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Review on diagnostic approach of ultrasound in Veterinary practice

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Abstract

Ultrasound waves represent sound waves that exceed normal human audible frequency range of 20 to 20,000 Hertz. Diagnostic ultrasound imaging depends on the computerized analysis of reflected ultrasound waves (echoes), which non-invasively build up fine images of internal body structures. This paper conducted to review the use and principle of ultrasound in veterinary medicine. The transducer of ultrasound produces sound waves (pulse) and receives the sound beam (echo) after the sound got reflected by a reflecting surface. Transducers contain multiple piezoelectric crystals or materials that are able to convert electrical energy in to mechanical energy and vice versa when stimulated electrically. .It is unique in its ability to image patient anatomy and physiology in real time, providing an important, rapid and noninvasive means of evaluation. Ultrasonography provides information about size, shape, and location of structures; moreover. It also provides information about the soft-tissue architecture of the structure or organ being examined though it is not suitable to diagnose air containing structures and bone due to their strong reflecting property. The wavelength of ultrasound influences the resolution of the images that can be obtained; the higher the frequency, the shorter the wavelength and the better the resolution.

Keywords: Noninvasive, resolution, real time, transducer, ultrasonography

Introduction

For a considerable number of years after Roentgen first described the use of ionizing radiation at that time called ‘X-rays’ in 1895, this remained the only method for visualizing the interior of the body. Ultrasonography was one such method that showed particular potential and greater benefit than X-ray-based imaging. Since the 1990s, the use of ultrasound (US) has become a common diagnostic method as a result of the new advances made in the development of US scans: smaller size, high level of autonomy, high image quality and accessible prices. The development and improvement in different diagnostic imaging modalities particularly US, computed tomography, magnetic resonance imaging e.t.c leading to earlier and more accurate diagnoses of disease using noninvasive techniques(Quintela et al. 2012).

Diagnostic ultrasound is a non-invasive diagnostic technique based on the pulse-echo principle used to image inside the body. It is portable, free of radiation risk, and relatively inexpensive when compared with other imaging modalities, such as magnetic resonance and computed tomography. Furthermore, ultrasound images are tomographic, i.e., offering a “cross-sectional” view of anatomical structures. The images can be acquired in “real time,” thus providing instantaneous visual guidance for many interventional procedures including those for regional anesthesia and pain management. Ultrasound is a versatile imaging technique that can reveal the internal structure of organs, often with astounding clarity. This imaging technique is unique in its ability to image patient anatomy and physiology in real time, providing an important, rapid and noninvasive means of evaluation (Nelson, 2006).

Diagnostic ultrasound probes, called transducers, produce sound waves with frequencies above the threshold of human hearing (above 20KHz), but most transducers in current use operate at much higher frequencies in the megahertz (MHz) range. The hand-held transducer, which houses the piezoelectric crystals, can vary in frequency and crystal configuration. In general, the higher the resonant frequency the greater the resolution but the lower the penetrations of the sound beam. For most small animals, transducers in the range 4-12 MHz are used. The applicability of these transducer configurations depends on whether a small or large area of surface contact, is applicable to the anatomy being imaged and the cost one is willing to encumber for a machine. The most versatile transducer configuration for small animal imaging is the sector scan because the narrow part of the image is at the skin surface and the viewed area gets wider with increasing depth in the patient (Ronald and Daniel, 2003).

Ultrasound transducers (probes) contain multiple piezoelectric crystals which are interconnected electronically and vibrate in response to an applied electric current Piezoelectric crystals or materialsare able to convert mechanical pressure (which causes alterations in their thickness) into electrical voltage on their surface (the piezoelectric effect). A pulse of high-frequency sound (ultrasound) is transmitted into the body. This pulse travels through the body until it reaches a reflecting surface, at this time a portion of the ultrasound pulse (the echo) is reflected back toward the source of the pulse. Piezoelectric crystals, which create sound in response to electronic stimulation and create electronic signals in response to sound stimulation, are the two-way conduit between the computer and the patient. A computer tracks the time that elapses from the beginning of the pulse to the time the echo is received, which allows determination of the reflecting surface's position in two-dimensional space viewable on a video screen (Qiu et al., 2015).
The amount of the ultrasound pulse that is reflected determines the brightness of the point produced in the two-dimensional image and whether or not anything can be seen beyond that point (e.g. acoustic shadow). Should the ultrasound beam encounter tissues or objects with very different acoustic properties to general soft tissues (e.g., bone, air, metal), near-complete reflection will occur. If an adequate number of points can be transmitted and received, a composite image of the reflecting surfaces can be displayed. This image is updated by sending multiple pulses and receiving multiple echoes in a relatively short period. This real-time image can be recorded on videotape or the video display can be "frozen" on an area of interest and recorded on photographic film or electronic media for future computer-based transfer, manipulation, and even transmission to a remote site for second opinion (Ronald and Daniel, 2003). Therefore based on this the objectives of this paper are:

The echoes reflected from a body part being examined also can be displayed along a moving, time-oriented graph. This display is referred to as M-mode and is used most often in cardiology to display quantitatively the size of heart valves, heart chambers, heart walls, and great vessels, as well as the motion of the ventricular walls, heart valves, and major vessels. B modeis a similar technique, but the echoes are displayed as points of different grey-scale brightness corresponding to the intensity (amplitude) of each signal another mode is A mode which is out dated due to the fact it conveys a limited information (Jain and Swaminathan, 2015). Therefore based on this the objectives of this paper are:

- To highlight on basic ultrasonography principles.
- To review the diagnostic use of ultrasound in veterinary medicine.

Literature Review

Uses of Ultrasonography

Ultrasound is commonly used to monitor uterine anatomy, involution and pathology. In addition, it has been used to detect pregnancy, study embryonic mortality, monitor foetal development, and determine foetal sex. Recent advances in ultrasound technology in both hardware and software have resulted in the production of superior images and the widespread use of ultrasound. Ultrasonography provides information about size, shape, and location of structures; moreover, it also provides information about the soft-tissue architecture of the structure or organ being examined (Abd El-Aty and Medan, 2010). Ultrasonography is best for distinguishing solid from cavities (fluid-filled) structures and provides internal detail not demonstrated radiographically. (Thrawat et al. 2012) used trasnabdominal examination of ultrasound for the diagnosis of johns diseased in goats, according to them this imaging modality is a unique method for non-invasive evaluation of the location, diameter, motility, wall and intraluminal contents of various parts of the intestine. (Zongo et al. 2015) employed the use of ultrasound to assess postpartum uterine involution and ovarian activity.

(Kurt and Cihan, 2013) evaluated 100 cattle ultrasonographically in order to identify their abdominal disorders. The importance and advantages of ultrasonography were evaluated by testing the findings of radiography and abdominocentesis in suspicious case and discovered ultrasonography not only provided definitive results, but also dispelled doubts raised by techniques applied in previous or subsequent procedure.) ultrasound has a great role on the formulating clear diagnosis on gastrointestinal disorders in dogs. The whole thickness of stomach or intestinal wall can be visualized and measured, as well as adjacent structures such as lymph nodes. Also can be assessed the gastric and intestinal motility, observing the peristaltic movements in real time (Mălăncuş et al. 2010).

Ultrasonography is ideally suited for evaluation of animals with pleural or peritoneal fluid. In those patients with pleural fluid, mediastinal masses, or cardiac disease, ultrasonography provides information that may not be evident on the radiograph. Pulmonary lesions usually are not accessible for ultrasonographic examination unless the area of lung involved is against the thoracic wall or surrounded by soft tissue–equivalent lung infiltrate that permits sound penetration. Although ultrasonography is not as useful for broad examination of the axial, appendicular skeleton or the skull as are survey radiographs, some information may be obtained from ultrasonographic evaluation of muscles, tendons, and the joints, as well as examination of the orbit and brain (in animals with open fontanels) (Qiu et al. 2015).

In small-animal reproduction, Doppler ultrasound has been used to diagnose and monitor canine pregnancy since 1970, by using Doppler ultrasound; it is possible to perform a precise assessment of maternal and fetal blood flow patterns from vessels as well as fetal and maternal cardiac chambers. The vessels routinely examined are the uterine, umbilical, and fetal middle cerebral arteries (Blanco et al. 2008). Doppler imaging for increased sensitivity of tissue vascularity, the injection of ultrasonographic contrast agents that enhance both vessel and tissue echogenicity, tissue harmonic imaging in which multiples of the usually imaged frequencies are used to increase image clarity, and three-dimensional ultrasonographic imaging for enhanced spatial understanding of the imaged pathology (Campani et al. 1998).

Ultrasonographic Technique

The quality of the ultrasonographic image is determined by the transducer selected, the gain settings on the machine, and the preparation of the patient. Patient preparation should include clipping the hair over the region of interest. Hair will trap air and this interferes with sound transmission. In areas with thin or fine hair, the air may be eliminated by wetting the hair with water or alcohol. After the hair has been clipped or dampened, ultrasonographic gel is used to ensure good contact and sound transmission from the transducer to the animal's tissues (Sippel et al. 2011).
The gain settings on the machine are used to vary the strength of the echo that returns from the structure of interest. Because the strength of the ultrasound beam decreases with increasing depth within the tissues, the machine can be adjusted to compensate for the loss of signal. In most machines this compensation is variable, with a slope that adjusts for the increasing loss of signal caused by sound reflection and refraction from tissues interposed between the transducer and the deepest structure to be imaged. The transducer should be selected based upon the thickness of the area that is being examined and, if possible, the transducer focal zone should match the depth of the general area of interest (Szabo, 1998).

Decreasing transducer frequency correlates with increased depth of ultrasonographic penetration with an accompanying loss of resolution. The transducer that is selected should be of a frequency that adequately penetrates the subject without having to set the gain too high. If the signal is not strong enough (e.g., the image is too black), the gain setting should be increased or a lower frequency transducer selected. If the signal is too bright, the gain should be decreased or a higher-frequency transducer selected. The use of a high-frequency transducer at high gain settings to compensate for lack of ultrasonographic penetration produces artifacts that may result in incorrect interpretation (Powis, 1986).

Image Formation and Image Processing in Ultrasound

Ultrasound imaging systems uses piezoelectric transducers as source and detector. Piezoelectric crystals vibrate in response to an alternating voltage, and when placed against a patient's skin and driven at high frequencies produce ultrasound pulses that travel through the body. As they travel outwards and encounter different layers within the body the ultrasound waves are reflected back towards the source. The returning signal drives the crystals in reverse and produces an electronic signal that is processed to construct the image. Medical ultrasound imaging is commonly used for obtaining diagnostic medical images, as a compact and affordable diagnostic tool. It uses beam forming techniques to construct an image of the interrogated medium (Qiu et al. 2015).

Transmit Signal Processing

The signal processing in an ultrasound scanner begins with the shaping and delaying of the excitation pulses applied to each element of the array to generate a focused, steered and apodized pulsed wave that propagates into the tissue (Szabo, 1998). Many characteristics of the transmitted acoustic pulse are adjusted in a manner that is linked closely with some adjustment in the received signal processing, the simplest link being the setting of a particular imaging mode. For example, standard pulse shaping includes the length of the pulse that is adjusted for different lines depending on whether the returned echoes are ultimately to be used for contributing to B-scan, pulsed Doppler or colour Doppler imaging modes (Wells, 1998).

Receive Channel Level Processing

Echoes resulting from scattering of the sound by tissue structures are received by all elements within the transducer array. Processing of these echo signals routinely begins at the individual channel (element) level with the application of apodization functions, dynamic focusing or steering delays, and mix-down processing (for some older scanners) to reduce the cost of the former. Knowledge of the speed of sound is important here. Conversely in some experimental scanners repeated guesses were made for the average sound speed and some measure of image sharpness was used as a means of estimating the sound speed in the medium. This property is not usually extracted in routine use of ultrasound scanners but was found to be useful for some diagnostic problems (Szabo, 1998).
Methods studied for deriving the correction functions have thus far included use of image derived geometrical information combined with knowledge of sound speeds, channel level iterative phase adjustment algorithms that employ cost functions involving speckle brightness or measures of coherence between channels, and so-called time reversal. Channel level signal processing has also been investigated as a means of removing acoustical clutter signals. One example of this is the so-called velocity-guided median filtering method, taken from ideas employed in seismological acoustical signal processing (Hill, 1998).

Beam forming

This is the process by which the signals on separate channels, each received from a different transducer element, are combined to form a single signal representative of the echoes received from the tissues by the defined transducer aperture. Both analogue and digital beam formers are still in use although the latter are rapidly gaining dominance as their cost decreases, due to their greater flexibility and precision (Szabo,1998). Aperture subdivision and partially coherent beam forming improves the speckle and other SNR, at the expense of spatial resolution but with net benefit to low contrast lesion detect ability (Hill, 1998).

Echo signals corresponding to individual beam-formed lines are processed using a very wide variety of techniques, for a wide range of objectives. Frequency demodulation and other methods used to extract blood flow information, and to create colour flow images, represent a large and important subject. All ultrasound scanners amplify the echo signals and compensate for attenuation losses. Low noise pre-amplifiers are necessary to maximize penetration at a given operating frequency. Applying some of the amplification before beam forming takes advantage of the noise averaging properties of the beam forming process. Swept gain, or time-gain compensation (TGC), is applied to compensate for changes in echo signal strength with depth. These may be due to attenuation loss or diffraction loss or gain (Wells, 1998).

Dynamic adjustment of the center frequency of this filter has been used both in an attempt to correct for the downshift in center frequency of a pulse as it propagates and to track this downshift. The former attempts to maintain consistent spatial resolution and image appearance with depth whilst the latter strategy aims to maximize SNR at all depths. Filtering is also used, as mentioned earlier, to detect in the echo signal the presence of harmonics of the transmitted center frequency. Such harmonics may arise in the transmitted beam as it propagates nonlinearly or may come from non-linear acoustic scattering by microbubble ultrasound contrast media (Cosgrove, 1998).

Image Definitions

Air, bone and mineralized structures have strong reflecting surfaces. That is, the ultrasound waves do not penetrate to the structures lying behind them. An acoustic shadow is thus created. The result of this is bright reflection known as the hyperechoic effect. In contrast, fluids produce an anechoic effect, a black image, since the reflection of the ultrasound waves is reduced or absent. Structures with densities lying between those showing effects of hyperechoicity and anechoicity produce a range of grey-scale images. These reflections are compared with hyperechoic effects and may be described as hypoechoic. Fat causes attenuation of the ultrasound due to an increased absorption of the ultrasonic ray resulting in a poor resolution. The acoustic impedance of tissue is determined by density and stiffness of the medium (Kremkau, 1993). An increase in either the density or the stiffness of a medium increases the acoustic impedance. Increases in the propagation speed also increase the acoustic impedance. Only small differences in acoustic impedance occur between the various soft tissues and organs in the body, whereas large differences exist between the soft tissues and bone or structures containing air (Nyland and Matoon, 1995).

Table 1: Acoustic impedance of different tissues (Curry et al. 1990)

Tissue	Acoustic impedance (106) kg/m2 sec
Air	0.0004
Fat	1.38
Water (50)	1.54
Brain	1.58
Blood	1.61
Kidney	1.62
Liver	1.65
Muscle	1.70
Bone	7.8
Lens	1.84

Resolution

Three types of resolution are found in ultrasound imaging, axial resolution, lateral resolution and elevation resolution. Axial resolution is the minimum reflector separation required along the direction of the ultrasound travel (scan time) to produce separate echoes. This resolution depends on the transducer frequency and it cannot be more than half the pulse length because of the overlap of returning echoes reflected off interfaces spaced closely together (Karsten and James, 2008). Lateral resolution refers to the ability to resolve adjacent point’s perpendicular to the axis of the sound beam along the plane of the scan. It depends on the ultrasound beams diameter (width) which varies with the transducer frequency and the distance from the transducer. Acceptable lateral resolution is usually found for several centimeters along the beam axis on either side of the focal point (focal zone). Elevation resolution refers to the ability to resolve adjacent point’s perpendicular to the beam axis and scan plane. This resolution is determined by the beams diameter (height) which also varies with the transducer frequency and the distance from the transducer (Merritt, 1998).

Table 2: Depth and axial resolutions obtained by different transducer frequencies (Nyland and Matton, 1995).

Frequency	Imaging depth (cm)	Axial Resolution (mm)
2.0	30	0.77
3.5	17	0.44
5.0	12	0.31
7.5	8	0.20
10.0	6	0.15

Transducers

The transducer is responsible for the transmission and reception of ultrasound waves. The piezoelectric material is a ceramic such as lead zirconate titanium that is embedded into an epoxy matrix. The piezoelectric elements can be shaped into rectangular, planar disks, and concave disks depending on the shape of the scanner head and the frequency that is needed. Transducers are made up of a number of layers that facilitate the sending and receiving of the ultrasound pulse. Starting at the surface, a typical transducer comprises: protective layer, lens, matching layers, an active piezoelectric material (with electrodes and connections), and backing block. The backing material is applied to the piezoelectric crystal to allow damping to prevent excessive ringing of the crystal after excitation. The lens allows the ultrasound energy to be focused upon a fixed area of interest (Vollmers, 2005).

The transducer is the mechanical part also commonly known as a probe, which has direct contact with tissue. Therefore ultrasound transducers convert electric voltage into ultrasound energy and incident ultrasound back into electrical voltage. There are several types of transducers which vary in image shape (Rantanen, 1993).

Transducers frequencies

A wide range of transducer frequencies is currently available from low frequency transducers imaging at 2.0 MHZ to high frequency transducers imaging at 10.0 MHZ. Ultra high frequency transducers exist for specialty imaging. As the transducer frequency gets lower the deeper the penetration and lesser the resolution will be. The high frequency sound waves penetrate the body tissue at a speed of 1450 to 1580 meters per second, depending on the type of tissue Routinely, 7.5 MHZ penetrates a depth of 4-6 cm, 5 MHZ penetrates 10-12 cm, 3.5MHZ penetrates 15-20 cm and 2.5 MHZ penetrates 25-30 cm. To reach superficial structures a standoff pad can be used to transfer the focal zone to a higher level (Allen and Stone, 1990).The selection of the appropriate transducer for an examination depends upon the structure being evaluated, and the depth of the area from the transducer surface and the acoustic properties of the intervening tissues (Powis, 1986).

Focusing

Focusing the beam results in reduced beam diameter and improved lateral resolution. Focusing of the beam can occur only in the near field of the ultrasound beam. Beam focusing characteristics are variable for each transducer and frequency and should be obtained from the manufacturer at the time ultrasound equipment is purchased (Powis, 1986). The focal distance and focal zone can be verified with an ultrasound test object. A number of devices are available commercially for testing imaging performance. Focusing can be performed dynamically or manually (Kremkau, 1993).

Modes of Echo Display

There are three types of echo display; these are A (amplitude) mode, M (Time Motion) mode and B (brightness) mode. The last two modes are used more frequently in clinical applications in veterinary medicine. A mode: It is based on the pulse echo technique. The A-mode represents the instantaneous echo signal amplitude versus time after transmission of an acoustical pulse. Each amplitude peak corresponds to a tissue interface of different impedances. The position of the interface can be established by measuring the difference in the peaks. The A-mode output is poor for visualization but the information can be obtained quickly (Jain and Swaminathan, 2015).

M Mode this is a 1-dimentional or ice-pick view of depth displayed against time. It is used in echocardiography to obtain high resolution images of the cardiac structures moving over time B-mode is the natural progression from A-mode where the information is presented as an image. The data from the B-mode is combined to produce a two-dimensional grey scale image. A black to white grey level denotes the intensity. If the pulse does not return from the tissue then it is given a 0 value (black) from the image processor whereas if the pulse returns un attenuated then the grey level value is assigned (white) (Vollmers, 2005)

B-mode is the most commonly used modality in diagnostic practices today. B mode is a 2-dimentional display of the returning echoes; the amplitude of the returning echo stored in memory is converted to the brightness of a dot that represents that returning echo. The location of the dot corresponds to the location of the echo reflector within the tissue cross section. This cross section may be obtained as a single frozen image (static B mode) or numerous frames can be acquired and displayed within one second and this is called Real time B mode (Nyland et al. 1995).

Artifacts

Artifacts are the imaging errors while using ultrasound. These are generally a result of interactions between sounds and media that lead to inaccurate representation of structures since they usually do not follow anatomical boundaries. While some artifacts can be misleading, some are helpful for diagnoses like stones or pneumothorax. The commonly encountered artifacts are acoustic shadowing, acoustic enhancement, reverberation, mirror effects, comet tail artifacts (Jain and Swaminathan, 2015).

Acoustic shadowing**:** Shadowing is an artifact, which appears due to solid reflective structures like a bone or stone. The ultrasound beam can travel beyond this structure and as result; the artifact appears as a shadow.

Acoustic enhancement**:** When there is a change in medium along the path of a beam, through which the ultrasound waves can penetrate easily, there may be a bright-enhanced area distal to the medium that is enhanced. This occurs due to the inherent time gain compensation built into most systems to allow increasing amplitude of signals returning from deeper structures to compensate for attenuation (Dennison et al. 2012).

Reverberation**:** Reverberation artifact occurs due the reflection of the beam between two structures of high acoustic impedance, like pleura. The wave moves forwards and backwards between these structures and appears as parallel lines. With deeper imaging, the density of these lines gradually decreases, as the reflected signals become weaker from greater depths. The artifact appears as a striped pattern of these lines with alternating bright and dark areas. Comet tail artifacts**:** The comet tail artifact is due to the interrogation of a highly reflective structure in the path of the ultrasound beam. It is a special form of reverberation artifact. Mirror image artifact**:** This kind of artifact is seen when the ultrasound beam strikes a structure of a high acoustic impedance the similar mirror image appears mimicking a virtual object, for example in case of diaphragm. The mirror image is more hypoechoeic than the actual structure (Jain and Swaminathan, 2015).

Safety Considerations

Because bio effects, some of which are harmful, may be caused by ultrasound under certain exposure conditions, there is a hypothetical possibility that ultrasonic imaging may not be completely safe (Wells, 1986). Moreover, the ultrasonic exposure levels used by commercially available scanners have been steadily increasing, in order to obtain more information (Duck and Martin, 1991).

The World Federation for Ultrasound in Medicine and Biology (Wfumb, 1992) has published the following statements on thermal effects in clinical applications. B-mode imaging: known diagnostic ultrasound equipment as used today for simple B mode imaging operates at acoustic outputs that are not capable of producing harmful temperature rises. Its use in medicine is therefore not contraindicated on thermal grounds. This includes endoscopic, transvaginal and transcutaneous applications. Doppler diagnostic equipment has the potential to produce biologically significant temperature rises, specifically at bone-soft tissue interfaces. The effects of elevated temperatures may be minimized by keeping the time for which the beam passes through any one point in tissue as short as possible.
Although the data on humans are sparse, it is clear from animal studies that exposures resulting in temperatures less than 38.5^{o}C can be used without reservation on thermal grounds. This includes obstetric applications. Transducer heating: a substantial source of heating may be the transducer itself. Tissue heating from this source is localized to the volume in contact with the transducer. The possibility that non-thermal effects of ultrasound may be hazardous in some situations is more contentious. Cavitation, defined as the formation or activity of gas- or vapor-filled cavities (bubbles) in a medium exposed to an ultrasonic field, is the phenomenon of most concern. Other possible non-thermal mechanisms include radiation force, acoustic torque and acoustic streaming (Barnett et al. 1994).

Conclusion and Recommendations

Ultrasound applies to all acoustic energy with a frequency above human hearing (20,000 hertz). Diagnostic ultrasound is a non-invasive diagnostic technique based on the pulse-echo principle used to image inside the body. It involves exposing part of the body to high-frequency sound waves to produce pictures of the inside of the body. Diagnostic ultrasound transducers usually called probes contain piezoelectric crystals made up of Zinc zarconate generate sound wave or pulse when stimulated electrically. This pulse travels through the body until it reaches a reflecting surface, at this time a portion of the ultrasound pulse (the echo) is reflected back toward the source of the pulse. The reflected echos can be displayed as A, B or M mode. Ultrasonography provides information about size, shape, and location of structures its real-time nature in examination, allowing studies of moving structures most commonly used for pregnancy diagnosis, though it has several clinical significances. Till now no harm full effect on ultrasound has not discovered rather than generation of heat as a result of sound beam attenuation.

Based on the above conclusion the following recommendations are forwarded.

- Ultrasonography allows the confirmation of suspected diagnosis based on clinical signs individually, to provide the necessary evidence to diagnose a specific disease.
- The use of ultrasound is a helpful technique for the clinical assessment of anomalies in animals; it should be included in the routine diagnostic procedure.
- For betterment of application of US understanding the use of ultrasound technology should be given extra attention.
- Researches should be continued to expand the use of ultrasound beyond diagnosis in veterinary medicine.

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