Chapter 7

Ultrasound Guidance for Botulinum Neurotoxin Therapy

Cervical Dystonia

Panagiotis Kassavetis, Michael E. Farrell and Katharine E. Alter

Introduction

Idiopathic cervical dystonia (CD) is characterized by sustained muscle contraction leading to abnormal postures and twisting movements of the head and neck. Patients with CD report functional limitations and pain associated with the muscle pulling or twisted postures. The combination of pain and posturing affects many activities of daily living and quality of life and limits participation in work, family life and avocational interests.

Treatment options for patients with CD include manual or physical therapy, oral medications, surgical procedures such as denervation and myotomy, deep brain stimulation and botulinum toxin therapy (BoNT). BoNT is the gold standard for treatment of the abnormal postures and movements associated with CD. It provides a long duration of symptomatic relief of the pain or postures associated with CD with minimal side effects (Costa *et al.*, 2005; Simpson *et al.*, 2008; Truong *et al.*, 2010; Comella *et al.*, 2011; Rodrigues, 2021). The complex regional anatomy in the craniocervical region increases the potential risks of injections in this area. Ultrasound guidance provides useful information about the depth and thickness of the target muscles, structures to be avoided when inserting/advancing a needle, a safe path to the target and the location of the injectate within the muscle. When treating patients with CD, ultrasound is frequently combined with electromyography (EMG) guidance which provides additional information about muscle activity and potential contribution to a posture. This chapter provides a review of ultrasound guidance for injections for craniocervical dystonia

Ultrasound and Other Imaging Guidance Techniques

A variety of imaging modalities are used for procedural guidance for BoNT/chemodenervation procedures include B-mode ultrasound (US), CT guidance, fluoroscopy and endoscopy (Glass *et al.*, 2009; Lee *et al.*, 2009; Hong *et al.*, 2012). Of these techniques, B-mode US has emerged as the primary imaging modality for BoNT injections based on a number of factors, including anatomical accuracy, portability/accessibility and patient acceptance, among others.

During US-guided BoNT procedures, B-mode and Doppler imaging are used to visualize the structures of interest (target muscles, vessels, nerves, organs), a safe path to the target, the needle and the location of the injectate. The distinct advantage of B-mode US is the provision of real-time continuous guidance for the needle and target throughout the procedure. Compared with other image guidance techniques, US also has a lower risk profile (no ionizing radiation), the equipment is portable and procedures guided in this way are less costly than using fluoroscopy or CT.

Ultrasound-Guided Botulinum Neurotoxin Injections for Cervical Dystonia

Technical Requirements and Techniques

Equipment required to perform US-guided chemodenervation procedures includes a US machine, linear transducers of various frequencies and/or sizes, a coupling agent to reduce skin impedance (US gel or saline) and procedural supplies (transducer covers, needles, gloves, etc.) (Alter 2010; Davidson and Jayaraman, 2011; Alter *et al.*, 2012; Alter and Karp, 2017).

The primary mode of US used to guide chemodenervation procedures is B-mode, although Doppler imaging is a useful tool to visualize and avoid vascular structures in the head and neck. The majority of machines come with factory-installed musculoskeletal and/or glandular imaging presets. These presets speed system navigation, reduce the time for scanning or procedure setup and optimizes imaging of the structures of interest. Sonographers can also set up customized presets and annotation systems to meet their individual scanning needs.

Transducers

Transducers come in various sizes and configurations. Linear transducers are best suited for most US-guided BoNT procedures, including those for craniocervical muscles. The frequency of a transducer determines the depth of sound wave penetration as well as the image resolution (through sampling frequency). Higher-frequency transducers provide better image resolution, but this is at the expense of depth of penetration. For the vast majority of head and neck injections, a linear transducer with a frequency range between 4 and 5 MHz on the lower range and 12 to 18 MHz on the higher range are sufficient. Higher frequencies (>18 MHz) may be useful when scanning very superficial muscles or structures. A small footprint transducer such as a "hockey stick" is valuable for irregular surfaces, small spaces or smaller patients.

Ultrasound Basics for Tissues

With B-mode US imaging, structures are described based on their echotexture. During B-mode US imaging, structures with a higher water content appear hypoechoic or dark when few US waves are reflected back to the transducer. Structures that are more highly reflective of ultrasound waves (i.e., those with a lower water content) will appear hyperechoic or bright because more of the US waves are reflected back to the transducer. Muscle is made of a mixture of tissue types and therefore has a mixed echotexture appearance, with the contractile element fibers appearing hypoechoic and the intramuscular connective tissue or surrounding fascia appearing relatively hyperechoic. Tendons are hyperechoic, highly anisotropic and fibrillar in appearance. Nerves are less hyperechoic or fibrillar than tendons and have a fascicular appearance, particularly in short axis. Vessels are anechoic (black). Bone is mirror-like and highly reflective of US waves. Therefore, the cortex of bone will appear hyperechoic, and since no US waves penetrate the cortex, acoustic shadowing (hypoechoic/dark) will be observed underneath (Smith and Finnoff, 2009a; Alter, 2010; Alter *et al.*, 2012).

Imaging Techniques

An important technical pearl is that the width of the US beam created by a transducer is much narrower than the width/footprint of the transducer. As a result, if the transducer is placed in contact with the skin and held in a static position, only a thin slice of the region directly under the US beam is visualized. To completely image a structure or target requires the operator to "scan," or move the transducer up/down, back/forth to fully image the entire region of interest. This "scout" scan is required prior to any procedure, as it provides the clinician with useful information about structures of interest, the depth/location of the target, the best/safe path to the target, structures to be avoided (nerves, vessels) and the presence of anatomical variations or masses (Smith and Finnoff, 2009a, 2009b; Alter 2010; Alter *et al.*, 2012)

When scanning with US, muscles/structures can be imaged either in the transverse (short axis, Fig. 7.1a) or in the longitudinal (long-axis) plane (Fig. 7.1b). The contour lines of muscles and their neighboring structures are best identified in short axis, as long-axis views only reveal a thin imaging slice of the region under the beam (Fig. 7.1b). However, it is recommended to scan in both planes to determine which provides the best view of the target, the surrounding structures and a clear path to the target of injection.

When used for procedural guidance, B-mode US provides real-time, continuous visualization of a structure and the location of the needle throughout the procedure, but only if the needle is kept within the beam produced by the transducer. Needle visualization can often be improved using machine-specific software such as beam steering or a needle enhancement preset (Alter and Karp, 2017) . Sometimes needle visualization can also be improved with color Doppler during needle movement/jiggling (Hamper *et al.*, 1991). However, color

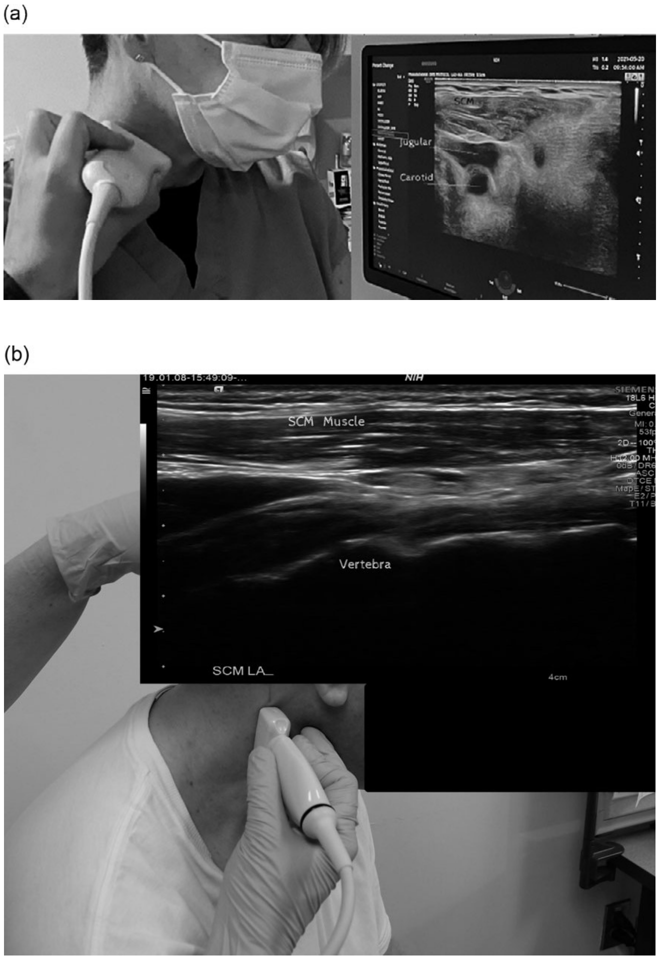

Fig. 7.1 (a) Short-axis (cross-sectional) ultrasound scan, anterior cervical region. (b) Long-axis (longitudinal) B-mode ultrasound scan, sternocleidomastoid muscle, anterior cervical region.

Doppler causes decrease of the image quality; therefore, it should be used only intermittently and not throughout the whole procedure.

When using an in-plane approach (Fig. 7.2a–c), the needle is inserted along the length of the transducer. When this technique is performed optimally (Fig. 7.2c), the entire needle, including the tip, will be visualized at the same time. Due to anisotropy, needle visualization is optimized by inserting the needle perpendicular to the ultrasound beam, which requires a flat (Fig. 7.2a,c), rather than steep (Fig. 7.2b), angle of insertion relative to the transducer. In the out-of-plane approach, the needle is inserted through the short axis of the transducer (Fig. 7.3a–c). When using an out-of-plane technique, the needle is viewed in short axis and, therefore, appears as a hyperechoic dot. When using the out-of-plane technique, a "walk-down" technique is used to ensure that the tip of the needle is in the target structure (Smith and Finnoff, 2009b; Alter, 2010; Alter *et al.*, 2012). When using a walk-down technique, the clinician jiggles or vibrates the needle during insertion and at the same time fans or slides the transducer to maintain the needle tip

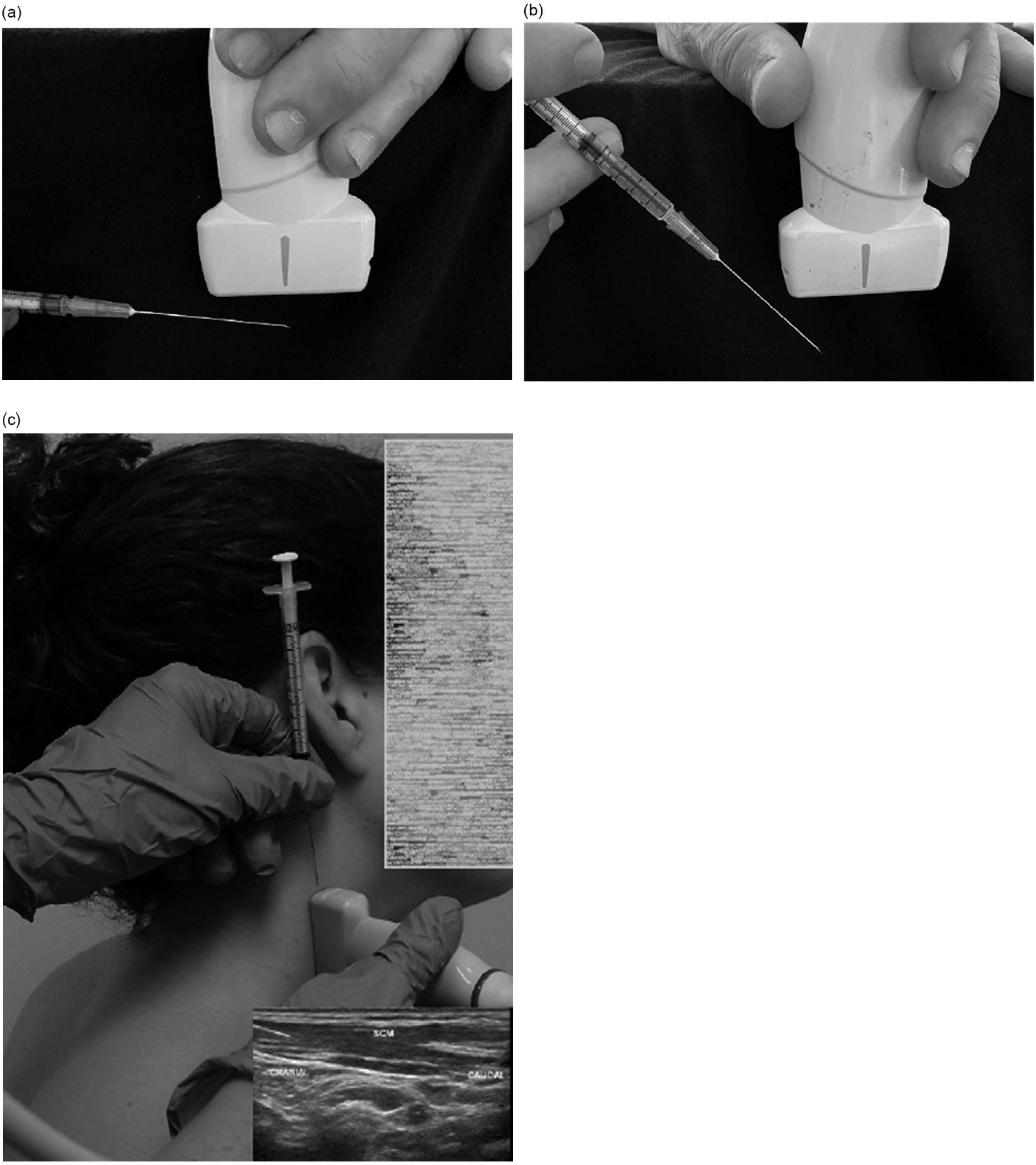

Fig. 7.2 (a) In-plane technique with flat angle of needle insertion. (b) In-plane technique with shallow angle of needle insertion. (c) In-plane view of needle, sternocleidomastoid muscle, long-axis ultrasound scan.

within the US beam, as the needle approaches the target. If the needle–transducer insertion angle is steep (Fig. 7.3a) (~10 degrees), rather than shallow (Fig. 7.3b), then this helps to keep the tip of the needle under the transducer/within the US beam and decreases the amount of transducer repositioning/fanning/sliding. When a needle is inserted at a shallow angle, the tip can easily pass beyond the US beam and therefore may be in an untargeted muscle or structure. With experience, the

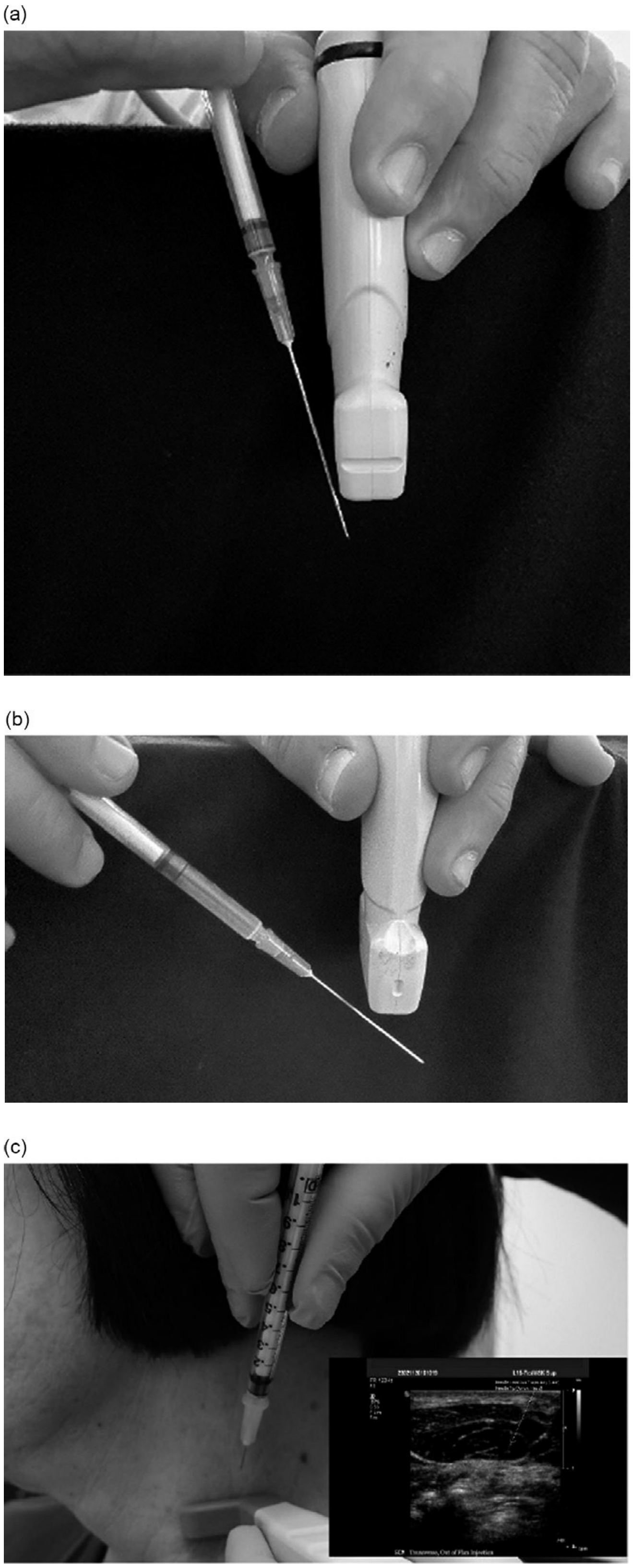

Fig. 7.3 (a) Out-of-plane technique with steep angle of needle insertion. (b) Out-of-plane technique with shallow angle of needle insertion. (c) Out-of-plane view of needle.

sonographer should be able to easily calculate or predict the trajectory of the tip of the needle and follow it accurately with the US beam during out-of-plane technique. The two techniques each have advantages and disadvantages, and clinicians are advised to be skilled in both in-plane and out-of-plane approaches. While the in-plane technique is theoretically preferred (the entire needle is visualized), this technique can be technically challenging and difficult to perform when targeting superficial muscles. Depending on the training of the sonographer, the out-of-plane technique can also be accurate in most muscles (Alter *et al.*, 2012; Walter *et al.*, 2018).

In addition to providing direct assessment about the depth/location of the target and the needle, US also provides information about the volume of injectate and resulting distention of the muscle as the injection is performed. This added information can guide the clinician during the procedure to avoid injection of excess volume at one injection site.

Muscle Selection

A careful clinical examination with active and passive range of motion (sometimes under anesthesia) is essential for determining the target muscles. Particular attention should be paid in patterns that can easily be confused, such as neck (-collis) versus head (-caput) postures. A range of potential doses for each muscle is sufficient and the final determination can be made based on EMG activity (if EMG is used concurrently with the US) and based on the sonographic appearance of the muscle (taking into account bulk, atrophy, abnormal echogenicity due to fibrosis or other reasons and injectate volume). Groups of adjacent muscles that can be targeted with the same insertion along the path of the needle are: 1. Trapezius and levator scapulae (Fig. 7.4a), 2. Longus colli and longus capitis (Fig. 7.4b) 3. Splenius capitis, semispinalis capitis and OCI (Fig. 7.4c).

Positioning of the Transducer

Target muscles can be visualized in the long or short axis. For identification of muscles and adjacent structures, the short axis is preferable, as it reveals the contour lines of the various structures and allows simultaneous visualization of multiple adjacent structures (Figs. 7.1a, 7.4b. 7.4c). However, the long axis is particularly useful when targeting specific muscles such as the levator scapulae (Fig. 7.4a). Another consideration regarding the positioning of the transducer is the orientation relative to the US machine display. Each transducer has a mark or notch that orients to screen left of the US display. Consistency in orienting the transducer/positioning of the notch is essential to facilitate identification of the structures and avoid errors. The authors prefer to use the following conventions: in longitudinal scans the transducer is oriented on the patient so that screen left is rostral and screen right is caudal. In cross-sectional scans, the transducer is oriented on the patient so that left of the display screen represents medial (or anterior) and screen right is lateral (or posterior). In this convention, images obtained on the right or left side of the

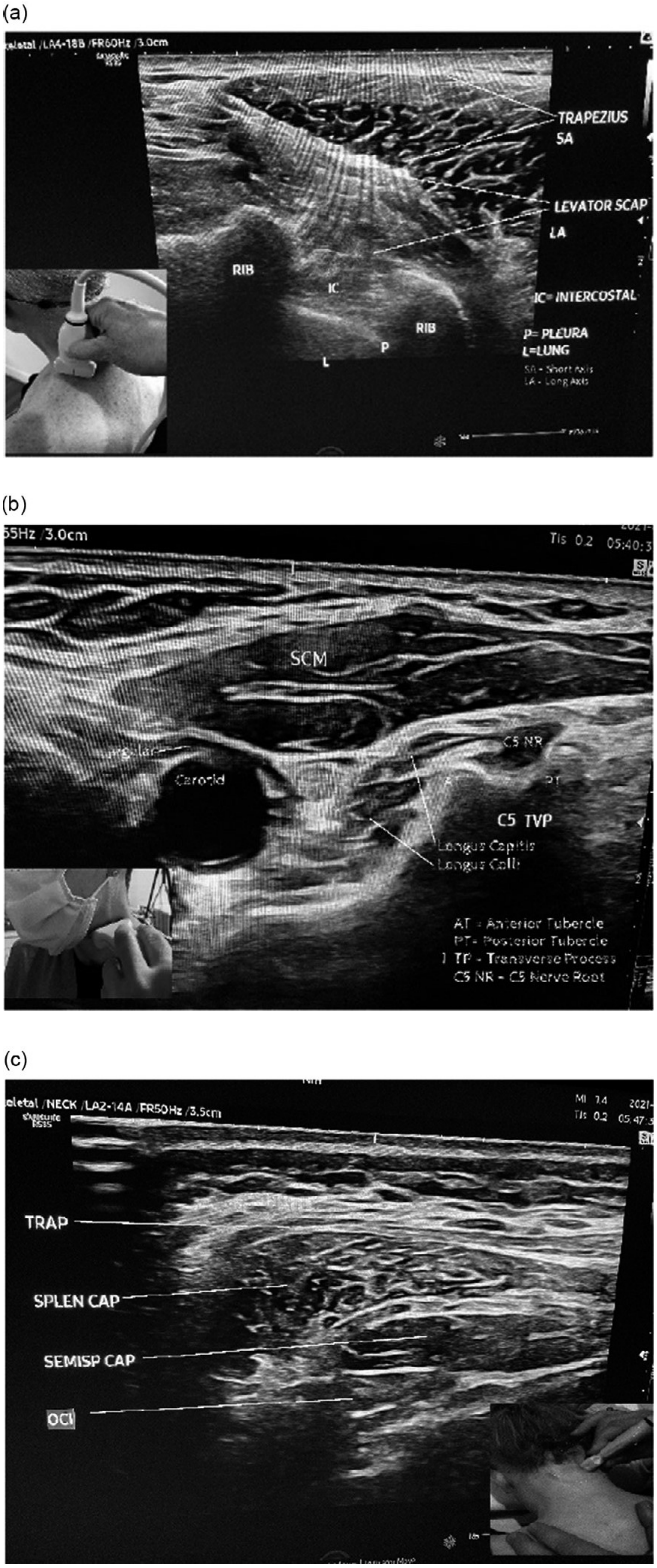

Fig. 7.4 (a) B-mode ultrasound image of levator scapulae (long axis), trapezius (short axis).(b) Short-axis B-mode ultrasound image of longus colli and capitis at C5 level. (c) Short-axis B-mode ultrasound image, posterior neck muscles.

body will appear the same. Other authors or sonographers may prefer to position the transducer–patient–display so that the ultrasound image is a direct reflection of the way the patient is positioned relative to the sonographer. In these conventions the images obtained from the right and left side of the body will be mirror images. These mirror images may be confusing for some novice sonographers who are unfamiliar with muscle pattern recognition.

Commonly Targeted Muscles

Anterior Neck Muscles

Sternocleidomastoid

The superficially located sternocleidomastoid can be imaged either in long-axis/longitudinal (Figs. 7.1b, 7.2c) or in short-axis/transverse plane (Figs. 7.1a, 7.4b). The transverse plane typically provides a better assessment of the contour lines of the various muscles, fascial planes between muscles, as well as the location of adjacent neurovascular structures (Figs. 7.1a, 7.4b). Scanning in both planes is recommended, a short-axis/transverse-plane scout scan should always be performed first and is then followed by a long-axis/longitudinal scan. The clinician can then choose a scanning plane that provides the best view of the sternocleidomastoid, its depth, thickness and also structures to be avoided including the carotid and jugular vessels (Fig. 7.5). The sternocleidomastoid can be approached with either an in-plane or out-of-plane needle insertion. Injections are most often performed in the upper one-third or proximal portion of the muscle to reduce the risk of dysphagia (Truong *et al.*, 1989).

Longus Colli and Capitis

These muscles are located deep in the anterior cervical region (Figs 7.4b, 7.6a, 7.6b). With US guidance, Doppler imaging should be employed for visualization of the carotid and internal and external jugular veins (Fig. 7.6b). A novel lateral approach with contralateral head rotation can sometimes provide a better window between the neurovascular bundle anteriorly and the vertebral transverse processes posteriorly (Farrell *et al.*, 2020). Depending on the dose, a single or multiple injections may be required. Because of their anatomical orientation and proximity, both muscles can be targeted/injected with one needle insertion, which is typically performed between levels C4 and C6. Selection of the level of injection directly in front of the anterior tubercle is preferable, as the boney structure (the tubercle) can stop the needle from damaging more posterior structures such as the nerve root or the vertebral artery.

Anterolateral Neck Muscles

Scalene Complex

The scalene muscles (anterior, middle, posterior) are located in the antero-lateral cervical region within the interscalene triangle, posterior and deep to the adjacent sternocleidomastoid Figs. 7.5, 7.7. When performing US-guided scalene injections,

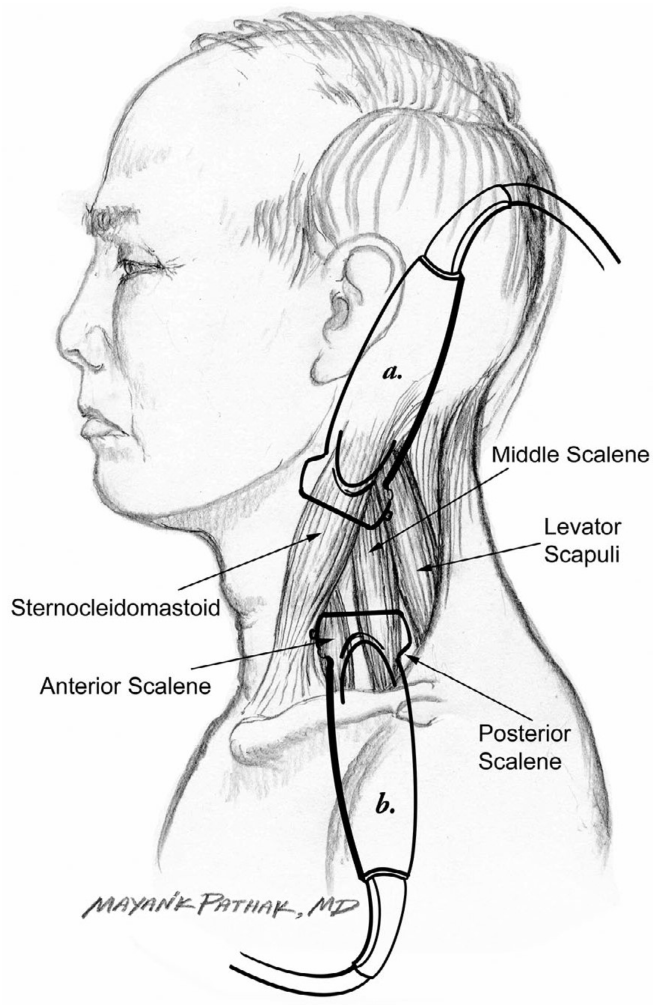

Fig. 7.5 Anatomical illustration of the sternocleidomastoid muscle and scalene muscles with US transducer position and orientation.

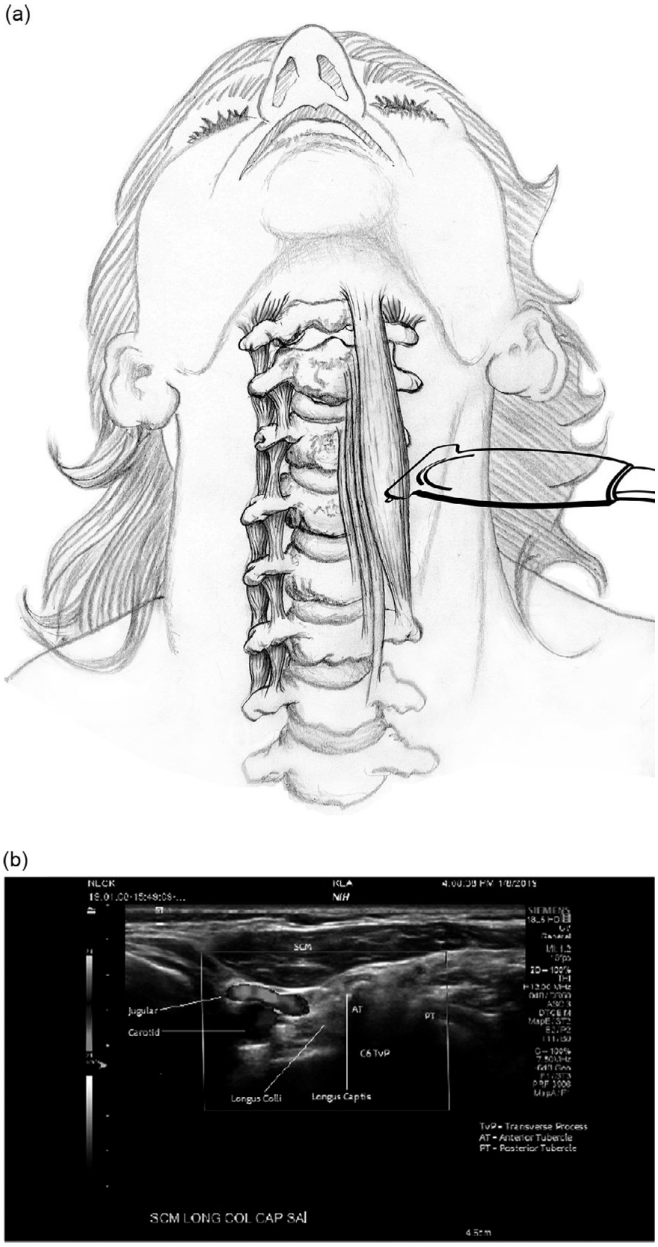

Fig. 7.6 (a) Anatomical illustration longus capitis and colli muscles. (b) Short-axis, color Doppler US image, longus capitis and colli muscles at C6 level. AT: anterior tubercle, PT: posterior tubercle, SCM: sternocleidomastoid.

a short-axis/transverse view of the muscle provides the best view of the contour lines of these muscles, the fascial planes between the sternocleidomastoid, scalene muscles, vessels and nerves (Fig. 7.7). In the transverse view, the roots/trunks of the brachial plexus are easily distinguished as they descend through the neck, running between the anterior and middle scalene muscles (Fig. 7.7). Color Doppler imaging will confirm that these circular hypoechoic structures have no flow and are therefore nerves, not vessels (Fig. 7.7b). The phrenic nerve lies within the fascial plane between the sternocleidomastoid muscle (SCM) and the anterior scalene (Fig. 7.7c). US allows injectors to avoid "spearing" the phrenic neve during needle insertions into the anterior scalene.

Posterior Neck Muscles

Levator Scapulae

The levator scapulae can be approached either from an anterior location where it lies deep to the trapezius (Fig. 7.4a) or, alternately, from the posterior region at its insertion on the scapula, where it again lies deep to the trapezius muscle (Figs. 7.8, 7.9a, 7.9b). It is often best to perform a preliminary scan using both an anterior and posterior approach to determine which technique provides the best view of and approach to the muscle. The authors typically use the anterior approach, especially for patients complaining of muscle pain in this region.

Muscle atrophy, which may occur after repeated injections in any muscle, may make visualization of the levator scapulae

(a)

(b)

(c)

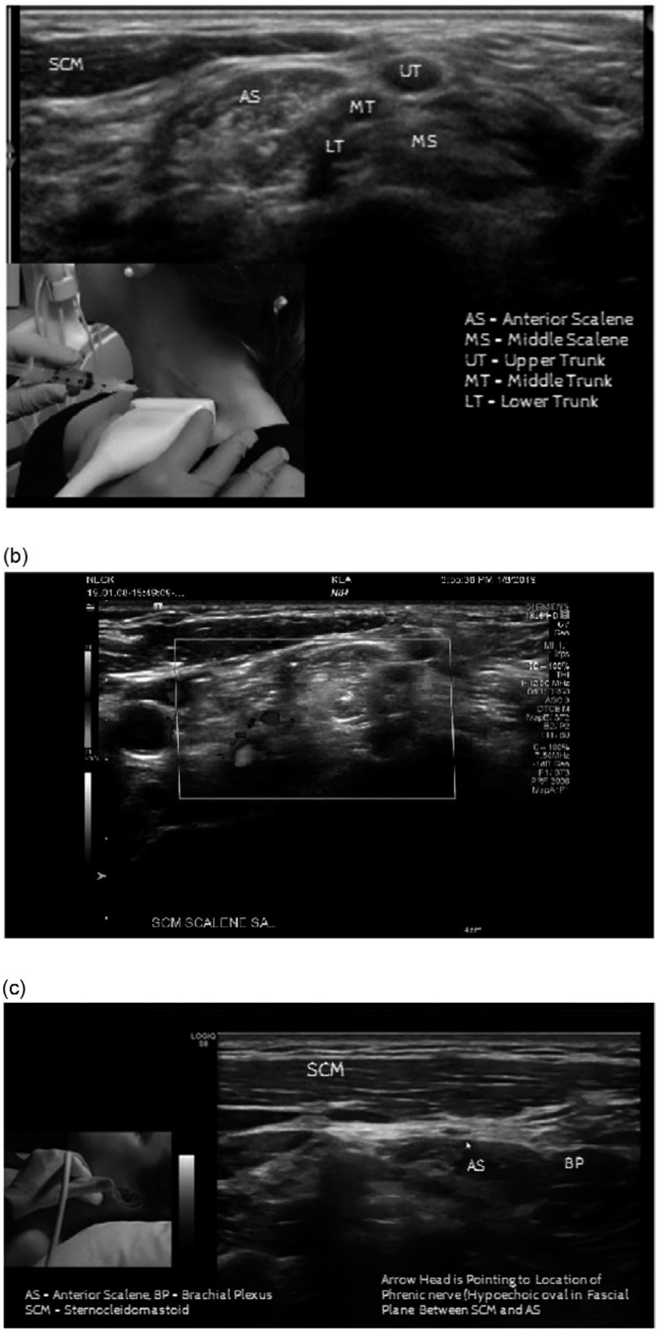

Fig. 7.7 (a) Short-axis B-mode US image, interscalene triangle. (b) Short-axis color Doppler Image, interscalene triangle. (c) Short-axis B-mode image demonstrating relationship between phrenic nerve, SCM, and anterior scalene. AS: anterior scalene, BP: brachial plexus, UT: upper trunk, MT: middle trunk, LT: lower trunk, MS: middle scalene, SCM: sternocleidomastoid.

difficult, but the injections using the anterior approach may be less problematic due to the clearly defined fascial planes between the levator and overlying trapezius. The levator scapulae is adjacent/deep to the trapezius muscle using either an anterior or posterior approach (Figs. 7.4a, 7.9a, 7.9b); therefore, both muscles can be injected during the same needle insertion. When injecting the levator scapulae, it is preferable to identify a portion of the muscle that lies over a rib. This reduces the risk of inadvertent advancement of the needle through intercostal space and into the pleura and lung.

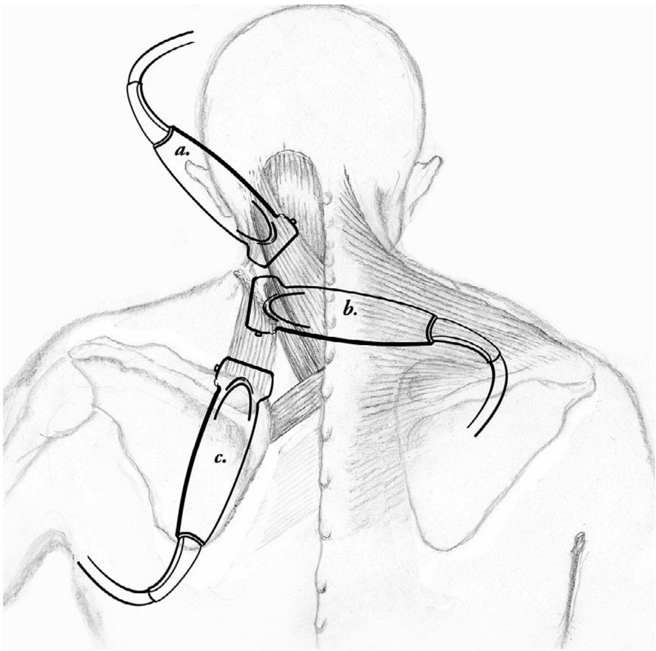

Fig. 7.8 Anatomical illustration posterior cervical muscles. One transducer over the splenius capitis/cervices. Two transducers over the levator scapulae in long and short axes.

Splenius Capitis

When using US guidance, the splenius capitis can be approached from the proximal anterolateral region at the level of the mastoid, just distal to its origin from the ligamentum flavum. At this level (i.e., the mastoid), the splenius capitis lies deep to and posterior to the sternocleidomastoid and deep to and anterior to the trapezius (Fig. 7.10). The splenius capitis/cervices can also be approached posteriorly where it lies deep to the trapezius (Fig. 7.4c).

Trapezius

The trapezius is divided into descending (formally upper), transverse (formally middle) and ascending (formally lower) sections. For patients with CD, injections are generally directed to the descending and transverse regions. The trapezius is the most superficial muscle in the posterior upper back/neck and generally easy to target. The descending/upper cervical section of the trapezius is approached from either a longitudinal or a transverse direction (Fig. 7.4a,c). Lying deep to the trapezius in this region are the splenius capitis/cervices, semispinalis capitis and oblique capitis inferioris (Fig. 7.4c). The transverse or middle portion of the trapezius is often targeted, along with the levator scapulae (Fig. 7.4a) for patients with shoulder

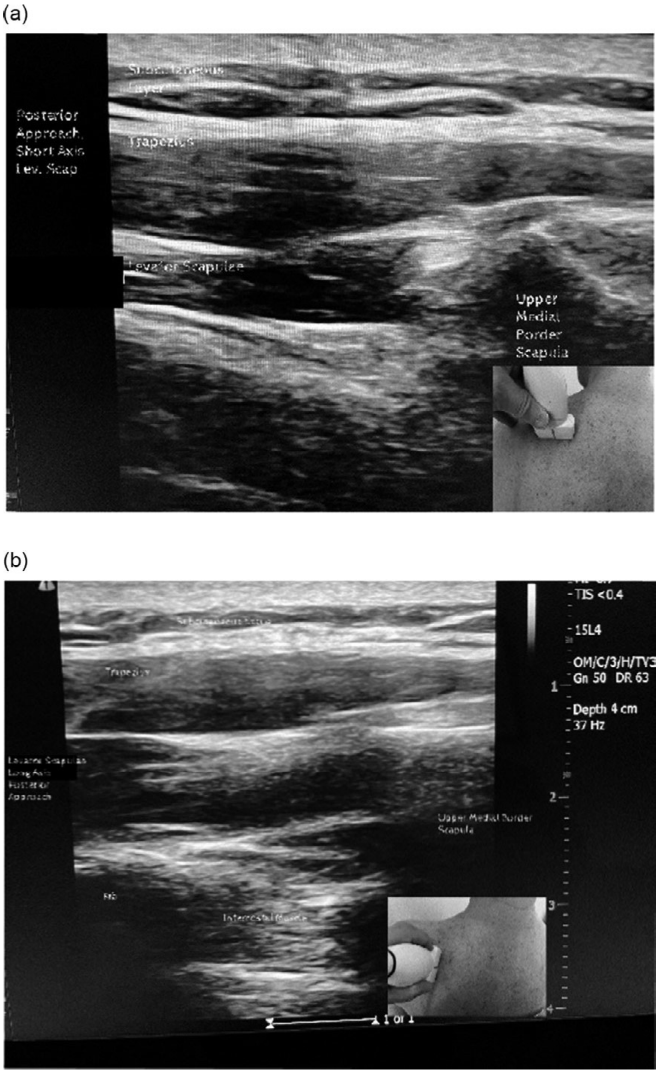

Fig. 7.9 (a) Short-axis B-mode US image, posterior approach levator scapulae. (b) Long-axis B-mode US image levator scapulae, posterior approach.

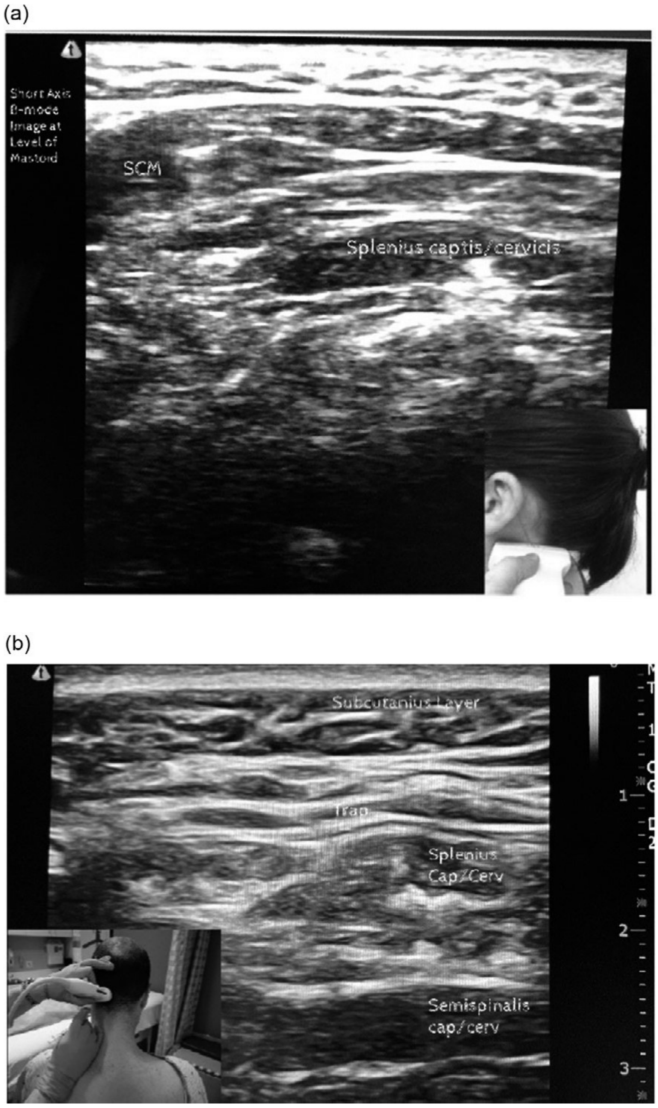

Fig. 7.10 (a) Short-axis B-mode image, splenius capitis at level of mastoid. (b) Short-axis B-mode image, posterior cervical approach splenius semispinalis muscles.

elevation or subjective reports of pain in this region of the muscle.

Splenius Capitis/Semispinalis Capitis/Obliquus Capitis Inferior

As described above, the splenius capitis can be approached either at the level of the mastoid (Fig. 7.10a) or from a posterior direction, where it lies deep to the trapezius (Figs. 7.4c, 7.8, 7.10b). If approached at the C2 level, the splenius capitis, semispinalis capitis and obliquus capitis inferior can all be visualized with US imaging and can be injected using an out-of-plane approach where the needle is inserted through the skin and into the three levels of muscles to be injected (Fig. 7.4c).

Longissimus Capitis

This muscle can be visualized by moving the transducer slightly lateral from the location described above for the posterior approach to the splenius/semispinalis muscles. In the transverse axis, it appears oval or round and well defined in-between the lateral edge of the semispinalis and the splenius capitis (Fig. 7.11). It is a relatively thin muscle, and repeated injections can cause atrophy, making identification of the muscle more challenging.

Summary

The use of US guidance has a number of advantages over other techniques, including increasing evidence that supports a higher accuracy for most US-guided procedures (Lee *et al.*, 2009; Henzel *et al.*, 2010: Hong *et al.*, 2012). Additional studies are needed to evaluate whether this increased accuracy leads to improved treatment efficacy and reduced risk. US guidance

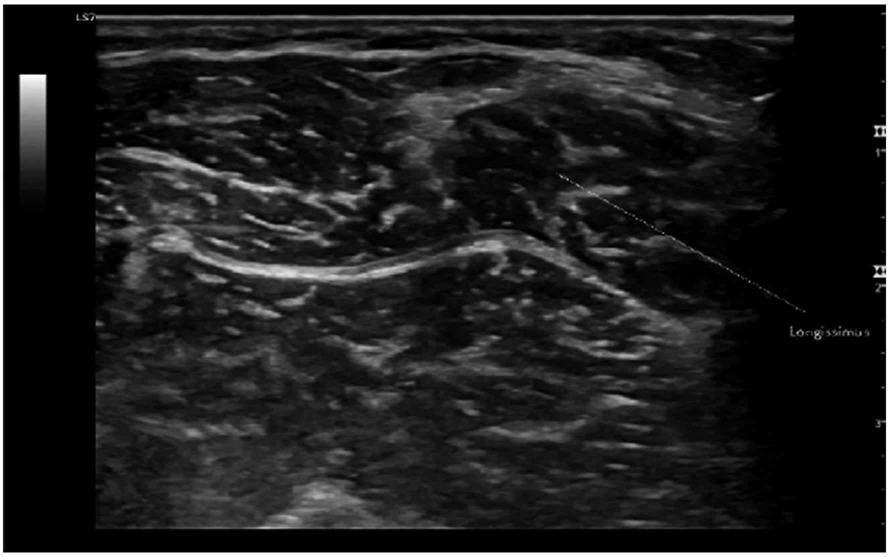

Fig. 7.11 Short-axis B-mode image, longissimus capitis, longissimus cervicis.

seems to be the way forward for guided BoNT injections. The time spent and the effort required to acquire this skill is offset by potential benefits to patients.

Hands-on training at live courses, time spent with an experienced colleague and the use of reference materials can all help physicians to acquire the skills required for US-guided BoNT procedures. The authors recommend that physicians begin to use US as an "add-on" technique to whatever guidance technique is currently used. This strategy allows the physician to achieve the repeated hands-on practice to acquire the skills needed for US imaging and procedural guidance.

References

Alter KE (2010). High-frequency ultrasound guidance for neurotoxin injections. *Phys Med Rehabil Clin N Am*, **21**, 607–30.

Alter KE, Hallett M, Karp B (eds.) (2012). *Ultrasound-Guided Chemodenervation Procedures: Text and Atlas*. New York: Demos Medical, pp. 84–107.

Alter KE, Karp BI (2017). Ultrasound guidance for botulinum neurotoxin chemodenervation procedures. *Toxins (Basel)*, **10**, 18. https://doi.org/10.3390/toxins10010018

Comella CL, Jankovic J, Truong DD, Hanschmann A, Grafe S (2011). US. XEOMIN Cervical Dystonia Study Group. Efficacy and safety of incobotulinumtoxinA (NT 201, XEOMINVR, botulinum neurotoxin type A, without accessory proteins) in patients with cervical dystonia. *J Neurol Sci*, **308**, 103–9.

Costa J, Espírito-Santo C, Borges A *et al.* (2005). Botulinum toxin type B for cervical dystonia. *Cochrane Database Syst Rev*, **1**, CD004315.

Davidson J, Jayaraman S (2011). Guided interventions in musculoskeletal ultrasound: what's the evidence? *Clin Radiol*, **66**, 140–52.

Farrell M, Karp BI, Kassavetis P *et al.* (2020). Management of anterocapitis and anterocollis: a novel ultrasound guided approach combined with electromyography for botulinum toxin injection of longus colli and longus capitis. *Toxins (Basel)*, **12**(10), 626. https://doi.org/10.3390/toxins12100626

Glass GA, Ku S, Ostrema JL *et al.* (2009). Fluoroscopic, EMG-guided injection of botulinum toxin into the longus colli for the treatment of anterocollis. *Parkinsonism Relat Disord*, **15**, 610–13.

Hamper UM, Savader BL, Sheth S (1991). Improved needle-tip visualization by color Doppler sonography. *AJR Am J Roentgenol*, **156**, 401–2. https://doi.org/10.2214/ajr.156.2.1898823

Henzel KM, Munin MC, Kiyonkuru C *et al.* (2010). Comparison of surface and ultrasound localization to identify forearm flexor muscles for botulinum toxin therapy. *PM R*, **2**, 642–6.

Hong JS, Sathe GG, Niyonkuru C *et al.* (2012). Elimination of dysphagia using ultrasound guidance for botulinum toxin injections in cervical dystonia. *Muscle Nerve*, **46**, 535–9.

Lee IH, Yoon YC, Sung DH, Kwon JW, Jung JY (2009). Initial experience with imaging-guided intramuscular botulinum toxin injection in patients with idiopathic cervical dystonia. *AJR Am J Roentgenol*, **192**, 996–1001.

Rodrigues FB, Duarte GS, Castelão M *et al.* (2021). Botulinum toxin type A versus anticholinergics for cervical dystonia. *Cochrane Database Syst Rev*, **4**, CD004312. https://doi.org/10.1002/14651858.CD004312.pub3

Simpson DM, Blitzer A, Brashear A *et al.* (2008). Assessment: botulinum neurotoxin for the treatment of movement disorders (an evidence-based review). Report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology. *Neurology*, **70**, 1699–706.

Smith J, Finnoff JT (2009a). Diagnostic and interventional musculoskeletal ultrasound: part 1. Fundamentals. *PM R*, **1**, 64–75.

Smith J, Finnoff JT (2009b). Diagnostic and interventional musculoskeletal ultrasound: part 2. Clinical applications. *PM R*, **1**, 162–77.

Truong D, Brodsky M, Lew M *et al*. (2010). Long-term efficacy and safety of botulinum toxin type A (Dysport) in cervical dystonia. *Parkinsonism Relat Disord*, **16**, 316–23.

Truong D, Lewitt P, Cullis P (1989). Effects of different injection techniques in the treatment of torticollis with botulinum toxin. *Neurology*, **39**(Suppl), 294.

Walter U, Dudesek A, Fietzek UM (2018). A simplified ultrasonography-guided approach for neurotoxin injection into the obliquus capitis inferior muscle in spasmodic torticollis. *J Neural Transm (Vienna)*, **125,** 1037–42. https://doi.org/10.1007/s00702-018-1866-4