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ORIGINAL COMMUNICATION

Clinical Importance of Ligamentous and Osseous Structures in the Cervical Uncovertebral Foraminal Region

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The vertebral artery, cervical spinal nerves, spinal nerve roots, and the bony and ligamentous tissue related to the cervical vertebrae are structures whose anatomy determines the path of a surgical approach. Defining the anatomy and, in particular, determining the precise location of vulnerable structures at the intervertebral foramen and the uncovertebral foraminal region (UVFR), a region defined by the uncinate process anteriorly, the facet joint posteriorly and the foramen transversarium laterally, has critical significance when selecting the safest surgical approach. We studied the anatomy of the vertebral artery, cervical spinal nerves, and spinal nerve roots within the UVFR in six cadaver specimens. We also obtained measurements of bony structures in 35 dry cervical vertebral columns, from C3–C7. The uncinate process (UP) projects superiorly from the posterolateral aspect of each cervical vertebral body, except for the first and second vertebrae. Because the posterior part of the UP lies adjacent to the vertebral artery, spinal nerve, and spinal nerve roots, its resection creates sufficient space to decompress these structures directly. The posterolateral surface of the UP is covered by ligamentous tissue that originates from the posterior longitudinal ligament and protects the neural and vascular structures during their decompression in the UVFR. Clin. Anat. 16:404–410, 2003. © 2003 Wiley-Liss, Inc.

Key words: cervical spine; anterior cervical discectomy; uncinate process; uncovertebral level; neural foramen; foraminotomy; vertebral artery

INTRODUCTION

Precise knowledge of the anatomy of the cervical uncovertebral foraminal region (UVFR), the area defined by the uncinate process anteriorly, the facet joint posteriorly, and the foramen transversarium laterally (Fig. 1), is essential for safe anterior cervical surgery and to ensure adequate decompression of neural and vascular structures. Although anterior cervical surgery is common for cervical spondylosis and cervical disc disease, few studies address the anatomical relationships in the UVFR (Veleanu, 1975; Pech et al., 1985; Grundy et al., 2000; Ebraheim et al., 1996a,b; Heary et al., 1996; Oh et al., 1996; Pait et al., 1996). The anterior discectomy technique adequately exposes the midline vertebral canal but provides limited exposure of the more lateral UVFR, where direct decompression of neural and vascular structures may be required. If the condition producing radiculopathy, such as an osteophyte, is in the UVFR, the standard anterior cervical approach is not sufficient because of limited exposure due to the posterior part of the uncinate process (UP) (Hakuba, 1976; Jho, 1996; Kumar et al., 1998; Grundy et al., 2000). On occasion, wider exposure and resection of the entire UP is needed for spondylomyeloradiculopathy (Isu et al., 1997; George et al., 1999). The aim of this study was to define the anatomic relationships of the neural, vascular, and ligamentous structures in the UVFR that would be helpful in planning an anterior cervical approach that includes removal of the posterior part of the UP.

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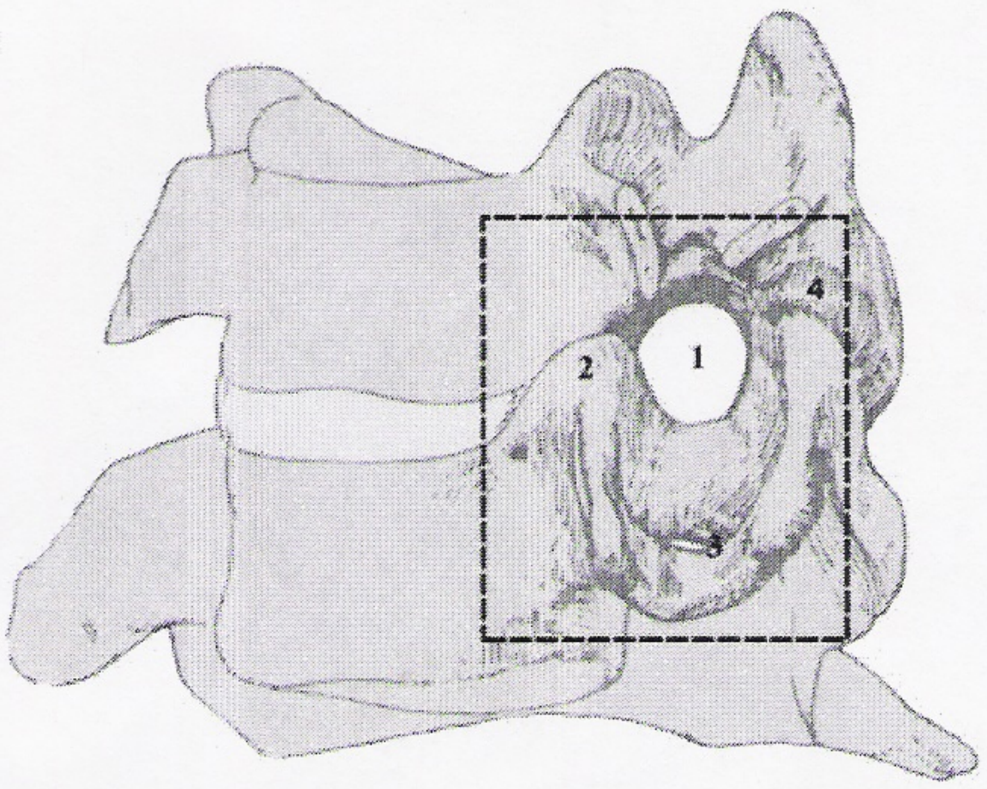

Fig. 1. Lateral view of the uncovertebral foraminal region, the area defined by the uncinate process anteriorly, facet joint posteriorly, and foramen transversarium laterally. 1, intervertebral foramen; 2, uncinate process; 3, foramen transversarium; 4, facet joint.

MATERIALS AND METHODS

Dry Cervical Vertebrae Measurements

In this part of the study we carried out a morphometric analysis on dry cervical vertebrae from the C3–C7 levels (Fig. 2). A total of 175 cervical vertebrae from 35 adult cervical vertebral columns were examined. All specimens were of unknown gender, similarly sized, and without prominent spondyloarthropathic changes. All paired structures were measured on only one side because of apparent symmetry and the mean values calculated. The following measurements were made: greatest height of the UP from its tip to the superior surface of the vertebral body; width of the UP from its medial to lateral surface of the largest part of its base; anteroposterior (AP) length of the UP between its posterior and anterior borders above the superior surface of the vertebral body; AP midline width of the vertebral body in the axial plane; and greatest side-to-side width of the vertebral body between the outer base surfaces of UPs in the axial plane; and the distance between each pair of UPs between their anterior borders. We also measured the minimal length of the posterior part of the UP that needs to be resected for sufficient decompression of the UVFR; these measurements were based on the minimal length of uncusectomy necessary for full foraminotomy. All measurements were obtained using an electronic digital caliper. The difference in various parameters was analyzed with a Student's *t*-test and significant difference was determined to be $P \leq 0.05$.

Cadaveric Microsurgical Dissections

In the second part of the study, six formalin-fixed cadaveric cervical spines were dissected from vertebral levels C3–C7. All cadavers were male and between 50 and 60 years of age. Dissection was carried out under 4× magnification with an operating microscope (Zeiss, Opmi 6, Germany). The longus colli muscles were reflected and an anterior cervical discectomy carried out. The medial walls of the UPs and the posterolateral corners of the vertebral bodies were brought into direct vision. Bilaterally, the posterolateral portions of the vertebral body edge and UPs were drilled to obtain an anteromedial approach to the UVFRs. The anterior surface of the posterior longitudinal ligament (PLL) was exposed along its posterolateral turns on the vertebral body and carefully dissected. The PLL was then partially excised to study its relationship to the vertebral artery, spinal nerve, nerve roots, and other ligamentous structures in the UVFRs. Subsequently, the PLL was completely opened to explore the epidural space, spinal nerve, and nerve roots (Fig. 3). Finally, the vertebral artery and its associated venous plexus were displayed (Fig. 4).

RESULTS

Dry Cervical Vertebrae Measurements

The measurements for cervical vertebrae C3–C7 are shown in Table 1. Measurements for each vertebra show minor variations; however, differences were not statistically significant. The greatest UP height in-

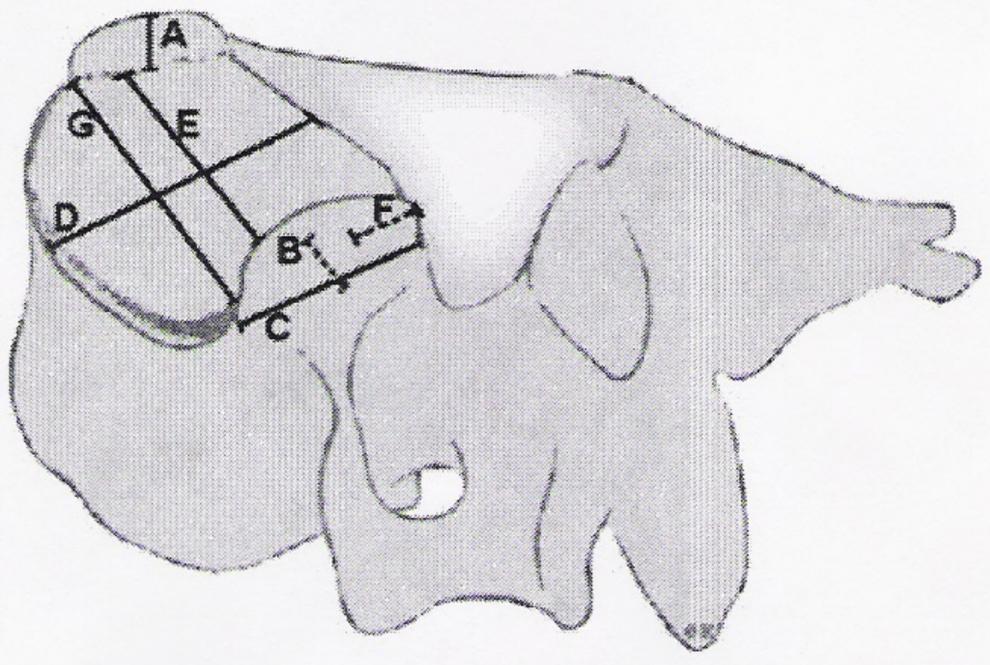

Fig. 2. Schematic illustration of the measurements taken on dry cervical vertebrae. **A:** Greatest height of uncinate process (UP). **B:** Greatest width of UP. **C:** Length of UP. **D:** AP midline width of vertebral body. **E:** Greatest side-to-side width of vertebral body between the outer base surfaces of UPs. **F:** Minimal length of UP resected during uncusectomy for full foraminotomy and decompression of uncovertebral foraminal region. **G:** Distance between anterior borders of UPs.

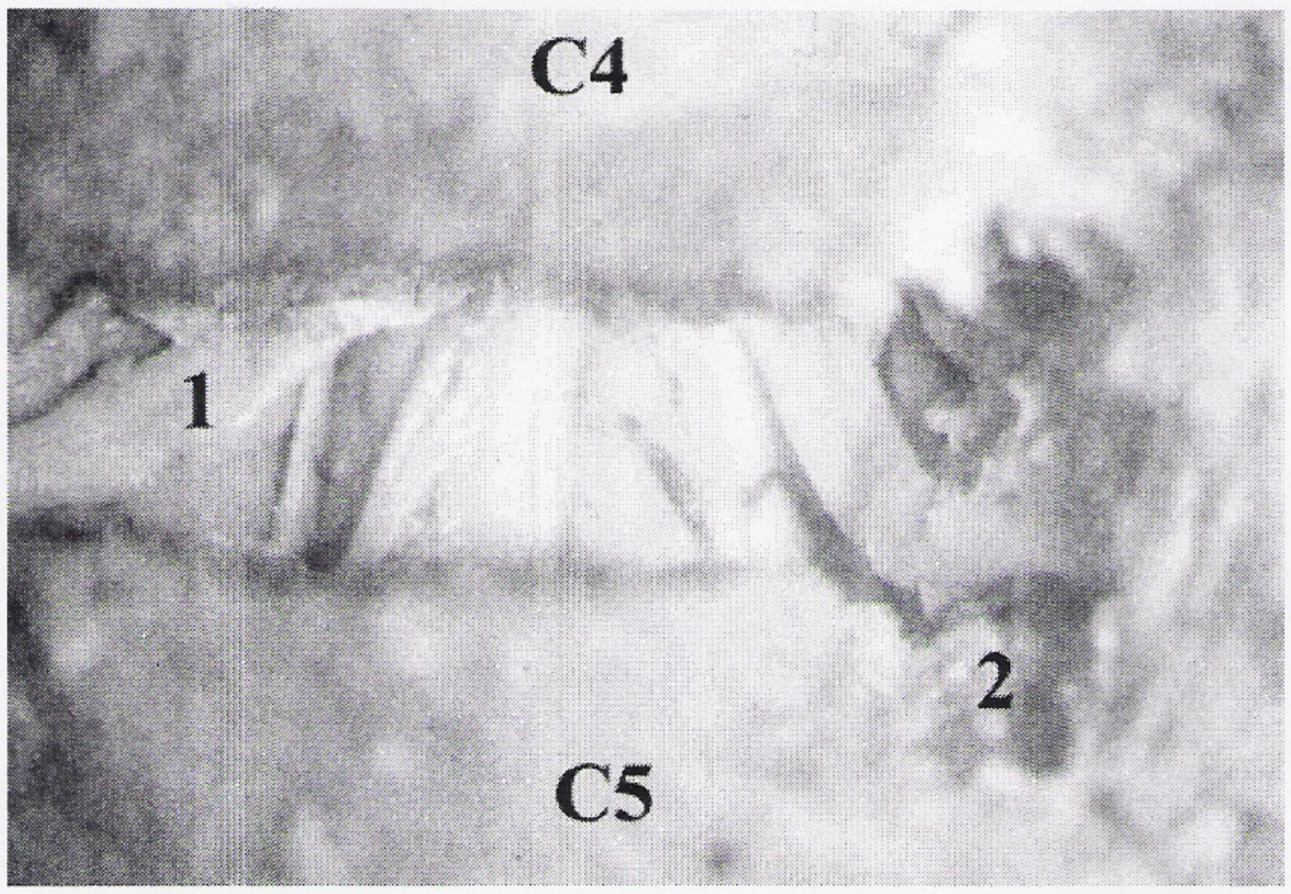

Fig. 3. Anterior view of the spinal cord and spinal nerve roots after anterior discectomy, total bilateral uncusectomy, and wide drilling of a posterolateral corner of the superior surface of the vertebral body. The posterior longitudinal ligament and dura mater were excised to expose the spinal nerve roots in the uncovertebral foraminal region. 1, spinal nerve roots; 2, site of extensive uncusectomy.

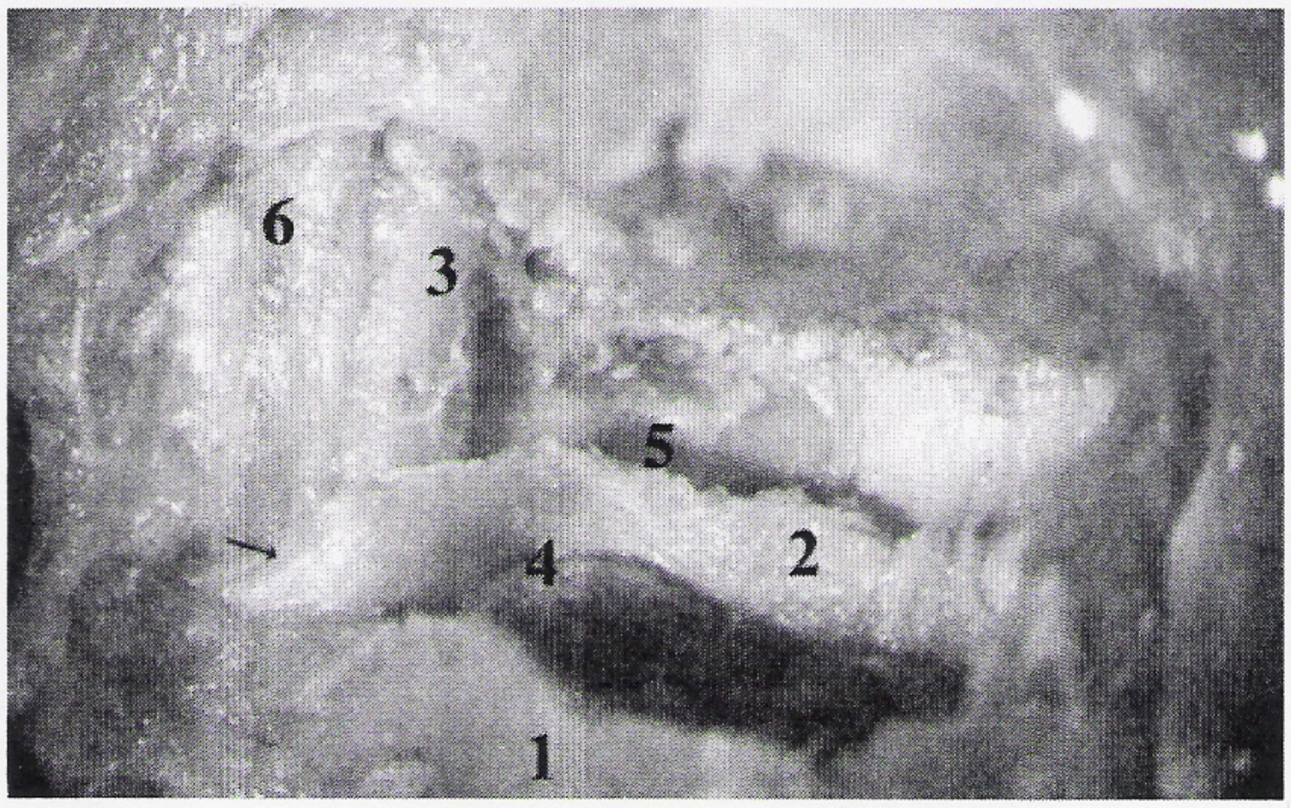

Fig. 4. Anterolateral view of neurovascular structures in the right uncovertebral foraminal region after partial removal of the uncinate process (UP) and posterior longitudinal ligament (PLL). The PLL makes a right angle at the posterior edge of the UP. An extension of the PLL covers the lateral aspect of the UP and protects the vertebral vessels. We termed this extension of the PLL perivascular ligamentous tissue (arrow). 1, anterior longitudinal ligament; 2, PLL; 3, vertebral artery; 4, posterior part of UP; 5, spinal nerve roots; 6, vertebral vein.

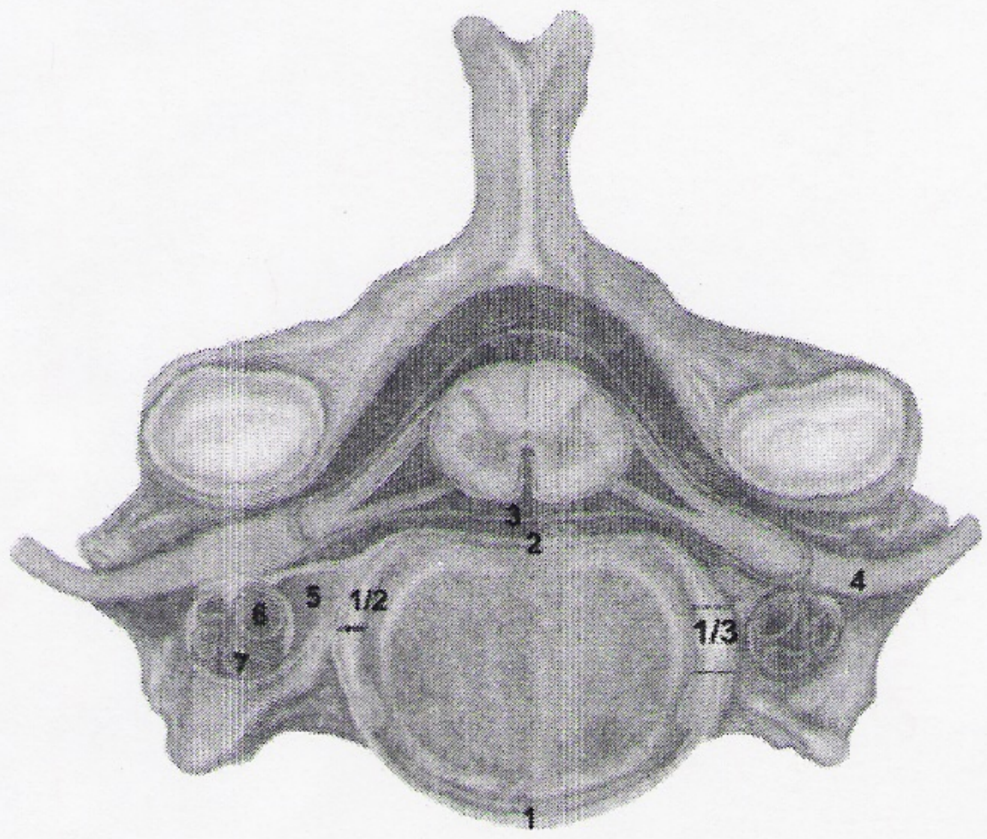

Fig. 5. The right side of this drawing represents upper cervical levels in which approximately one third resection of the uncinate process (UP) is required for full foraminotomy. The left side represents lower cervical levels in which approximately 50% of the UP is resected for full foraminotomy. The two layers of the perivascular ligamentous tissue (PVLT) cover the vascular structures in the uncovertebral foraminal region. 1, anterior longitudinal ligament; 2, posterior longitudinal ligament; 3, spinal dura mater; 4, left spinal nerve; 5, two layers of PVLT; 6, vertebral artery; 7, vertebral vein.

TABLE 1. Anatomic Measurements of 35 Dry Cervical Vertebral Columns[a]

Parameter	Cervical vertebrae				
	C3	C4	C5	C6	C7
A	4.83 ± 0.89	5.56 ± 0.96	5.66 ± 1.07	6.39 ± 0.95	6.63 ± 1.29
B	5.06 ± 0.84	5.01 ± 0.91	5.32 ± 1.44	5.06 ± 1.17	5.11 ± 1.11
C	11.05 ± 1.71	12.22 ± 1.95	12.21 ± 1.47	12.76 ± 1.62	12.74 ± 1.93
D	14.02 ± 1.39	14.73 ± 1.61	15.01 ± 1.38	15.79 ± 1.65	15.60 ± 2.27
E	16.49 ± 1.82	17.00 ± 1.91	18.18 ± 1.74	19.23 ± 1.59	20.51 ± 1.54
F	3.85 ± 0.33	4.21 ± 0.73	4.51 ± 0.58	4.88 ± 0.49	4.97 ± 0.64
G	16.08 ± 1.68	16.18 ± 1.62	17.90 ± 1.87	18.72 ± 2.26	20.95 ± 2.53

[a]A, greatest height of uncinate process (UP); B, greatest width of UP; C, length of UP; D, anteroposterior midline width of vertebral body; E, greatest side-to-side width of vertebral body between outer base surfaces of UPs; F, minimal length of the posterior part of the UP that needs to be resected for decompression of uncovertebral foraminal region; G, distance between anterior borders of UPs. See Figure 2. All measurements are in mm (mean ± SD).

creased from C3–C7; mean values ranged from 4.83 ± 0.89 mm at C3 to 6.63 ± 1.29 mm at C7. The mean values for the greatest width of the UP ranged from 5.06 ± 0.84 mm at C3 to 5.11 ± 1.11 mm at C7. The mean width of the UP at C5 was larger than at other levels; this anatomic feature may be consistent with the clinical occurrence of cervical spondylosis due to excessive cervical segmental motion at this level (Ebraheim et al., 1996; Marchiori and Henderson, 1996). Mean values for the AP length of the UP were 11.05 ± 1.71 mm at C3, 12.22 ± 1.95 mm at C4, 12.21 ± 1.47 mm at C5, 12.76 ± 1.62 mm at C6, and 12.74 ± 1.93 mm at C7; thus, they tended to increase gradually from C3–C7. The mean AP midline width along the superior surface of the vertebral body increased from 14.02 ± 1.39 mm at C3 to 15.60 ± 2.27 mm at C7. The ratio between mean length of the UP and the AP midline width of the vertebral body was relatively constant from C3–C7, ranging from 0.78–0.81, indicating a correlation between these two measurements ($r = 0.96$). The greatest side-to-side width of the vertebral body gradually increased from a mean of 16.49 ± 1.82 mm at C3 to 20.51 ± 1.54 mm at C7.

The minimal length of the posterior part of the UP that needed to be resected for decompression of the UVFR varied with the involved cervical level. The UP is located more posterior to the anterior border of the vertebral body at lower cervical levels, whereas it is located more anterior at upper cervical levels (Pait et al., 1996; Ebraheim et al., 1997). Measurements of the length of the posterior part of the UP that needed to be resected for adequate decompression of the UVFR are shown in Table 1; mean values ranged from 3.85 ± 0.33 mm at C3 to 4.97 ± 0.64 mm at C7. The anterior distance between the anterior borders of UPs increased from a mean of 16.08 ± 1.68 mm at C3 to 20.95 ± 2.53 mm at C7 (Table 1); these values correlated with the AP midline widths of the vertebral bodies, except for C7 ($r = 0.91$).

Cadaveric Microsurgical Dissection

The relationships of the intervertebral foramen, UP, PLL, and vertebral vessels were studied in cadaveric cervical vertebral columns. The UP is a bony ridge projecting from the posterolateral aspect of the cervical vertebral body; on the inferior aspect of the superior vertebral body a posterolateral area articulates with the UP. This articulation is covered posterolaterally by ligamentous tissue extending from the PLL that divides into anterior and posterior bundles: the anterior bundle covers the entire lateral aspect of the UP; both bundles surround the vascular contents of the foramen transversarium. We termed these bundles perivascular ligamentous tissue (PVLT). Excision of both bundles of the PVLT after removal of the UP exposes the neurovascular contents of the UVFR (Figs. 4, 5). The ventral root of the spinal nerve is adjacent to the UP anteriorly and pedicle inferiorly. At the caudal end of the intervertebral foramen, posterior to the posterolateral edge of the superior surface of the vertebral body, the ventral and dorsal nerve roots and dorsal root ganglion are completely exposed. The vertebral artery resides in an anterolateral position within the UVFR, following a posterior to anterior course through the C3–C6 foramina transversaria (it travels posteriorly again at the C7 level) and becoming slightly more distant from the spinal nerve roots from C3 through C7. The lateral aspect of the vertebral artery is covered by a venous plexus (Fig. 5).

DISCUSSION

Failure of decompression through the posterolateral corner of the vertebra via the posterior cervical approach in cervical spondylosis has been reported (Kumar et al., 1998; Chin and Ozuna, 2000). Anterior cervical discectomy is an accepted approach for spondylodiscopathies for decompressing the spinal nerve

roots and spinal cord by removing the degenerated disc and osteophyte complex (Cloward, 1958; Chesnut et al., 1992). The limit of bone drilling may vary (Rock and Ausman, 1991; Jho, 1996; Kumar et al., 1998; Klein et al., 1999) and inadequate decompression with anterior cervical surgery has been shown with MRI (Clifton et al., 1990). Anterior discectomy with excessive resection of the UP may impair the cervical dynamics, resulting in increased motion, and requiring graft fusion. It is thought that excessive mobility and stress at one level creates new degenerative changes at adjacent levels (Lestini and Wiesel, 1989; Ebraheim et al., 1997; Kotani et al., 1998; Panjabi, 1998; Hilibrand et al., 1999). It is difficult to remove the posterolateral osteophytes and UP extensively in the UVFR because of the risk of vascular and neural damage (Sugar, 1981). Therefore, the relationships of neurovascular structures in the UVFR is pivotal for developing a minimally invasive approach and for avoiding unnecessary resection even in the presence of extensive cervical spondylomyelopathy.

Dry bone measurements can be important for surgical considerations. Results from the present study showed that, on average, the height of the UP gradually increased from C3–C7, but the width did not change significantly, being broadest at C5 (5.32 ± 1.44 mm) (Table 1). UP parameters A, B, and F in Table 1 generally showed a slight increase from C3–C7. Morphologic differences of the UP at different vertebral levels have been reported by several investigators (Panjabi et al., 1991; Pait et al., 1996; Ebraheim et al., 1996a, 1997; Uğur et al., 2000); the width of the UP was the most important measurement for decompressing the spinal nerve roots posterolaterally.

The location of the UP in a motion segment predisposes to uncovertebral osteophyte formation, which, in turn, produces intervertebral foraminal stenosis and neural compression (Manabe et al., 1988; Milne, 1991). The laterally projecting uncovertebral osteophytes and overlying fibroligamentous thickening can also produce compression of the vertebral artery (Prescher, 1998; Strek et al., 1998). Uncovertebral osteophytes can create surgical difficulties due to obscured anatomical details when decompressing a stenotic intervertebral foramen (Hakuba, 1976; Ebraheim et al., 1996a,b; Jho, 1996). Each cervical level presents different patho-anatomic relationships with the anterior cervical approach (Ebraheim et al., 1996b). The UP is located posterolaterally on cervical vertebrae C6 and C7 and laterally on vertebrae C3–C5, and the distance between the UPs increases gradually from C3–C7 (Citow and Macdonald, 1999; Uğur et al., 2000). These anatomic variations at different vertebral levels, as well as the pathology that is present, may change the surgical approach (George and Laurian, 1989; Kiwerski, 1991; George et al., 1993).

The UPs delimit the outer border of the anulus fibrosus; the vertebral arteries lie laterally and the spinal nerves posterolaterally. The PVLT, which originates from the PLL, is located lateral to the UPs at the posterolateral corners of the vertebral body. Based on our observations during microsurgery, there may be less risk of injury to the spinal nerve and vertebral artery than previously thought due to the covering of the PVLT (Fig. 5). Brigham and Tsahakis (1995) researched complications after resection of the posterior portion of the UP and could not find any cases of associated vascular injury; they did not mention any ligamentous structure covering the UP.

Decompression of the spinal nerve is often inadequate with anterior cervical discectomy because of insufficient lateral exposure. Drilling and curettage of the posterior part of the UP, however, creates sufficient space for direct decompression of the spinal nerves and nerve roots. Further removal of the UP may be unnecessary for partially extruded lateral disc fragments (Fig. 5). In the case of pure intraforaminal extensive disc sequestration or extensive uncovertebral osteophyte formation, further removal is carried out through the space obtained after drilling the UP and excising the PVLT. Precise anterior foraminotomy is only accomplished by removing the posterior part of the UP and the posterolateral edge of the vertebral body that adjoins the pedicle. During an anterior cervical approach, the UP is located anterior to the anterior border of the vertebral body on the coronal plane in the upper cervical spine, whereas it is located posterior to the anterior border in the lower cervical spine. Anatomically, the UP runs obliquely from ventral to dorsal, in a lateral-to-medial direction (Oh et al., 1996). Due to these different anatomical positions, the relationship of the UP to the anterolateral wall of the intervertebral foramen displays variations; thus, foraminotomy via anterior discectomy is different in the upper and lower cervical levels. For example, it is possible to carry out neural decompression by removing approximately the posterior third of the UP in the upper cervical level, whereas it is only possible to achieve complete foraminotomy by removal of approximately the posterior half of the UP at lower cervical levels (see parameters C and F in Table 1). The vertebral artery and its associated venous plexus are immediately lateral to the UP in the UVFR (Fig. 5). Complete removal of the UP is unnecessary and carries the risk of neural and vascular injury,

especially at the upper cervical levels (Vaccaro et al., 1994; Ebraheim et al., 1996; Oh et al., 1996; Pait et al., 1996; Klein et al., 1999). It is reasonable to study the exact location of the UP, spinal nerves, spinal nerve roots, and vertebral artery before surgery.

The current study shows that the UP and surrounding PVLT are important structural considerations for decompression in the UVFR. In this context, the UP may be rightfully considered the entrance gate to the spinal nerve and vertebral artery. We conclude that understanding the spinal nerve and vertebral artery locations and their relationships with adjacent anatomic entities in the UVFR define safe standards that protect against unwarranted damage during microsurgery.

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