Diagnostic Ultrasound Imaging in Domestic Animals: Two-Dimensional and M-mode Echocardiography

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ABSTRACT. Two-dimensional (linear scanning) and M-mode echocardiography in normal cattle, horses, goats and dogs were examined to obtain fundamental information for clinical application. The cardiac window, which allows penetration of the ultrasound beam, was defined in the left and right 3rd and 4th intercostal spaces near the olecranon in cattle, goats and dogs, and in the area above the olecranon of the 4th and 5th spaces in horses. It was possible to identify the cardiac valves, cavities and walls, and to observe their configuration and motion by both methods. In particular, in cattle and horses, using real time two-dimensional imaging, in spite of the impossibility of observing the short-axis view due to ribs, it was relatively easy to visualize the morphology and movement of the intracardiac structures, and it was easy to choose the location and direction of the probe for M-mode imaging. However, obtaining the typical M-mode echocardiograms of cardiac valves was not as easy as that of the ventricles, especially in cows, in which the ossa cordis seemed to have an effect on imaging of the mitral and aortic valves. After observing the two-dimensional long-axis echocardiogram from the cardiac window of each structure, manipulation of the probe according to the tomogram readily produced the M-mode tracing of the target structure.—Key words: domestic animals, two-dimensional and M-mode echocardiography, ultrasound.

INTRODUCTION

Diagnostic ultrasound imaging (echocardiography) is a noninvasive, innocuous means for evaluating structural and functional aspects of intracardiac structures. Two basic modalities of the imaging, two-dimensional [5] and M-mode echocardiography (or ultrasonocardiotomography and ultrasound cardiology), have been applied in delineating certain cardiac disorders in man and used in conjunction in order to cover the defects of each other [3, 4].

Since Yamada, H. et al. [17] first reported the benefits of M-mode echocardiograms in bovine cardiac lesions, recent experimental studies in normal horses [10], swine [11], cats [12] and dogs [2, 8, 9, 16], and clinical studies [1, 6, 13, 14, 15, 20] using M-mode imaging have been reported in the literature of veterinary medicine. However, M-mode echocardiographic examinations have not been fully performed on the tricuspid and pulmonary valves in normal domestic animals, excluding some reports in dogs [2, 16], and there have been no such examinations done on the left-side of the heart in cattle as yet. Moreover, two-dimensional imaging in animals has not been investigated, except for a few reports [18].

In this paper, normal cattle, horses, goats and dogs were examined using two-dimensional (linear scanning) and M-mode echocardiography to obtain fundamental information on their clinical application.

MATERIALS AND METHODS

Animals, equipment and recording methods: Echocardiograms were recorded from the following normal animals: 18 cattle, 4
horses, 6 goats and 7 dogs, which were the same animals used in our previous study [19]. An electronic linear scanner for two-dimensional echocardiography (EUB 25-M, Hitachi Medical Corp., Tokyo, with 3.0, 3.5 and 5.0 MHz transducers), and an ultrasonic recorder for M-mode scanning (Echocardiograph SSD-110S, Aloka Co. Ltd., Tokyo, with a 2.25 MHz probe) were used in this study. The former can also display M-mode echograms. Photographic recordings in the former were made by a Polaroid camera, and recordings in the latter were done by a line scan recorder for continuous recording on sensitive papers (UCG recorder SSZ-91, Aloka), or by a Polaroid camera used simultaneously with an electrocardiogram. Image presentation followed the accepted standards [19].

Experimental procedures: Animal position and the basic preparation for ultrasonic examination were made in the same manner as in the previous paper [19].

Identification of cardiac echoes: The intracardiac structures observed from echoes were identified by injecting an echo-generating solution into the vessels [2, 3, 8, 10]. Several ml of indocyanine green (2.0–5.0 mg/ml) laden with microbubbles were injected intravenously as its solution.

After confirming the origin of the cardiac echoes by anatomical examination, as previously reported [19], and the anatomical specimens were sectioned so that the ultrasound beam could penetrate through the long-axis of the heart, corresponding to the images obtained by intercostal scanning in standing animals.

RESULTS

1. Location and direction for scanning
The Table shows the standard location and direction for scanning each intracardiac structure of normal domestic animals. Examinations were facilitated by extending the right or left forelimb as far forward as the animals would tolerate, and was made by intercostal scanning. The animals were usually scanned from the higher space shown in the Table. However, the short-axis two-dimensional image could not be visualized in almost all of the animals, due to the acoustic shadows occurring from the ribs.

Moreover, the mitral valve (MV) and/or its apparatus were also imaged when the transducer was placed on the left thoracic wall in the 4th intercostal space near the olecranon (5th and above in horses) and oriented caudal. The aortic root and valve (AoR, AV) were also observed when the transducer was applied to the same wall in 3rd or 4th space near or above the olecranon and angled rightward or somewhat cranial. Also the tricuspid valve (TV) and right ventricular outflow tract (RVOT) were visualized when the pulmonary valve and root (PV, PuR) were scanned. In the above locations and directions, however, imaging was not always sufficient, unlike the results in bovine and equine sucklings. On one hand, the images were observed and recorded by two-dimensional imaging more readily and clearly than by M-mode imaging.

2. Imaging patterns of intracardiac structures

Typical imaging patterns obtained according to the Table were as follows.

Mitral valve (MV): Two-dimensional echocardiogram or ultrasonocardiogram (UCT) toward the MV were imaged as if the examiner were observing the long-axis section of the heart (Fig. 1a). The MV, which had an opening in diastole and a closure in systole motion of the leaflets in real time display, and was often accompanied by echoes of chordae tendineae, was noted between the left atrium and ventricle (LA, LV) leftward to the right atrium and ventricle (RA, RV) and interventricular septum (IVS) (Fig. 1a).

M-mode echocardiogram or ultrasound cardiogram (UCG) of the MV were obtained
<table>
<thead>
<tr>
<th>Cardiac structures</th>
<th>Scanning</th>
<th>CATTLE &amp; GOATS (Standing)</th>
<th>HORSES (Standing)</th>
<th>DOGS (Recumbent, standing, sitting)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral Valve</td>
<td>Location</td>
<td>R-3, 4 ICS*: slightly dorsal to the right olecranon</td>
<td>R-4, 5 ICS: dorsal to the right olecranon</td>
<td>R-3–5 ICS: slightly dorsal to the right sternal border</td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td>Caudad to the left olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aortic Valve</td>
<td>Location</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Same as above</td>
</tr>
<tr>
<td></td>
<td>Direction b)</td>
<td>Slightly caudal to the left olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tricuspid Valve</td>
<td>Location</td>
<td>Same as above (area very slightly dorsal to the location of mitral valve)</td>
<td>Same as above</td>
<td>Same as above</td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td>Slightly caudal to the left olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary Valve</td>
<td>Location</td>
<td>L-3, 4 ICS: slightly dorsal to the left olecranon</td>
<td>L-4, 5 ICS: slightly dorsal to the left olecranon</td>
<td>L-3, 4 ICS: slightly dorsal to the left sternal border</td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td>Craniad to the right olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventricles c)</td>
<td>Location</td>
<td>L-R-3, 4 ICS: vicinity of each olecranon</td>
<td>L-R-4, 5 ICS: slightly dorsal to each olecranon</td>
<td>L-R-3–5 ICS: slightly dorsal to each sternal border</td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td>Caudal to the opposite olecranon</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) This Table shows the location and direction in which each structure was best imaged.
b) Slightly dorsocraniad to the direction of the mitral valve.
c) These indicate the location and direction in which the short-axis of the ventricles was imaged.
* R(L)–3, 4 ICS means the 3rd and 4th intercostal spaces on the right (left) thoracic wall.
Fig. 1. a) Two-dimensional echocardiogram or ultrasoundcomd tomatogram (UCT) toward the mitral valve (MV) in an equine suckling and its schema.

b) M-mode echocardiogram or ultrasound cardiogram (UCG) of the SML and LML in a cow. Abbreviations: D: Dorsal, V: Ventral, R (L)–3 (4): Scanning in Right (Left) 3rd (4th) intercostal space, Pe: Pericardium, TW: Thoracic Wall. Other abbreviations follow those given in the text. *The next Figures also follow Figure 1.

easily by manipulating the probe for UCG or the single beam line within the display of the UCT (white line in Fig. 1a) according to the observed UCT. The septal mitral leaflet (SML) inscribed an “M”-like motion during diastole with “E” and “A” waves, while the lateral mitral leaflet (LML) formed a “W” shaped image of lesser magnitude (Fig. 1b). Moreover, only the SML was delineated by orienting the probe or beam line slightly
dorsal to the direction of the two leaflets.

Aortic valve (AV): The AV was observed within the AoR running from the left ventricular outflow tract (LVOT) between the RA (and/or RV) and the LA (Fig. 2a). In the real time UCT of AV, the edge of the cusp moved more than the base, and the cusp had a semiluminar configuration.

The AV UCG indicated an opening of the valves in systole and a single line closure pattern in diastole (Fig. 2b), but two cusps of AV were hardly detected simultaneously, and only one cusp was usually recorded easily.

Tricuspid valve (TV): When detecting the
MV or AV, the leaflet and/or chordae tendineae of TV were displayed in many cases (Figs. 1a, 2a, 3b). However, the TV in UCT tended to appear clearly in systole and obscurely in diastole (Fig. 3a).

The motion of TV excursion showed the "M" shaped pattern to be the same as the SML (Fig. 3b), though the UCG of TV was rarely recorded completely during the systole and diastole, and usually only in one or the other.

Pulmonary valve (PV): With the left forelimb extended more cranial than the limb position at the scan of the other valves, the UCT toward PV was obtained, in which the pulmonary artery (PA), aorta (Ao), RA, RVOT and IVS were also depicted (Fig. 4a). The motion of PV was the same as that of AV in real time.

The UCG of PV was traced as an opening in systole and closing in diastole by setting the probe for UCG in accordance with the UCT (Fig. 4b).

Ventricles: The image pattern was examined along the short-axis of the ventricles, in which each cardiac dimension was measured on the UCG [2, 3, 7–12], because of the possibility of visualizing the ventricles in a number of tomograms. The UCT of this view was consistent with the UCT of the MV (Fig. 1a), and the UCG of the ventricles was recorded by inserting the ultrasound beam.
Fig. 7. Long-axis sectional view toward the MV. OC: Ossa Cordis, P: Probe, T: Transducer.

Fig. 8. Long-axis sectional view toward the AV.

Fig. 9. Long-axis sectional view toward the PV. *Figures 7, 8 and 9 show the sections of the heart presumably penetrated by the ultrasound beam in calves and their diagrams toward each cardiac valve.
between the edge of the MV and the papillary muscle (Figs. 1a, 5a). Furthermore, the left ventricle containing the orifice of MV was also observed from the approach on the left side (Fig. 5b).

The echogram of the ventricular wall was delineated thickening of the walls in systole and thinning of them in diastole, whereas that of the ventricular cavities was traced reversely, in contrast with wall motion (Fig. 5a).

3. Identification of cardiac echoes

**Contrast echocardiography:** It was observed that the contrast material injected intravenously flowed into the RA and then out to the PA via the PV after passing through the RVOT in real time, but that no contrast echoes (CE) appeared within the Ao (Fig. 6). The other structures were also verified in the same manner. The coronary artery (CA) was also visible within the IVS, through it was imaged vaguely (Fig. 6).

**Long-axis sectional views of the heart presumably penetrated by ultrasound beam:** The standard long-axis views toward the MV, AV and PV, respectively, were prepared from the present results (Figs. 7, 8, 9).

The long-axis view toward the MV, which contained the short-axis of the ventricles, is shown in Figure 7. The UCT which corresponded to the slice was represented in Figure 1a. The A of the view is the longitudinal sectional view, in which each UCG of the SML, SML and LML, and ventricles was recorded by matching the probe with the direction of 1, 2 and 3, respectively (Figs. 1b, 5a, 7).

The B of the view in Figure 8 indicates the plane toward the AV. Figure 2a corresponds to Figure 8. This plane was sectioned in the same cutting line, slightly cranial to A of the view. The direction of 4 in vivo is situated slightly dorsocranial to that of 3.

By observing these two slices, it was understood that the TV and its apparatus tended to appear when scanning the MV or AV (Figs. 1a, 2a, 3b, 7, 8).

The view toward the PV is exhibited in Figure 9. The UCT and UCG, which were compatible with C of the view and the orientation of 5, are shown in Figures 4a and 6, and 4b, respectively.

4. Differences among animal species

In bovine and equine sucklings, it was very easy to visualize each intracardiac structure clearly (Figs. 1a, 2a, 3b, 6).

In yearlings and cows, however, the valves could not be imaged as easily as the ventricles; in particular, there was no ease obtaining typical UCG of the MV and AV. In cattle and horses, the UCG of the TV was often traced only in diastole.

In the UCT of cows and mares, it was impossible to visualize both the right and left ventricular walls (RVW, LVW) at the same time (Fig. 3a, 4a): the viewing range with the equipment used in this investigation was as deep as 23.0 cm.

On one hand, intracardiac structures were imaged more readily and clearly in mares than in cows, especially on UCG. In horses, the intercostal spaces for scanning were somewhat different from those in the other species (Table).

In dogs fixed in various positions and in goats, echocardiography was accomplished relatively easily. Unfortunately, in dogs, especially middle and small-sized dogs, since the clear UCT on the display was rarely obtained, the two-dimensional imaging was utilized for observing the real time UCT and selecting the location and direction for the M-mode method.

**DISCUSSION**

In this work, normal animals were investigated by the use of two-dimensional and M-mode echocardiography.

The cardiac window, which allows penetration of the ultrasound beam in each animal (ultrasound cannot penetrate air-filled and bone tissues), was defined, as shown in the Table and in Figures 7, 8, 9. These windows
were roughly consistent with the previous studies by the M-mode method [2, 8, 9, 13, 16]. The UCG of each cardiac structure (Fig. 1b, 2b, 3b, 5a), except for the PV, was similar to that reported in man [3, 4, 21] and animals [2, 8-12, 16, 20], and labelling of the MV and TV UCG followed the above cited papers (Figs. 1b, 3b). However, the MV UCG lacking “A” wave was also recorded in animals with sinus tachycardia, and as reported, the “A” point disappeared normally with a decrease in the duration of diastole [9, 21]. In horses, goats and dogs, the MV among four cardiac valves was most easily recorded in the M-mode method as shown in man [4, 21] and dogs [16, 20], whereas in young and in adult cattle, the UCG of MV and AV were not readily recorded. In cattle, from the considerations that the M-mode tracing displays the acoustic shadow or reverberation generated by the ossa cordis, A and B of the view (Figs. 7, 8) and anatomical examination, it was thought that the ossa cordis had an effect on imaging of the valves, and that the cardiac window was narrower than that in horses, which resulted in this recording.

In the AV UCG, “a” dip followed by atrial contractions and/or fluttering during the ejection period were sometimes noted, which are also recorded normally in man [4, 21].

It has been reported that the UCG of TV and PV is hardly recorded normally in man [4, 21] and dogs [9, 20]. Though the present results of TV UCG were analogous to the extent of rarely obtaining the TV UCG completely, in cattle and horses, the UCT and UCG of the TV were obtained relatively easily compared with those in dogs. In particular, in real time UCT by linear scanning, the TV, its orifice and RV could be clearly observed morphologically and dynamically (Fig. 3a), and the UCG of TV was recorded often at diastole, differing from the recording during systole in man [21] and dogs [16, 20].

Echocardiographic recording on the PV was accomplished in almost all animals, as discussed in other reports of dogs [8, 16]. It was necessary to extend the left forelimb as far cranial as the animal could tolerate for recording. In addition, two-dimensional imaging displayed obviously the configuration and motion of two out of three semilunar cusps (Figs. 4a, 6). The UCG pattern of PV was not similar to that of man [3, 4, 21]. Real time UCT and C of the view (Fig. 9) may explain the two factors which seem to result in such recordings as the TV and PV in UCG. The first factor is the cranial movement of the heart itself in systole, which prevents the beam from tracing the edge of the TV and PV continuously. The second is that recording differs from those in man [3, 4, 7] in respect to the scan position and direction owing to anatomical differences.

In order to overcome the limitation of the instrument with respect to viewing depth in large animals, the LV should be observed from the left thoracic wall and the RV from the right side. This procedure is more easy to obtain clinical information than the M-mode method, which is capable of imaging both RVW and LVW together. But by the M-mode scan only, the echocardiographic measurement can be calculated [3, 4].

In goats and dogs, especially middle and small-sized dogs, an obscure UCT was obtained because the linear type transducer could not be fastened firmly to the convex thoracic wall, and the transducer was too large compared with the intercostal spaces. However, it was possible to observe roughly the cardiac motion and structure in real time display. Further, in such dogs, various views were visible due to the thin ribs, the acoustic shadow of which had little effect on the real time UCT. In dogs, the sector scanning commonly used in man [3, 7] with respect to two-dimensional imaging, and the small size probe with high frequency used in the M-mode method may be suited for exact examinations.
In man [3, 4, 7], the main echocardiographic measurement, which has been investigated also in animals by only the M-mode method [2, 8–12, 15], has been calculated from individual M-mode tracings of three directions, after confirming a two-dimensional long-axis image by the use of left parasternal scanning. However, in this study, a tomogram such as that used for man could not be depicted, apart from a few cases of dogs, as the heart position tended to shift within the thorax. Practically, the transducer has to be oriented in two directions to observe the MV and AV tomograms, respectively.

These pictures on the display were similar to the apical or subcostal four-chamber views in man [4, 5, 7], although the transducer location and its manipulation were greatly different from those of man. It seems that such tomograms result from the variation in the incident direction of ultrasound beam to the heart, due to the difference in the long-axis orientation of the heart within the thorax between animals and man. Moreover, these observations suggest that the UCGs drawn from the right side in animals are analogous but not quite identical to those of man. However, it appers that there is no great essential difference, since the left ventricle was possibly regarded as an ellipsoid of gyration [3, 4].

In any case, after observing the two-dimensional long-axis echocardiogram from the cardiac window of each structure (Table), by directing the probe according to the UCT, the UCG of target structure is readily produced.

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REFERENCES


要約

家畜における超音波画像診断に関する研究—超音波心臓断層法およびM-モード心エコー法について： 山田義則・戸尾健明（北海道大学兽医学部附属家畜病院）—正常な牛、馬、山羊および犬における超音波心臓断層法（リニア走査法）ならびにM-モード心エコー法が、その臨床応用に必要な基礎的資料を得る目的で検討された。超音波ビームが透過可能な、いわゆるcardiac window は、牛、馬、山羊、犬では左・右第 3・4 肋間隙の肋頭付近に、馬では第 4・5 肋間隙の肋頭背側に限定された。両法により、心臓の各弁膜、腔、壁の同定およびその形態ならびに動態観察が可能であった。特に牛、馬では、肋骨のため心臓の横断像が観察不可能な場合も、実時間超音波心臓断層法により、心内構築の形態および動態の映像化が比較的容易であり、また M-モード心エコー法用プローブの走査部位ならびに方向の選択が容易であった。しかし、各弁膜の典型的な M-モード心エコー図は、心室の心エコー図ほど容易には得られず、ときに牛では心房が懸垂弁および大動脈弁の拡大に影響を与えていると思われた。各検査が得られる走査部位から心臓の長軸断層像を観察し、その断層像にもとづいてプローブを操作すると、容易に目的とする心内構築の M-モード心エコー図が得られた。