fig. 4). They had age-appropriate numbers of myelinated axons, no increased intervening fibrous tissue, and lacked inflammatory cell infiltrates.

In the sections of the lower trunk at the site of cervical rib compression, there was a modest increase in fibrosis in the nerve fascicles. The epineurium was thickened with intersecting fibrous bands, and the perineurium appeared fibrotic. Many of the blood vessels were hyalinized. The nerve fascicles contained frequent intraneural collagenous nodules in this area, and focal mucinous degeneration was identified (Figs. 5–7). There was no nerve fiber or myelin loss. Evaluation of sections from similar anatomical locations in the control patients revealed rare intraneural collagenous nodules but no significant epineurial or perineurial fibrosis. There was no myxoid or mucinous degeneration. None of the specimens contained any inflammatory cell infiltrates.

Sections of the lower trunk beyond the regions of compression exhibited mild epineurial and perineurial fibrosis. Occasional axonal spheroids were seen with both Sevier–Munger silver staining and neurofilament immunohistochemistry. Scattered (but fewer) intraneural collagenous nodules were also seen in these sections. There was no nerve fiber or myelin loss. Evaluation of sections of the brachial plexus in control patients obtained from corresponding anatomical locations revealed age-appropriate fibrosis, normal myelinated axons, and only rare intraneurial collagenous nodules.
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Discussion

We evaluated the gross and histological findings of 3 lower trunks of the lower brachial plexus from 3 specimens obtained from 2 cadavers, which were compressed by aberrant cervical ribs, and these data were compared with those obtained in 2 age-matched anatomical controls. The compressed plexus lower trunks were largely unremarkable prior to the areas of compression, where they exhibited epineurial fibrosis, vascular hyalinization, mucinous degeneration, and frequent intraneural collagenous nodules. These histological findings were absent in the control nerve specimens. Similar microscopic findings are seen in specimens obtained in patients with localized interdigital neuritis (Morton neuroma), a dissimilar nonneoplastic localized condition with similar pathophysiology. Localized interdigital neuritis most commonly occurs on the plantar surface of adults and presents as painful point tenderness corresponding to the nerve lesion between the third and fourth toes. However, its cause is thought to be chronic repetitive nerve trauma, as well as ischemia resulting from vascular and perivascular fibrosis. It can be postulated that chronic compression from a cervical rib and subsequent fibrosis, vascular hyalinization, and ischemic damage might likewise have caused similar histological findings in our specimens.

The classic finding in the patient with true neurogenic TOS is the so-called Gilliatt–Sumner hand with the most dramatic degree of atrophy observed in the abductor pollicis brevis, with lesser involvement of the interossei and hypothenar muscles. As predicted, sensory loss is restricted to the ulnar aspect of the hand and forearm, due to the known compression primarily of the lower trunk of the brachial plexus.

As seen in our specimens, a cervical rib is a variation that arises from the transverse process of C-7 (or rarely C-6 and very rarely C-5). In this condition, the thoracic outlet is moved 1 vertebral segment superiorly and the cervical rib takes on all or most of the characteristic features and muscle attachments of a normal T-1 rib. In cases in which there

![Fig. 3. Anterior view of the cadaver with cervical ribs. The right cervical rib (arrow) is shown. Note the lower trunk of the brachial plexus (LT). For reference, the anterior scalene (AS) muscle is seen.](image)

![Fig. 4. Neurofilament immunohistochemical evaluation of a cervical rib specimen proximal to the area of compression near the C-8 spinal nerve’s contribution to the lower trunk. Normal populations of both large and small axons are seen in the nerve fascicles. Original magnification × 220.](image)

![Fig. 5. Photomicrograph of the lower trunk in a specimen with a cervical rib. Note the presence of intraneural collagenous nodules (arrow) that are surrounded by myxoid degenerative material. H & E, original magnification × 110.](image)
is a cervical rib, the lower trunk of the brachial plexus must take the most acute course of the plexus and is thus predisposed to compression and traumatic neuritis.

Although the specific pathophysiological changes in neurogenic TOS have yet to be elucidated, comparative analysis of other compression neuropathies will likely prove useful. In studying the histological changes of radial nerve compression in humans, Mackinnon and colleagues described changes in the perineurium and the endoneurial microvessels as well as the presence of Renaut bodies as the earliest noted histological abnormalities. Nerve fiber disease varied from fascicle to fascicle, and the myelinated and unmyelinated fiber populations responded differently to chronic compression. After studying histological data from induced compression neuropathy in spinal nerve roots, Cornefjord et al. concluded that axonal injury cannot alone explain the reduction in nerve conduction velocity, and that the morphological basis for the functional changes must be sought at the subcellular level. Using a dog model to study lumbar nerve root compression, Yoshizawa et al. reported that intraradicular edema caused by alteration of the blood–nerve barrier is the most important factor in the nerve root dysfunction due to chronic compression.

Although the presence of a cervical rib or fibrous band has been repeatedly associated with TOS, the presence of these same factors observed in healthy individuals during routine autopsy prompts further exploration to discover the precise mechanisms behind these symptoms. To further complicate the picture, Roos has found that arteriograms and nerve conduction studies generally fail to be of value in establishing accurate diagnoses in these cases. The direct observation of the scalene triangle and its contents, exposed during supraclavicular decompression procedures, helps clarify this confusion. Fibrous bands and persistent adhesions are often visualized and limit the normal movement of the plexus and impose deformation and swelling, adhering it to adjacent structures. According to Ellis, careful resection of perineural adhesions results in the normalization of blood flow in the appropriate dermatomes with resolution of distal vasospasm. The relief of these symptoms and signs of vasospasm following neurolysis implies that they originated from the relevant plexus roots. Based on intraoperative experience, Ellis proposed that brachial plexus roots develop a neurogenically induced inflammation with nerve endings traveling through fibrotic tissue, which provide a cytokine-based mechanism for continued, repetitive neural inflammation without demyelination or frank neuronal death. This would explain the lack of findings on electrodiagnosis or imaging modalities given the small size of the fibrotic lesions.

Despite the fact that we observed no evidence of gross pathological changes such as hypothalamic atrophy in our cadaveric specimens, it is impossible to know if symptoms (for example, paresthesias) existed in life with such actions as abduction of the arm, which would place more tension on the lower trunks of the brachial plexus. Accordingly, one limitation of our study lies with the fact that we are unable to correlate the histopathological changes we observed in the presence or absence of clinical symptoms. That said, considering the similar changes observed by others in known cases of compression neuropathy combined with the established association between cervical ribs and TOS, it seems likely that a correlation does exist.

Conclusions

Cervical ribs found incidentally may be a cause of histological changes to the lower trunk of the brachial plexus. Therefore, the clinician may wish to observe or perform further evaluation in such patients.

References

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