Review Article

PRINCIPLE, APPARATUS AND TECHNIQUES OF ULTRASONOGRAPHIC IMAGING AND ITS PRACTICAL APPLICATION IN VETERINARY MEDICINE

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Introduction

Ultrasonography is an exciting imaging technique and diagnostic tool based on sound waves. Ultrasound waves represent a sound wave exceed the human audible frequency range (>20000 Hz), however frequency between 2-15 MHz are mainly used for diagnosis purpose. Ultrasound waves travels in a pulse and when it is reflected back it becomes an echo. It is pulse echo principle which is used for ultrasound imaging of structure inside body. Ultrasonography is viewed as the single most versatile addition to the noninvasive and nonsurgical armamentarium of the veterinary clinician.

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 “crosssectional” view of anatomical structures. Ultrasonography provides information about size, shape, and location of structures. The aim of this review is to highlight on basic ultrasonography principles and the diagnostic use of ultrasound in veterinary medicine.

Ultrasonographic Machine

Most of the ultrasound machines are equipped with a 3, 5, and 7.5 MHz probe. Large animal practices and newer ultrasound machine may also have a 10 MHz transducer Larger the number, higher the frequency of sound waves emitted from the probe (7.5 millions of cycles per second verses 3 million cycles per second). 10 MHz transducers used for horse tendon, 7.5 MHz for average size dog as well as 3.5 MHz for very large size dog and deep structure study. An ultrasound imaging system consists of a transducer and an image display unit.

Principle

Ultrasound transducers (probes) contain multiple piezoelectric crystals which are interconnected electronically and vibrate in response to an applied electric current Piezoelectric crystals or materials are 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 medium 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).

Types of Transducers

The applicability of 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. There are three types of transducers,

i) Linear

These are composed of thin rectangular clips lined up side by side, each producing sound waves. The beam thus produces is rectangular shape and permit a good visualization of superficial structures with an easy analysis of the anatomical relationship. This can be used for abdominal scan in small animals or by doing slight modification in shape of transducer (rectal or vaginal transducer) it can be used for diagnosis of, urinary bladder or uterus examination etc .in large animals.

ii) Convex

The composition of this transducer is similar to that of linear except that the crystals are placed in a curvilinear fashion. Thus with the same, contact area imaging of a greater area can be effected.

iii) Micro- Convex and Sector

Such transducers contain a single or more crystal which oscillate or rotate to produce a fan shaped beam. The small size gives them more maneuverability and access to more organs through a small contact area.

A. Image Display Unit

Display mode: there are three modes of display in diagnostic ultrasound i.e., A, B and M modes.

i) A-Mode (A stand for amplitude)

Amplitude mode (A-mode) ultrasound imaging is a single dimensional display of the amplitude and distance of the returning echo. The returning echoes are displayed as spikes or peaks originating from a horizontal baseline; the height of the peak is proportional to the amplitude of the returning echoes. Echo depth is represented by the location of the spikes on the baseline. Because more time is required for the echoes to return from deeper structure, the spikes of deeper echoes are seen further down the baseline.

ii) B-Mode (B stand for brightness)

Brightness-mode (B-mode) ultrasonic imaging is a two-dimensional display of returning echoes which allows structures to be readily identified and enables the analysis of anatomical relationships to be made. The transducer is moved across the surface of the body and the cross sectional anatomy is depicted. The returning echoes are displayed on the ultrasound screen as series of grey dots. The brightness of the dots is proportional to the amplitude of the returning echoes while the location of each dot corresponds to the anatomic location of the echo generating structure

iii) M-Mode (M stand for motion)

This is an adaptation of real, time scanning. It records the position and motion of the echo and resembles B- mode. The echo dots are produced by moving structures move back and forth along a vertical baseline. This movement is recorded over time and displayed as a moving, one dimensional image. With M-mode, the transducer is held in place over the moving organ and the display is printed on an oscilloscope or moving strip of light sensitive paper. M-mode is used primarily in echocardiographic studies of heart to measure cardiac wall motion and valve excursions.

The ultrasound mode that is most frequently used for the examination of animals is B- mode, real-time imaging. Real-time imaging refers to the live or moving display, in which echoes are recorded continuously on a non storage cathode ray display screen. This image may be frozen and photographed or recorded on a videotape.

Selection of Ultrasound Wave Frequency

The frequencies most commonly used in diagnostic ultrasound include 3.5, ·5.0 and 7.5 MHz. The resolution power of the equipment is dependent upon the frequency of the sound waves. Higher frequency wave's arc used for imaging superficial structures and provides greater detail with better resolution; however, the depth of the penetration is sacrificed by the production of an improved image. Low frequency waves provide greater tissue penetration and are suitable for deep organs. However, the image quality is poor with low frequency transducers (Buckrell, 1988). The characteristics of wave frequencies used in diagnostic ultrasound are given in **Table 1**.

Table 1: Depth and axial resolutions obtained by different transducer frequencies (Nyland and Matton, 1995).

Frequency	Imaging depth (cm)	Period (μS)	Wave length (mm)
2.0	30	0.50	0.77
3.5	17	0.29	0.44
5.0	12	0.20	0.31
7.5	8	0.13	0.20
10.0	6	0.10	0.15

Clinical Application of Ultrasonography

In veterinary practice, ultrasonography has been used in reproduction filed (pregnancy diagnosis, determination of fetal sex, diagnosis of follicular and luteal cyst, evaluation of superovulatory response, reproductive tract, follicular aspiration of oocytes for in-vitro fertilization and embryo transfer programme also for assessing lesions of the testes and epididymis in goats (Ahmad et al., 1991), dogs (England, 1991) and seminal vesicles in horses (Malmgren and Sussemilch, 1992)), pathological lesions of various organs including liver, spleen, kidneys etc(Andualem T, et.al., 2017)

Ultrasound guidance has traditionally been used to obtain biopsies of masses or abdominal organs, but more recently, it has gained increased recognition for musculoskeletal use (Genovese et.al., 1997, Dyson, 1991), including injection of cervical articular facets (Chope, 2008; Matoon et.al. , 2004), navicular bursa (Spriet et.al. , 2004), coxofemoral joints (David et.al., 2007), sacroiliac joints (Cousty et.al., 2008), tendon and ligament injury (Denoix and Audigie, 2004), orthopaedic surgery (Chen et.al. , 2005).

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).

Ultrasonographic Imaging 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).

Interpretation of Ultrasonic Images

Ultrasonic images are usually displayed as white against black background. Various terms used to describe the image include i) Hyperechogenic: This represents the bright echoes that appear as white on screen. Such images are given by highly reflective interfaces of dense tissues such as fetal bones, bovine cervix etc. ii) Hypoechogenic: These appear as grey image on dark screen and are given by interfaces of moderate reflection. Iii) Anechoic or echoiuscent: In absence of an echo the images appear as black on screen and are presented by complete transmission of sound waves like follicular fluid, chorionic or amniotic fluid.

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

Tissue	Acoustic impedance (106) kg/m^2 sec	Tissue	Acoustic impedance (106) kg/m^2 sec
Air	0.0004	Blood	1.61
Fat	1.38	Kidney	1.62
Water	1.54	Liver	1.65
Brain	1.58	Muscle	1.70
Lens	1.84	Bone	7.8

Image Quality and Examining Conditions

Examination conditions must be optimized for better production and interpretation of ultrasound images. It is found to be interaction of four factors i.e. operator, scanner environment and animal. The ultrasound instrument should be placed close to the operator at eye level to control the adjustments and to facilitate viewing. A high quality probe is another prerequisite. The intensity of ambient light should be dim to reduce reflections and avoid excessive brightness or contrast. As mentioned earlier animals must be well restraints for better interpretation of ultrasound image.

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).

i) 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.

ii) 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).

iii) 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.

iv) 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 Consideration

Diagnostic ultrasound 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 (Wfumb, 1992).

Conclusion and Recommendations

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. 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.

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