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ORIGINAL PAPER

Ultrasound-guided radiofrequency neurotomy in cervical spine: sonoanatomic study of a new technique in cadavers

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AIM: To develop an ultrasound-guided technique for radiofrequency (RF) cervical medial branch neurotomy and to validate the accuracy of this new method.

MATERIALS AND METHODS: Five non-embalmed, fresh cadavers were used; three male and two female cadavers with a median age at death of 67.2 years (range 50–84 years). This study was conducted in two parts. First, two of the cadavers were used to define the sonographic target point for RF cervical medial branch neurotomy using high-resolution ultrasound (12 to 5 MHz). The needles were guided to five consecutive cervical medial branches in the cadavers under ultrasound guidance. Subsequently, the position of the ultrasound-guided needle was verified using C-arm fluoroscopy. Ultrasound-guided RF neurotomy was performed to the C5 medial branches in all five cadavers. In the three cadavers not used in the first part of the study, ultrasound-guided RF neurotomy without C-arm fluoroscopic confirmation was performed to the C3–C7 medial branches. The accuracy of neurotomy was assessed by pathological examination of the cervical medial branches obtained through cadaver dissection.

RESULTS: In all five cadavers, the sonographic target point was identified in all C3–C7 segments with the 12 to 5 MHz linear transducer. In all 20 needle placements for the first and second cadavers, C-arm fluoroscopy validated proper needle tip positions. In all five cadavers, successful neurotomy was pathologically confirmed in 30 of 34 cervical medial branches.

CONCLUSIONS: Ultrasound-guided cervical medial branch neurotomy was successfully performed in 30 of 34 cervical medial branches in five cadavers. However, before eliminating fluoroscopic validation of final needle tip positioning, the technique should be validated in symptomatic patients.

Introduction

Percutaneous radiofrequency (RF) neurotomy of the medial branches of the cervical dorsal rami is a palliative procedure used to treat pain caused by cervical facet joint disease. First described by Schaerer[1] in 1978, the procedure gained momentum in 1995 following a randomized control trial

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by Lord *et al.*[2] that clearly showed its intermediate-term effectiveness compared with the placebo control. Despite the increasing use of cervical medial branch neurotomy, published reports are few and vary in selection criteria, techniques used, and outcomes.[1–6]

The location of the cervical medial branches is relatively constant and the anatomy is well described.[7] The validated technique for both blocking the medial branches with local anaesthetic and performing RF lesioning involves the precise placement of needles on the waists of the cervical articular pillars using fluoroscopic C-arm guidance. A potential alternative to fluoroscopy-guided needle placement is the use of ultrasonography-assisted guidance. Although ultrasound has been demonstrated to facilitate spinal periradicular injections,[8,9] and the performance of nerve and facet joint blocks in the lumbar spine,[10,11] no published reports describe ultrasound-guided RF neurotomy of the cervical medial branch. Accordingly, the purpose of the present study was to validate a method for ultrasound-guided RF neurotomy of the cervical medial branch, including the required ultrasound views and sonographic landmarks. To achieve these objectives the procedure was performed in fresh cadavers. The following were evaluated: the ideal ultrasonic planes required to identify the target point in the cervical articular pillars, guide needle placement, and once placed, whether subsequent neurotomy achieved adequate neurolysis of the medial branch.

Materials and methods

Study design

Five non-embalmed, fresh cadavers were used; three male and two female cadavers with a median age at death of 67.2 years (range 50–84 years). Four cadavers had a normal body mass index and one was obese. The approval of our hospital ethics committee was obtained for this project. This study was conducted in two parts. The first part was designed to identify the sonographic target points for RF cervical medial branch neurotomies and assess whether these sonographic target points correlated with fluoroscopic target points for RF neurotomy. For this purpose, two of five cadavers were used. In addition, computed tomography (CT) was performed after contrast medium injection through needles placed at the C5 medial branch, in order to evaluate the anatomic detail, including the relationship between sonographic target points and the intervertebral foramen, as well as the placement of the needle tips. In the second part, ultrasound-guided RF neurotomy with fluoroscopic confirmation was preliminarily performed at one level (C5 medial branch) in two cadavers that were used in the first part of this study, and ultrasound-guided RF neurotomy without fluoroscopic confirmation was subsequently performed at the C3 medial branch through the C7 medial branch in the remaining three cadavers. Then, the success or failure of the neurotomies was determined based on histological evaluation of nerves obtained from cadaver dissection.

Development of the sonographic target point

To assess the sonographic anatomy of the cervical medial branch and to develop the necessary ultrasound views, cadavers were examined using high-resolution ultrasound in a prone position using a 12 to 5 MHz linear transducer (Volusion-I; GE Medical Systems, Milwaukee, WI, USA). Imaging commenced in a sagittal plane, by positioning the transducer on the facet joints, obtaining a longitudinal image of the articular pillars (Fig. 1a). With a 90° rotation of the transducer (Fig. 1b), an axial plane scan was performed, obtaining a transverse image of an assumed cervical medial branch that traversed the articular pillars and ran between the multifidus muscle and longissimus muscle, corresponding to the course of the cervical medial branch (Fig. 1c, d). It was hypothesized that the cervical medial branches appear as a curvilinear hypoechoic band that runs from the lateral aspect of their ipsisegmental articular pillars parallel to the intermuscular plane. These assumed cervical medial branches surrounding the lateral curved portion of the articular pillars were defined as the target point for RF neurotomy.

Fluoroscopic validation of the sonographic target point

The above-described sonographic target points were identified at the C3–C7 segments in the first and second cadavers. Subsequently, 20 G, 10 cm RF needles were introduced using real-time, in-plane ultrasound guidance to the target point of each segment (Fig. 2). The long-axis view was used to localize the target segment and an axial plane scan was performed to investigate their associated medial branches. To localize the different spinal levels, the cervicothoracic transition was delineated by means of coronal sonogram. A cross-axis view was fundamentally obtained to

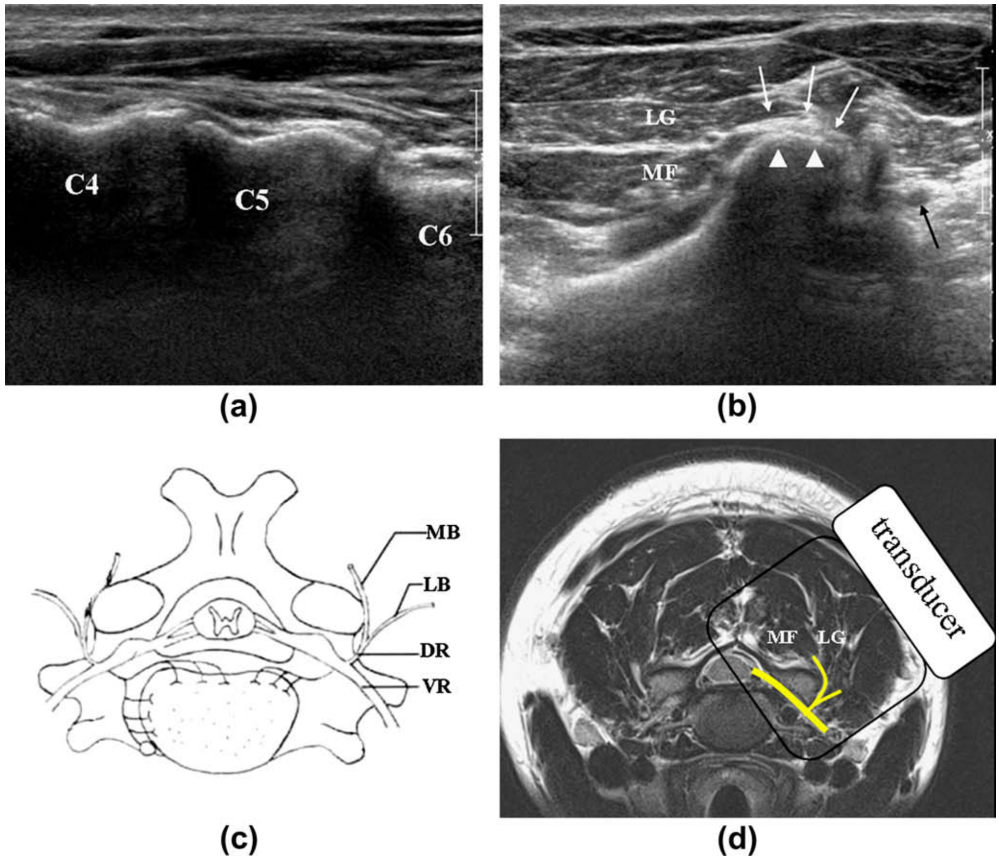


Figure 1 (a) Longitudinal ultrasound image of the cervical spine demonstrating the articular pillars of C4—C6, using a linear transducer (12 to 5 MHz). Note the characteristic shallow grooves between the superior articular process and inferior articular process. (b) Axial transverse ultrasound image in the vicinity of these grooves showing the sonographic target point, which corresponds to the hypoechoic band (arrows) surrounding the lateral curved aspect of the articular pillar (arrow heads). It is hypothesized that cervical medial branches appear as a curvilinear hypoechoic bands. The hypoechoic round structure (black arrow) is thought to be the ventral ramus of the spinal nerve. (c) Schematic drawing showing the anatomy of the cervical medial branch. (d) Corresponding axial T2-weighted magnetic resonance (MR) image demonstrating the course of the cervical medial branches, which cross the articular pillar and run between the multifidus muscle and longissimus muscle. The box outlines the location of the ultrasound image (b). MF, multifidus; LG, longissimus; MB, medial branch; LB, lateral branch; DR, dorsal ramus; VR, ventral ramus.

verify the needle tip position at the lateral aspect of the articular pillar, the target point for RF neurotomy. Although the long-axis view was not clear enough to verify the tip of needle, this view was obtained again, and the needle tip position in the longitudinal plane of the articular pillar was evaluated. C-arm fluoroscopy was performed in the anteroposterior view, oblique view, and lateral view to confirm needle position. Needle position was evaluated according to the International Spine Intervention Society guidelines[12] as follows: (1) in lateral views, C5 medial branches are fairly constantly located over the middle fifth of the C5 articular pillar, but how the medial branches are located progressively higher on their respective articular pillars at levels progressively further away from the C5 level. (2) In anteroposterior view, the C4 and C5 medial branch are located in the concavity of their respective articular pillar. The C3 and C6 medial branch are most often found in the concavity of their respective articular pillar, but sometimes lie lateral to the convexity of their adjacent facet joint. The C7 medial branch is most often located on the corner formed by the junction of the C7 superior articular process and the root of the C7 transverse process, but is sometimes located further cephalad towards the tip of the superior articular process, or further laterally over the root of the transverse process.

CT evaluation of the sonographic target point

To determine whether or not the hypoechoic band, which was assumed to be a cervical medial branch,

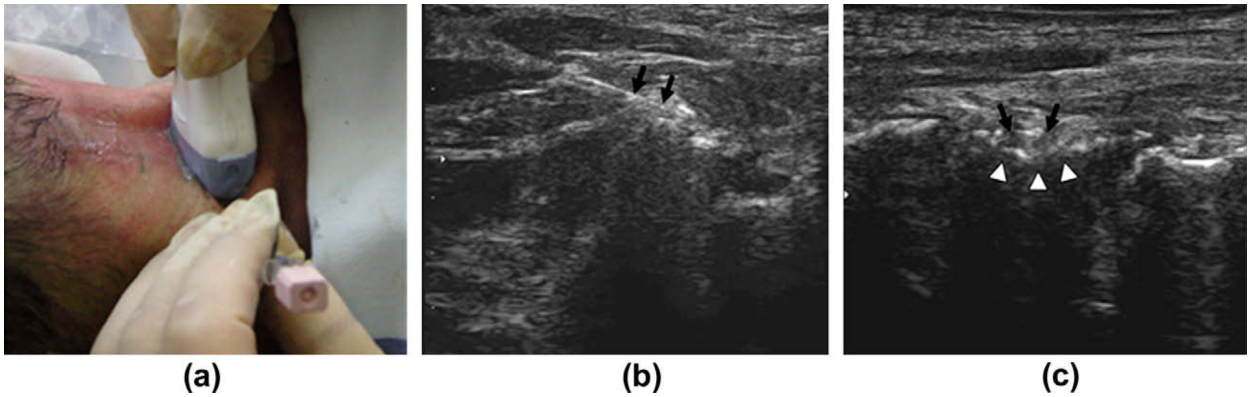


Figure 2 Under real-time ultrasound guidance (a) a 20 G, 10 cm needle was inserted at the medial end of the transducer exactly in the ultrasound plane. Cross-axis (b) and long-axis (c) views show the needle tip (arrows) was placed at the target point in which the C5 cervical medial branch crosses the waist of the ipsisegmental articular pillar (arrowheads).

was enclosed in a perineural space, the tips of 23 G, 5 cm spinal needles were placed on the target points of the C5 cervical medial branch using ultrasound guidance, and with the needle tips in place and after injecting 0.1 ml contrast medium (Omnipaque 300; Nycomed Amersham, Country Cork, Ireland), the needle position was immediately verified and the contrast spread pattern evaluated by examining the specimen using CT (Brilliance 64; Philips, Cleveland, OH, USA). This procedure was performed from beginning to end on the CT table to avoid the movement of the needles during transfer.

RF neurotomy and determination of successful neurotomy

In three cadavers, the two senior authors (C.H.K., L.S.H.) performed ultrasound-guided RF neurotomies of the C3—C7 medial branches without C-arm fluoroscopic confirmation and in two cadavers, the only C5 medial branch with C-arm confirmation. The authors guided the 10 mm exposed tip of the 20 G, 10 cm RF needle along a paramedian path to reach the medial branch as it crossed the curved lateral aspect of its segmental articular pillar. Using a NEURO THERM JK 5 RF generator, the adjacent tissue was heated for 90 s at a measured tissue temperature of 80 °C.

After heating followed by careful dissection, the authors exposed and macroscopically examined each medial branch in all five cadavers. The branches were then removed at the exit of their neural foramen and fixed in 12% neutral buffered formalin solution, embedded in paraffin. These specimens were sectioned in 4 μm section widths and were stained with haematoxylin and eosin to assess the damage of the nerve fibres. The efficacy was assessed by calculating the numbers of specimens in which a successful coagulation of nerve tissue had been confirmed by microscopic examination.

Results

Part 1

Sonographic target points using the cross-axis and long-axis view were feasible for needle guidance in the first and second cadavers, and no case required more than 5 min placing the needles at each target segment. C-arm fluoroscopy verified that 20 needle placements in two cadavers exactly corresponded with the fluoroscopic target points, as recommended by the International Spine Intervention Society guidelines. The sonographic target points of the C4 and C5 medial branches constantly corresponded to the concavity of the waist of their articular pillars. However, C-arm fluoroscopy in these two cadavers showed that the sonographic target points of other medial branches were located progressively higher on their respective articular pillars at levels progressively further away from the C5 level (Fig. 3). Although the C7 medial branch exhibits considerable variation in location and it does not usually cross the ambiguous waist of the articular pillar, the assumed cervical medial branches and their target points were clearly visualized lying on the upper edge of the transverse process in all five cadavers using the described sonographic technique.

In the second cadaver, the CT examination verified the correct position of the C5 articular

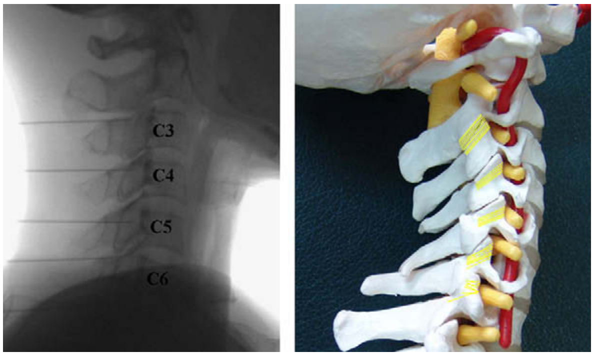
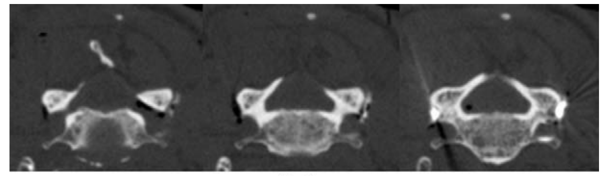
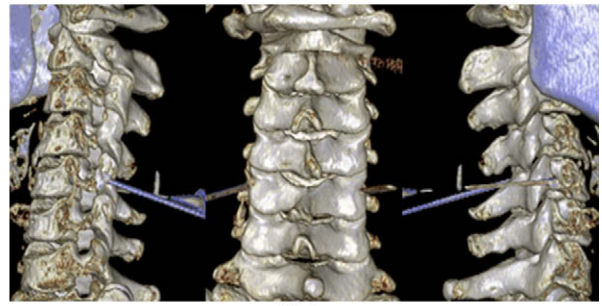


Figure 3 C-arm fluoroscopy after ultrasound-guidance shows that the needle tip for the C5 medial branch is located over the middle portion of the C5 articular pillar, but other medial branches are located progressively higher on their respective articular pillars at levels progressively further away from the C5 level. The needle tip for the C7 medial branch is obscured at the base of the neck, due to overlying shoulder girdles. These locations of needle tips applied to the C3 through C7 medial branch correspond with the distribution of cervical medial branches, which is represented as oblique yellow lines in a cervical model on the basis of International Spine Intervention Society guidelines.



(a)



(b)

Figure 4 Sequential axial CT images (a) show needle tips at the target points for both-sided C5 medial branch neurotomies, and typical localized air and contrast medium spread reaching the location of the cervical medial branch. The exact placement of the needle tips was again verified by three-dimensional rendered CT images (b).

pillar target site, and showed the injected contrast material had spread from the curved lateral aspect of the articular pillar, in which the needle tip was placed, to the C4—C5 neural foramen (Fig. 4). This spread pattern of contrast material indicated that the hypoechoic structure used as the sonographic target point was enclosed in the perineural space containing the cervical medial branch originating from spinal nerve in the neural foramen.

Part 2

In 30 of 34 neurotomies, successful coagulation of the cervical medial branches was confirmed (Table 1). The histological examination of nerves was consistent with acute electrocautery injury manifested by oedema, coagulation, and homogenization of cytoplasmic contents, and fading or smearing of nuclear chromatin (Fig. 5). All of four C5 medial branches obtained from the two cadavers used in the first part of the study were successfully coagulated. In the remaining three cadavers in whom RF neurotomies were performed from the C3—C7 medial branches, two of six C7 medial branches could not be exposed during cadaver dissection. Although the acquisition of the C7 medial branches failed in initial cadaver dissection, four C7 medial branches in the remaining two cadavers were successfully obtained through cadaver dissection. In three of these four C7 medial branches, successful coagulation of the medial branches was identified on pathological examination. The left C7 medial branch in the fourth

Table 1 Radiofrequency neurotomies and their outcomes in five cadavers

Cadaver no./sex/age (years)	Neurotomy level	C-arm fluoroscopic confirmation	Neurotomy side	Outcome (% success)	Failed medial branch
1/F/84	C5	Yes	Both	100% (2/2)	
2/F/50	C5	Yes	Both	100% (2/2)	
3/M/69	C3, C4, C5, C6, C7	No	Both	80% (8/10)	both C7[a]
4/M/65	C3, C4, C5, C6, C7	No	Both	90% (9/10)	left C7[b]
5/M/68	C3, C4, C5, C6, C7	No	Both	90% (9/10)	left C6[c]

[a] No acquisition of nerve tissue on cadaver dissection.
[b] Failed coagulation of nerve tissue on pathological examination.
[c] Muscle tissue not nerve tissue on pathological examination.

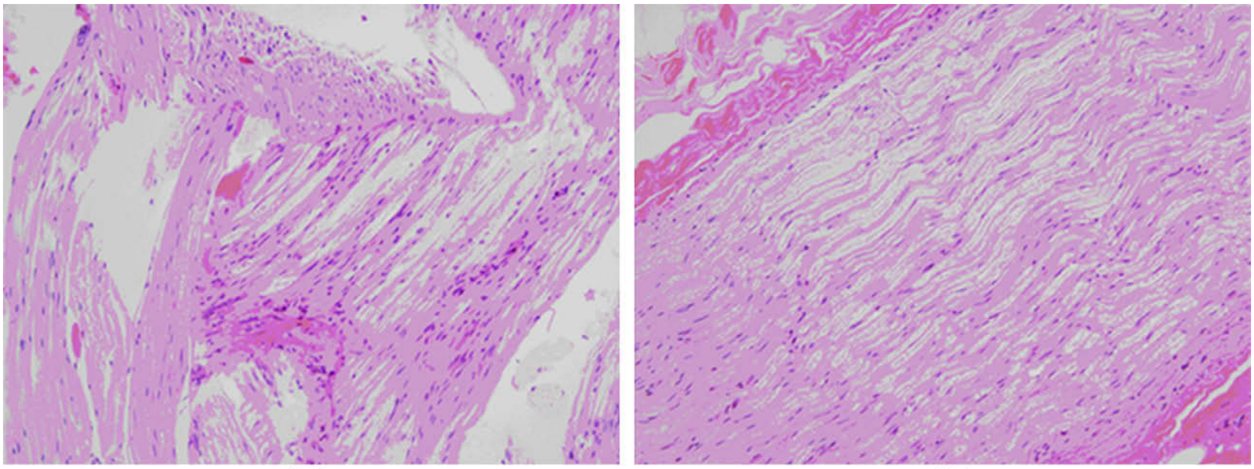


Figure 5 Pathological specimen of the left C7 medial branch obtained from the fifth cadaver shows cauterized nerve (a) compared with failed coagulation (b) of the left C7 medial branch obtained from the fourth cadaver.

cadaver was not coagulated (Fig. 5). In the fifth cadaver, the pathological specimen presumed to be the left C6 medial branch proved to be muscle tissue. Therefore, a successful neurotomy was pathologically confirmed in 26 of 30 medial branches in which ultrasound-guided neurotomy was performed without C-arm fluoroscopic confirmation.

Discussion

The technique of ultrasound-guided RF cervical medial branch neurotomy has not previously been reported. In the present study a method for ultrasound-guided RF cervical medial branch neurotomy using five fresh cadavers was described and validated. Using the described sonographic cross-axis and long-axis view, it was shown that the target point on the curved lateral aspect of the articular pillars can be easily identified, the RF needle quickly positioned, and subsequent neurotomies will coagulate the medial branch. Visualizing both the bone landmarks of the articular pillars and the medial branches, 30 of 34 ultrasound-guided RF neurotomies were successfully performed and verified in five cadavers.

Others have demonstrated the technique and benefits of using real-time ultrasound needle guidance when performing regional and peripheral nerve blocks.[13–16] Greher *et al.*[11,17] reported the clinical feasibility of ultrasound-guided lumbar medial branch block. In their study, they respectively performed 28 and 50 ultrasound-guided lumbar medial branch blocks in five patients and five embalmed cadavers, and reported a high success rate verified by identifying successful needle tip position and spread of injected contrast medium following CT visualization. In contrast to Greher *et al.*,[11,17] high-quality sonographic views were used in the present study to define the ultrasound-guided approach to the cervical medial branches.

Sluijter and Koetsveld-Baart[5] described a technique for percutaneous RF coagulation of cervical dorsal rami. In their technique, electrodes were introduced laterally to the facet joints and their position monitored by oblique fluoroscopy to ensure adequate displacement from the spinal nerve and ventral ramus. However, this technique may be inappropriate if the target point used is dangerously close to the spinal nerve and the vertebral artery. If the innervation of the facet joint is the desired target point, a more suitable target point for diagnostic injections of local anaesthetic or for RF lesions is suggested by Bogduk.[7] Based on their anatomic studies, they report that the cervical medial branches run around the anterolateral, lateral, and posterolateral aspects of their ipsisegmental articular pillars. The C5 medial branch occupies the lateral concavity of the articular pillar. At other levels, the medial branches differ and vary slightly in their location, with variation becoming greater at levels furthest displaced from C5.[12] This archetypical relationship and variation between nerve and bone were also substantiated in this study using the target point of ultrasound guidance.

In the present study, the electrodes were introduced parallel from a posterior paramedian entry point so that the final needle position was over the lateral or anterolateral aspect of the articular pillar and oblique to the target nerve. According to Bogduk *et al.*,[18] effective percutaneous medial branch neurotomy could be achieved only when both an oblique and posterior needle insertion was made to introduce the electrodes parallel to the target nerve. Because ultrasonic guidance as described allows direct visualization of the target nerve, the electrodes could be placed directly on the target medial branches and RF ablation further confirmed perfect localization. Because successful lesioning was confirmed in 30 of 34 pathologically examined specimens, only one needle insertion using the present ultrasound-guided approach may be sufficient.

Each cervical spinal dorsal ramus, except the first, divides into medial and lateral branches that all innervate muscles, and the medial branches of the second to fourth, and usually the fifth, often innervate the skin. Except for the first and second, each dorsal ramus passes back medial to a posterior intertransverse muscle, curving round the articular process into the interval between semispinalis capitis and semispinalis cervicis.[19] The third cervical dorsal ramus is intermediate in size between the second and fourth, and it is thought to be directly or indirectly responsible for one form of headache syndrome.[20] It lies deep to trapezius and give rise to the deep medial branch, which is involved in the innervation of the C3—C4 zygapophysial joint, and the superficial medial branch, which is the third occipital nerve, and which innervates the C2—C3 zygapophyseal joint.[7] The third occipital nerve pierces the trapezius to end in the skin of the lower occipital region, medial and connected to the greater occipital nerve. In the present study, ultrasound-guided RF neurotomy was performed only for the C3 deep medial branches because the appropriate bone landmarks of the third occipital nerve could not be evidenced which was demonstrable on the ultrasound. Although the third occipital nerve measures some 1.5 mm in diameter, all other medial branches are less than 1 mm.[21] Furthermore, they do not run directly on the bone of the articular pillar and they are displaced from the bone surface by a distance of between 1—2 mm.[21] Therefore, ultrasound-guided RF neurotomy, which is based on the direct visualization of the medial branches, is expected to be useful in comparison with fluoroscopy-guided neurotomy using the bone landmarks. The C3, C6, and C7 medial branches appeared small and tricky to visualize using ultrasound. Despite their small diameter, RF neurotomies for the C3 and C6 medial branches were successfully performed in three cadavers, except for one C6 medial branch neurotomy. However, the success rate of the C7 medial branch neurotomy was not satisfactory based on the present data, in which no detection of the C7 medial branch through cadaver dissection was considered to be a failure.

Some limitations should be noted in the current study. First, the ultrasound technique and subsequent success rate should be validated in symptomatic patients because the results of a cadaver study may not reflect the clinical situation. Second, histological changes of the cadaver medial branches in which RF ablation was performed will not be the same in living patients because the cellular reactions no longer exist after death and because there is not perfusion after death. Third, RF neurotomy was considered to be successful if the coagulation necrosis occurred anywhere in the nerve obtained through cadaver dissection, regardless of the extent and location of the coagulation necrosis. Therefore, the study was unable to test the efficacy of RF neurotomy.

In conclusion, in the present study the sonographic target point necessary for ultrasound-guided RF neurotomy of the cervical medial branch was described and localised successfully in 30 of 34 cervical medial branches in five cadavers. According to the present data, ultrasound seems to be a promising guidance technique for C3—C6 medial branch neurotomy. Despite the feasibility of using ultrasound guidance, fluoroscopic guidance is the criterion standard and is the only clinically proven method of positioning needles for cervical medial branch neurotomies. If subsequent studies for symptomatic patients confirm the validity of ultrasound guidance, this technique could replace fluoroscopy, thus eliminating radiation exposure and simplifying the technique for cervical medial branch neurotomies.

Acknowledgement

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