PAIN MEDICINE
Volume * • Number * • 2008

Ventral Innervation of the Lateral C1–C2 Joint: An Anatomical Study

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ABSTRACT

Objective. Clinical observation has suggested the presence of ventral cervical extra-articular pain pathways in patients with C1–C2 joint pain. However, the existence of ventral innervation to the C1–C2 joint has not been documented. The objective of this study was to determine whether ventral innervation to the lateral C1–C2 joint exists, and to describe its relational anatomy.

Design. Gross and microscopic dissection was performed on 11 embalmed human cadavers. Wire segments were placed on identified ventral plexus nerves and radiographic imaging obtained in multiple planes. Histologic staining of prevertebral plexus nerves was performed with Osmium and compared with tissue controls.

Results. A superficial and deep cervical prevertebral plexus was identified terminating in the ventral joint capsule of the C1–C2 joint in all cadavers examined (21 sides). The location of the deep cervical prevertebral plexus was consistent within the C2 ventral gutter. Osmium staining confirmed the presence of myelin in plexus specimens.

Conclusion. In this study, two cervical prevertebral plexuses (superficial and deep) were identified that have not previously been described. Terminal branches of the plexuses entered the ventral joint capsule of the lateral C1–C2 joint and were seen approaching the dens. Findings provide and explanation for the clinical observation that electrical stimulation in the C2 ventral gutter can reproduce headache in patients with C1–C2 joint pain.

Key Words. Cervical Anatomy; Lateral Atlanto-Axial Joint; Innervation; Headache; Diagnosis

Introduction

Two lines of evidence implicate the lateral atlanto-axial joints as a source of upper cervical pain and headache. In normal volunteers, noxious stimulation of these joints with injections of contrast medium produces pain in the suboccipital region and occiput [1]. In some patients with headache, anaesthetizing the lateral atlanto-axial joint with peri-articular [2] or intra-articular [3–7] injections of local anaesthetic relieves pain in the occipital region and pain referred variously to the parietal, temporal, and frontal regions of the head.

Although local anaesthetic blocks can be used to diagnose pain stemming from the lateral atlanto-axial joints, the means by which to treat it have not been firmly established. According to two descriptive studies, headaches stemming from the lateral atlanto-axial joints can be relieved by arthrodesis of the joints [8,9], but this is a major undertaking for patients whose joints are otherwise stable and whose only symptom is neck pain or headache. Simpler means of treatment have remained elusive.

The dorsal lateral atlanto-axial joint capsule receives *several* articular branches from the ventral ramus of C2, which crosses the posterior aspect of the joint capsule [10], and the sinuvertebral nerve

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doi:10.1111/j.1526-4637.2008.00493.x

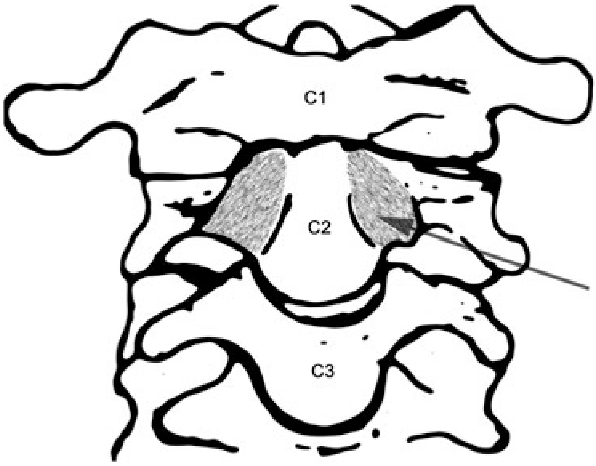

Figure 1 C2 ventral gutter: image of upper cervical spine, ventral aspect. Shaded area denotes C2 ventral gutter. Gray arrow simulates an electrode and points to where electrical stimulation typically reproduced headache.

[11,12]. However, the proximity of these articular branches to the C2 spinal nerve precludes the consideration of percutaneous radiofrequency neurotomy due to the risk of damage to this large spinal nerve. Extirpation *or percutaneous rhyzolysis* of the C2 ganglion is an unappealing option because of the numbness that it produces and the risk of subsequent anaesthesia dolorosa [13]. Intra-articular injections of corticosteroids have been advocated [7], but their efficacy has not been tested in a controlled trial, and intra-articular injection of corticosteroid has been refuted in a controlled trial for zygapophyseal joint pain [14].

In an effort to explore alternative means of treating atlanto-axial joint pain, one of the present authors undertook a pilot study [15]. This study involved 18 patients, whose headache was relieved by intra-articular blocks of the lateral atlanto-axial joint. As a preparation for radiofrequency treatment, percutaneous sensory stimulation, with a 22G electrode, was used to identify possible pain pathways from the joint, in these patients. Low-voltage stimulation over the ventral aspect of the vertebral body of C2, near its junction with the transverse process (Figure 1) reproduced the patient's headache. Injection of contrast medium at this site opacified a diagonally orientated space, congruent with the concave gutter that marks the anterolateral aspect of the C2 vertebral body (Figure 2). The C2 ventral gutter is bounded medially by the C2 vertebral body, dorsally by the base of the C2 transverse process, ventrally by the belly of the longus cervicis, laterally by the anterior intertransversarius, and caudally by the anterior tubercle of the C3 transverse process. It is separated from the C2–3 intervertebral foramen by a tough connective tissue membrane (Figure 3).

All 18 patients underwent controlled blocks of the C2 ventral gutter, using sufficient local anaesthetic (0.5–0.7 mL) to fill the gutter. Blocks were considered positive if short-lasting relief occurred

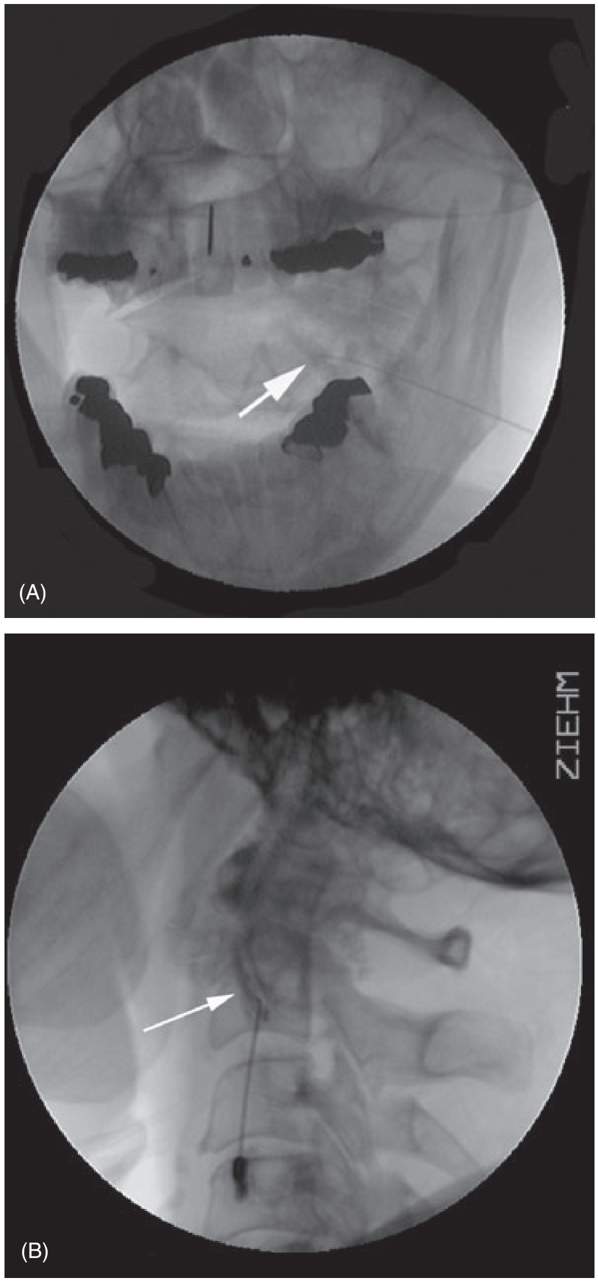

Figure 2 Fluoroscopic images of an injection of contrast medium (arrow) into the ventral gutter. (A) Antero-posterior view. (B) Lateral view.

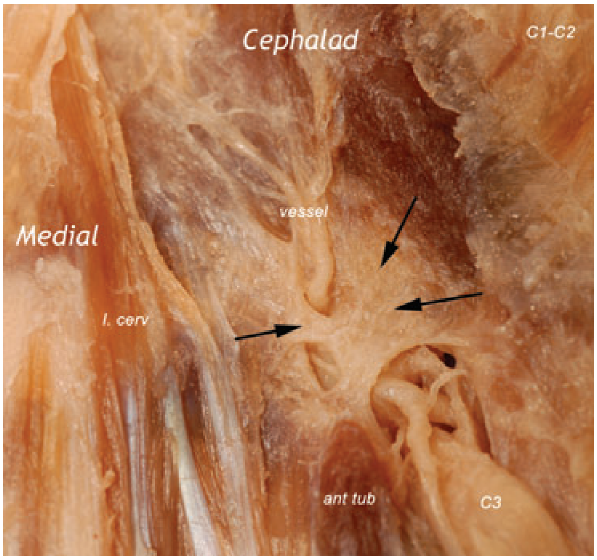

Figure 3 A dissection of the connective tissue membrane that separates the C2 ventral gutter from the C2–3 intervertebral foramen. The arrows point to the membrane. C3 = ventral ramus of C3 spinal nerve; *l. cerv* = longus cervisis muscle; ant tub = anterior tubercle of C3 transverse process; C1–C2 = ventral articular capsule of lateral C1–C2 joint; vessel = penetrating artery entering C2 ventral gutter through the connective tissue membrane.

after a short-acting agent (lidocaine) was used, and if long-lasting relief occurred after a long-acting agent (bupivacaine) was used.

Six patients had headache only, which was relieved by blocks of the C2 ventral gutter. They subsequently underwent radiofrequency thermocoagulation of the C2 ventral gutter. After a mean follow-up period of 21 months, four experienced 90–100% relief of headache, one experienced 60–90% relief, and one had less than 60% relief.

Twelve patients had neck pain as well as headache. Blocks of the C2 ventral gutter relieved their headache, yet not their neck pain; but their neck pain was relieved by blocks of cervical medial branches. These patients underwent combined radiofrequency thermocoagulation both of their C2 ventral gutter, and the medial branches responsible for their neck pain. After a mean follow-up period of 15 months, six patients experienced 90–100% relief of headache, two experienced 60–90% relief, and four had less than 60% relief.

An anatomical basis for these clinical observations is lacking. Textbooks of anatomy provide no description of nerves in the C2 gutter. Nor does any description appear in the journal literature. Classical descriptions portray the upper cervical ventral rami as forming the cervical plexus over the anterior surface of the scalenus medius [16]. In the plane of the prevertebral fascia, anterior to longus cervicis and the anterior tubercles of the transverse processes, grey rami communicantes leave the sympathetic trunk and reach the upper cervical rami [16,17]. Outside the intervertebral foramina, branches of the ventral rami and grey rami join to form the vertebral nerve [18–20], which accompanies the vertebral artery, and gives rise to the upper cervical sinuvertebral nerves [19–21]. Otherwise, the cervical ventral rami are understood to innervate the longus cervicis and longus capitis [16] but details of the course and location of these nerves are lacking. In addition, although studies have demonstrated an innervation to the atlanto-occipital and lateral atlantoaxial joints from their dorsal aspects [10], there is no evidence that these joints received any innervation from their ventral aspects.

The present study was undertaken to explore an anatomical basis for the apparent sensitivity of the C2 vertebral gutter to noxious stimulation, and its role in apparently producing relief of headache ostensibly stemming from the lateral atlanto-axial joint following the creation of radiofrequency thermal lesions. The results extend our knowledge of the innervation of the upper cervical spine and lateral atlanto-axial joints.

Methods

Dissections were performed on embalmed cadavers from the gross anatomy program of the University of New England College of Osteopathic Medicine (Biddeford, ME). Cadavers were selected from those used by students, provided that the anterior cervical structures including the longus capitis, the lateral atlantoaxial joint capsules, and the structures medial to the middle scalene were intact. Six additional cadavers were used for subsequent microscopic dissection of the neck. Gross dissection was performed using an illuminated magnifying lens (1.5×) and operative loupes (Zeiss, 4×) in five cadavers (10 sides). Microscopic dissections were performed with the aid of a 10–40× binocular surgical microscope with fiber-optic illumination (Weck, Nikon optics) in six cadavers (11 sides).

In specimens with the occiput intact, the head was carefully disarticulated at the atlanto-occipital joint, with the ventral joint capsule preserved as much as possible. In every specimen, the ventral rami of the C2, C3, and C4 spinal nerves were identified and carefully freed from surrounding connective tissue and vessels. The cervical viscera were removed, preserving the prevertebral musculature. The longus capitis was identified and removed fascicle by fascicle with fine-tip forceps. Branches arising from segmental spinal nerves were carefully identified, and their course exposed relative to the intertransversarii, longus cervicis, longus capitis, vertebral artery, C2 ventral gutter, and the ventral capsule of the lateral atlanto-axial joint. The medial and lateral bands of the longus cervicis were removed, fascicle-by-fascicle, permitting small branches to these muscles and deeper structures to be carefully identified and preserved.

At each stage of dissection, digital photographs were taken (Nikon D100, 28–105 mm Nikkor Macro lens, 60 mm or 105 mm Nikkor Micro lens with PK-13 extension tube) and immediately downloaded to an on-site laptop computer. Digital images were labelled as recorded utilizing digital imaging software (Adobe Photoshop, Seattle, WA). In 10 sides following gross dissection, fine wire segments were shaped to conform to the nerves in the C2 ventral gutter, and carefully laid directly on these nerves. The specimens were then placed on a radiolucent table and fluoroscopic radiographs (Zhiem Vista, Riverside, CA) were obtained in the anterior-posterior and lateral projections. Radiographic images were printed as acquired on transparency film and stored as digital bitmap images on removable magnetic media (Iomega 250 MB Zip drive) for subsequent transfer to on-site laptop computers.

Once a consistent pattern emerged from gross dissection, microscopic dissection was performed to identify the relationships of the superficial and deep cervical prevertebral plexuses with the vertebral artery, deep prevertebral musculature, spinal nerves, and the capsules of the ventral atlanto-occipital and atlanto-axial joints. Following exposure of the C1, C2, and C3 ventral gutters, the anterior tubercles of segmental transverse processes were carefully removed with fine-tip bone ronguers under microscopic visualization. To further delineate the relationships of the deep cervical prevertebral plexus with the vertebral artery, the transverse process and part of the vertebral body of C2 and the lateral aspect of the lateral atlanto-axial joint was also removed.

In one intact specimen not used by students, dissection from the skin to the superficial and deep cervical prevertebral plexuses was performed under the microscope without disarticulating the occiput. The cervical sympathetic trunk and other cervical plexuses were carefully preserved, and communicating branches and gray rami carefully exposed. Superficial and deep cervical prevertebral plexuses were subsequently harvested and rinsed with distilled water to remove embalming chemicals, then stained with a 1% Osmium solution. Tissue whole mounts were prepared and cover slipped with glycerol. Examination was done with a Leitz microscope at 250–400× magnification. For histological controls, Osmium-stained sections of epimysium, small vessels, adipose tissue, and strands of diaphanous connective tissue were compared with samples of brachial plexus.

Results

During the early phases of the dissections, the familiar cervical plexus and the plexus accompanying the carotid arteries were identified. However, once these were mobilized or resected, deeper dissection revealed two further plexuses.

Deep to the longus capitis and ventral to the anterior tubercules of the cervical transverse processes and intervertebral foramina, branches from the C1–3 ventral rami formed a superficial cervical prevertebral plexus, consisting of numerous interconnecting arcades (Figure 4). Some of the laterally located branches from this plexus terminated in the longus capitis and longus cervicis. Others ascended along the ventral aspect of the anterior intertransversarius, over the ventral capsule of the lateral atlanto-axial joint and toward the ventral capsule of the atlanto-occipital joint. Medially located branches of the plexus passed ventral or through the bellies of the anterior intertransverse muscles at C2–C3 and C3–C4, and ascended toward the dens, superficial to the ventral surface of the longus cervicis at the level of C2. Some of these ascending branches formed loops along the ventral surface of the longus cervicis and communicated with the lateral branches of the plexus. Other medial branches supplied twigs to the intertransversarii and longus cervicis, before sending penetrating branches either between the bellies of these muscles or through the belly of the longus cervicis to reach a deeper plexus lying in the ventral gutter of C2.

The deep cervical prevertebral plexus was located deep to the longus cervicis and within the periosteum of the C2 vertebral body in its ventral gutter (Figure 5). Nerves composing the deep plexus primarily arose from the ventral ramus of C3, and passed medially, superficial to the vertebral artery, in close association with nerves of the vertebral plexus. After passing over the vertebral

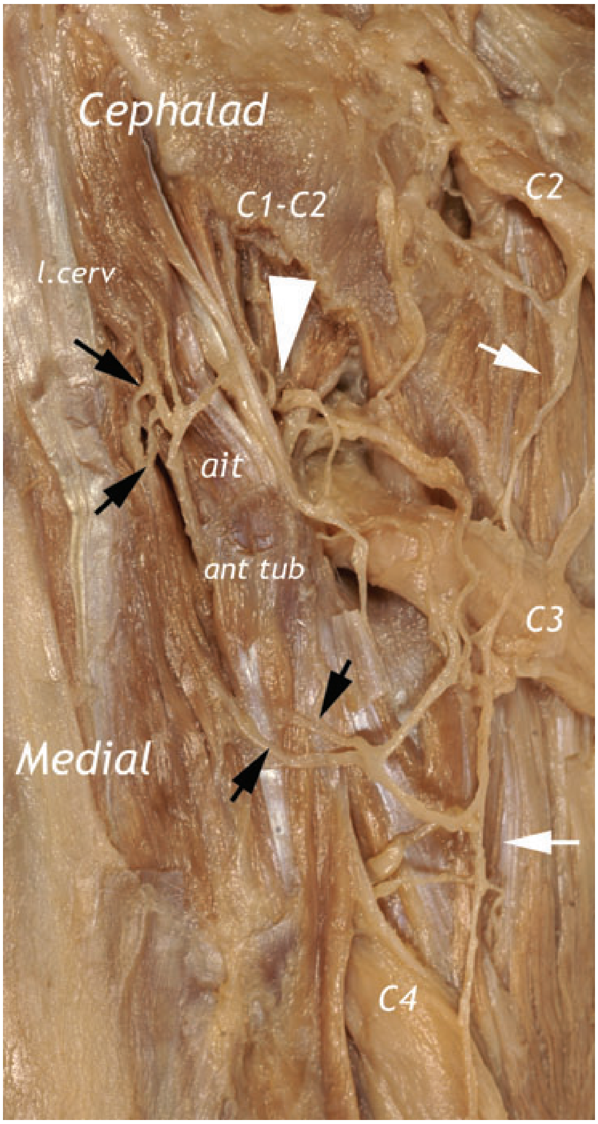

Figure 4 Superficial cervical prevertebral plexus: the superficial cervical prevertebral plexus (black arrows) can be seen arising from the C3 ventral ramus (large white triangle) and lies superficial to the ventral aspect of the longus cervicis (*l. cerv*) and intertransversarius (*ait*). More laterally located branches of the plexus can be seen bridging the ventral rami of C2, C3, and C4 (white arrows). Ant tub = anterior tubercle of C3 transverse process.

artery, these nerves entered the fascia covering the C2 ventral gutter, after penetrating a tough connective tissue membrane that separated the ventral neural foramen from the gutter, and ascended medially to enter the ventral capsule of the lateral atlanto-axial joint and the anterior atlanto-axial membrane.

The superficial cervical prevertebral plexus was seen in all 21/21 sides dissected. Variations of the plexus were seen, including medially oriented branches from the ventral C3 ramus that passed over the anterior tubercle of the C3 transverse process, as well as branches that passed caudal to the anterior tubercle, ventral to the C3–C4 anterior intertransversarius, before ascending over the longus cervicis toward the dens.

At least one nerve was identified representing the deep cervical prevertebral plexus in all 21/21 sides examined. In 12 sides, more than one nerve was identified. Small arteries arising from the vertebral artery were also seen in the C2 ventral gutter, but typically travelled medial to the nerves of the deep cervical prevertebral plexus. In two sides, a contribution to the deep plexus appeared to arise primarily from the vertebral plexus. In a

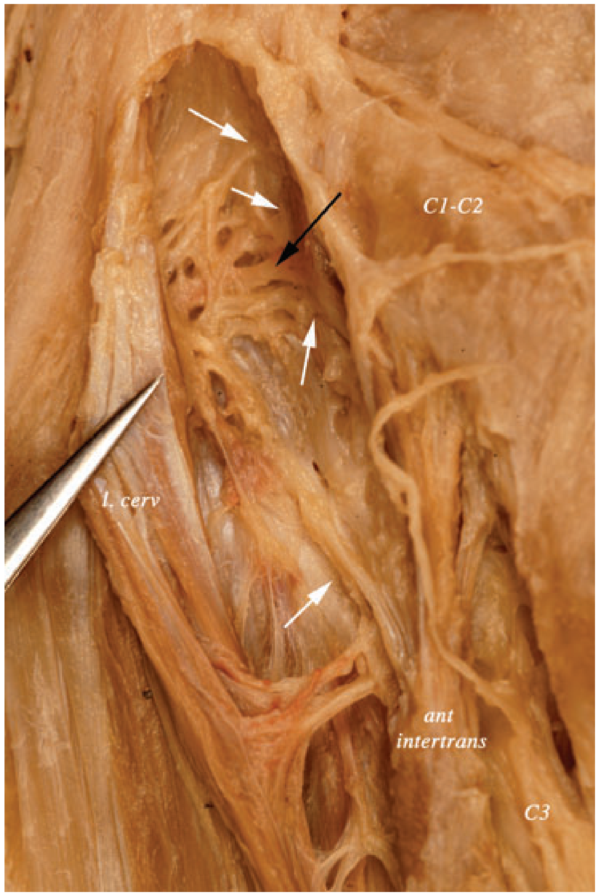

Figure 5 Deep cervical prevertebral plexus: branches of the deep cervical prevertebral plexus (white arrows) can be seen within the C2 ventral gutter. The longus cervicis (*l. cerv*) is retracted medially to expose the gutter. Branches from the plexus terminate along the ventral joint capsule of the lateral C1–C2 joint (C1–C2). A vein can be seen as well (black arrow). Ant intertrans = anterior belly of the C2–C3 intertransversarius muscle; C3 = C3 ventral ramus.

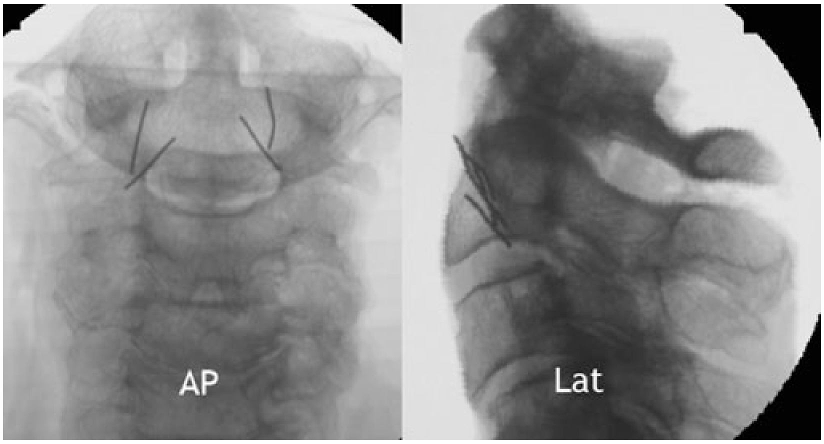

Figure 6 Fluoroscopic wire study: wire segments placed on the deep cervical prevertebral plexus are imaged in the anterior-posterior and lateral planes in a representative cadaveric specimen.

further two sides, the deep cervical prevertebral plexus was formed either solely by a contribution from the C4 ventral ramus, or by both the C3 and C4 ventral rami. The C4 contribution travelled cephalad in the C3 ventral gutter, before entering the C2 gutter. In six sides studied microscopically, the deep cervical prevertebral plexus communicated with the plexus of the vertebral artery.

Radiographic imaging of wires placed over the deep cervical prevertebral plexus in the C2 ventral gutter demonstrated a consistent pattern with regard to identifiable bony landmarks (Figure 6).

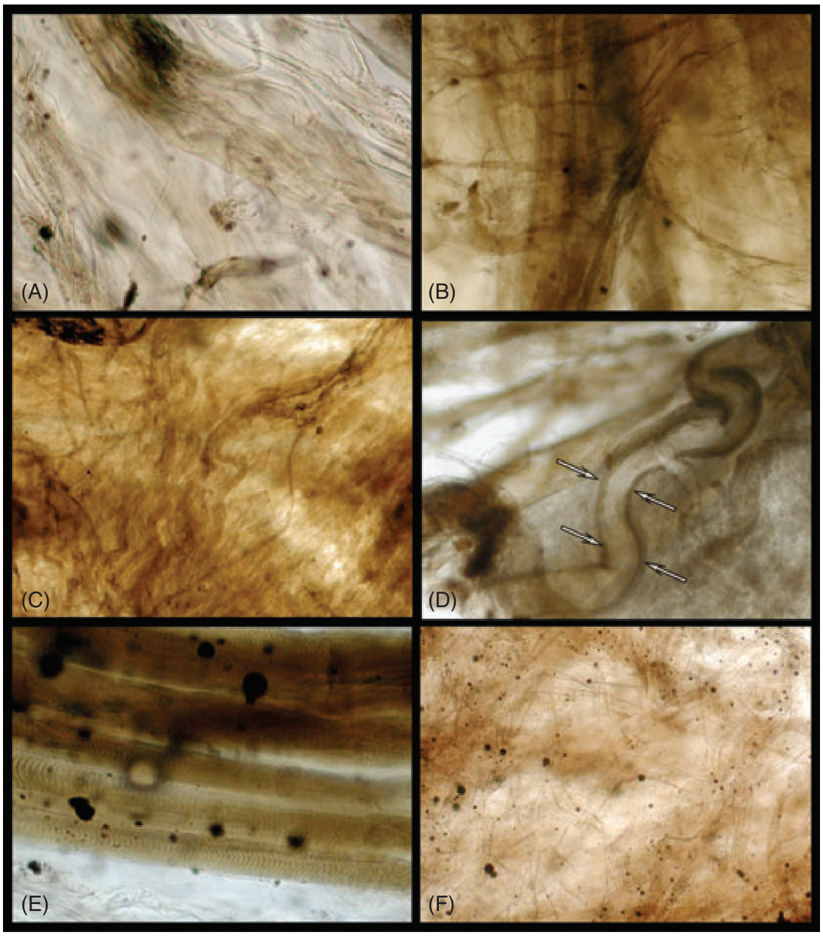

Figure 7 Histology of the deep and superficial cervical prevertebral plexus. All specimens stained with 1% Osmium. (A) Photomicrograph of a whole mount of a prevertebral nerve of the deep cervical prevertebral plexus in the ventral gutter of C2 illustrating axon-like profiles (100×). (B) Photomicrograph of portions of the superficial cervical prevertebral plexus between C3 and C4 (100×) illustrating axon-like profiles. (C) Photomicrograph of the origin of the deep cervical prevertebral plexus at the ventral ramus of C3 illustrating dense bundles of wavy axons (100×). (D) Histological control comparison photomicrograph of a blood vessel (arrows; 100×). (E) Histological control comparison photomicrograph of skeletal muscle (100×). Note clearly visible striations. (F) Histological control comparison photomicrograph of connective tissue (perimycium) illustrating randomly directed poorly staining collagen bundles (40×).

The segments of wire followed a medial and cephalad course along the ventral lateral aspect of the C2 vertebral body, medial to the transverse process of C2, approaching the ipsilateral base of the dens and its articulation with the anterior arch of C1.

Histology

Osmium stained samples of the deep and superficial cervical prevertebral plexuses revealed wavy bundles of fibres containing darkly staining globules of myelin characteristic of poorly fixed degenerating nerve tissue. These bundles could be traced for considerable distances along the nerves of the plexuses (Figure 7).

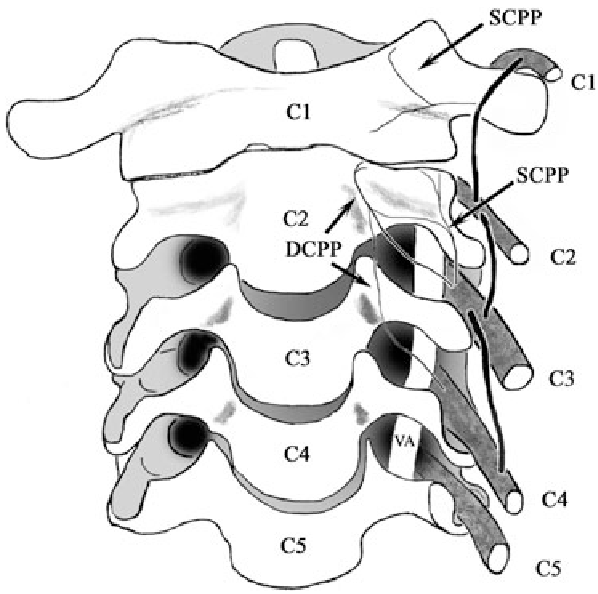

Figure 8 A summary sketch of the SCPP and DCPP. The prevertebral muscles and connective tissues have been removed, leaving only the bones and joints as landmarks. The arcade branches of the SCPP are shown together with their principal branches that lie ventral to the anterior intertransversarii and longus cervicis, and their terminal branches to the lateral atlanto-axial joint. The DCPP is depicted, arising from the C3 ventral ramus, and lying in the C2 prevertebral gutter, deep to longus cervicis. This plexus communicates with the C4 ventral ramus and with the superificial plexus. Terminal branches pass to the lateral atlanto-axial joint. SCPP = superficial cervical prevertebral plexus; DCPP = deep cervical prevertebral plexus.

Discussion

The two prevertebral plexuses identified in the present study have not previously been described. Presumably, anatomists previously had no call to explore the detailed distribution of prevertebral branches of the upper cervical ventral rami, being satisfied that they simply supplied the prevertebral muscles. In contrast, the present study was prompted by clinical interest in pain ostensibly stemming from the lateral atlanto-axial joint.

In that regard, the present dissections demonstrated that, in addition to supplying prevertebral muscles, terminal branches of both the superficial and deep cervical prevertebral plexuses reach the ventral capsule of the lateral atlanto-axial joint (Figure 8). Under the microscope, these terminal branches were seen to attach firmly to the joint capsule. Histological examination of these nerves proximal to the joint confirmed their neural identity. However, difficulties inherent in staining embalmed material precluded histological confirmation of actual entry of these nerves into the joint capsule or the specific types of nerve fibres within these plexuses. Nevertheless, the consistent and close proximity of these nerves to the joint provides circumstantial evidence that the lateral atlanto-axial joint receives a ventral innervation. Moreover, this innervation stems from the ventral ramus of C3 and sometimes possibly also from C4. This has not been reported previously. To date, the joint has been regarded as having only a dorsal innervation [10–12]. The differential contribution of ventral or dorsal innervation with regard to chronic pain arising from the joint remains to be determined.

The present anatomical data provide explanations for the clinical observations that prompted the study. The presence of nerves in the C2 ventral gutter correlates with sensations being evoked by a stimulating electrode placed in the gutter. The putative distribution of these nerves to the lateral atlanto-axial joint corresponds with the evoked sensation being reproduction of headache in patients previously shown to obtain relief of pain following intra-articular blocks of the lateral atlanto-axial joint. This also correlates with the relief of headache following the injection of local anaesthetic into the C2 ventral gutter. The tight physical boundaries of the gutter explain why contrast medium remains well contained when injected into the gutter. In particular, the fibrous membrane between the gutter and the C2–3 intervertebral foramen prevents spread of injectate into the foramen and the longus cervicis covering the gutter prevents spread into the prevertebral muscles and prevertebral space. These anatomical features render the C2 ventral gutter a suitable target point for selective diagnostic blocks of the nerves to the ventral capsule of the lateral atlanto-axial joint.

All of these features provide an anatomical foundation for the exploration of the clinical utility of procedures involving the C2 ventral gutter. In the light of previously presented pilot studies [15], clinical studies could explore the yield of ventral diagnostic blocks of the atlanto-axial joint in patients with headache, and the efficacy of radiofrequency coagulation of the cervical prevertebral plexus nerves. However, it is not the role of this study to describe how this should be done, as the skills and precautions necessary are vital and distinct. Percutaneous procedures in the cranio-cervical junction—including access to the C2 ventral gutter—must be performed with great caution and a thorough understanding of relational anatomy to avoid injury to nearby cervical viscera, vessels, and nerves.

References

1 Dreyfuss P, Michaelsen M, Fletcher D. Atlanto-occipital and lateral atlanto-axial joint pain patterns. Spine 1994;19:1125–31.
2 Ehni G, Benner B. Occipital neuralgia and the C1–2 arthrosis syndrome. J Neurosurg 1984;61:961–5.
3 Busch E, Wilson PR. Atlanto-occipital and atlanto-axial injections in the treatment of headache and neck pain. Reg Anesth 1989;14(suppl 2):45.
4 McCormick CC. Arthrography of the atlanto-axial (C1–C2) joints: Technique and results. J Intervent Radiol 1987;2:9–13.
5 Aprill C, Axinn MJ, Bogduk N. Occipital headaches stemming from the lateral atlanto-axial (C1–2) joint. Cephalalgia 2002;22:15–22.
6 International Spine Intervention Society. Lateral atlanto-axial joint blocks. In: Bogduk N, ed. Practice Guidelines for Spinal Diagnostic and Treatment Procedures. San Francisco: International Spinal Intervention Society; 2004:138–51.
7 Narouze SN, Casanova J, Mekhail N. The longitudinal effectiveness of lateral atlantoaxial intra-articular steroid injection in the treatment of cervicogenic headache. Pain Medicine 2007;8(2):184–8.
8 Joseph B, Kumar B. Gallie's fusion for atlantoaxial arthrosis with occipital neuralgia. Spine 1994;19:454–5.
9 Ghanayem AJ, Leventhal M, Bohlman HH. Osteoarthrosis of the atlanto-axial joints—long-term follow-up after treatment with arthrodesis. J Bone Joint Surg 1996;78A:1300–7.
10 Paluzzi A, Belli A, Lafuente J, et al. Role of the C2 articular branches in occipital headache: An anatomical study. Clin Anat 2006;19:497–502.
11 Lazorthes G, L'innervation Gaubert J. L'innervation des articulations interapophysaire vertebrales. Comptes Rendues de l'Association des. Anatomistes 1956;43:488–94.
12 Bogduk N. The anatomy of occipital neuralgia. Clin Exp Neurol 1980;17:167–84.
13 Lozano A, Vanderlinden G, Bachoo R, Rothbart P. Microsurgical C-2 ganglionectomy for chronic intractable occipital pain. J Neurosurg 1998;89:359–65.
14 Barnsley L, Lord SM, Wallis BJ, et al. Lack of effect of intraarticular corticosteroids for chronic pain in the cervical zygapophyseal joints. N Engl J Med 1994;330:1047–50.
15 Yin W. C2 neurotomy for cervicogenic headache. ISIS 11th Annual Scientific Meeting. Orlando, FL; 2003.
16 Standring S (ed). Gray's Anatomy, 39th edition. Edinburgh: Elsevier Churchill Livingstone; 2005:554–5.
17 Kimmel DL. The cervical sympathetic rami and the vertebral plexus in the human foetus. J Comp Neurol 1959;112:141–61.
18 Bogduk N, Lambert G, Duckworth JW. The anatomy and physiology of the vertebral nerve in relation to cervical migraine. Cephalalgia 1981;1:1–14.
19 Kimmel DL. Innervation of the spinal dura mater and dura mater of the posterior cranial fossa. Neurology 1960;10:800–9.
20 Bogduk N, Windsor M, Inglis A. The innervation of the cervical intervertebral discs. Spine 1989;13:2–8.
21 Mendel T, Wink CS, Zimny ML. Neural elements in human cervical intervertebral discs. Spine 1992;17:132–5.