

An Attempt to Estimate the Pulmonary Artery Pressure in Dogs by Means of Pulsed Doppler Echocardiography

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ABSTRACT. The pulmonary artery blood flow was determined in 40 dogs by pulsed Doppler echocardiography as a non-invasive means for estimating pulmonary artery pressure. Most of these dogs had become infected with heartworm disease which has been known to often cause pulmonary artery hypertension. From the flow velocity profile, four parameters, i.e., the Doppler tracing pattern, right ventricular ejection acceleration time (AT), and the ratios of AT to heart rate (AT/HR) and right ventricular ejection time (AT/ET), were obtained and their correlations with the pulmonary artery pressure determined invasively were investigated. Although the morphological pattern of flow velocity hardly allowed quantitative estimation of the pulmonary artery pressure, a relatively good negative correlation ($P < 0.01$) was obtained between the systolic pulmonary artery pressure and AT ($r = -0.71$), AT/HR ($r = -0.67$) or AT/ET ($r = -0.84$). The present results indicate that pulsed Doppler echocardiography is applicable to the estimation of pulmonary artery pressure and that AT/ET has the closest correlation with directly measured pulmonary artery pressure.—**KEY WORDS:** canine, Doppler echocardiography, heartworm disease, pulmonary hypertension.

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Increased pulmonary artery pressure in dogs is typically associated with canine heartworm disease, and various other cardiac diseases. The measurement of pulmonary artery pressure is important in determining the pathological condition and prognosis of these diseases.

Although it is possible to estimate the presence of pulmonary hypertension to some extent by radiography or electrocardiography, cardiac catheterization is necessary in order to achieve accurate measurement. It is an invasive approach and is hence disadvantageous, and its repeated use is hardly feasible.

In human beings pulmonary artery pressure is estimated non-invasively from variations in the echo from the pulmonary valve by M-mode echocardiography, and from changes in the pulmonary artery flow velocity pattern determined by pulsed Doppler echocardiography [10, 11]. It is also known that the Doppler method is technically easier and allows more accurate estimation than M-mode echocardiography [1, 2, 4, 10, 11].

As pulsed Doppler echocardiography in dogs has been only meagerly described, the present study was undertaken to examine a possible correlation between changes in the flow velocity pattern obtained by pulsed Doppler echocardiography and the direct measurement obtained by cardiac catheterization.

MATERIALS AND METHODS

Dogs: Forty dogs weighing 5.6–26.0 kg, ranging in age from 1.5 to 13 years, were subjected to this study. Thirty-seven dogs were brought into the author's small animal hospital due to canine heartworm disease or asymptomatic heartworm infection, and their heartworms were removed with flexible alligator forceps inserted through the right jugular vein. The other three dogs were healthy experimental dogs with no heartworms (Table 1).

Equipment used: An EUB-165 ultrasonic diagnostic apparatus (Hitachi Medical Corporation, Tokyo, Japan) with a 3.5 or a 5.0 MHz electronic sector probe was used.

A Dinascop DS-503 (Fukuda Denshi Co., Ltd, Tokyo, Japan) was used for sphygmomanometry. The transducer used was a Seaman Deltran II Disposable Transducer (Utah Medical., U.S.A.). Cardiac catheterization was carried out with either a Fr 7 or 8 wedge pressure catheter (Johnson & Johnson Medical, U.S.A.). The data were recorded on a modified ECG/Phonosystem FD-21P (Fukuda Denshi Co., Ltd.).

Pulsed Doppler method: Doppler recording was carried out in dogs under OF anesthesia after premedication with acepromazine 0.1 mg/kg or droperidol 0.25 mg/kg, plus ketamine 5.0 mg/kg or under GOF anesthesia without premedication. The dog was positioned in left lateral recumbency during examination. By setting the echo window at the middle between the sternal border and the costochondral junction of the left 3rd to 5th intercostal spaces, the short-axis view of the bifurcation of the pulmonary artery or the long-axis view of the right ventricular outflow tract was obtained. The flow velocity patterns were recorded according to the methods shown in Fig. 1.

The following precautions were taken when recording flow velocity patterns.

- 1) The direction of the Doppler beam was oriented as parallel as possible to the presumed direction of blood flow.
- 2) The sample volume (SV) was set at 1 mm in length. The SV was initially positioned near the center of the pulmonary valve orifice, and modified slightly when necessary to obtain the maximum flow velocity pattern by color-flow mapping (CFM) and the pulsed Doppler method.
- 3) One or 3–5 well defined flow velocity patterns were

Table 1. Summary of Doppler index and hemodynamic findings

No.	Breed	Sex	Age	Weight (kg)	PAP S/D(M)	Type	AT/ET	AT(msec)	AT/HR	No.	Breed	Sex	Age	Weight (kg)	PAP S/D(M)	Type	AT/ET	AT(msec)	AT/HR
1	Mong	♂	2?	8.3	16/ 5(9)	I	43.8	79	64.2	21	Mong	♀	4	7.2	26/12(17)	III	33.3	56	49.1
2	Shiba	♀	5	7.0	16/ 7(11)	I	40.4	74	69.2	22	Mong	♂	5	11.3	32/15(22)	III	38.3	74	56.1
3	Mong	♀	2	9.4	17/ 5(11)	I	40.9	81	66.4	23	Mong	♂	6?	13.4	37/23(28)	III	24.4	31	31.3
4	Mong	♂	7	7.2	21/ 7(12)	I	47.3	71	55.9	24	Mong	♀	4	7.5	42/19(29)	III	20.3	48	31.4
5	Shiba	♂	1.5	7.6	21/ 7(12)	I	35.3	71	60.1	25	Shiba	♂	5	9.8	42/22(31)	III	19.4	41	28.7
6	Mong	♀	2	8.1	23/ 7(16)	I	37.0	69	72.6	26	Mong	♀	6	5.6	43/18(28)	III	26.0	51	52.6
7	Mong	♂	8	17.1	23/ 7(13)	I	36.8	76	66.1	27	Mong	♀	7	18.8	43/24(32)	III	24.0	46	37.1
8	Mong	♂	3	15.0	23/11(15)	I	39.2	84	72.4	28	Mong	♂	14	10.0	45/21(31)	III	15.6	36	25.5
9	Mong	♂	4	12.2	16/ 4(8)	II	37.6	64	62.7	29	Mong	♂	6	15.0	45/21(31)	III	23.4	41	33.9
10	Sheltie	♀	3	13.5	21/ 6(12)	II	46.4	79	67.0	30	Mong	♂	10	20.0	59/29(41)	III	23.1	56	60.2
11	Mong	♀	6	11.6	21/ 9(12)	II	41.3	86	83.5	31	Shiba	♂	5	10.2	66/15(40)	III	19.8	36	29.3
12	Shiba	♀	9	12.2	23/ 7(14)	II	33.9	38	31.9	32	Mong	♂	7	25.0	74/23(42)	III	16.2	31	27.0
13	Mong	♀	6	14.0	23/ 9(14)	II	44.3	79	57.7	33	Mong	♀	8	8.6	103/39(71)	III	17.9	43	36.8
14	Mong	♀	10	20.7	27/11(18)	II	40.7	31	23.3	34	Sheltie	♂	5	6.0	104/19(51)	III	14.4	18	9.7
15	Mong	♂	3	9.8	27/15(19)	II	32.0	56	46.7	35	Mong	♀	12<	13.2	25/13(17)	IV	39.3	81	62.8
16	Mong	♂	4.5	20.0	28/ 9(16)	II	35.5	64	50.0	36	Shiba	♂	10	14.4	39/ 9(22)	IV	28.7	46	31.5
17	Shiba	♀	2	10.9	30/11(17)	II	32.5	43	35.2	37	Spitz	♀	8	8.3	44/25(31)	IV	25.3	38	22.5
18	Mong	♂	13?	23.0	31/16(22)	II	29.8	86	71.7	38	Mong	♂	10	7.4	68/28(42)	IV	18.8	33	26.2
19	Mong	♂	10	17.0	21/ 5(11)	III	35.8	71	69.6	39	Shiba	♀	3	9.4	72/34(47)	IV	18.9	38	28.4
20	Shiba	♀	5	7.4	26/11(16)	III	33.9	56	35.0	40	Mong	♀	5	11.5	102/39(70)	IV	14.8	25	18.7

PAP=Pulmonary arterial pressure; S=Systolic; D=Diastolic; M=Mean; AT=Acceleration time; ET=Ejection time; HR=Heart rate.

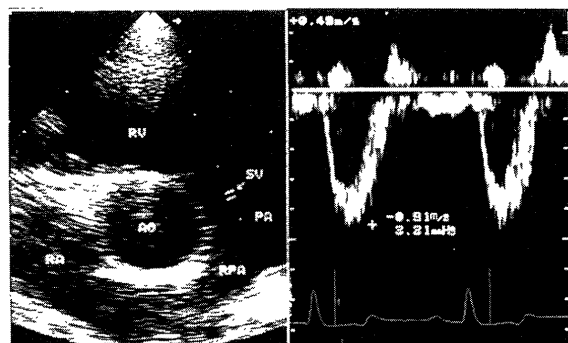


Fig. 1. Parasternal short-axis view (Left) demonstrating positioning of sample volume in proximal pulmonary artery and representative simultaneous noninvasive spectral wave form (Right). AO = aorta; RPA = right pulmonary artery; RA = right atrium; RV = right ventricle; SV = sample volume.

chosen for measurement. When several wave patterns were chosen. They were averaged for analysis.

- 4) The pulse repetition frequency was adjusted adequately within the range 4–10 KHz to obtain the maximum flow velocity pattern devoid of artifacts.
- 5) The maximum available sweep speed (140 mm/sec) was always used for recording flow velocity patterns to minimize any errors in measurement.
- 6) The range of the wall filter was 200–500 Hz.

To estimate the pulmonary artery pressure from the flow velocity pattern, two indices were determined (Fig. 2). One was the right ventricular ejection time (ET) from the start to the end of ejection flow, and the other was the right ventricular ejection acceleration time (AT) from the beginning of ejection to the peak velocity. The ratio of AT to ET (AT/ET) was then calculated.

Measurement of pulmonary artery pressure: Immediately after Doppler recording, the pulmonary artery pressure was measured by cardiac catheterization.

A catheter was inserted through the right jugular vein.

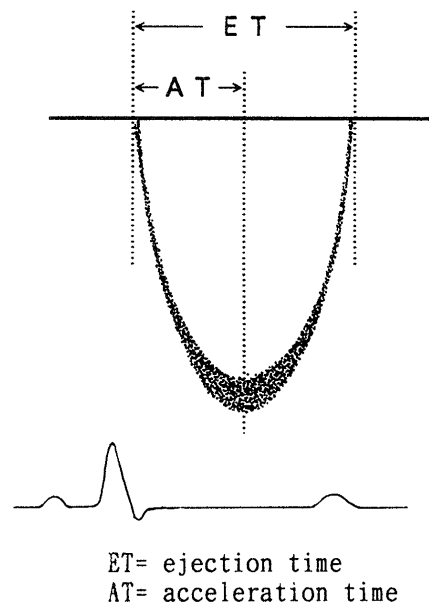


Fig. 2. Doppler index. Demonstration of measurement of acceleration time (AT) and right ventricular ejection time (ET) from pulmonary artery spectral wave form.

After confirming under fluoroscopic guidance that the tip of the catheter was in the pulmonary trunk, the pulmonary artery pressure (systolic, diastolic, mean) was determined from the characteristic features of the pulmonary artery pressure wave pattern.

RESULTS

The results of this study are shown in Table 1. During the experiments, I could detect several pulsed Doppler wave patterns, and categorized them into 4 different types according to their pattern of wave distribution.

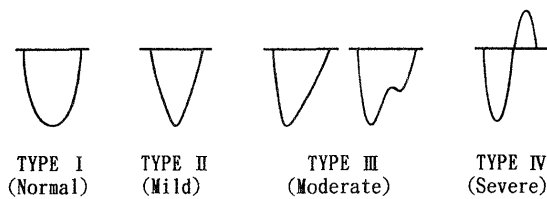


Fig. 3. Four flow velocity patterns. Four types of flow velocity pattern in pulmonary artery. When the pulmonary artery pressure is normal, the flow velocity pattern is a dome-like one with a peak at mid-systole (Type I). As pressure increases, the peak becomes sharper (Type II). With further increase in pressure, the peak shifts to an earlier phase (pre-ejection period), or sometimes to a wave form with another peak or notch in the latter half of the ejection period (Type III). When the pressure rises further, the pulmonary artery flow velocity decelerates and the latter half of the wave form is lost or reversed (Type IV).

Four types of flow velocity pattern (type I-IV) are shown schematically in Fig. 3. Types I-IV indicate normal, mild, moderate and severe pulmonary artery pressure, and typical examples of these types are shown in Fig. 4.

On the basis of the data shown in Table 1, the relationship between each type of flow velocity pattern and the directly measured pulmonary artery pressure is shown in Fig. 5. Although a certain relationship was suggested between the type of flow velocity pattern and the pulmonary artery pressure, it was difficult to estimate the pulmonary artery pressure from the type of tracing pattern alone.

There was a relatively good correlation between AT/ET and systolic, mean or diastolic pulmonary artery pressure,

with correlation coefficients of -0.84 , -0.85 and -0.82 , respectively ($P < 0.01$) (Fig. 6). When the logarithms of these pulmonary artery pressures were plotted against AT/ET, a better correlation were obtained, with correlation coefficients of -0.90 , -0.90 and -0.83 , respectively (Fig. 7).

The coefficients of correlation between AT and the systolic, mean and diastolic pulmonary artery pressures were -0.71 , -0.63 and -0.69 ($P < 0.01$), respectively. The correlation with AT was therefore poorer than that with AT/ET. The correlation coefficients between AT and the logarithms of the respective pulmonary artery pressures were -0.77 , -0.66 and -0.69 , showing a similar trend.

The AT/HR ratio was obtained in order to correct AT for heart rate, and the correlation between the pulmonary artery pressure and this parameter was examined. The coefficients of correlation between AT/HR and the systolic, mean and diastolic pressures were calculated to be -0.67 , -0.60 and -0.65 ($P < 0.01$), respectively, and those between AT/HR and the logarithms of systolic, mean and diastolic pressures, -0.73 , -0.64 and -0.72 (Table 2) respectively.

DISCUSSION

It is known that the normal pulmonary artery flow velocity in humans has a dome-like pattern with a peak at mid-systole, as in Type I shown in Fig. 3. When the pulmonary artery pressure increases, the peak becomes sharper (Fig. 3, Type II). As pressure further increases pressure, the pattern changes to a pointed wave form with a peak shifted to an earlier phase (pre-ejection period), or sometimes to a wave form with another peak or notch in

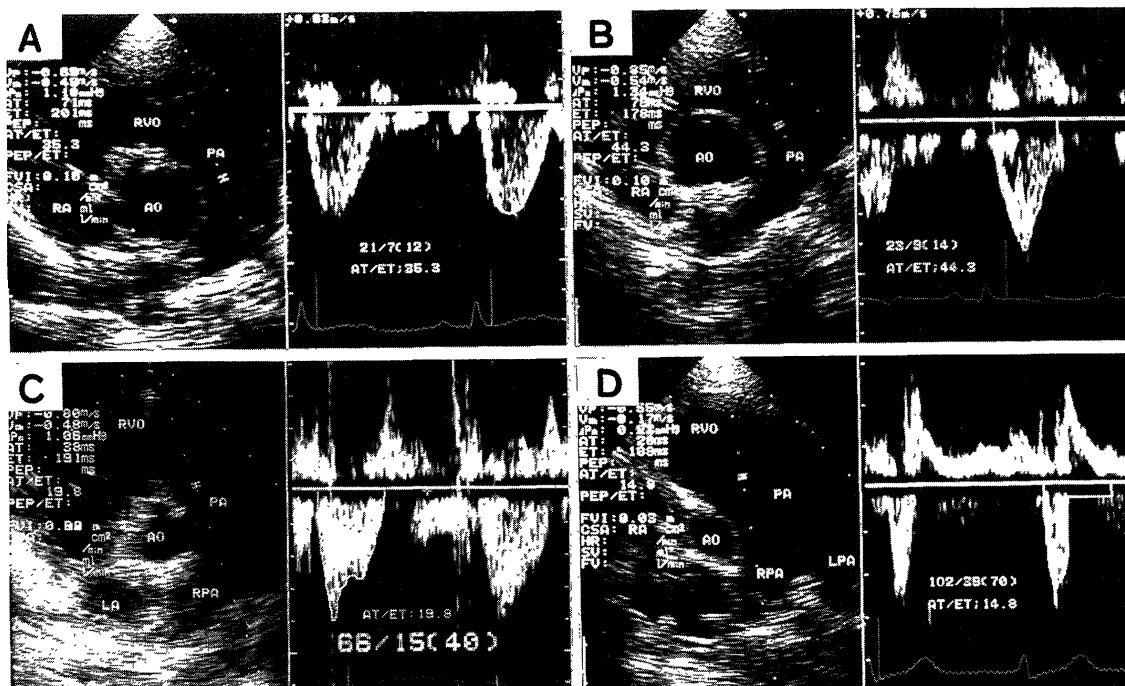


Fig. 4. Representative examples of four types were Type I (A), Type II (B), Type III (C) and Type IV (D), respectively.

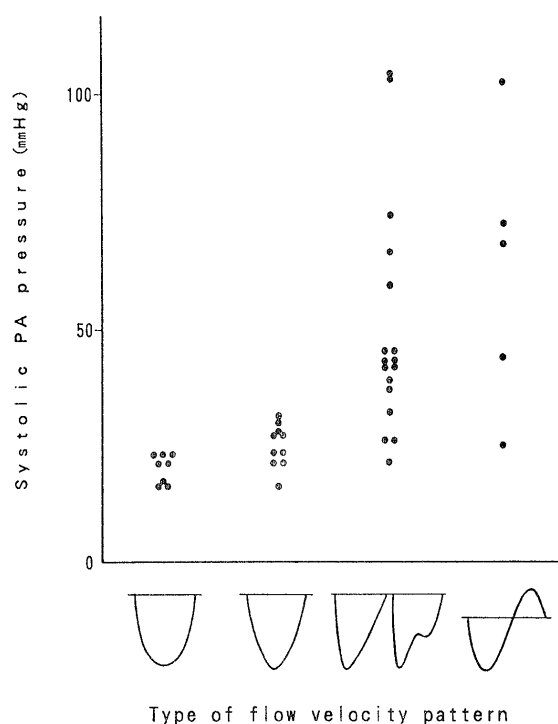


Fig. 5. The relationship between each type of flow velocity pattern and the directly measured pulmonary artery pressure.

the latter half of the ejection period (Fig. 3, Type III). When the pressure rises further, the pulmonary artery flow velocity decelerates, and the latter half of the wave form is therefore lost or reversed (Fig. 3, Type IV).

In the present study, a similar trend was obtained, and the pulmonary artery flow velocity patterns showed 4 types of variation (Fig. 4). However, as shown in Fig. 5, it seemed difficult to estimate the pulmonary artery pressure from the type of wave form alone.

On the other hand, there was a good correlation between AT/ET and the measured pulmonary artery pressure, indicating the applicability of this method at

least to the assessment of the presence or absence of increased pulmonary artery pressure in a daily clinical setting. The present investigation revealed two major problems associated with this method. One was occasional difficulty in distinguishing between noise and signal components in the pulmonary artery flow velocity pattern. This is an important point when measuring various parameters, and misreading can result in considerable measurement error.

There was the other problem in which the end-point of some Doppler waves could not be defined clearly due to natural fading of these waves. This phenomenon is a significant consideration for measurement of ET. In this case, it is necessary to search for a better wave form by finely adjusting the set point for the SV or the angle of the ultrasonic beam.

The SV has been set at various positions in previous studies, some researchers using a site just under the orifice of the pulmonary valve and at the center of the pulmonary artery. In the present study, the SV was located preliminarily at the center of the pulmonary valve orifice, and a cross-section providing a good image of pulmonary artery flow was obtained by fine adjustment by the color Doppler procedure. Thereafter, the site of the SV was modified when necessary. This method is more advantageous than the usual one involving setting by the pulsed Doppler method alone in that it allows easier and quicker detection of the blood flow.

The correlation between the AT obtained from the Doppler flow velocity pattern and the directly measured pulmonary artery pressure has been examined in human subjects [2]. However, there have been discrepancies from researcher to researcher; some have reported a fairly closer correlation between the mean pulmonary artery pressure and AT ($r = -0.84$) compared with AT/ET ($r = -0.80$) [2], whereas others have stated that the correlation with AT was not very close ($r = -0.65$), although a close correlation was seen with HR-corrected AT or within a certain range of HR (60–100/min) [1]. In dogs which have a markedly higher HR than humans, the

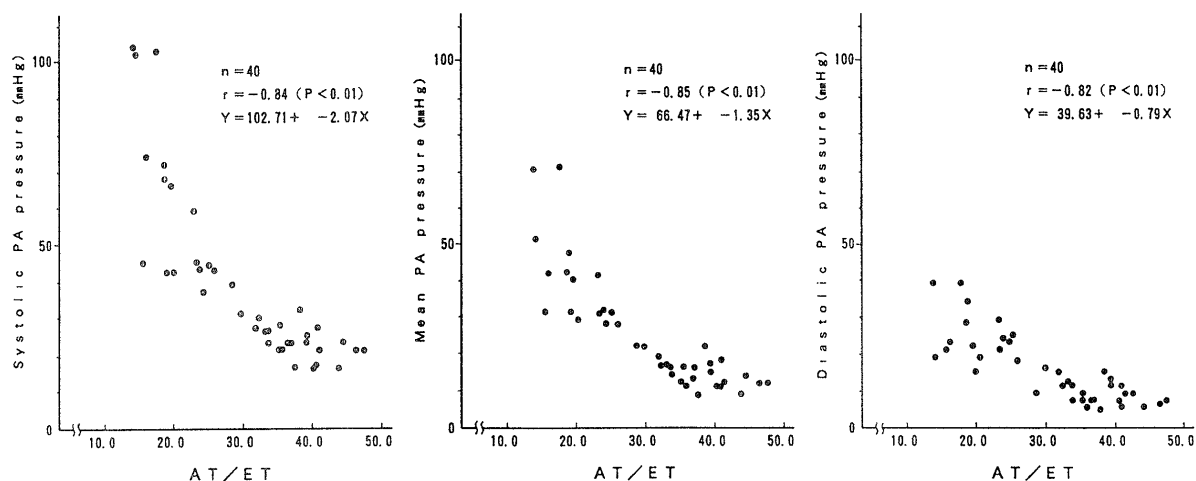


Fig. 6. Correlation between pulmonary artery (PA) pressure and acceleration time / ejection time (AT/ET).

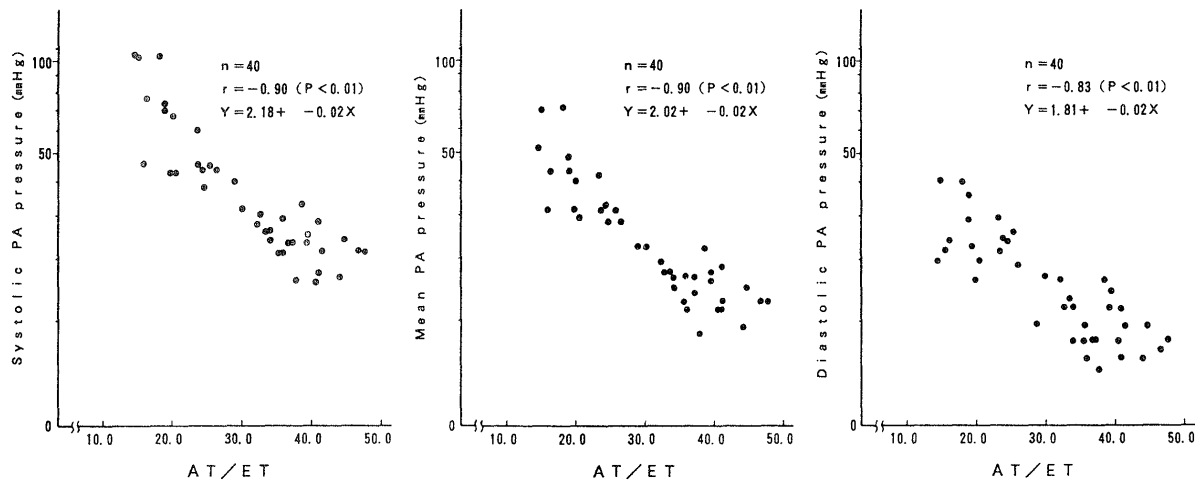


Fig. 7. Correlation between the logarithms of pulmonary artery (PA) pressure and acceleration time / ejection time (AT/ET).

Table 2. Summary of correlation coefficients relating different hemodynamic measurements to Doppler indexes

Doppler Index	Hemodynamic Measurement	r Value
AT ^{a)}	SPAP ^{b)}	-0.71
AT	MPAP ^{c)}	-0.63
AT	DPAP ^{d)}	-0.69
AT	Log ^{c)} SPAP	-0.77
AT	Log MPAP	-0.66
AT	Log DPAP	-0.69
AT/HR ^{f)}	SPAP	-0.67
AT/HR	MPAP	-0.60
AT/HR	DPAP	-0.65
AT/HR	Log SPAP	-0.73
AT/HR	Log MPAP	-0.64
AT/HR	Log DPAP	-0.72

a=Acceleration time; b=Systolic pulmonary artery pressure; c=Mean pulmonary artery pressure; d=Diastolic pulmonary artery pressure; e=Logarithms; f=Acceleration time/heart rate;

coefficient of correlation between AT and the pulmonary artery pressure was found to be low, and that between HR-corrected AT (AT/HR) and the pulmonary artery pressure was even lower.

These results suggest that AT decreases as pulmonary artery pressure increases. It therefore seems that AT is not very helpful in estimating pulmonary artery pressure, even though it can be obtained easily from the Doppler recording.

Of all the parameters examined, AT/ET showed the closest correlation with the pulmonary artery pressure. Therefore, visualization of ET is of great significance.

Another method for estimating pulmonary artery pressure is also available. Tricuspid regurgitation can be detected by the continuous wave Doppler method, and the right ventricular atrial pressure difference is calculated from the maximum flow velocity of regurgitation according to Bernolli's law. This is then added to the assumed right atrial pressure to obtain the systolic right ventricular pressure, i.e., systolic pulmonary artery pressure. This method is used frequently in human subjects, and its

accuracy is rated to be very high. A good correlation between measured values and those estimated in this way has also been observed in dogs [9]. However, this method necessitates detection of tricuspid regurgitation. Errors of measurement may occur theoretically if the maximum flow velocity is not determined correctly. In contrast, determination of the pulmonary artery flow velocity pattern has the advantage of being applicable to cases where there is no tricuspid regurgitation.

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