—Review Article—

Ultrasound-guided injections of the equine head and neck: review and expert opinion

Jessica P. JOHNSON[1]*, Tatiana VINARDELL[1,2] and Florent DAVID[1]

[1]Equine Veterinary Medical Center, A Member of Qatar Foundation, P.O. Box 6788, Doha, Qatar
[2]College of Health & Life Science, Hamad Bin Khalifa University, A Member of Qatar Foundation, P.O. Box 34110, Doha, Qatar

Ultrasound-guided injections can be used for a wide variety of conditions in the horse, including both diagnostic and therapeutic applications. Benefits of ultrasound guidance include more accurate deposition of injectate compared with blind approaches. Improved identification of vital structures, including nerves and blood vessels, allows their avoidance and thus reduces procedure-associated complications. Validation of such ultrasound-guided techniques has shown that they can be easily learnt by inexperienced veterinarians, assuming a proper knowledge of the sonographic anatomy. In many cases they can be employed in the field with a high level of accuracy, using widely available equipment, and with complete adherence to the sterility principles. Many ultrasound-guided injection techniques of the axial skeleton in the horse have been described in past years, enabling the equine veterinarian to perform more accurate treatments of specific anatomical areas. The goal of this review is to discuss diagnostic and therapeutic ultrasound-guided injection techniques of the skull and cervical spine in the horse, including those for the retrobulbar space, maxillary and inferior alveolar nerves, atlanto-occipital and atlanto-axial junctions, and cervical articular process joints, as well as the 1st cervical nerve, the C2 and C3 nerve plexus, and the 6th, 7th, and 8th cervical nerve roots.

Key words: *equine, horse, injection, ultrasound, ultrasound-guided*

J. Equine Sci.
Vol. 32, No. 4
pp. 103–115, 2021

Ultrasound (US)-guided percutaneous interventional procedures, such as biopsies, fine-needle aspirates, and diagnostic and therapeutic injections were first developed in human medicine between 1975 and 1980, using animals as models [46]. Similar diagnostic and therapeutic US-guided procedures were later developed in veterinary medicine between 1980 and 1985 [32, 45]. Interestingly, while the first clinical report highlighting the value of a US-guided joint aspiration in humans was published by Gompels and Darlington in 1981, it took many years for equine veterinarians to truly grasp the value of such US-guided techniques, with the first US-guided joint injections attributed to Dr. Jon Vedding Nielsen and his colleagues in 2003 for their work on cervical articular process joints [19].

US-guided injection techniques require a precise parallel alignment between the needle and the transducer to allow the needle tip to stay in focus in the ultrasound beam and to be seen on the screen [11]. Attachable needle-guide devices can be connected to the transducer to maintain the correct alignment of the needle in the US beam, but this can limit site accessibility and is not always practical for use on a conscious, moving animal since the needle is ‘locked’ in position [41, 52]. Therefore, ‘freehand’ techniques, in which the transducer and needle are held in different hands, are more commonly employed for equine patients, allowing the needle to be directed as required [11]. These techniques also allow for avoidance of undesired structures, such as blood vessels and nerves, thereby minimizing potential complications [12]. Other benefits of US-guidance include dynamic real-time imaging throughout the procedure, as well as observation of the injection itself [9, 53]. Precise localization of medication administration allows for the maximum therapeutic effect [10]. Furthermore, with regards to concerns about detection times for equine athletes, this

---

Received: May 17, 2021
Accepted: September 15, 2021
*Corresponding author. e-mail: jjohnson@qf.org.qa

precision also allows for more accurate withdrawal times to be estimated, as the pharmacokinetics differ significantly depending on whether drugs are injected intramuscularly or intra-articularly [29].

The goal of this review is to discuss diagnostic and therapeutic US-guided injection techniques of the skull and cervical spine in the horse, including those for the retrobulbar space, maxillary and inferior alveolar nerves, atlanto-occipital and atlanto-axial junctions, and cervical articular process joints, as well as the 1st cervical nerve (C1), the C2 and C3 nerve plexuses, and C6, C7 and C8 nerve roots.

The Skull

With the relatively high mortality rate associated with general anesthesia in horses [4, 27, 38], as compared with humans, there has been a move towards performing standing surgical procedures with the use of local anesthetic techniques and sedation where possible [16, 17]. In the case of the equine head, standing surgeries provide the additional benefit of minimizing hemorrhage by maintaining the surgical site above the level of the heart, as shown recently for standing alar fold resection, a notoriously bloody surgery when performed under general anesthesia [28].

Some of the nerves of the equine head are superficial and easily palpable beneath the skin surface, while others must be injected based on external bony landmarks [15]. For this reason, relatively few nerve blocks are performed on the equine head using US-guidance, but some recent publications describe its use and improved success rates [34, 39].

Retrobulbar space

An US-guided technique for administration of local anesthetics in the retrobulbar space has been described in horses to facilitate surgical procedures of the globe in both sedated and anaesthetized horses [34]. Advantages of US-guidance include reduction of potential complications, such as inadvertent penetration of the globe, hemorrhage, damage to the optic nerve, and epidural or subarachnoid anesthesia due to intrameningeal injection [34]. With traditional blind injection approaches, there is a risk of optic nerve sheath puncture, which could lead to the development of neuritis or permanent damage to the nerve [34]. As this retrobulbar space block is most commonly performed for the purpose of enucleation, it is possible that the optic nerve sheath is commonly damaged but that the damage goes unnoticed.

Morath *et al*. (2013) performed a prospective experimental cadaver study on 20 Warmblood skulls in which US-guided injection of contrast medium was performed within the cone formed by the retractor bulbi muscle, and its location was confirmed using computed tomography (CT) [34]. In their description of the technique, a 5–8 MHz microconvex transducer was applied to the upper eyelid with the eye closed. US was performed in both horizontal and vertical planes to visualize the optic nerve ventromedially [34]. A 10 cm, 21 G spinal needle was introduced at the rostral aspect of the supraorbital fossa, caudomedial to the caudal aspect of the zygomatic process [34]. It was aimed in a craniomedial direction to a point caudal to the eyeball in the cranio-central aspect of the cone formed by the retractor bulbi muscle (Fig. 1) [34]. They reported successful intraconal needle placement in 55% (22/40) of the injected orbits on first needle placement, with a desirable distribution of injectate caudally towards the orbital fissure in all cases where the needle placement was intraconal [34]. They also reported no eyeball penetration [34]. In 1 of the 40 injections, there was a suspicion of puncture of the optic nerve sheath on CT, but there was no spread of contrast material towards the thalamus [34]. In only 10 of the 40 injections could the needle and optic nerve be imaged simultaneously on US [34]. Since one of the main advantages of using US-guidance for injections is the avoidance of vital structures, it would seem that the technique described by Morath *et al.* (2013) does not completely meet all the criteria to be classified as a safe US-guided injection technique, as the relevant structures cannot all be visualized simultaneously in real time during the procedure. Ultrasound was mainly used to control the needle positioning after placement, explaining the low success rate on first needle placement, as performed in the early days for navicular bursa injection before this technique was refined as a true US-guided procedure [13, 47]. A supraorbital approach was selected for needle insertion while the US transducer was placed on the upper eyelid. This combination did not always allow needle placement in the same ultrasonographic plane as the optic nerve, certainly impairing the performance of their technique. Therefore, there is still room for refinement of this technique to make it truly efficient and safe as an US-guided injection technique. There is also a need for more information regarding the use of this technique in clinical cases, as well as studies comparing its efficacy to blinded techniques. The authors of this review have also used a linear transducer instead of a microconvex transducer applied in a vertical orientation over a closed upper eyelid for this US-guided technique. This transducer is usually more widely available and provides a better image resolution compared with a microconvex transducer, with better hand grip and stability.

Maxillary nerve

US-guidance for local anesthesia of the maxillary branch of the trigeminal nerve (sensory innervation only) has also been described [39]. Desensitization of the maxillary nerve is performed for surgical procedures of the ipsilateral para-

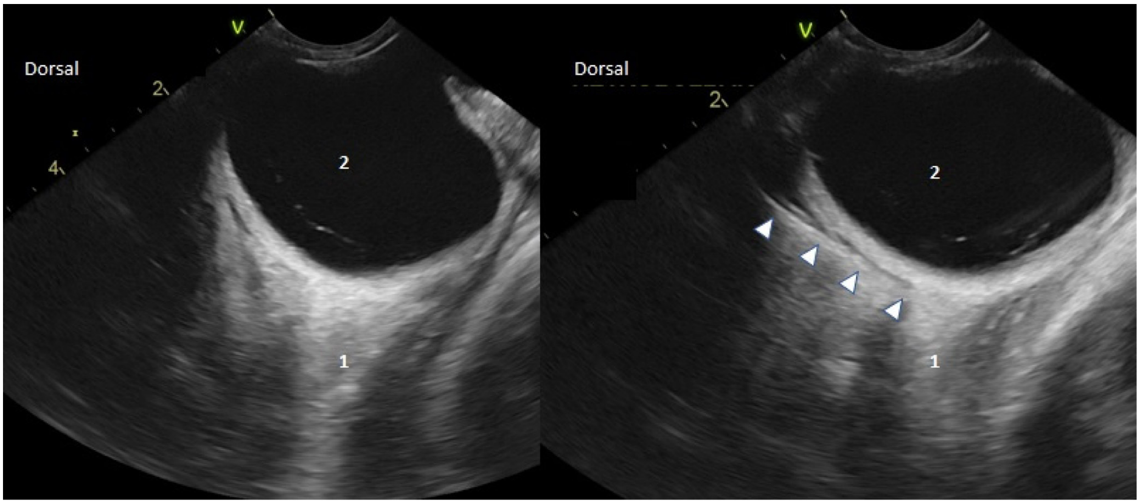

Fig. 1. The left side shows an ultrasound image of a globe taken with a 5–8 MHz microconvex transducer applied in a vertical position to an upper eyelid with the eye closed. (1) Optic nerve surrounded by the retractor bulbi muscle cone, (2) vitreous chamber. The right side shows the same image with an 18 G spinal needle (arrowheads) introduced dorsal to the transducer, with the tip adjacent to the retractor bulbi muscle cone.

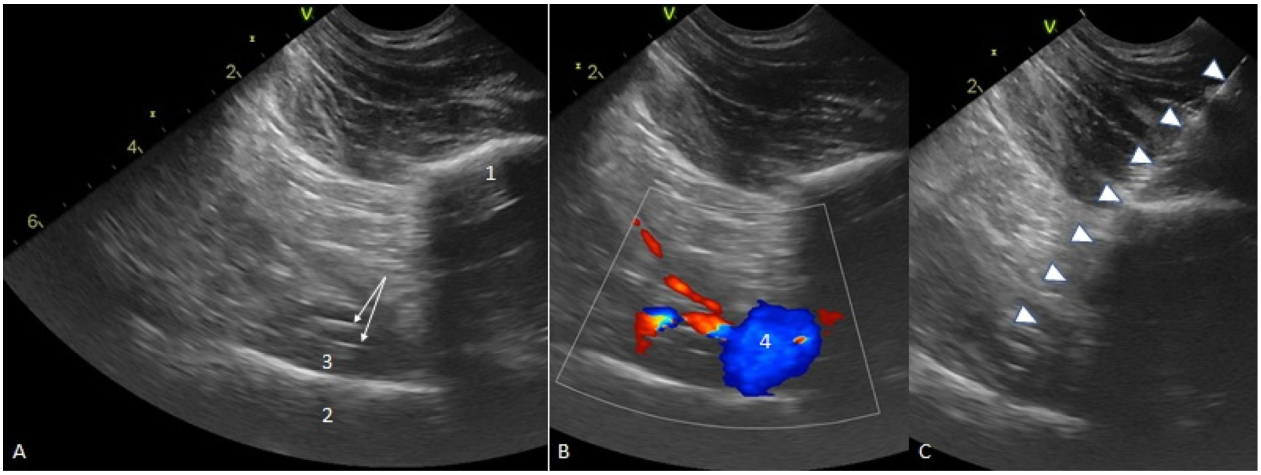

Fig. 2. Image A demonstrates image acquisition of the pterygopalatine fossa using a microconvex transducer (dorsal to left). (1) Tuberosity of maxillary bone; (2) palatine bone; (3) maxillary nerve, with Infraorbital artery (arrows) seen as two parallel hyperechogenic lines within the nerve fascicles. Image B demonstrates image acquisition for the same area as image A, with color flow Doppler highlighting the deep facial vein (4) and its branches adjacent to the tuberosity of the maxillary bone. Image C shows the introduction of the 18 G spinal needle (arrowheads) ventral to the transducer.

nasal sinuses and nasal passage, as well as dental procedures on the ipsilateral maxillary arcade [3, 15, 51]. This nerve block also has diagnostic analgesia applications for the investigation of idiopathic headshaking in horses [36]. O’Neill *et al.* (2014) developed and applied an US-guided injection technique (Fig. 2) [39]. In their technique, a 5–8 MHz microconvex probe set at 6 MHz was placed in a dorsoventral orientation, ventral to a line connecting the medial and lateral canthi of the eye and immediately caudal to the facial crest [39]. Angling the beam rostrally and ventrally in the direction of the last maxillary cheek tooth on the contralateral side allowed visualization of the maxillary and sphenopalatine fossa, the palatine bone, and the infraorbital artery, with the hypoechoic maxillary nerve and periorbital fat adjacent (Fig. 2) [39]. Following skin preparation and desensitization of the skin at the point of needle introduction, an 18–20 G, 90 mm spinal needle was introduced 1 cm ventral to the transducer and aimed towards the point where the dorsal maxillary and sphenopalatine fossa met the palatine bone, just dorsal to the infraorbital artery (Fig. 2) [39]. The needle was advanced until contact was made with bone and then withdrawn 5 mm [39]. In the 8 clinical cases reported by O'Neill *et al.* (2014), a successful block was achieved using 10–20 m*l* mepivacaine hydrochloride (confirmed by loss of sensation of the ipsilateral nares) in all cases within 15 min of injection [39]. The procedure was well tolerated by all standing sedated horses, and no adverse effects were reported [39]. Use of US-guidance combined with color flow Doppler allows identification of the deep facial vein, as well as more accurate visualization of the infraorbital artery, which is surrounded by fascicles of the maxillary nerve, thereby allowing avoidance of these vital structures [39]. It has subsequently been shown that in the hands of inexperienced operators, use of US-guidance for injection of the maxillary nerve results in a significantly higher success rate (65.4% vs. 50%), as demonstrated by the deposition of contrast material in contact with the maxillary nerve on CT [49]. Furthermore, in this study, use of a novel needle guidance positioning ultrasound system further improved success rates, bringing them up to 83.3% [49]. Potential complications of this procedure include the perforation of vessels such as the deep facial vein and infraorbital artery, resulting in suborbital hemorrhage, which can theoretically lead to exophthalmos [39, 49]. Even with US-guidance, Stauffer *et al.* (2017) found a complication rate of 50% (defined as contrast identified within surrounding vasculature or periorbital structures on CT), regardless of whether needle guidance positioning software was utilized or not [49]. Therefore, as for any US-guided procedure, the process must be performed using aseptic techniques, including the preparation of the site, use of sterile gloves, and use of a sterile US probe cover, in order to avoid the risks associated with the development of a suborbital abscess. The authors of this review use this technique on a regular basis for a variety of procedures, including ipsilateral maxillary dental procedures and sinusotomies, and find it an effective and easy-to-learn technique. Working close to the eye necessitates a good plane of sedation and a nose twitch. Inadequate restraint and patient movement can lead to inadvertent perforation of the aforementioned blood vessels despite the use of color flow Doppler, resulting in hemorrhage and hematoma formation. This manifests as swelling at the injection site. In the authors' experience, this has been adequately managed with the application of local pressure and maintenance of the head above the level of the heart, with no further adverse sequelae occurring. Successful desensitization of the maxillary nerve can be achieved with 10 m*l* of local anesthetic and is indicated by loss of sensation in the ipsilateral nares.

Infraorbital nerve

Although their report lacked details on ultrasonographic guidance itself, Roberts *et al.* (2006) described the use of US to guide the placement of a percutaneous electrical nerve stimulation (PENS) therapy probe 1 mm superficial to the infraorbital nerve, where the nerve exits the infraorbital foramen, in order to perform a minimally invasive neuromodulatory treatment for trigeminal-mediated headshaking in horses [43]. The authors of this review do not have experience with the above technique, but US localization of the infraorbital foramen is relatively easy (Fig. 3) and can be used to avoid puncturing the nerve and associated head jerking movements.

Inferior alveolar nerve

Commonly referred to as a 'mandibular nerve block', local anesthesia of the inferior alveolar nerve (IAN), a branch of the trigeminal nerve, desensitizes the ipsilateral mandibular teeth and portions of the gingiva and is commonly performed to facilitate dental extraction [20, 51]. Several extra-oral blind approaches have been described in the horse, including 'vertical', 'angled', and 'caudal' approaches [15, 51], based on the use of external landmarks to approximate the position of the IAN where it enters the mandibular foramen. An intra-oral approach has also been described, and clinical assessment of this technique resulted in satisfactory anesthesia of 100% of 51 blocks performed on 43 horses [22]. Although high accuracy rates have been obtained with blind techniques, several complications have been reported. These include lingual trauma likely due to inadvertent anesthesia of the lingual nerve and hematoma formation following accidental puncture of the nearby vessels [5, 51]. Another reported complication following the intra-oral approach in the horse was abscess development in the pterygoid fossa [22].

Johnson *et al.* (2019) described an US-guided approach for injection of the IAN, which they performed on cadavers, based on the location of the mandibular foramen [25]. Using a 10 MHz microconvex transducer in a horizontal plane, the mandibular foramen was identified on the axial surface of the horizontal ramus of the mandible [24]. The point where the axial aspect of the mandible becomes concave was identified, which was in the caudal third of the bone where the surface is irregular in the region of the insertions of the medial pterygoid muscles. By manipulating the transducer in a dorsoventral orientation, the mandibular foramen could be identified as a 3 mm break in the surface continuity of the bone at a depth of approximately 4–6 cm from the skin [24] (Fig. 4). A straight 18–20 G, 9 cm spinal needle was introduced lateral to the transducer and advanced in a vertical direction under ultrasonographic visualization, along the medial aspect of the bone, to a point where it made contact

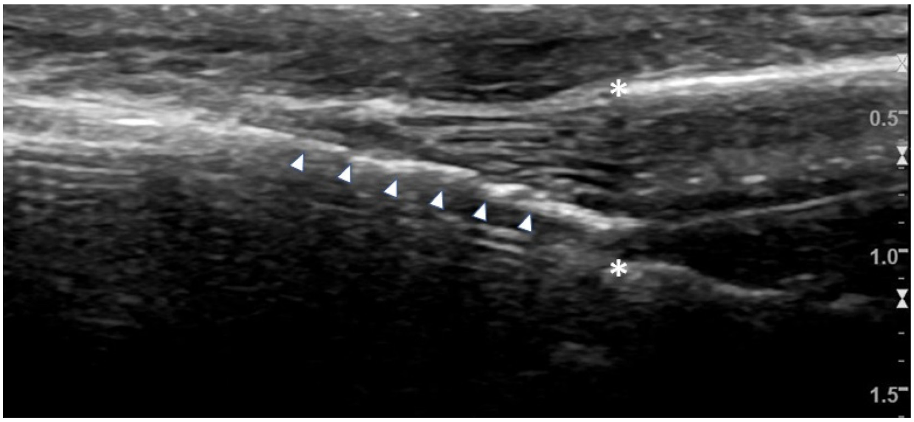

Fig. 3. Eighteen G spinal needle (arrowheads) entering the infraorbital foramen from the rostral side (left side of the image). *Infraorbital foramen.

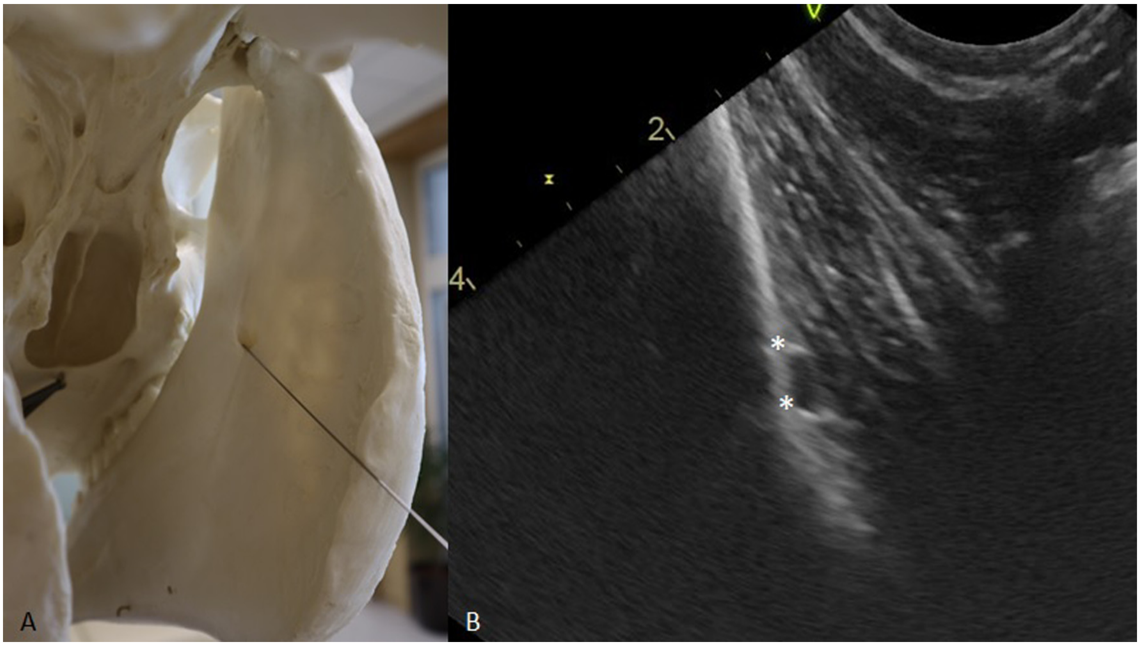

Fig. 4. (A) Anatomical specimen showing the mandibular foramen on the axial aspect of the mandible. (B) Ultrasound image taken using a 10 MHz microconvex transducer in a horizontal plane, showing bone drop out at the level of the mandibular foramen. *Mandibular foramen.

with the bone adjacent to the foramen [24].

This technique was slightly more accurate (68.8%; 11/16) on post-mortem dissection than a previously published blinded ventral approach (59.1%; 13/22), although the difference in injectate volume could explain the small variation in outcome [20, 24]. Given that approximately 2/3 of all injections, regardless of injectate volume, resulted in methylene blue staining of the lingual nerve, it is likely that inadvertent desensitization of the lingual nerve will occur despite US-guidance [24]. Thus, the authors of this review do not advise performing IAN blocks bilaterally and recommend fasting the horse until sufficient time has elapsed for the local anesthetic effects to wear off. Use of small volumes of short-acting local anesthetics is also recommended. Since its initial description, the authors have conducted this US-guided IAN block on a number of clinical cases and found the procedure to be challenging. Further investigation to assess its efficacy in clinical cases, and to compare with previously described blind approaches, is indicated.

The Cervical Region

Atlanto-occipital and atlanto-axial junction for cerebrospinal fluid centesis, injection, and epidural catheter placement

In the proximal cervical region, US-guided atlanto-occipital and atlanto-axial punctures have been reported for the collection of cerebrospinal fluid (CSF), for myelography, and for endoscope placement for epiduroscopy [1, 14, 40, 42]. CSF collection can easily be performed on the standing horse, whereas myelography is commonly performed under general anesthesia [40]. These techniques can also be used for medication of the epidural or subarachnoid space or for placement of a catheter [23, 30]. Muylle *et al.* (1975) proposed that such catheters may facilitate administration of spinal analgesia, tetanus antitoxin, and/or anti-inflammatory therapy [35], but other potential applications also exist, such as delivery of stem cells [2]. US-guidance allows verification of correct needle placement in the epidural space or the subarachnoid space as well as improvement of the safety of the procedure [1, 40].

Atlanto-Occipital Space

Depecker *et al.* (2014) reported use of the parasagittal approach, which was first described by Audigié *et al.* in 2004, for US-guided atlanto-occipital (AO) puncture in the standing horse [1, 14]. In their report, a 5–7.5 MHz microconvex or 3.5–5 MHz convex probe was used [14]. For this technique, the probe was placed at the caudal level of the wings of the atlas, in a parasagittal orientation, approximately 3 cm abaxial to the dorsal midline [14]. Once the AO subarachnoid space was visualized, the probe was adjusted with a slight obliquity to identify the central canal of the spinal cord, and an 18–20 G, 9 cm spinal needle was introduced approximately 2 cm cranial to the probe and guided in a caudoventral orientation into the subarachnoid space [14]. Audigié *et al.* (2004) also described a sagittal approach from the dorsal midline, but its use is limited to horses under general anesthesia due to difficult access when performed standing [1]. Using the sagittal approach, Audigié *et al.* reported successful access to the atlanto-occipital space in 5 out of 6 horses [1]. In one horse, however, the authors experienced 'tenting' of the dura mater ventrally by the needle bevel, which necessitated redirection in order to avoid damage to the spinal cord, thereby requiring a second attempt that was ultimately successful [1]. Despite this occurrence, there was no evidence of blood contamination in any of the 6 CSF samples [1]. This 'tenting' phenomenon has been reported in the dura mater of humans, and if it occurs during a blind puncture, it may prevent the occurrence of the 'popping' sensation as the needle enters the subarachnoid space, thereby resulting in incorrect needle placement [1, 26]. This again demonstrates the value of ultrasound-guidance for the verification of needle location.

The authors prefer using a modified version of the Audigié and Depecker techniques, in which the US-guided CSF aspiration is performed using a transverse (relative to the spinal cord axis) view on the atlanto-occipital space and the needle is inserted lateral to the transducer, with a relatively flat angle relative to the ground (Fig. 5) [1, 14]. The subarachnoid space is bigger in this location (approx. 1 cm), which is preferred to C1–C2 (<<1 cm) [40], making the risk of hitting the cord less likely. Also, the angle of attack of the needle is very flat, with the needle inserted on

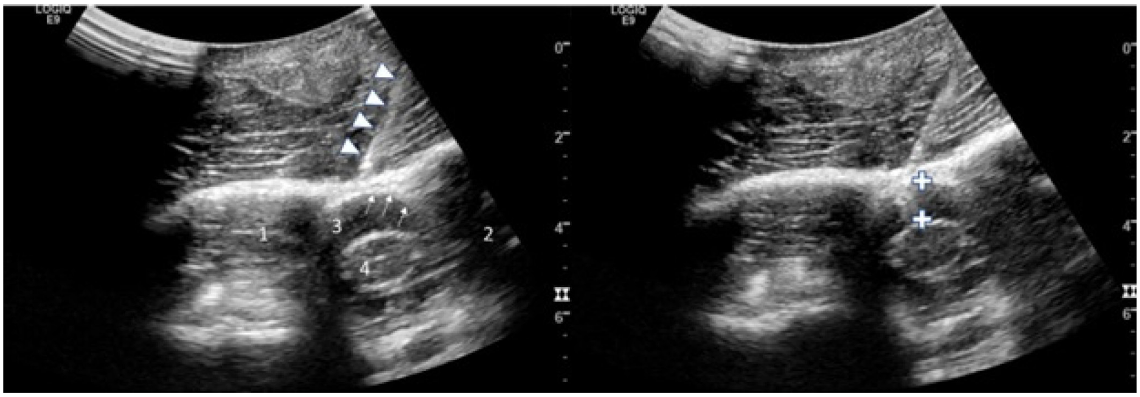

Fig. 5. The left side shows a transverse image of the US-guided approach for injection into the subarachnoid space in the atlanto-occipital region. The needle (arrowheads) is in contact with the dorsal atlanto-occipital membrane. (1, 2) Atlas; (3) atlanto-occipital subarachnoid space; (4) spinal cord, with arrows indicating the dura mater. The right side shows a transverse US image of the atlanto-occipital space with the needle penetrating the dura mater and tip within the subarachnoid space, away from the spinal cord. The depth of the subarachnoid space at this location is the distance between two + signs (0.91 cm in this case).

the side of the neck, compared with the very steep angle with the sagittal/parasagittal techniques [1, 14]. If the horse should rear up during the procedure and the needle is inadvertently pushed further into the vertebral canal, the chance for the needle to hit the cord would be reduced in the authors' opinion. For this procedure, the operator stands beside the horse, with no need to drape the head or stand on a stool. The authors use a combination of acepromazine (0.02 mg/kg IV) and xylazine (0.2–0.3 mg/kg IV) for sedation during the procedure, and a macroconvex transducer can be used if a microconvex transducer is not available. An assistant holds the halter and the ipsilateral ear forward, the skin is desensitized at the site of needle insertion, and skin preparation is repeated immediately after a skin bleb is created. A 9 cm, 20 G spinal needle with stylet is driven through the dura mater under US-guidance. Once the needle is secured in the subarachnoid space, the needle body is held close to the skin as a safety precaution. Finally, as described by Depecker *et al.* (2014), an assistant removes the stylet, connects the extension, and aspirates the CSF slowly in a sterile manner [14]. At all times, the operator holding the probe and driving the needle has their hands in direct contact with the horse neck as a countermeasure in the case of sudden head movement. Replacement of the volume of aspirated CSF with preservative-free sterile 0.9% saline solution is recommended in cases where increased intracranial pressure is suspected.

Atlanto-Axial Space

Pease *et al.* (2010) described a CSF aspiration technique using a transverse atlanto-axial (AA) acoustic window in the standing sedated horse [40]. In this technique, the horse is restrained in stocks with a lip twitch. The authors of this technique recommended sedation with detomidine hydrochloride followed by morphine sulfate approximately 3 min later, as morphine is considered to provide superior central nervous system analgesia compared with butorphanol [40]. Adequate restraint is paramount to ensuring patient compliance and to avoid inadvertent perforation of the spinal cord. Using a 4–10 MHz microconvex transducer oriented in a dorsoventral direction, the probe is positioned at the level of C1–C2, approximately 3 cm ventral to the midline of the mane [40]. This can also be performed using a macroconvex transducer. A transverse image is obtained, and the probe is moved caudally from the caudal aspect of the transverse process of C1 until the spinal cord and subarachnoid space are visible [40]. The subarachnoid space has a 'mildly echoic, striated appearance', which is believed to be due to trabeculae connecting the arachnoid mater and the pia mater [40]. It lies, on average, 4 cm from the skin surface [40]. Following aseptic preparation and a local skin block, an 18–20 G, 9 cm spinal needle is guided ventral to the transducer in a dorsomedial direction and into the subarachnoid space (Fig. 6). A distinct 'pop' or sudden loss of resistance is felt on penetration of the dura mater [40]. Of 13 horses included in the report by Pease *et al.* (2010), only one required a second attempt at centesis due to a reverberation artefact obscuring visualization of the needle [40]. No adverse reactions, such as tossing of the head, movement, or discomfort, were observed in any of the 13 horses during the procedure or after the acquisition of the sample [40]. Twenty-four hours post-procedure, a post-mortem dissection performed on two horses for reasons unrelated to the procedure did not reveal any signs of hemorrhage at the injection site [40]. Some authors advocate removal

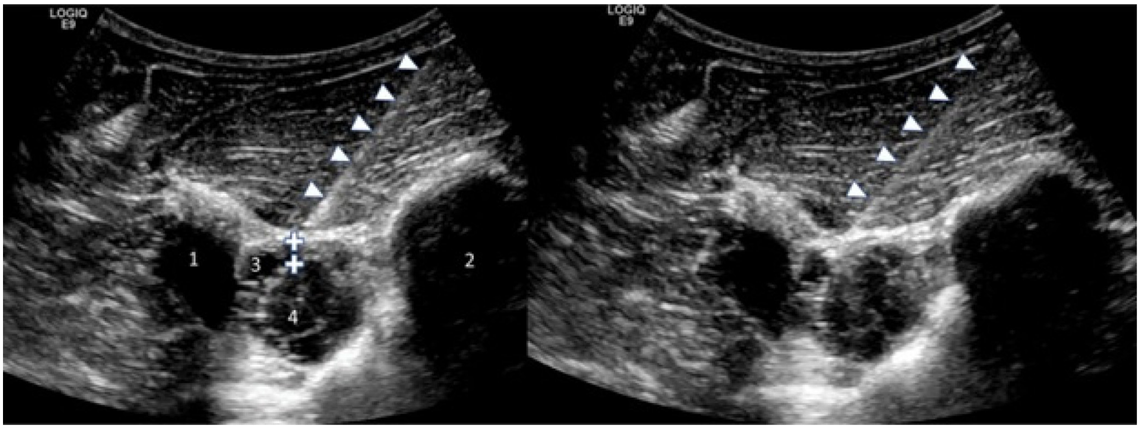

Fig. 6. The left side shows a transverse image of the US-guided approach for injection into the subarachnoid space in the atlanto-axial region. The needle (arrowheads) is in contact with the dorsal atlanto-axial membrane. (1, 2) Axis, (3) atlanto-axial subarachnoid space, (4) spinal cord. The depth of the subarachnoid space at this location is the distance between two + signs (0.36 cm in this case). The right side shows a transverse US image of the atlanto-axial space with the needle penetrating the dura mater and tip within the subarachnoid space.

of the stylet prior to perforating the dura mater in order to avoid inadvertent trauma to the spinal cord [40]. One advantage of this technique is that the needle insertion is made further away from the ears and poll region, which can be a difficult region to clip and aseptically prepare properly due to the halter and ears being in close proximity. Also, the operator stands to the side of the horse, which is contrary to Depecker's technique. One disadvantage of this technique is the width of the subarachnoid space at this location, with it being smaller (approximately 0.5 cm) compared with that at the AO site, which has a width of approximately 1 cm (Fig. 5) [14, 40]. In addition to puncture at this site for diagnostic purposes, there are also therapeutic indications. For example, US-guided epidural injection of corticosteroids at the AA junction has been reported as a successful treatment for neck pain in a horse caused by suspected dorsal nerve root impingement at the fifth cervical vertebra [30].

Cervical articular process joints

Three anatomical approaches for US-guided injection of the cervical articular process joint have been reported, including the cranial, dorsal, and craniodorsal approaches [7, 25, 31, 37]. If the needle gets lost during the US-guided procedure, the cranial approach has the potential to travel close to the vertebral foramen and inflict serious nerve or vessel damage [31]. For this reason, the dorsal and craniodorsal approaches are considered the safest techniques for teaching inexperienced veterinarians. The craniodorsal technique is favored, as it allows joint margins to be clearly identified and facilitates visualization of the needle as it enters the joint [25, 37]. A 10 MHz microconvex transducer has been shown to be associated with a shorter procedure time and fewer redirects [25], but macroconvex and linear transducers can also be used successfully (Fig. 7a and 7b). Although there is no proven significant difference in accuracy of injection between the use of 18 G and 20 G spinal needles, 18 G needles are subjectively easier to visualize due to their wider gauge and are less pliable, so they may be easier to guide in deep muscle plains, especially when experience with this technique is limited [25]. However, wider gauge needles are more traumatic, and one co-author of this review advocates the use of finer needles, such as 21 G needles, to reduce iatrogenic damage to cartilage and to ease intra-articular placement.

Restraint is achieved using sedation, and the head is held in a neutral position or rested on a head stand; desensitization of the skin at the intended injection site is achieved using a local anesthetic. With the transducer oriented perpendicular to the long axis of the cervical spine, the desired articular process joint is identified. It can be challenging to ensure proper identification. The authors of this review recommend identifying C2 in the cranial portion of the neck by palpating its prominent dorsal ridge, applying the transducer immediately onto it, and then localizing the C2–C3 articular process joint ultrasonographically. This joint is smaller and more dorsal than other caudal cervical articular processes. Once the C2–C3 articular process joint is identified, moving the transducer slowly caudal and counting each articular process will ensure proper identification. Once on the desired target, the transducer is then rotated up to 45 degrees cranially (counterclockwise for the left side and clockwise for the right side) and advanced cranially until the most cranial aspect of the articular process joint is visualized [25]. The image is manipulated until the joint space is at its widest. A 9 cm spinal needle (18–21 G) is then introduced approximately 1–2 cm craniodorsal to the transducer (Fig. 7c) and directed using US-guidance so that its angle of approach matches that of the joint, allowing it to pass into the joint space [25]. Once the needle tip is seated in the joint, the stylet is removed. Aspiration may yield retrieval of synovial fluid if a sample is desired for analysis. Injection can then be performed. If met with

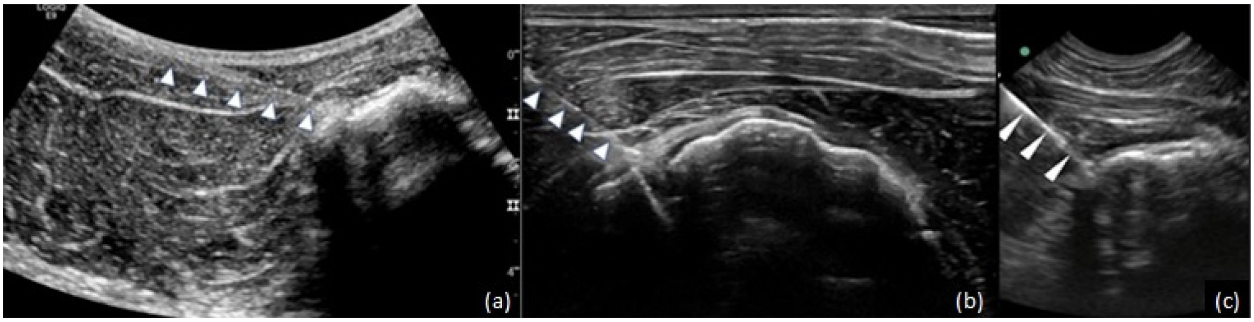

Fig. 7. (a) US-guided dorsal approach to the C4–C5 cervical articular process joint using an 18 G needle (arrowheads) and macroconvex transducer. (b) US-guided dorsal approach to the C5–C6 cervical articular process joint using an 18 G needle (arrowheads) and linear transducer. (c) US-guided cranio-dorsal approach to the C5–C6 cervical articular process joint using an 18 G needle (arrowheads) and microconvex transducer.

resistance, the needle may be either slightly withdrawn or rotated 180 degrees, or both, until no resistance to injection is encountered [25]. It is recommended to replace the stylet in the needle prior to withdrawal in order to minimize dragging of injectate through the periarticular soft tissues [25]. According to Johnson *et al.* (2017), image quality is poorer for the more caudal articular process joints compared with the more cranial ones, due to their greater depth [25]. Despite the greater depth, the authors found that all injections could be performed in their cadaver specimens with a 9-cm spinal needle [25]. However, the increased thickness of subcutaneous fat in the caudal neck in over-conditioned animals can lead to reduced image quality [25]. According to Haussler *et al.* (2019), the C7–T1 articulation had the highest prevalence of abnormal bony changes, with 91% affected at this vertebral level [21]. Therefore, the authors believe it is important to pay particular attention to the treatment of C7–T1, which is easily recognizable by the divergence of the vertebral vessels, and to take care when injecting for optimal efficacy.

First cervical nerve and C2–C3 plexus

US-guided stimulation of the first cervical nerve at the alar foramen of the atlas (C1) was first reported by Mespoulhès-Rivière *et al.* in 2016 as a technique in horses to assist in the placement of a stimulating needle [33]. The authors describe positioning the horses in stocks, with standing sedation and the head resting on an adjustable support in slight extension, and using a 5–8 MHz microconvex transducer with the probe placed on the cranial aspect of the wing of the atlas, perpendicular to the skin, in a craniolateral-to-caudomedial direction at approximately 60° to 80° relative to the sagittal plane [33]. By adjusting the probe, the lateral vertebral and alar foramen could be identified by the vertebral artery exiting the alar foramen and its descending branch travelling dorsally [33]. With the transducer focused on these arteries in a longitudinal orientation, it was moved slightly caudally until the first cervical nerve came into view, which was seen as an echogenic structure passing the groove which connects the alar and intervertebral foramina, entering the lateral aspect of the alar foramen [33]. The stimulation needle was introduced 2–3 cm medial to the probe in a medial-to-lateral direction and angled 30° to 45° relative to the horizontal plane, and it was then advanced under US-guidance until it made contact with the bone adjacent to the first cervical nerve, at the lateral aspect of the alar foramen [33]. All procedures were performed using aseptic techniques, and color flow Doppler was utilized to avoid perforation of blood vessels. Three stimulation experiments were performed in 6 horses, bilaterally, and US-guided stimulation was deemed successful in all attempts [33]. Horses reacted to skin penetration in 25% of the attempts, necessitating additional sedation with butorphanol [33]. Repeat ultrasonographic examination at 24 hr post-procedure did not reveal any hematoma formation at the stimulation site [33]. One horse developed a superficial hematoma unilaterally following each successive procedure, but it did not preclude ultrasonographic visualization of the desired structures and subsequently resolved without treatment [33].

Subsequently, this technique was employed by Rossignol *et al.* (2018) in order to assess the efficacy of reinnervation of the cricoarytenoideus muscle following modified first and second cervical nerve transplantation in horses for the treatment of laryngeal neuropathy, and no complications were reported [44].

An US-guided approach has also been described for locoregional anesthesia of the second and third cervical nerves in order to perform standing prosthetic laryngoplasty in horses [6]. The main benefit of such a targeted nerve block in this case is that it avoids the tissue edema that occurs as a result of local infiltration and can obscure important surgical landmarks, as well as the increased hemorrhage associated with induced vasodilation [6]. In their report, Campoy *et al.* (2018) compared the US-guided cervical plexus block with a local tissue infiltration of mepivacaine for standing prosthetic laryngoplasty [6]. To do this, horses were sedated, the site was aseptically prepared, and a multifrequency linear transducer was applied in a cranio-caudal direction in the middle of the second cervical vertebral body, ventral to the omotransversarius muscle and caudal to the parotid gland [6]. The short axis of the ventral spinal branch of C2 appeared as 1–2 discoid shapes, with an external hyperechoic outline and a hypoechoic core, situated in the interfascial plane, between the longus capitis and cleidomastoideus muscles (Fig. 8) [6]. The transducer was manipulated until this image was visualized, a 20 G, 9 cm Tuohy needle was guided between the aforementioned muscle bellies until the tip was adjacent to the aforementioned ventral spinal branch of C2, and injection of 40 m*l* 2% mepivacaine was then performed (Fig. 8), which could be seen dissecting between the two muscle planes when imaged in real time during the injection, indicating successful injection [6]. Out of 17 horses that underwent the US-guided approach, all underwent successful laryngoplasty with an additional 10 m*l* of 2% mepivacaine infiltrated subcutaneously caudal to the caudal aspect of the incision site [6]. The results of this study indicated that US-guided plexus injection resulted in a significantly improved surgical field compared with that of the tissue infiltration technique, and no adverse effects were reported [6].

Cervical nerve roots

Cruz-Sanabria *et al.* (2019) described for the first time a

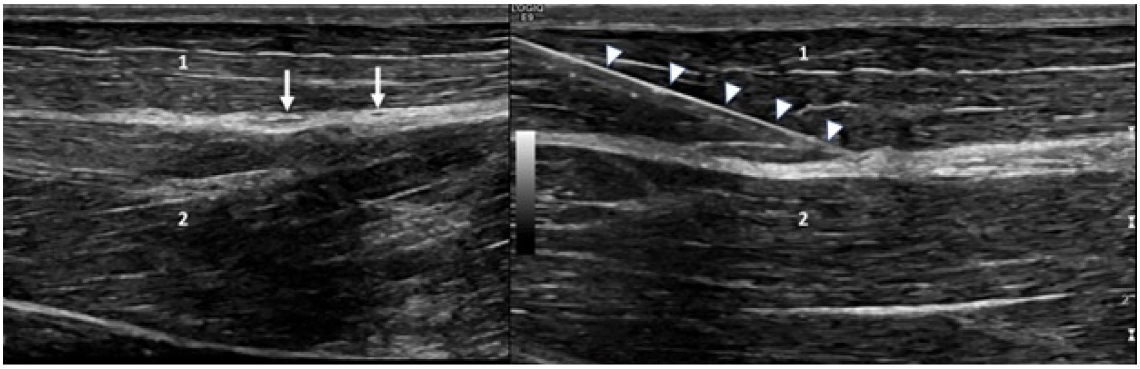

Fig. 8. The left image shows the location of the ventral spinal branch of C2, appearing as two discoid shapes (arrows), with an external hyperechoic outline and hypoechoic core, situated between the longus capitis (1) and cleidomastoideus muscle bellies (2). The right image shows the introduction of the 18 G spinal needle from the caudal side (left side of the image), with the tip between the two muscle planes, lying adjacent to the ventral branch.

technique for US-guided perineural injection of the cervical nerve roots [8]. The results of their cadaver study indicated that US-guided perineural injection was significantly more likely to result in successful iodinated contrast delivery to the cervical nerve roots (100%) when compared with both intra-articular (0%) and periarticular caudal (33.3%) approaches, as evaluated by CT or MRI [8]. However, there was no significant difference between perineural and periarticular cranial approaches [8]. This study highlighted the feasibility of perineural injection techniques as a potential treatment option for cervical radiculopathy in the horse. Touzot-Jourde *et al.* (2020) published a pilot cadaver study of four horses in which they described an US-guided perineural injection technique for the *ramus ventralis* of the 7th and 8th cervical nerves in the horse [50]. A total of 10 injections were performed, and all were deemed accurate using a large volume of injection (7 m*l* or 14 m*l*), as demonstrated by evidence of dye staining a portion (2/10) or the entire (8/10) cross section of the *ramus ventralis* nerve trunks [50]. Some diffusion was noted in the epidural space in 5/10 injections [50]. Although the number of injections was small and the study was performed on cadavers, it demonstrates some potential for using a technique adapted from this study to diagnose and treat cervical radiculopathy in the horse. The described technique uses a 5–8 MHz US transducer [50]. According to their description, the starting position for the transducer was perpendicular to the long axis of the cervical spine, at the level of the C7–T1 cervical articular process joint [50]. In order to visualize the C8 *ramus ventralis*, the transducer was moved caudoventrally approximately 20 degrees by orienting the probe cranially and ventrally (*i.e.,* in a counterclockwise motion on the left side of the neck, clockwise on the right) [50]. The transducer was then moved to follow the course of the nerve over the vertebral body, between the articular and transverse processes, in order to obtain the optimal position to visualize the nerve in longitudinal section [50]. Injection was performed with a 20 G, 9 cm spinal needle, which was introduced approximately 2 cm caudoventral to the transducer, and advanced until it was within 5 mm of the nerve [50]. For the C7 *ramus ventralis*, the same procedure was performed, one segment cranially [50]. This technique has not yet been reported in clinical cases.

The authors of this review have used a different technique in several clinical cases where clinical signs attributed to cervical nerve radiculopathy did not respond to the administration of systemic NSAIDs and corticosteroid injection within the corresponding cervical articular process joint(s). After multiple cadavers, or asymptomatic and symptomatic horse US examinations, we came to the conclusion that it is not possible to visualize the short cervical nerve roots in the horse. As shown by Touzot-Jourde *et al.* (2020), only the *ramus ventralis* of the cervical nerves can be recognized ultrasonographically in some cases/locations, but at a certain distance from the nerve root itself [50]. To make sure the needle could be safely sited as close as possible from the cervical nerve root, Fouquee *et al.* (2021) have aimed to localize the adjacent vascular structures to the nerve roots, using 2D US and color Doppler [18]. For this, a curvilinear transducer is applied in a vertical fashion and the targeted cervical articular process joint is identified [18]. The transducer is moved ventrally, until almost losing completely the articular process. The transverse process of the cranial vertebra can create an acoustic shadow over the vertebral foramen if the transducer is too cranial. Once the intervertebral foramen is well visualized, keeping the vertical orientation, the transducer is displaced caudally by less than a centimeter, to focus on the caudal aspect of the

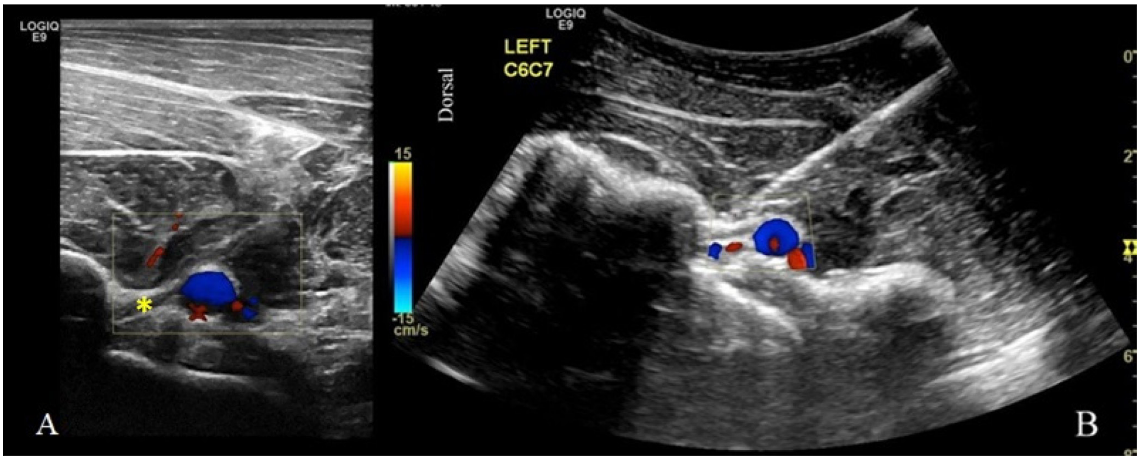

Fig. 9. (A) An image acquired with a 12 MHz linear transducer shows the ventral branch of C7 (*) crossing obliquely over and immediately dorsal to the vertebral vessels. The location of the vertebral vessels and collaterals is confirmed using Doppler mode. In cases where the ventral branch of cervical nerve root cannot be clearly observed, the vertebral artery and vein are used as the main landmarks to guide the injection. (B) An image acquired with a 6 MHz linear transducer shows C7 nerve root ultrasound-guided injection. The 18 G, 9 cm spinal needle is inserted until the tip is visualized in contact with the nerve. The final approach is performed with color flow Doppler to ensure there is no blood flow where the needle tip is inserted.

intervertebral foramen [18]. The vertebral artery (axial and dorsal relative to the vertebral vein; ventral relative to the cervical nerve root) and vein (ventral and abaxial) are identified [51]. After blebbing the skin with local anesthetic, the needle is inserted ventral to the curvilinear transducer, and then guided towards the vertebral foramen, and advanced immediately dorsal to the vertebral artery (Fig. 9) [18]. It is crucial to take great care to not penetrate a vertebral vessel or to lose the needle tip at any time. A total volume of 3–4 m*l* of a mix of short- and long-acting corticosteroids is injected per nerve root. This technique has been tested on 5 anesthetized horses (60 injections), and the injectate deposition was noted to be in direct contact (approx. 75%) with or close vicinity (approx. 25%) to the C3–C8 cervical nerve roots [18]. Although not published yet, this same technique (Fig. 9) has allowed one of the co-authors of this review to obtain significant improvement or complete resolution of the clinical signs in cases of cervical radiculopathy, either temporarily or permanently. Additional work is needed before this technique or that of Touzot-Jourde *et al.* (2020) can be recommended for the treatment of cervical radiculopathy cases in the horse.

Conclusion

This review demonstrates the wide range of clinical applications that ultrasound guidance can provide for both diagnostic and therapeutic procedures of the equine skull and neck. Ultrasound-guided injection techniques provide more accurate deposition of injectate compared with blind approaches. Improved visualization of vital structures, including nerves and blood vessels, allows their avoidance and thus reduces procedure-associated complications. Ultrasound guidance is no longer limited to injections, as evidenced by the various clinical applications described in this review, from the placement of epidural catheters to electrostimulation of cervical nerves. Not only is ultrasound guidance a much-valued technique for procedures on the head and neck of the horse, it is also a valued technique for procedures elsewhere on the body, including the rest of the appendicular skeleton, where it is increasingly used alongside interventional procedures and as an aid in surgery [48]. New developments in this field are constantly evolving, bringing with them new techniques and making ultrasound guidance an increasingly popular and utilized modality worldwide.

References

1. Audigié, F., Tapprest, J., Didierlaurent, D., and Denoix, J.M. 2004. Ultrasound-guided atlanto-occipital puncture for myelography in the horse. *Vet. Radiol. Ultrasound* **45**: 340–344. [Medline] [CrossRef]
2. Barberini, D.J., Aleman, M., Aristizabal, F., Spriet, M., Clark, K.C., Walker, N.J., Galuppo, L.D., Amorim, R.M., Woolard, K.D., and Borjesson, D.L. 2018. Safety and tracking of intrathecal allogeneic mesenchymal stem cell transplantation in healthy and diseased horses. *Stem Cell Res. Ther.* **9**: 96. [Medline] [CrossRef]
3. Bardell, D., Iff, I., and Mosing, M. 2010. A cadaver study comparing two approaches to perform a maxillary nerve

block in the horse. *Equine Vet. J.* **42**: 721–725. [Medline] [CrossRef]

4. Bidwell, L.A., Bramlage, L.R., and Rood, W.A. 2007. Equine perioperative fatalities associated with general anaesthesia at a private practice—a retrospective case series. *Vet. Anaesth. Analg.* **34**: 23–30. [Medline] [CrossRef]
5. Caldwell, F., and Easley, J. 2012. Self-inflicted lingual trauma secondary to inferior alveolar nerve block in 3 horses. *Equine Vet. Educ.* **24**: 119–123. [CrossRef]
6. Campoy, L., Morris, T.B., Ducharme, N.G., Gleed, R.D., and Martin-Flores, M. 2018. Unilateral cervical plexus block for prosthetic laryngoplasty in the standing horse. *Equine Vet. J.* **50**: 727–732. [Medline] [CrossRef]
7. Chope, K. 2008. How to perform sonographic examination and ultrasound-guided injection of the cervical vertebral facet joints in horses. *Proc. Am. Ass. Equine Practnrs.* **54**: 186–189.
8. Cruz-Sandabria, J.A., Gaschen, L., Bragulla, H., Mitchell, M., and Leise, B. 2019. Cervical Perineural Injection Technique. 2019 ACVS Surgery Summit, Las Vegas.
9. David, F., Rougier, M., Alexander, K., and Morisset, S. 2006. ultrasound-guided injection of coxofemoral joint in horses. 15th annual meeting of ECVS, Seville.
10. David, F., Cousty, M., and Rossier, Y. 2007. How to do ultrasound-guided injections of the sacroiliac region in horses. 53rd annual convention of AAEP, Orlando.
11. David, F. 2009. How to perform ultrasound-guided injections? pp. 182–183. Proceedings British Equine Veterinary Association Congress, Birmingham.
12. David, F., Heiles, P., and Smith, R.K. 2012. Ultrasound-guided injections of deep anatomic structures. Equine Musculoskeletal Ultrasound Imaging Days, Vienna.
13. David, F. 2013. Ultrasound-guided navicular bursa injections. Vet-PD Ultrasound-guided injection Techniques & Therapeutics, University College Dublin, Dublin.
14. Depecker, M., Bizon-Mercier, C., and Courouce-Malblanc, A. 2014. Ultrasound-guided atlanto-occipital puncture for cerebrospinal fluid analysis on the standing horse. *Vet. Rec.* **174**: 45. [Medline] [CrossRef]
15. Doherty, T., and Schumacher, J. 2010. Dental restraint and anesthesia. pp 243–244. *In*: Equine Dentistry, 3rd ed. (Easley, J., Dixon, P.M., and Schumacher, J. eds.), Saunders Elsevier, Philadelphia.
16. Easley, J.T. 2014. Standing surgery. Preface. *Vet. Clin. North Am. Equine Pract.* **30**: xiii–xiv. [Medline] [CrossRef]
17. Ford, T.S. 1991. Standing surgery and procedures of the head. *Vet. Clin. North Am. Equine Pract.* **7**: 583–602. [Medline] [CrossRef]
18. Fouquet, G., Abbas, G., Johnson, J.P., Pompermayer, E., Harel, C.M., Aldous, E., Puchalski, S., and David, F. 2021. Ultrasound-guided Injections of Cervical Nerve Roots (C3-C8) in Anesthetized Horses. 2021 ACVS Surgery Summit, Chicago.
19. Gompels, B.M., and Darlington, L.G. 1981. Septic arthritis in rheumatoid disease causing bilateral shoulder dislocation: diagnosis and treatment assisted by grey scale ultrasonography. *Ann. Rheum. Dis.* **40**: 609–611. [Medline] [CrossRef]
20. Harding, P.G., Smith, R.L., and Barakzai, S.Z. 2012. Comparison of two approaches to performing an inferior alveolar nerve block in the horse. *Aust. Vet. J.* **90**: 146–150. [Medline] [CrossRef]
21. Haussler, K.K., Pool, R.R., and Clayton, H.M. 2019. Characterization of bony changes localized to the cervical articular processes in a mixed population of horses. *PLoS One* **14**: e0222989. [Medline] [CrossRef]
22. Henry, T., Pusterla, N., Guedes, A.G., and Verstraete, F.J. 2014. Evaluation and clinical use of an intraoral inferior alveolar nerve block in the horse. *Equine Vet. J.* **46**: 706–710. [Medline] [CrossRef]
23. Hurcombe, S.D., Morris, T.B., VanderBroek, A.R., Hopster, K. 2020. Cervical epidural and subarachnoid catheter placement in standing adult horses. *Front. Vet Sci.* **7**: 232. [CrossRef]
24. Johnson, J.P., Peckham, R.K., Rowan, C., Wolfe, A., and O'leary, J.M. 2019. Ultrasound-guided inferior alveolar nerve block in the horse: assessment of the extraoral approach in cadavers. *J. Vet. Dent.* **36**: 46–51. [Medline] [CrossRef]
25. Johnson, J., Stack, J.D., Rowan, C., Handel, I., and O'Leary, J.M. 2017. Ultrasound-guided approach to the cervical articular process joints in horses: a validation of the technique in cadavers. *Vet. Comp. Orthop. Traumatol.* **30**: 165–171. [Medline] [CrossRef]
26. Johnson, P.J., and Constantinescu, G.M. 2000. Collection of cerebrospinal fluid in horses. *Equine Vet. Educ.* **12**: 7–12. [CrossRef]
27. Johnston, G.M., Eastment, J.K., Wood, J., and Taylor, P.M. 2002. The confidential enquiry into perioperative equine fatalities (CEPEF): mortality results of phases 1 and 2. *Vet. Anaesth. Analg.* **29**: 159–170. [Medline] [CrossRef]
28. Kallmyr, A., Giving, E.M., Moen, L.O., Øverlie, M., Holm, T., and David, F. 2020. Complete resection of the alar folds in eight standing horses with a bipolar dividing and vessel-sealing device. *Vet. Surg.* **49**: 521–528. [Medline] [CrossRef]
29. Knych, H.K., Vidal, M.A., Casbeer, H.C., and McKemie, D.S. 2013. Pharmacokinetics of triamcinolone acetonide following intramuscular and intra-articular administration to exercised Thoroughbred horses. *Equine Vet. J.* **45**: 715–720. [Medline] [CrossRef]
30. Marks, D. 1999. Cervical nerve root compression in a horse, treated by epidural injection of corticosteroids. *J. Equine Vet. Sci.* **19**: 399. [CrossRef]
31. Mattoon, J.S., Drost, W.T., Grguric, M.R., Auld, D.M., and Reed, S.M. 2004. Technique for equine cervical articular process joint injection. *Vet. Radiol. Ultrasound* **45**:

238–240. [Medline] [CrossRef]

32. McGahan, J.P., Phillips, H.E., Nyland, T., and Tillman, P.C. 1983. Sonographically guided percutaneous cholecystostomy performed in dogs and pigs. *Radiology* **149**: 841–843. [Medline] [CrossRef]
33. Mespoulhès-Rivière, C., Brandenberger, O., Rossignol, F., Robert, C., Perkins, J.D., Marie, J.P., and Ducharme, N. 2016. Feasibility, repeatability, and safety of ultrasound-guided stimulation of the first cervical nerve at the alar foramen in horses. *Am. J. Vet. Res.* **77**: 1245–1251. [Medline] [CrossRef]
34. Morath, U., Luyet, C., Spadavecchia, C., Stoffel, M.H., and Hatch, G.M. 2013. Ultrasound-guided retrobulbar nerve block in horses: a cadaveric study. *Vet. Anaesth. Analg.* **40**: 205–211. [Medline] [CrossRef]
35. Muylle, E., Oyaert, W., Ooms, L., and Decraemere, H. 1975. Treatment of tetanus in the horse by injections of tetanus antitoxin into the subarachnoid space. *J. Am. Vet. Med. Assoc.* **167**: 47–48. [Medline]
36. Newton, S.A., Knottenbelt, D.C. and Eldridge, P.R. 2000. Headshaking in horses: possible aetiopathogenesis suggested by the results of diagnostic tests and several treatment regimes used in 20 cases. *Equine Vet. J.* **32**: 208–216. [Medline] [CrossRef]
37. Nielsen, J.V., Berg, L.C., Thoefnert, M.B., and Thomsen, P.D. 2003. Accuracy of ultrasound-guided intra-articular injection of cervical facet joints in horses: a cadaveric study. *Equine Vet. J.* **35**: 657–661. [Medline] [CrossRef]
38. Niimura Del Barrio, M.C., David, F., Hughes, J.M.L., Clifford, D., Wilderjans, H., and Bennett, R. 2018. A retrospective report (2003–2013) of the complications associated with the use of a one-man (head and tail) rope recovery system in horses following general anaesthesia. *Ir. Vet. J.* **71**: 6. [Medline] [CrossRef]
39. O'Neill, H.D., Garcia-Pereira, F.L., and Mohankumar, P.S. 2014. Ultrasound-guided injection of the maxillary nerve in the horse. *Equine Vet. J.* **46**: 180–184. [Medline] [CrossRef]
40. Pease, A., Behan, A., and Bohart, G. 2012. Ultrasound-guided cervical centesis to obtain cerebrospinal fluid in the standing horse. *Vet. Radiol. Ultrasound* **53**: 92–95. [Medline] [CrossRef]
41. Penninck, D.G., and Finn-Bodner, S.T. 1998. Updates in interventional ultrasonography. *Vet. Clin. North Am. Small Anim. Pract.* **28**: 1017–1040. [Medline] [CrossRef]
42. Prange, T., Derksen, F.J., Stick, J.A., Garcia-Pereira, F.L., and Carr, E.A. 2011. Cervical vertebral canal endoscopy in the horse: intra- and post operative observations. *Equine Vet. J.* **43**: 404–411. [Medline] [CrossRef]
43. Roberts, V.L., Patel, N.K., and Tremaine, W.H. 2016. Neuromodulation using percutaneous electrical nerve stimulation for the management of trigeminal-mediated headshaking: a safe procedure resulting in medium-term remission in five of seven horses. *Equine Vet. J.* **48**: 201–204. [Medline] [CrossRef]
44. Rossignol, F., Brandenberger, O., Perkins, J.D., Marie, J.P., Mespoulhès-Rivière, C., and Ducharme, N.G. 2018. Modified first or second cervical nerve transplantation technique for the treatment of recurrent laryngeal neuropathy in horses. *Equine Vet. J.* **50**: 457–464. [Medline] [CrossRef]
45. Smith, S. 1985. Ultrasound-guided biopsy. *Vet. Clin. North Am. Small Anim. Pract.* **15**: 1249–1262. [Medline] [CrossRef]
46. Solbiati, L. 1998. New applications of ultrasonography: interventional ultrasound. *Eur. J. Radiol.* **27**(Suppl 2): S200–S206. [Medline] [CrossRef]
47. Spriet, M., David, F., and Rossier, Y. 2004. Ultrasonographic control of navicular bursa injection. *Equine Vet. J.* **36**: 637–639. [Medline] [CrossRef]
48. Stack, J.D., Cousty, M., Sanders, R., and David, F. 2016. Techniques and indications for intraoperative ultrasound in horses. *Vet. Surg.* **45**: 936–942. [Medline] [CrossRef]
49. Stauffer, S., Cordner, B., Dixon, J., and Witte, T. 2017. Maxillary nerve blocks in horses: an experimental comparison of surface landmark and ultrasound-guided techniques. *Vet. Anaesth. Analg.* **44**: 951–958. [Medline] [CrossRef]
50. Touzot-Jourde, G., Geffroy, O., Tallaj, A., Gauthier, O., and Denoix, J.M. 2020. Ultrasonography-guided perineural injection of the *Ramus ventralis* of the 7 and 8th cervical nerves in horses: a cadaveric descriptive pilot study. *Front. Vet. Sci.* **7**: 102. [Medline] [CrossRef]
51. Tremaine, W. 2007. Local analgesic techniques for the equine head. *Equine Vet. Educ.* **19**: 495–503. [CrossRef]
52. Vaughan, B., Whitcomb, M.B., and Maher, O. 2009. How to improve accuracy of ultrasound-guided procedures. AAEP Proceedings **55**: 438–448.
53. Whitcomb, M.B. 2014. Ultrasound in equine practice—where we've been, where we are now, and where we need to go. AAEP Proceedings **60**, Salt Lake City.