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BASIC PRINCIPLES OF DIAGNOSTIC ULTRASONOGRAPHY

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INTRODUCTION

Diagnostic ultrasound is a non-invasive and innocuous technique which permits tissue interphases to be detected and their shape, size and structure described. Various types of tissues, including those within an organ, can also be differentiated with this technique. However, the inability of sound waves to penetrate gas or bone is a primary disadvantage of ultrasonography.

This technique has recently been introduced into the field of veterinary medicine where it is commonly used for the diagnosis of pathological lesions of various organs including liver, spleen, kidneys etc. In the field of animal reproduction, this technique has been successfully used for detection of oestrus, diagnosis of early pregnancy, monitoring morphological and physiological changes of the ovaries and tubular genitalia, and for the diagnosis of pathological lesions of these organs. More recently, its use in assessing the lesions of the testes and epididymides in goats and rams (Ahmad *et al.*, 1991), dogs (England, 1991) and seminal vesicles in horses (Malmgren and Sussemilch, 1992) has been documented.

In Pakistan, diagnostic ultrasonography is gaining wide spread popularity in human medicine. However, it seems quite new for the veterinarians and livestock farmers. Therefore, the principles and procedures of this useful technique have been presented in this paper.

Definition of diagnostic ultrasound

Ultrasound is defined as sound waves of any frequency that is above the normal hearing range of the human ear i.e. greater than 20,000 Hertz (cycles per second). Frequencies commonly used in diagnostic ultrasound range from 1.0 to 10.0 megahertz (MHz). Ultrasonography is an advanced form of acoustic sensing in which high frequency sound waves are transmitted into the body, reflected back and displayed as a video image (Pechman and Eilts, 1987; Barr 1988).

Production of ultrasound waves

An ultrasound imaging system consists of a transducer and an image display unit. Pulses of ultrasound are generated by Piezoelectric crystals housed within a transducer. These crystals have unique pressure-electric properties i.e. they convert electric energy into ultrasound and vice versa. When a pulsed electric current is applied, characteristic vibrations are produced in these crystals which result in acoustic pressure (sound) waves in the contiguous tissue. These sound waves are sent into the body where they travel through the tissues. The latter have the ability to either propagate or reflect these sound waves to varying degrees. The proportion of sound beam that is echoed is received by the same piezoelectric crystals in the transducer and converted to electrical impulses. The ultrasound instrument processes the echo information, the latter is displayed on the ultrasound screen. The physical characteristics of a tissue determine what proportion of the sound beam will be reflected (Pierson *et al.*, 1988).

Ultrasound display formats

There are three main ultrasound display formats (Rantanen and Ewing, 1981):

a. Amplitude mode

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.

b. Brightness mode

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.

c. **Motion mode**

The motion mode (M-mode) is used for imaging the moving structures. The echo dots produced by moving structures move back and forth along a vertical baseline. This movement is recorded over time and displayed as a moving, one dimentional image. With M-mode, the transducer is held in place over the moving organ and the display is printed on a 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 nonstorage cathode ray display screen. This image may be frozen and photographed or recorded on a videotape.

Another type of ultrasonography is the doppler ultrasound which has been used for many years in medicine as a tool for monitoring foetal heart rate during labour. This is also useful in detecting and quantifying the presence, direction, speed and character of blood flow in various vessels. This information is presented as an audible sound and visually as a flow-versus-time plot or as a colour-coded two-dimensional presentation. Any of these presentations can be evaluated and used for diagnostic purposes (Kremkau, 1993).

Types of scanners

There are two basic types of real time, B-mode ultrasound scanners available on the veterinary market: linear array scanners and sector scanners. In linear array scanners, the transducer contains many crystals arranged side by side in a row, and the sound waves are emitted perpendicular to the transducer along the row of crystals. The waves produced by each crystal travel parallel to those produced by neighbouring crystals in a linear array. Therefore, the resulting image is rectangular, the width of the image corresponds to the length of the active portion of the transducer. The images of the tissue closest to the transducer are at the top of the screen. These transducers are suited for examination of superficial organs such as testes, epididymides, tendons in horses, measurement of back fat in pigs, uterus and ovaries in large animals when examined per rectum (Pierson *et al.*, 1988).

Sector scanners contain a single crystal which oscillates or rotates to produce a fan-shaped beam. In such transducers, each pulse originates from the same starting point, but subsequent pulses go out in slightly different direction from the previous ones. This results in a sector scan, which is shaped like a slice of pie. The small size and manoeuvrability of these transducers allow ready access to most of the thoracic and abdominal viscera. The only limitation is that very superficial structures may not be readily identified due to the shape of the beam. Sector scanners, however, require less skin surface contact which can reduce the scanning time required per animal (Barr, 1988)

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 waves are used for imaging superficial structures and provide 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.

Technique

Ultrasound examinations are most rewarding when they are conducted to answer specific questions raised by a thorough diagnostic workup. The animal can be examined in various positions, including standing, sitting, or dorsal or lateral recumbency. Obese animals are poor candidates for this examination as the thick deposits of fat cause acoustic attenuation. Ultrasonography in animals requires hair removal as the trapped air is a highly reflective to the transmission of the sound beam. An ultrasonographic coupling gel is applied to the transducer to ensure close contact between the skin and the transducer by excluding the air. The transducer is positioned over the area of interest and a good quality image is obtained by manipulating the transducer. In large animals, transrectal ultrasonography can be done for imaging the reproductive tract.

Principles of interpretation

When identifying and evaluating a possible lesion ultrasonically, the internal echo pattern, borders and the

Fig.1 Ultrasonograph taken with a B-mode linear array scanner. A thick anechoic layer of fluid (arrows) is surrounding the left testis (LT). The right testis (RT) is normal.

Fig.3 Ultrasonograph of a sperm granuloma (marked by arrows) showing mixture of echoic and hypoechoic areas.

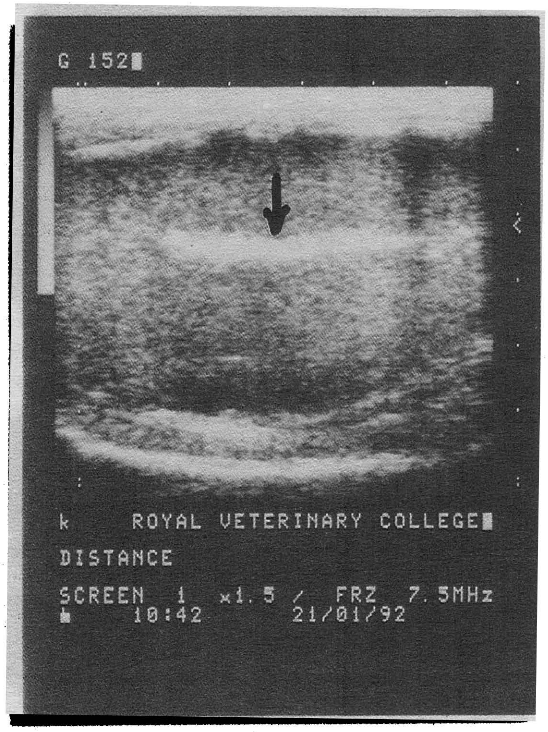

Fig.2 Ultrasonograph of the testis showing hyperechoic line (arrow) representing the fibrous mediastinum testis.

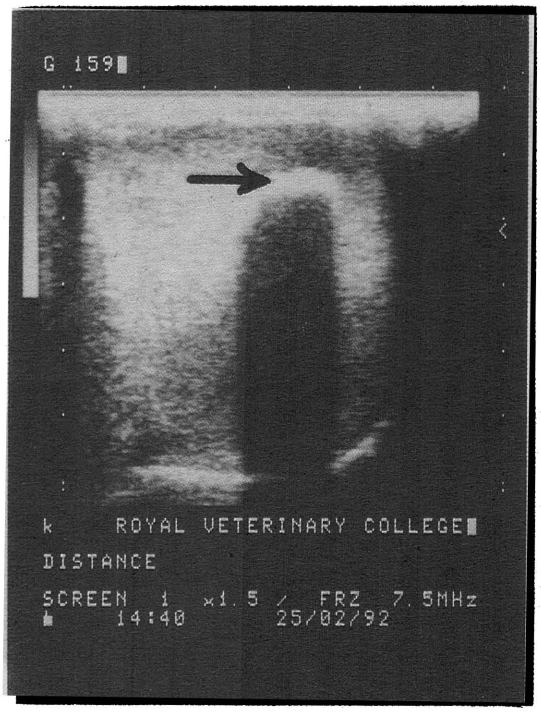

Fig.4 Acoustic shadowing (black area) below a hyperechoic mass (arrow).

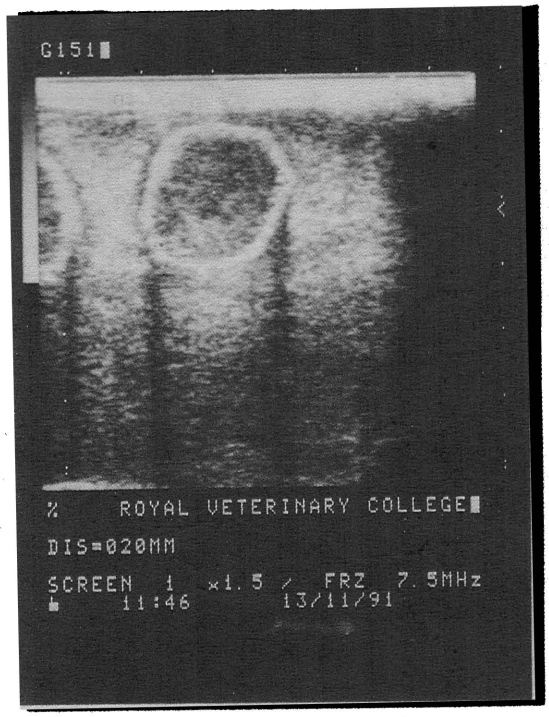

Fig.5 Acoustic shadowing below the curved surface of a lesion.

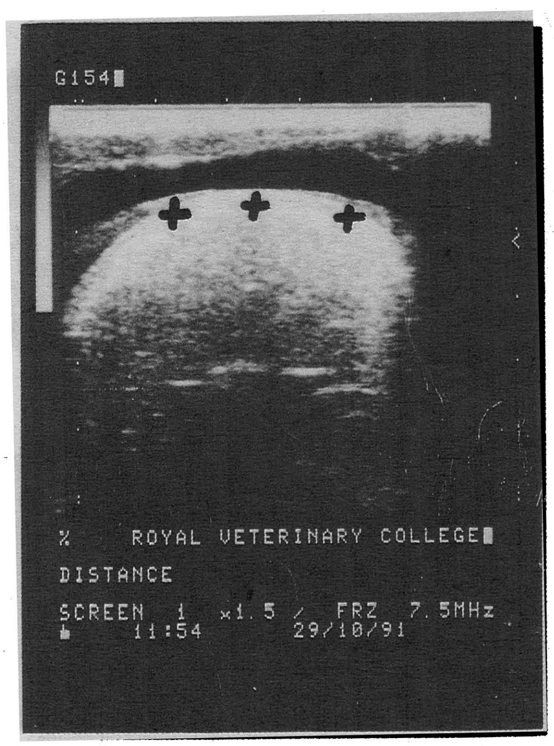

Fig.6 Enhanced through transmission (+ + +) below the anechoic (black) fluid.

Fig.7 Reverberation artifact (arrow) characterized by series of hyper-echoic lines placed parallel to one another.

adjacent echo patterns should be observed. The echo pattern of any lesion is relative to the echogenicity of the adjacent tissue. Internal echo patterns are described as hyperechoic (increased), isoechoic (normal), hypoechoic (decreased) or anechoic compared with normal echo pattern of the surrounding tissues.

Depending upon their density and stiffness, various organs and tissues of the body vary in their ability to reflect the sound waves, i.e. echogenicity. Fluid filled structures, such as cysts and graafian follicles, do not reflect the sound waves and thus appear black on the B-mode ultrasound display. Such images are termed as anechoic or non-echoic and the structures generating such images are called anechogenic or non-echogenic (Fig. 1). Hard structures such as bones and fibrous tissue reflect most of the sound waves and thus appear white on the display. Such images are termed as hyperechoic or simply echoic and the structures generating such images are known as hyperechogenic or echogenic (Fig. 2). Hypoechoic pattern may be seen in cystic structures that contain fluid that is more cellular, such as abscesses, haematomas or neoplasms. Complex lesions appear as a mixture of echoic and hypoechoic areas and are seen with granulomata or other tissue that contain necrotic or cystic areas (Fig. 3).

Parenchymal organs have characteristic echo patterns based on varying cellularity and stromal composition, i.e. increased stromal connective tissue

Table 1: Characteristics of wave frequencies used in diagnostic ultrasound

Frequency (MHz)	Period (μS)	Wave length (mm)	Imaging depth (cm)
2.0	0.50	0.77	30.0
3.5	0.29	0.44	17.0
5.0	0.20	0.31	12.0
7.5	0.13	0.21	08.0
10.0	0.10	0.15	06.0

MHz = Megahertz μS = Microseconds Source = Kremkau (1993)

results in increased echogenicity. The diffuse echo pattern of an organ may be reduced by infiltrative processes such as oedema, or increased by fibrous tissue, fatty infiltration or diffuse neoplastic cellular infiltration.

Commonly encountered artifacts

The principles of ultrasonography are based upon the ability of sound waves to be either reflected from, or propagated through, various tissue interfaces. However, certain tissues may also cause sound waves to bend, bounce back and forth or re-echo, or to become weakened or entirely blocked. As a result, distortions may appear on the ultrasound image which do not correspond to a real echo generating structure in the tissue. Such distortions are known as artifacts. Common artifacts include, acoustic shadowing, enhanced through transmission and reverberations (Park *et al.*, 1981; Ginther and Pierson, 1983).

Acoustic shadowing is the reduction in echo amplitude from reflectors that lie behind a strongly reflecting structure such as a bone or a stone. This is seen as a dark area below the hyperechoic images (Fig. 4). Acoustic shadowing can also occur behind the edges of structures that are not necessarily strong reflectors. In this case, the cause may be the defocusing action of a refracting curved surface (Fig. 5). The enhanced through transmission is the increase in echo amplitude from the structures that lie behind a weakly reflecting structures such as fluid-filled cavities. In such artifacts, hyperechoic images are seen below an anechoic image (Fig. 6). Acoustic shadowing and enhanced through transmission are often useful artifacts for determining the nature of masses (Kremkau and Taylor, 1986). Reverberations can occur when a sound beam bounces back and forth between the transducer and a strong reflector like a bone. Such artifacts are represented on the ultrasound images by hyperechoic lines placed below and parallel to one another and the real hyperechoic image (Fig. 7).

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