Pulsed Wave Doppler and Color Flow Doppler Evaluation in Healthy Dogs and Dogs with Cardiac Disease

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Abstract Doppler echocardiography gives a physiological assessment of blood flow within the cardiac chambers, across valve orifices and in the great vessels. Pulsed wave Doppler can detect flow pattern in a very discrete region of simultaneously imaged 2-D echocardiographic plane. Twenty apparently healthy dogs and twenty affected dogs with dilated cardiomyopathy and mitral valve insufficiency ten each were selected for the study and subjected to detailed color flow and pulse wave Doppler study. In color flow Doppler studies a normal mitral and tricuspid flow were red in color as the flow is towards the transducer and when the nyquist limit exceeded it had a layers of blue superimposed on it. Aortic flow was seen as hues of blue and red and because of depth of the aorta nyquist limit was low and aliasing was commonly seen. In pulmonary flow the flow was usually blue in color as it was away from the transducer and total reversal of color was often seen as flow progress from high velocity during early systole to the lower velocities at the end of systole. In mitral valvular insufficiency two out often dogs showed jet occupying less than 20 per cent of atrium, three out of ten dogs showed jet occupying 20-50 per cent of atrium and five out of ten dogs showed jets occurring more than 50 per cent of atrium. In dilated cardiomyopathy mild to moderate jets were appreciated in four out of ten dogs in both mitral and tricuspid valves and two out of ten dogs showed mitral regurgitation alone.

Keywords Colour Flow Doppler; Pulse Wave Doppler; Dogs

1. Introduction

Colour flow Doppler imaging used pulsed wave technology to build a colour coded image of blood flow velocity superimposed on 2-D or M-mode anatomic image of the heart (Kirberger et al., 1992) Colour flow Doppler offers several advantages over the pulsed wave Doppler. First, region of normal and abnormal flow can be identified much faster because it cover a much greater area in each sample, thus increasing the efficacy of examination. Regurgitation jets and shunts are more rapidly identified and localized. Second, the colour display may be used to determine the direction of jet and help to align pulsed wave Doppler beam to the jet for more accurate velocity measurement. Finally colour flow display is more anatomically familiar and comprehensible to inexperienced examiners. To familiarize this technique among practicing veterinarians and to assess its viability in diagnosing heart
diseases in dogs. The present study was designed with following objectives: To evaluate the blood flow velocities and colour flow pattern at the level of the mitral, tricuspid, aortic and pulmonary valve in normal dogs and to document pulsed wave doppler velocities and colour flow in dogs with Dilated cardiomyopathy and Mitral valvular insufficiency.

2. Materials and Methods

Twenty apparently healthy adult dogs of different breeds, sexes and age groups attending the outpatient unit for general health checkup and vaccination were selected for the study. The breeds selected were Spitz (seven dogs), Labrador retriever (7 dogs) and non-descr ipt (six dogs). The dogs in this group were evaluated for normality by physical examination; lead II electrocardiograph, clinical laboratory values and two dimensional echocardiography. Apart from the normal study, ten dogs with dilated cardiomyopathy and ten dogs with mitral valvular insufficiency were selected for the study. Both healthy and diseased dogs were subjected to thorough pulsed wave Doppler and colour flow Doppler studies. The ultrasound machine used for the study was ALOKA Prosound SSD-3500SV with micro convex probe of frequency ranging from 3 to 6 MHz Along with the 2D imaging it has facilities of pulse wave Doppler and color flow Doppler.

2.1. Procedure for Doppler Examination

Three Doppler windows were used to get as parallel to blood flow as possible. These were the left caudal or apical four chamber view, the left caudal or apical five chamber view and the right parasternal short axis view at aortic valve level. Dogs were clipped over the examination area and placed on a specially constructed table for echocardiographic examination enabling all examination to take place from below the patient. All measurements were done by pulsed wave Doppler and colour flow Doppler.

The ultrasound machine used for the study was ALOKA Prosound SSD-3500SV with micro convex probe of frequency ranging from 3 to 6 MHz. The dogs were conscious throughout the examination and no drugs were used. The smallest cursor sampling seize (2 mm) was used to minimize artifact from the movement of cardiac structure (Kostucki et al., 1986). All the measurements in pulsed wave Doppler were taken in three sequential individual beats during normal sinus rhythm and averaged. Measurements were performed using electronic calipers on frozen screen images. Colour flow Doppler was superimposed on the same two dimensional images obtained for pulsed wave Doppler measurement. Imaging Plane and Sample Volume Position for Different Flow Areas (Kirberger et al., 1992) (Figure 1)

Mitral Valve Flow

Imaging plane: Left caudal (apical) four chamber view. Sample volume position: In the left ventricle just distal to the mitral annulus at the point of maximal opening of the mitral valve (Figure 1).

Left Atrial Flow

Imaging plane: Left caudal (apical) four chamber view. Sample volume position: One quarter of distance between the mitral annulus and the dorsal wall of the left atrium (Figure 1).

Tricuspid Valve Flow

Imaging plane: Left caudal (apical) four chamber view. Sample volume position: In the right ventricle just distal to the tricuspid annulus at the point of maximal opening of tricuspid valve (Figure 1).
Figure 1: Normal sample volume positions for Doppler studies

Right Atrial Flow

Imaging plane: Left caudal (apical) four chamber view. Sample volume position: One quarter of the distance between the tricuspid annulus and the dorsal wall of right atrium (Figure 1).

Aortic Valve Flow

Imaging plane: Left caudal (apical) long axis view of left ventricular outflow region. Occasionally an apical five chamber view was used to align more parallel to the ascending aorta. Sample volume position: In the ascending aorta at the distal end of the sinus of Valsalva (Figure 1).

Left Ventricular Outflow Tract Flow

Imaging plane: Left caudal (apical) long axis view of left ventricular outflow region. Occasionally an apical five chamber view was used to align more parallel to the outflow tract and aorta. Sample
volume position: In the left ventricle just proximal to the aortic valve and midway between the septum and open anterior mitral valve leaflet (Figure 1).

**Pulmonary Valve Flow**

Imaging plane: Right parasternal short axis view of the right ventricular outflow tract at the aortic valve level. Sample volume position: In the pulmonary artery just distal to the valve (Figure 1).

**Right Ventricular Outflow Tract**

Imaging plane: Right parasternal short axis view of the right ventricular outflow tract at the aortic valve level. Sample volume position: In the right ventricle just proximal to the pulmonary valve and midway between the aortic wall and right ventricular wall (Figure 1).

3. Results and Discussion

3.1. Mitral Valve Flow

The mean + standard error and range of mitral valve flow were presented in Table 1.

| Area                        | Mean ± SE | Range  |
|-----------------------------|-----------|--------|
| **Mitral Valve Flow**       |           |        |
| Peak E Velocity             | 69±2.60   | 50-90  |
| Peak A Velocity             | 50±3.20   | 30-70  |
| Ratio E:A                   | 1.43±0.05 | 1.14-2.0 |
| **Left Atrial Flow**        |           |        |
| Peak E Velocity             | 56.5±2.56 | 40-80  |
| Peak A Velocity             | 36.5±2.35 | 25-60  |
| **Tricuspid Flow**          |           |        |
| Peak E Velocity             | 58.5±3.20 | 40-90  |
| Peak A Velocity             | 40.0±3.12 | 30-70  |
| Ratio E:A                   | 1.40±0.04 | 1.16-1.71 |
| **Right Atrial Flow**       |           |        |
| Peak E Velocity             | 49±3.43   | 30-85  |
| Peak A Velocity             | 35.5±3.42 | 20-75  |
| **Aortic Valve Flow**       |           |        |
| Peak Systolic Velocity      | 119±4.28  | 100-160 |
| **Pulmonary Valve Flow**    |           |        |
| Peak Systolic Velocity      | 103±5.03  | 70-140 |
| **Left Ventricular Outflow Tract** |       |        |
| Peak Systolic Velocity      | 103.5±4.35 | 75-140 |
| **Right Ventricular Outflow Tract** |       |        |
| Peak Systolic Velocity      | 91.5±4.47 | 60-130 |

During diastole the flow was positive and laminar with the two main phases to the flow each with a spike triangular appearance. The initial peak occurred during the rapid filling phase of early diastole with E being the point of peak velocity and the average E point velocity was 69±2.60 cm/sec with a range of 50-90 cm/sec. The second and usually smaller peak occurred in late diastole as a result of atrial contraction with A being the point of peak velocity. The average A point velocity was 50±3.20cm/sec with a range of 30-70 cm/sec. The mean E:A ratio was 1.43±0.05 with a range of 1.14-2.0 (Figure 2).
During systole a low velocity positive turbulent flow was found in 80 per cent of the dogs. In the present study the description of the wave form was in agreement with Kirberger et al., (1992). Peak E velocity was lower than the velocities reported by Belanger (2005) and Kirberger et al., (1992). Whereas peak A velocity was in agreement with Belanger (2005) who reported a range of 50-70 cm/sec. The reason behind the low peak E velocity may be the less number of dogs involved in the present study. In evaluating mitral and tricuspid valve flow, the origin of systolic positive turbulent flow signal is unclear. During early ventricular systole the arterial ventricular annulus move toward the cardiac apex (Tsakiris et al., 1971; Keren et al., 1986) and this movement of annulus toward sternum resulted in pushing the ventricle blood adjacent to the wall toward the transducer.

3.2. Left Atrial Flow

The mean ± standard error and range were presented in Table 1. During diastole the flow was positive and laminar and was similar to mitral valve flow. The peak velocity was slightly less than mitral flow velocity. The mean peak E velocity was 56.5±2.56 cm/sec with a range of 40-80 cm/sec and the mean A velocity was 36.5±2.35 cm/sec with a range of 25-60 cm/sec. During systole a low velocity turbulent flow found in 85 per cent of the dogs (Figure 3). Kirberger et al., (1992) reported that the mean peak E and A velocity as 76 cm/sec and 54 cm/sec respectively. This value was considerably higher than those reported in the present study. Similar to mitral valve flow less number of cases involved in this study may be quoted as a reason. The systolic positive flow in left atrium is probably caused by venous pulmonary inflow as described in man by Keren et al., (1986).
3.3. Tricuspid Flow

The mean + standard error and range were presented in Table 1. The diastolic flow was similar to that of the mitral valve flow with an E and A point. The average peak E velocity was 58.5±3.20 cm/sec with a range of 40-80 cm/sec and the average peak A velocity was 40.0±3.12 cm/sec with a range of 25-60 cm/sec. Inspiration resulted in higher velocities especially in E peak. The average E:A ratio was 1.40±0.04 with a range of 1.16 – 1.71. During systole a low velocity positive turbulent flow similar to that described for mitral valve was found in 90 per cent of the dogs (Figure 4). Similar description of wave form were reported by Kirberger et al., (1992) but the average velocity of peak E and A was considerably lower in the present study which may be due to less number of dogs involved.

![Figure 4: Pulse wave doppler measuring the tricuspid flow](image)

3.4. Right Atrial Flow

The mean + standard error and range were presented in Table 1. During diastole the flow was positive and laminar and similar to tricuspid valve flow but the peak velocity flows were lower than tricuspid flow. Respiration had a definite effect on flow velocities, with inspiration resulting in higher velocities. The average peak E velocity was 49.0±3.43 cm/sec with a range of 30-85 cm/sec and peak A velocity was 35.5±3.42 with a range of 25-75 cm/sec (Figure 5). During systole a low velocity laminar to turbulent positive flow was found in 90 per cent of the dogs and the main contributor of this flow was believed to be systemic venous return. Observations made in the present study was similar to Kirberger et al., (1992) except that velocities peak E and A were lower. As earlier, less number of cases involved in the study may be assumed as the reason.

![Figure 5: Pulse wave doppler of tricuspid flow](image)
3.5. Aortic Flow

The mean ± standard error and range were presented in Table 1. During systole the flow was negative and had a rapid laminar acceleration phase i.e. down stroke. Spectral broadening often started at the peak with the deceleration phase i.e. upstroke having widened spectrum. The rapid acceleration phase results in peak velocity being reached early in systole. The average peak velocity was 119±4.28 cm/sec with a range of 100-160 cm/sec. In 15 per cent of the cases, a negative low velocity turbulent flow was obtained during initial diastolic period. In the present study, the morphology of waveform is similar to findings of Kirberger et al., (1992). The present study was in full agreement with Yuill and O’Grady (1991) who reported the average peak velocity as 118 cm/sec.

3.6. Left Ventricular Flow

The mean ± standard error and range were presented in Table 1. During systole the flow was negative and similar to aortic flow but with lower velocities. The initial acceleration phase was laminar with spectral broadening starting at the peak and continuing at the deceleration of the phase. Diastolic flow usually had positive and negative flow components with the degree of each depending on exactly where in the outflow tract the cursor was placed. The positive diastolic flow was similar to mitral valve flow being laminar and biphasic and starting at the beginning of diastole representing mitral flow toward the cardiac apex. The average peak velocity was 103.5±4.35 cm/sec with arrange of 75-140 cm/sec. The description of waveform in the present study is in agreement with Kirberger et al., (1992) but the peak systolic velocity recorded in the present study was considerably lower than reported by the above author. The left ventricular outflow tract diastolic flow was similar to that described in man (Panayiotou and Byrd, 1990). The positive diastolic flow probably represents passive mitral flow contaminating the sampling site and the negative diastolic flow probably represents mitral valve flow being deflected at the cardiac apex back towards the aortic flow.

3.7. Pulmonary Flow

The mean ± standard error and range were presented in Table 1. During systole the flow was negative and the initial acceleration phase had a narrow spectral width but broadened slightly after the peak during the deceleration phase. Inspiration resulted in higher velocities. 25 per cent of dogs had low velocity negative diastolic flow which was late diastolic. The waveforms were similar in morphology to the finding reported by Kirberger et al., (1992). The peak systolic velocity was 103±5.03 cm/sec with a range of 72-100 cm/sec. The peak systolic velocity reported by Yuill and O’Grady was 96 cm/sec and this finding is in partial agreement with the present study.

3.8. Right Ventricular Outflow Tract

The mean ± standard error and range were presented in Table 1. During systole the flow was negative and similar to pulmonary artery flow but with low velocities. A positive diastolic flow was recorded in 60 per cent of dogs and negative diastolic flow was recorded in 70 per cent of dogs. The average peak systolic velocity was 91.5±4.47 cm/sec with a range of 60-130 cm/sec. Except for the velocity the wave pattern were similar to finding by Kirberger et al., (1992).

3.9. Normal Color Flow Doppler Studies

Mitral and Tricuspid Flow

Typical left apical four chamber view showed mitral flow as a red with brighter central area and when Nyquist limit was exceed the central area of flow may have layers of blue superimposed on it. The same was recorded for tricuspid flows. The red color flow was due to the direction of Red blood cells
towards the transducer and when the nyquist was exceeded the flow was layered with blue. Finding in the present study is in agreement with Boon (1998) and Kirberger et al., (1992).

**Aortic Flow**

Aortic flow was seen as hues of blue and red as blood leaves the left ventricle in a downward direction in the left apical five chamber view. The depth of aorta in this view resulted in a low Nyquist limit and wraparound and aliasing was seen. During early systole when the velocities were high, aortic flow showed an almost completely aliased signal, later in systole during deceleration much of the flow was accurately mapped as blue. The present study is in agreement with the color flow pattern reported by Boon (1998).

**Pulmonary Flow**

Pulmonary artery flow encoded on the transverse image of heart at the base in right parasternal short axis view was usually blue as blood leaves the right ventricle in a direction away from the transducer. Since the artery curves, this plane had a layering of color within the pulmonary artery profile. Total reversal of colors was often seen as flow progress from high velocity during early systole to slower velocities at the end of systole. The present study was agreement with Boon (1998).

**3.10. Pulsed Wave Doppler and Color Flow Doppler Studies in Mitral Valvular Insufficiency and Dilated Cardiomyopathy**

**Mitral Valvular Insufficiency**

The mean + SE and Range were presented in the Table 2. The average peak E velocity of the mitral valve, average peak systolic velocity of aortic valve and pulmonary valve were 122.5±5.43, 108.5±4.15 and 95.5±3.76 respectively. A highly significant increase in the peak E velocity of mitral valve was observed in the dogs with mitral valve insufficiency when compared to normal dogs. The increased E velocity may be due to increased atrial pressure or volume associated with mitral insufficiency. There was no significant difference in dogs with mitral valve insufficiency in aortic and pulmonary valve velocities. This indicates that the cardiac output is preserved and may be majority of dogs taken up for study was not having systolic failure.

In the present study attempt was made to measure the regurgitant jet velocity in left atrial side. Since only pulsed wave Doppler was used for this study, invariably all the dogs showed a velocity of more than 300 cm/sec beyond which it was not possible to measure. Kienele and Thomas (1995) reported that the peak velocity of mitral regurgitant flow as 500 cm/sec regardless of the magnitude of the regurgitant fraction and he also opined that if the peak velocity was less than 450 cm/sec, improper technique, very high left atrial pressure or misdiagnosis may be considered.

Color flow Doppler study of mitral regurgitation revealed that two out of ten dogs had jets occupying less than 20 per cent of atrium, three out of ten dogs had jets occupying 20-50 per cent of atrial area and five out of ten dogs had jets occupying more than 50 per cent of atrium and these jets were visualized in the atrium as a aliased regurgitant flow having a typical mosaic pattern.

| Table 2: Pulsed Wave Doppler Studies in Mitral Valvular Insufficiency and Dilated Cardiomyopathy |
|---------------------------------------------------------------|
| **Mitral Valvular insufficiency**                              |
| **Area**                                                      |
| **Normal**                                                    |
| **Mitral valvular insufficiency**                             |
| **F value**                                                   |
| Mitral valve flow                                            |
| Peak E systole                                               |
| 69 ±2.60                                                     |
| 122.5 ±5.49                                                  |
| 0.095**                                                      |
| Aortic valve flow                                            |

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Boon (1998) graded insufficiency as mild, moderate and severe based on the jets occupying the area of left atrium. He suggested that a jet that occupies less than 20 per cent of the atrium may be considered to represent mild insufficiency and that occupies 20-50 per cent of atrial area as moderate insufficiency and greater than 50 per cent as severe insufficiency. Muzzi et al., (2003) in a study on 61 dogs with mitral regurgitation opined that the assessment of regurgitation jet area by color flow Doppler mapping was useful in accurate identification and semiquantitative estimation of the severity of mitral regurgitation.

### Dilated Cardiomyopathy

The average E velocity of mitral valve and tricuspid valve affected in dilated cardiomyopathy were 99.5±4.24 and 55±3.16. The peak systolic velocity of aortic and pulmonary valve flow in dogs with dilated cardiomyopathy was 68±5.28 and 61.5±5.53. A highly significant increase in the peak E velocity of mitral valve was observed in dogs with dilated cardiomyopathy compared to normal whereas no significant difference was appreciated between normal dogs and dogs with dilated cardiomyopathy in peak E velocity of tricuspid flow.

A highly significant decrease in the peak systolic velocity of aortic valve flow and pulmonary valve flow was observed in dogs with dilated cardiomyopathy compared to normal. Boon (1998) appreciated increased E velocity in dogs with dilated cardiomyopathy and he attributed this to the increase in atrial pressure or volume associated with secondary mitral insufficiency. He also recorded low aortic and pulmonary velocities in dogs with dilated cardiomyopathy which may be due to systolic failure.

In the present study four out of ten dogs showed both mitral and tricuspid regurgitation which was appreciated as aliased regurgitant flow having a typical mosaic pattern but the jets were occupying less than 50 per cent of atrial area which indicated that it was only a mild to moderate insufficiency. Two out of ten dogs showed mitral regurgitation alone indicating more involvement of left side. The regurgitation appreciated in dilated cardiomyopathy was due to abnormal dilation of chamber and consequent leak in Atrioventricular valve.

### 4. Conclusion

From the above study it was concluded that pulsed wave Doppler was very useful in recording flow velocities at all the valvular levels in a noninvasive fashion, which makes this diagnostic aid as a less cumbersome and more reliable technique. Color flow Doppler studies covers a larger area of flow and was instantaneous and effective in diagnosing flow abnormalities especially in mitral valve disease. It was also helpful in grading the severity as mild, moderate and severe whereas its use in Dilated...
Cardiomyopathy was much limited. Therefore, colour Flow Doppler may be a real boon for an inexperienced personnel.

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