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Review Article

Advancement in Assessment of Cerebral and Spinal Circulation using Ultrasonography in Veterinary Practice - A Review

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Abstract

As clinical and imaging expertise has grown, technology and technique have advanced, and transducers for Doppler and colour Doppler imaging have become more widely available, advancements in neurosonographic diagnosis of cerebro-spinal disorders have progressed. Nowaday not only trans (TCD) and intra (iCD) cerebrospinal ultrasound imaging are being used but are collaborated with the latest possible imaging techniques to get fruitful outcome for a potential treatment of the condition. Some of the developments in neurosonographic diagnosis are discussed in this article.

Keywords: Neurosonographic; Doppler; Ultrasonography; Cerebro-Spinal Disorders

Introduction

Diagnosis of cerebral and spinal abnormalities by diagnostic ultrasonography has increased over time, whether they are congenital or acquired. If these conditions are detected early, they might have a better chance of being treated. A prompt diagnosis may not only prevent progressive sequelae but may also shed light on several potential treatment strategies. For examining the brain and spine, diagnostic medical sonography has significant benefits over other medical imaging techniques. It offers a rapid, affordable method that is safe (no ionising radiation exposure). As long as the cranium and vertebral column have not fully developed, neonates can also be seen using cerebral and spinal diagnostic medical sonography. Additionally, it can spot abnormalities in normal cerebro-spinal anatomy, congenital defects, and acquired disorders brought on by birth trauma and lumbar punctures. In addition to 2D imaging, diagnostic medical sonography also offers 3D, extended field of view (EFOV), and M-mode imaging.

Currently, there is no reliable non-invasive way to measure abrupt changes in CBF in newborn humans. The experimental techniques used to measure CBF in animals utilising electromagnetic flowmeters [30], radioactive tracers [37], and microspheres [36] are not transferable to humans and are being used in animals only. Radioactive xenon has been injected or inhaled into human adults [17,33]and babies [26,28] though its use in infants is restricted due to the invasive nature of the procedure and the radioactive chemical involved.

Although noninvasive, occlusion plethysmography in newborn newborns measures both extracranial and intracranial blood flow [6,7,24]. All of these techniques only allow for single or sporadic assessments; they do not allow for the detection of rapid changes in CBF. Transcutaneous Doppler ultrasound has recently been utilised to analyse changes in blood velocity in order to examine the cerebral circulation in human adults [15,35] and neonates [3]. This

method has the benefits of being non-intrusive and offering continual information. Its shortcomings include the challenge of determining the relationship between blood flow and velocity, as well as the difficulty of standardising the angle between the Doppler probe and the blood artery.

The significance of Doppler ultrasound in monitoring brain hemodynamics through the open anterior fontanelle in newborn humans was first acknowledged by Bada., *et al*. [3]. Instead of directly detecting blood velocity, they calculated the PI in an effort to reduce the Doppler's limitations. Because it is a ratio, the PI is believed to be an index of CVR and is less affected by probe location.

Doppler ultrasonography

A physicist named Christian Doppler first outlined an effect in 1843 that demonstrated how the apparent frequency of sound coming from a moving source might change [41]. One of the best methods for observing the vertebral canal and spinal cord directly during surgery to determine whether there are any changes is ultrasonography [12]. Most small animals' brains can be sufficiently scanned using a high-frequency transducer (7.5-12 MHz), giving the best resolution [12]. Our capacity to view and assess the vasculature supplying the brain and spinal cord has increased thanks to the development of colour-flow Doppler imaging (CFDI) and Doppler spectrum analysis [18,21].

Five methods of imaging by employing Doppler principle

- Continuous wave Doppler
- Pulsed wave Doppler
- Colour Doppler
- Power Doppler
- Spectral Doppler or Duplex scanning

The three Doppler formats frequently utilised in veterinary medicine are pulse wave (PW), continuous wave (CW), and colour doppler ultrasonography [8,11].

- **Continuous wave Doppler (CW):** Two piezoelectric crystals are used. It is used to detect blood flow but does not provide data on the depth, direction, or speed of the flow. Site-independent and utilised for velocities greater than 1.5 m/s is CW Doppler [23].
- **Pulsed wave Doppler (PW):** method for determining depth. Three fundamental technological requirements must be met in order to detect such mobile structures: high pulse repetition frequency, optimal transducer frequency, and insonation angle (less than 60°). Site-specific and particularly useful for low velocity (1.5 m/s) is pulsed wave doppler.
- **Colour Doppler (CD):** Pulse packets refer to pulse signals. Red indicates a flow direction toward the transducer, while blue indicates a flow direction away from the transducer.
- **Power Doppler or Energy mode imaging:** Imaging using Power Doppler or Energy mode calculates the intensity/amplitude

Power Doppler has several advantages over colour flow imaging, including

- Greater sensitivity to flow states
- Angle effects are not taken into account
- Aliasing, is not applicable

Disadvantages

- Velocity and direction cannot be assessed.
- Flash artefacts are signals from soft tissues.

Spectral Doppler

Vascular flow imaging using Duplex scanning (B mode + Pulsed wave Doppler) using Spectral Doppler. In order to diagnose stenosis, its severity, and the associated flow irregularities, sets of these indices must be applied.

Area of interest

Canine brain weighs 1% of its body weight yet uses 8% of its heart's total work output [34]. Understanding the spinal cord's vascular structure fundamentally is necessary for CFDI and Doppler spectrum analysis [18].

Brain

In 1664, Sir Thomas Willis researched on the basal intracranial arteries' anatomy. The internal carotid artery and its branches, along with the vertebral and basilar arteries, form the anterior and posterior circulatory systems, respectively, and are connected by the circle of Willis.

The anterior cerebral arteries (ACA) and middle cerebral arteries (MCA) are formed by the division of the internal carotid arteries (ICA), which enter the cranial cavity through the foramen lacerum (MCA). An anterior communicating (ACOM) artery connects the ACA to one another. The basilar artery, which runs over the ventral side of the pons and divides into the right and left posterior cerebral arteries, is formed posteriorly by the union of the right and left vertebral arteries (PCA). To complete the posterior portion of the Willis circle, the ICA on either side is joined to the PCAs via posterior connecting arteries [38].

In the case of proximal vascular obstruction, blood is diverted into the circle of Willis, a natural collateral channel. Only 18 to 20% of people have a full circle of Willis with balanced arterial pairs, nevertheless, because of numerous anomalies.

Spinal cord

Vertebral arteries run along the spinal cord's central (centrifugal) and peripheral (centripetal) sides, respectively.

Cerebral blood flow (CBF) is maintained constant by cerebral autoregulation over a broad range of cerebral perfusion pressure. However, damage or a change in the cerebral auto regulatory response may result from intravenous and volatile anaesthetics, cerebrovascular diseases, and trauma to the central nervous system. As a result, there are numerous methods for keeping track of changes in cerebral hemodynamic. These include the venous outflow technique and the ingestion or inhalation of 133 Xe [16]. These intrusive techniques, though, are only occasionally used in veterinary medicine.

Trans-cranial or trans-spinal duplex ultrasound

Aaslid devised the transcranial Doppler ultrasonography (TCD) technique [1]. It is a non-invasive procedure that may be used repeatedly and has no contraindications, allowing for the real-time assessment of blood flow velocity in the main cerebral arteries of individuals [1,29] Through the non-invasive assessment of CBF velocity, TCD may be helpful in identifying changes in CBF during excessive hemodynamic changes.

Blood flow is typically determined as the product of the mean blood flow velocity and the cross-sectional area of the blood vessels. CBF velocity, however, does not always correspond to changes in blood vessel cross-sectional area. As the diameter of the main trunk of the cerebral arteries barely changes, significant alterations in cerebral arteries are caused at the microcirculatory level [13]. As a result, an increase in CBF velocity seems to be more closely related to an increase in CBF.

Transcranial doppler ultrasound (TCD) methodologies

Assessment of Vessel can be done by three different windows in animals they are left temporal window, right temporal window and sub-occipital window. Sequence of assessment include left rostral communicating artery, middle cerebral artery, and caudal cerebral artery through left temporal window, the basilar artery via sub occipital window and the right rostral communicating artery, middle cerebral artery, and caudal cerebral artery utilizing the right temporal window.

The temporal region's dorsal to zygomatic arch is known as the temporal window [10]. Based on the flow direction and response to brief ipsilateral common carotid artery closure for three seconds, an artery can be identified. For basilar artery imaging, the sub occipital window is used. By gently moving the head and expanding the depth of the sample volume area, the basilar artery can be more easily identified. B mode is used to locate the foramen magnum, while Doppler colour mode is used to identify the vertebral arteries [10].

A typical low-resistance curves is seen when the rostral cerebral artery is scanned close to where it splits off from the internal carotid artery, with a flow going away from the probe and the curve showing below the baseline. Blood flow is reduced or its direction is reversed when the ipsilateral carotid artery is squeezed. Blood flow is toward the probe and the curve is above the baseline when the middle cerebral artery is assessed close to where it split off from the internal carotid artery. Blood flow in the middle cerebral artery is reduced and, in some dogs, stopped when the ipsilateral carotid artery is squeezed.

Blood flow is towards the probe and the curve is above the baseline when the caudal cerebral artery is assessed close to where it separates from the caudal communicating artery. The caudal cerebral artery's diameter is smaller than that of the middle cerebral artery, and compression of the ipsilateral carotid artery does not have any effect on the caudal cerebral artery's Doppler spectral pattern.

Basal artery colour flow images can be best seen in real-time with transcranial color-coded sonography, because the insonation angle may be adjusted, it allows for accurate blood flow velocity measurement and definite vessel identification [4].

Trans-spinal doppler ultrasound (TSD) methodology

The blood flow in vertebral arteries is in the direction of the probe. The foramen magnum allows for the visualisation of the paired vertebral arteries. From the intersection of the vertebral arteries, the basilar artery expands ventrally. The basilar artery's blood flow is away from the probe, which causes the curve to be below the baseline.

An evaluation of the normal cord morphology is a part of a sonographic examination of the spinal cord. In the subarachnoid space's anechoic CSF, the spinal cord is located in the spinal canal. An echogenic line dorsal and ventral to the canal indicates the dura mater, which surrounds the canal. The arachnoid sheet, which lines the cord and displays an echogenic line parallel to the surface of the chord, lines the cord. The cervical and lumbar sections of the spinal cord have the biggest diameters. The conus medullaris, which expands and becomes the filum terminale, is formed caudally by the tapering of the lumbar enlargement. The cauda equina's echogenic nerve roots surround the echogenic cord-like structure known as the filum terminale. It is challenging to separate the two for this reason. The filum terminale, however, frequently exhibits greater echogenicity than the nearby cauda equina. The filum terminale typically has a thickness of 2 mm or less [19].

The spinal cord shows as a centrally located, hypoechoic, cylindrical structure on a sagittal scan. These are the main echo complexes. Between the dorsal and ventral borders of the spinal canal, the normal cord is located halfway to one third of the way down. The thoracic and lumbar spinal cords appear more circular on a transverse view, while the cervical spinal cord has an oval appearance. In the conus medullaris, the cord's bulk starts to diminish. One or two echogenic spots appear in the cord's middle as the central echo complex. Typically, the conus level terminates at T12 and L1 or L2. It should be regarded as abnormal if it finishes at the L2-L3 disc space or lower.

Typically, the conus level terminates at T12 and L1 or L2. It should be regarded as aberrant if it finishes at the L2-L3 disc space or lower, and one should search for any tethering masses [19]. But it should be emphasised that a normal chord can sometimes be found around L3, especially in premature infants. The spinal cord should be at the centre of the canal in its usual position. Echogenic dentate ligaments that extend laterally from the chord's sides stabilise the spinal cord. M-mode can be used to demonstrate the rhythmic movement that the healthy spinal cord produces.

Intracranial or intraspinal ultrasound

Intraoperative ultrasonography (IOS) of the brain and spinal cord is performed following operations such ventral slots, laminectomies, or hemilaminectomies because of its bony cover [31], examination of the spinal cord and vertebral canal conditions in real time. Estimating the spinal cord lesion's vascularization and magnitude is one of its primary advantages.

Methodology

Intraspinal or intracranial ultrasound is done by window formation in the spine or skull respectively. Sterile saline (0.9 percent NaCl) solution is injected into the site in an attempt to prepare it for ultrasound. The surgical wound is filled with saline, and a broadband, 12-MHz, linear ultrasound probe is positioned 0.5 cm away from the spinal cord [32].

Parameters To be assessed

- Resistivity Index (RI)
- Pulsatility Index (PI)
- Systolic to Diastolic Ratio

Because there is typically low resistance in the intracranial arteries, blood flow is visible both during systole and the entire diastole. Systolic and diastolic flow relationships are measured by the resistive index, which is calculated as peak systolic flow velocity (PSV) minus end diastolic flow velocity (EDV) divided by PSV, and the pulsatility index, which is calculated as PSV minus EDV divided by mean flow velocity. The vessels in the Willis circle have resistive indices that vary from 0.5 to 0.8 [26]. All flow velocities rise linearly with increasing gestational age or infant weight, indicating no change in the resistive or pulsatility index's typical values [9].

Cerebro-spinal conditions, doppler parameters and their interpretation

Studies on brain perfusion have revealed a strong link between mean flow velocities and perfusion. A great way to image and eval-

uate the vessels of the circle of Willis, especially the middle cerebral artery in its echogenic fissure, is with transcranial sonography and doppler imaging. Better Doppler information can be gained from the nearly parallel relationship between the transducer and the artery than from the transfontanelle technique, which produces frequency changes that are close to zero (cos 900 = 0).

Transcranial Doppler sonography of the middle cerebral and basilar arteries is highly effective technique for assessing cerebral blood flow in dogs during hypotension and hypertension. Additionally, Doppler ultrasonography can be used to evaluate cerebral ischemia in dogs, and dogs with clinical symptoms of hydrocephalus had much higher RIs. The first month following delivery saw an increase in blood flow velocity, according to Doppler ultrasound research [19].

With sufentanil and propofol, cerebral blood flow has been observed to significantly decrease [40]. When dogs are sedated with isoflurane, no alterations in the pulsatility index (PI) or peak systolic velocity (PSV) in the basilar artery is seen [25]. Following mannitol administration, the resistance index (RI) in the canine rostral and caudal cerebral arteries increases [39].

Contrast neurosonography (CEUS)

Technical restrictions on transcranial Doppler ultrasonography include high degree of ultrasonic reflection and scattering, which results in a significant loss of energy, intracranial imaging is further constrained by the difficulty in detecting faint signals in cases of severely restricted blood flow, high grade stenosis, and cerebral vasospasm. Due to the high ultrasound emission energy required as a result of these restrictions, numerous ultrasound artefacts are created. Due to the high sample volume and associated increase in ultrasonic beam dispersion, the signal-to-noise ratio and spatial resolution are both compromised. As a result, many echo contrast agents, such as the galactose-based microbubble Levovist, were created and are now accessible for contrast enhanced neurosonography research [5].

Parameters to be assessed

- Latency period (TA) (In sec)
- Duration of optimum homogenous enhancement without fragmentation (In sec)
- Duration of Doppler signal enhancement above 3dB (In sec)

3D Ultrasonography

Planning and directing surgery for the spine and the brain using neuronavigation equipment has become common practise [14]. Standard 2D grayscale ultrasound images are transformed into a volumetric dataset using the three-dimensional (3D) ultrasound approach [22]. There is also a technology that creates the 3D US volume from digital raw data. By moving or tilting a pre-calibrated, tracked US probe across the area of interest, 100 to 200 2D photos are combined to form a 3D US volume. Creating a new 3D US volume, which might include both tissue and power Doppler data, takes roughly a minute.

Image fusion technique

In the realm of neuroradiology, ultrasound fusion is a new approach. Displaying live ultrasound data in conjunction with a reference series obtained from a different modality, such as CT, MRI, or PET [2]. This display improves ultrasound interpretation by allowing direct comparison with the reference images taken from the same advantage point [2]. Fusion imaging in neurology may make it easier to analyse vascular imaging

Conclusion

For early brain imaging while the fontanelles are still open, neurosonography continues to be the method of choice due to its affordability, mobility, and safety. The clinical use of advancements in neurosonography, such as 3-dimensional (3D) imaging, quantitative tissue characterisation, and contrast usage, is still in the research stage. Further study in these specialised fields will enable more precise measurement of important indicators of patient outcome.

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