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HeartAssist™ for Small Animals: Automatic View Classification and Measurement Tool for Small Animal Echocardiography

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Introduction

In the realm of veterinary medicine, echocardiography plays a pivotal role in both diagnosing and managing patients afflicted with cardiovascular disease. Precise quantitative assessment of cardiac structure and function holds paramount importance during the initial assessment, treatment planning, and subsequent follow-up. Nevertheless, while quantitative evaluation through echocardiography has certainly improved patient care, the current manual process of measuring echocardiographic parameters can be quite time-consuming, even for seasoned clinicians. Furthermore, this approach is heavily reliant on the clinician's experience level, and it is susceptible to variations caused by different observers.

Artificial intelligence (AI) is advancing rapidly in the field of diagnostic medical imaging, including echocardiography. Deep learning (DL), in particular, has significantly enhanced the accuracy of AI algorithms, enabling efficient, precise, and consistent automated measurements in echocardiography. HeartAssist™ is an AI software with DL technology, cooperating with ONTACT HEALTH CO., LTD, Seoul, Korea, which is commercially available as an integrated feature on the V8/V7/V6 machines from SAMSUNG MEDISON Co., Ltd, based in Seoul, Korea. By eliminating the need for manual intervention, HeartAssist™ is anticipated to reduce variability, ultimately allowing for reproducible measurements without the need for monotonous and laborious tasks.

Given the rising prevalence of cardiovascular disease and the simultaneous increase in demand for echocardiographic studies, fully automated quantitative echocardiographic evaluation can prove immensely beneficial in alleviating the examiner's workload and keeping solid operation for cardiovascular disease and research.

Workflow Comparison

M-mode, short for "Time-Motion Mode," is a representation on the screen consisting of undulating lines that correspond to the movement of specific points over time. This mode is commonly employed to assess the thickness of the ventricular walls and the inner diameter of the ventricles during both diastolic and systolic phases. Typically, this information is derived from three specific views: Right parasternal long axis 5 chamber view (RP5C), Right parasternal long axis 4 chamber view (RP4C), and Right parasternal short axis view (chorda tendineae view).

In traditional quantitative echocardiographic evaluation using M-mode, the following steps are involved: 1) identifying the appropriate view, 2) selecting the line of sight, 3) choosing the correct phases for end-diastole (ED) and end-systole (ES), 4) selecting the measurements to be taken, and 5) manually executing the measurements (Figure 1). Completing an echocardiographic examination in M-mode traditionally requires 8 separate keystrokes. In comparison, HeartAssist™ streamlines this intricate process with a single touch, decreasing the number of keystrokes by a remarkable 88% while still automatically providing the necessary measurements.

Figure 1. The workflow in M-mode in conventional (manual) measurement and HeartAssist™ for canine and feline

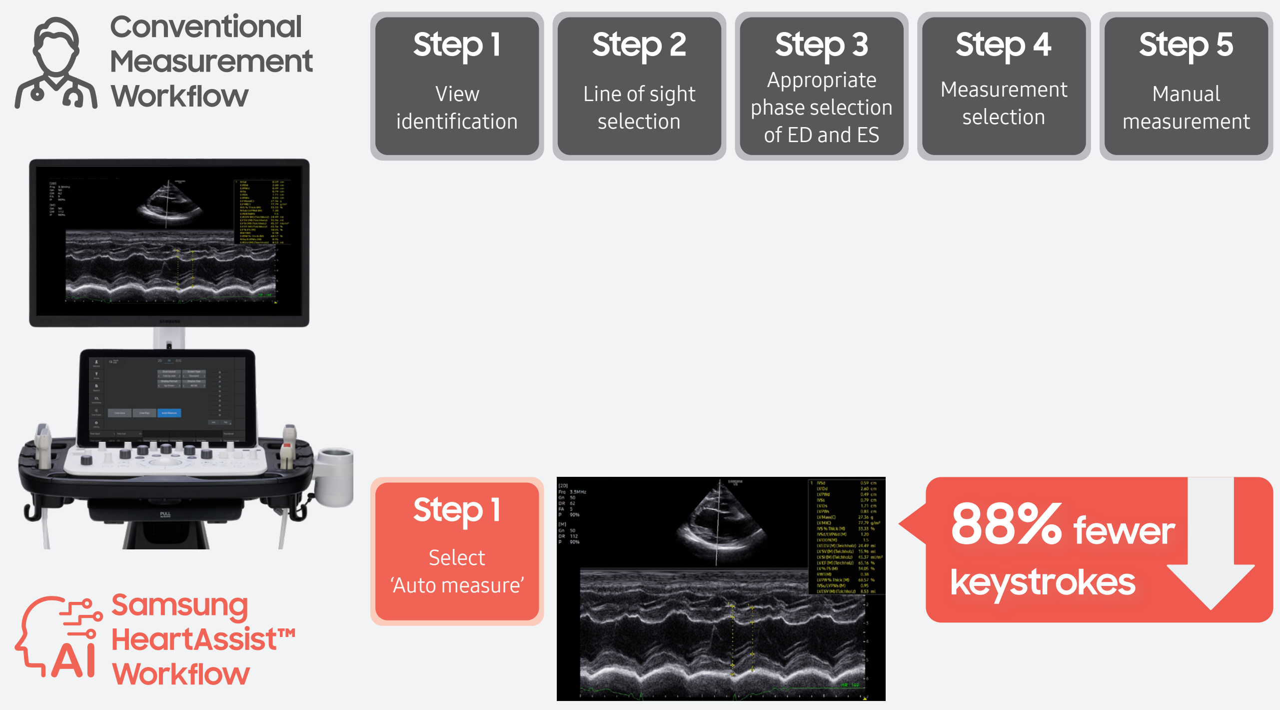


Figure 1. HeartAssist™ streamlines the process by simplifying the multiple keystrokes needed in conventional measurements. For instance, when measuring the M-mode parameters of the left ventricle, the conventional approach necessitates 8 keystrokes. In contrast, HeartAssist™ automatically identifies the M-mode image and delivers the necessary measurements by selecting "Auto Measure," remarkably decreasing keystrokes by 88%.

Pulse wave (PW) and Continuous wave (CW) spectral Doppler are commonly used for evaluation of cardiac hemodynamic flow. This can be obtained in various view including Left parasternal apical 4 chamber view (LA4C), Left parasternal apical 5 chamber view (LA5C), and Right parasternal short axis view.

In this mode, for example, evaluating CW mitral regurgitation flow velocity, conventional quantitative echocardiographic evaluation requires the following steps: 1) view identification, 2) select target valve and the type of Doppler parameter to measure 3) appropriate flow selection, 4) measurement selection, 5) manual measurement (Figure 2). As a result, compared to HeartAssist™, conventional measurement methods require two additional keystrokes to complete echocardiography of mitral regurgitation flow, as well as time and effort to draw the boundaries of regurgitation flow. HeartAssist™ automatically recognizes acquired Doppler images and can automatically draw the boundaries of regurgitation flow and simultaneously obtain measurements with a single keystroke, dramatically reducing complexity and time consumption compared to conventional measurement methods.

Figure 2. The workflow in Doppler mode in conventional (manual) measurement and HeartAssist™ for canine and feline

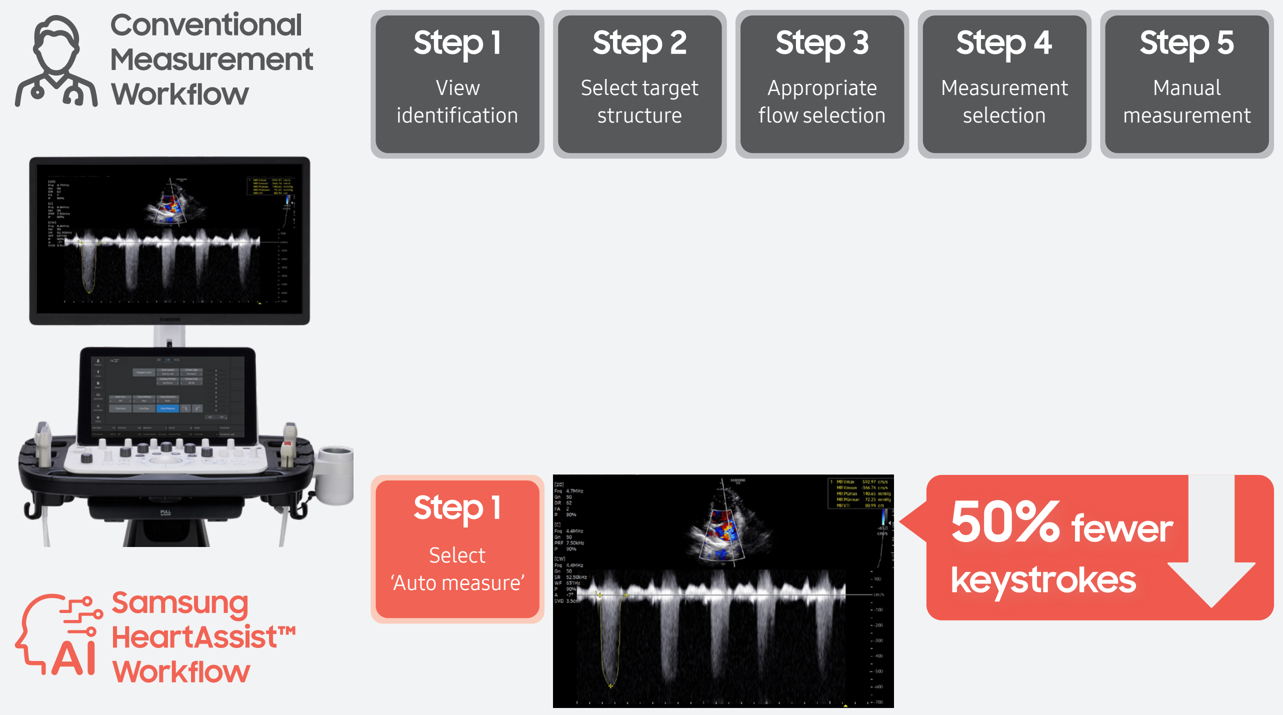


Figure 2. HeartAssist™ streamlines the process by simplifying the multiple keystrokes needed in conventional measurements. For instance, when measuring the parameters in the CW Doppler mitral regurgitation view, the conventional approach necessitates 2 keystrokes and envelope drawing. In contrast, HeartAssist™ automatically identifies the Doppler image and delivers the necessary measurements by selecting "Auto Measure," remarkably decreasing keystrokes by 50%.

Additionally, current echocardiographic guidelines advise that each parameter should be measured across two or more cardiac cycles to reduce variability between heartbeats.2 This approach enhances measurement accuracy but demands a significant investment of time and effort. Consequently, in routine clinical practice, this recommendation is often not fully implemented due to its inherently time-consuming and laborious nature.

HeartAssist™ addresses this challenge by delivering a time-efficient and comprehensive automatic view identification and measurement solution for canine and feline echocardiography. It achieves this by reducing the number of keystrokes required by an average of 62%. Furthermore, it eliminates the need for laborious envelope tracing in Doppler modes, thus alleviating veterinarians from the physical strain associated with monotonous, time-consuming measurements. This streamlined workflow not only enhances efficiency but also contributes to the improved quality of patient care in veterinary medicine.

Auto measurement

HeartAssist™ automatically measures required parameters in each view after it recognizes views. To evaluate the auto-measurement performance of HeartAssist™ for canine and feline, the acceptance rate is used as the key criterion, which is defined as the percentage of measurements that was accepted by four veterinarians specialized in veterinary imaging.

In following, an overview of how to use HeartAssist™ for canine and feline appropriately will be provided.

Below are some guidelines for ensuring accurate image analysis in M-mode and Doppler mode:

In M-mode, it's essential to display all the target structures within a single image. Specifically, when observing the left ventricle (LV), ensure that all LV structures, including the LV posterior wall, are visible in the frame. Failing to do so may result in improper auto-measurements.

For optimal Doppler image acquisition and subsequent auto-measurements, it's advisable to follow these guidelines:

Adjust the baseline level until the flow of interest is displayed optimally. In a Doppler image, the Doppler signal below the baseline is detected when the baseline is positioned above the center, and vice versa. However, when the baseline is centered, the algorithm automatically identifies the dominant flow. If significant Doppler signals are present on both sides, except for mitral annulus tissue Doppler imaging, the algorithm may struggle to detect the correct signal. To address this, veterinarians can adjust the baseline up and down according to the target Doppler signal, allowing the algorithm to identify the precise Doppler signal and provide auto-measurements accordingly.

When working with spectral Doppler, it's crucial for the operator to adjust the scale so that the spectral Doppler trace is displayed at its largest size without any aliasing effects. The sweep speed can also be adjusted to display an optimal number of beats in a single image, typically ranging from 4 to 6 beats as a recommended starting point. However, this can be further adjusted based on personal preference. Poor adjustments may lead to obtaining a Doppler envelope that is too small or including too many beats in a single image, potentially introducing significant variability in the measured values.

1) Overall acceptance

In veterinary medicine echocardiography, routine measurements for quantification are followed below.

* M-mode

In veterinary medicine, M-mode through LV (Teichholz's method) is routinely used. HeartAssist™ for canine and feline provides automatic measurements for this view (Table 1). HeartAssist™ automatically perform view identification and measurements by simple touch (Figure 1). When conducting automatic measurements for M-mode images, the rate of successful acceptance stood at 82% (Table 1).

Table 1. Acceptance rates for M-mode and Doppler auto-measurements

Mode	View	Measurement	Acceptance rate (%)
M-mode	LV	Interventricular septum LV Posterior wall	82
PW-mode	LVOT	Vmax VTI	100
	MV Inflow	E velocity A velocity Deceleration time	92
	RVOT	Vmax VTI	98
CW-mode	AR	V max Pressure half time	100
	MR	Vmax VTI	81
	TR	Vmax VTI	88
TDI	MV Annulus	e' velocity a' velocity s' velocity	80

Auto-measurements for parasternal long and short axis view and apical views were evaluated in 46 patients, 463 views. Acceptance rates were calculated at the level of view. Views which the researchers found not possible for measurement were excluded from the analysis. The 14 poorly enveloped views were also excluded.

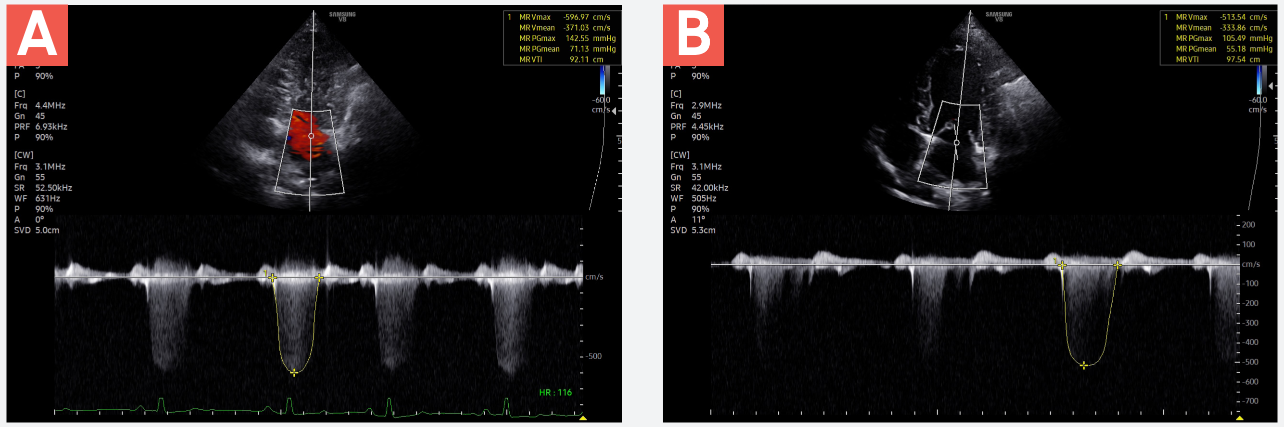
LV = Left Ventricle (with Teichholz method), LVOT = Left Ventricular Outflow Tract, MV = Mitral Valve, RVOT = Right Ventricular Outflow Tract, AR = Aortic Regurgitation, MR = Mitral Regurgitation, PR = Pulmonic Regurgitation TR = Tricuspid Regurgitation, Vmax = Maximal Velocity, VTI = Velocity Time Integral, M-mode = Time motion mode, PW-mode = Pulse wave spectral Doppler mode, CW-mode = Continuous wave spectral Doppler mode, TDI = Tissue Doppler Imaging

* Doppler

In veterinary medicine, Doppler mode through PW, CW, and TDI is routinely used.
The acceptance rate of PW mode, CW mode, and TDI mode initially ranged 92% ~ 100%, 52% ~ 100%, and 80%, respectively. However, when excluding poorly enveloped cases in CW mode, the acceptance rate significantly increased to 81%~100% (Table 1).
HeartAssist™ works well in all Doppler views except for CW Doppler regurgitation view. Even for the CW Doppler regurgitation view, the algorithm still works well if patients have well enveloped flow shapes (Figure 3). However, in patients that has regurgitation with not fully enveloped flow shape, the detection of the flow can be incorrect (Figure 3).

Figure 3. Optimal image acquirement of CW Doppler MR view

Appropriate | Inappropriate



A) When patient have well enveloped regurgitation flow, HeartAssist™ detects well on the flow

B) When patient have poorly enveloped regurgitation flow, this resulted in false detection by measuring too much area of the flow

2) Difference in ECG on/off

HeartAssist™ automatically divides the electrocardiogram (ECG) into segments and chooses the suitable cardiac phase for measurements, sparing the operator from the task of manually choosing the correct cardiac phase before taking measurements. In situations where the ECG data is not accessible, the software is still capable of automatically identifying the appropriate images using alternative cues.

For instance, M-mode can be analyzed without an ECG, based on the change in diameter. In the study, we expected use of ECG shows more accurate evaluation results.

But, it turned out that the acceptance rate of ECG on and off were 89%, and 92% respectively (Table 2). Thus, there were no significant difference between "ECG on" and "ECG off" (Figure 4). This could be a tremendous benefit on veterinary medicine because canine and feline are reluctant to having on ECG pad and putting on the ECG pad is highly time-consuming. As a result, HeartAssist™ reduce workload of veterinarians in echocardiographic examination, being a robust solution.

Table 2. Acceptance rates for ECG on/off auto-measurements

ECG on/off	Mode	View	Measurement	Acceptance rate (%)
ECG on	M-mode	LV	Interventricular septum LV Posterior wall	83
	PW-mode	LVOT	Vmax VTI	100
		MV Inflow	E velocity A velocity Deceleration time	93
		RVOT	Vmax VTI	98
	CW-mode	AR	V max Pressure half time	100
		MR	Vmax VTI	77
		TR	Vmax VTI	80
	TDI	MV Annulus	e' velocity a' velocity s' velocity	74
Average				89

ECG on/off	Mode	View	Measurement	Acceptance rate (%)
ECG off	M-mode	LV	Interventricular septum LV Posterior wall	81
	PW-mode	LVOT	Vmax VTI	100
		MV Inflow	E velocity A velocity Deceleration time	91
		RVOT	Vmax VTI	98
	CW-mode	AR	V max Pressure half time	100
		MR	Vmax VTI	88
		TR	Vmax VTI	100
	TDI	MV Annulus	e' velocity a' velocity s' velocity	87
Average				92

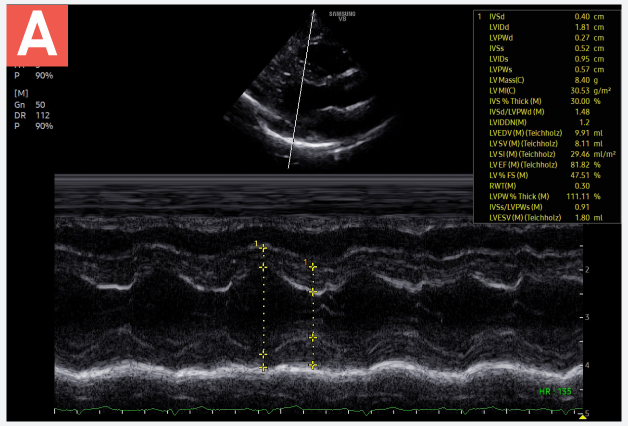
Auto-measurements for parasternal long and short axis view and apical views with, and without ECG were evaluated in 46 patients, 235 and 228 views, respectively. Acceptance rates were calculated at the level of view. Views which the researchers found not possible for measurement were excluded from the analysis.

LV = Left Ventricle (with Teichholz method), LVOT = Left Ventricular Outflow Tract, MV = Mitral Valve, RVOT = Right Ventricular Outflow Tract, AR = Aortic Regurgitation, MR = Mitral Regurgitation, PR = Pulmonic Regurgitation TR = Tricuspid Regurgitation, Vmax = Maximal Velocity, VTI = Velocity Time Integral, M-mode = Time motion mode, PW-mode = Pulse wave spectral Doppler mode, CW-mode = Continuous wave spectral Doppler mode, TDI = Tissue Doppler Imaging

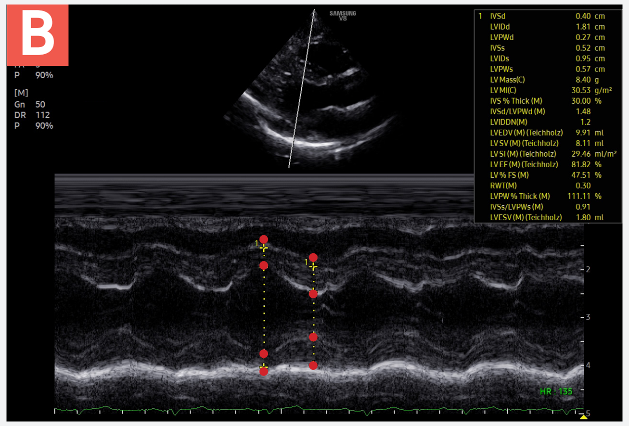
Figure 4. Analysis of M-mode with/without electrocardiogram (ECG)

Auto-measurement of "ECG on" and "ECG off" showed comparable results.
HeartAssist™ detected the ED and ES correctly on both cases (A and C), whereas manual adjustments were intermittently needed for points of interventricular wall and free wall (B and D).

ECG (+)

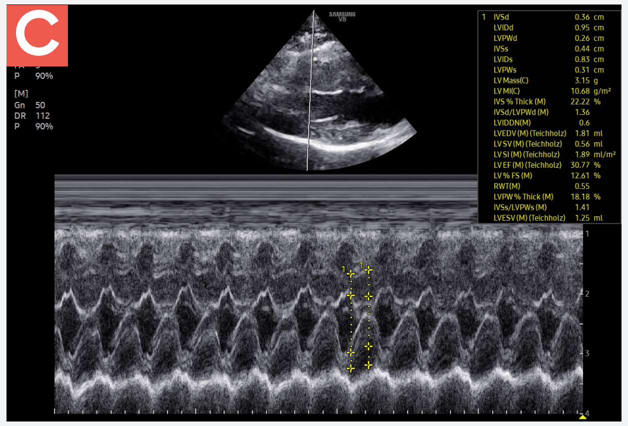


A) The M-mode image of patient was analyzed with ECG. The ED and ES of all cardiac cycles were correctly detected based on ECG flow.

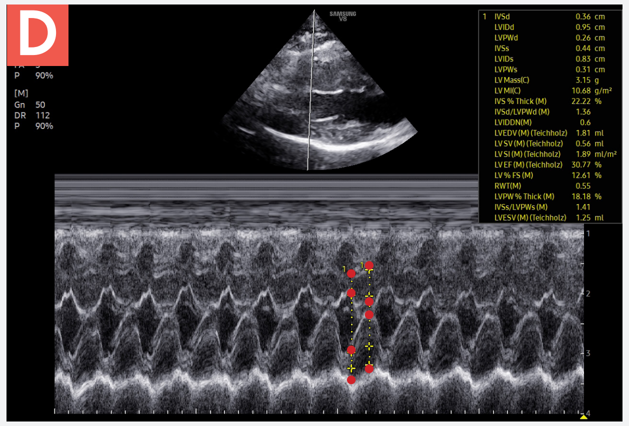


B) Manually adjusted image (red dots)

ECG (-)



C) The M-mode image of patient was analyzed without ECG. The ED and ES of all the cardiac cycles were correctly detected based on the change in diameter.



D) Manually adjusted image (red dots)

3) Difference in canine and feline

HeartAssist™ can be applied to either canine and feline. The acceptance rate of canine and feline was 93%, 82% respectively (Table 3). Species-variability exists, but this is mostly due to physiological differences; frequent EA fusion in feline.

Table 3. Acceptance rates for Canine and Feline auto-measurements

Species	Mode	View	Measurement	Acceptance rate (%)
Canine	M-mode	LV	Interventricular septum LV Posterior wall	84
	PW-mode	LVOT	Vmax VTI	100
		MV Inflow	E velocity A velocity Deceleration time	100
		RVOT	Vmax VTI	97
	CW-mode	AR	V max Pressure half time	100
		MR	Vmax VTI	80
		TR	Vmax VTI	88
	TDI	MV Annulus	e' velocity a' velocity s' velocity	87
Average				93

Species	Mode	View	Measurement	Acceptance rate (%)
Feline	M-mode	LV	Interventricular septum LV Posterior wall	76
	PW-mode	LVOT	Vmax VTI	100
		MV Inflow	E velocity A velocity Deceleration time	70
		RVOT	Vmax VTI	100
	CW-mode	AR	V max Pressure half time	-
		MR	Vmax VTI	100
		TR	Vmax VTI	-
	TDI	MV Annulus	e' velocity a' velocity s' velocity	63
Average				82

Auto-measurements for parasternal long and short axis view and apical views of canine, feline was evaluated in 346 views from 34 patients, and 117 views from 12 patients, respectively. Acceptance rates were calculated at the level of view. Views which the researchers found not possible for measurement were excluded from the analysis.

LV = Left Ventricle (with Teichholz method), LVOT = Left Ventricular Outflow Tract, MV = Mitral Valve, RVOT = Right Ventricular Outflow Tract, AR = Aortic Regurgitation, MR = Mitral Regurgitation, PR = Pulmonic Regurgitation TR = Tricuspid Regurgitation, Vmax = Maximal Velocity, VTI = Velocity Time Integral, M-mode = Time motion mode, PW-mode = Pulse wave spectral Doppler mode, CW-mode = Continuous wave spectral Doppler mode, TDI = Tissue Doppler Imaging

EA fusion is seen because of fast heart rate (tachycardia) and routinely seen in feline, compared to canine. In EA fusion, the algorithm may misidentify the E wave for A wave (Figure 5). In our study, EA fusion cases were detected only in felines; 5 out of 12. When we exclude these cases on feline, the acceptance rate of feline was increased to 96% (Table 4). From the result, we can expect satisfying acceptance rate regardless of species. Thus, HeartAssist™ can be widely applied to not only canine but also feline that have normal heart rate.

Table 4. Acceptance rates for Feline without EA fusion auto-measurements

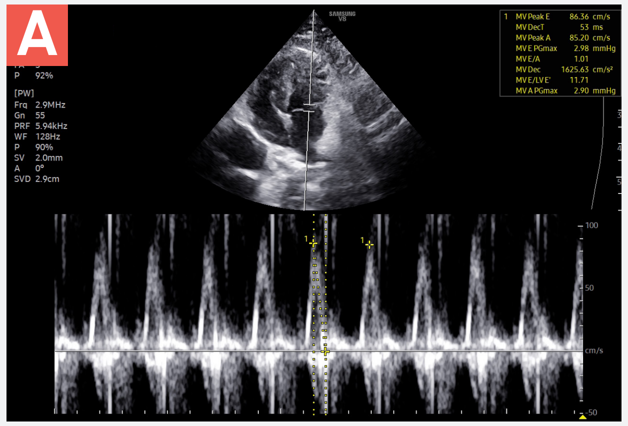
Species	Mode	View	Measurement	Acceptance rate (%)
Feline	M-mode	LV	Interventricular septum LV Posterior wall	75
	PW-mode	LVOT	Vmax VTI	100
		MV Inflow	E velocity A velocity Deceleration time	100
		RVOT	Vmax VTI	100
	CW-mode	AR	V max Pressure half time	-
		MR	Vmax VTI	100
		TR	Vmax VTI	-
	TDI	MV Annulus	e' velocity a' velocity s' velocity	100
Average				96

EA fusion were detected in 16 views from 5 feline patients and excluded from the analysis. No EA fusion cases in canine. Acceptance rates were calculated at the level of view. Views which the researchers found not possible for measurement were excluded from the analysis. The acceptance rates of PW-mode MV Inflow and TDI MV Annulus increased.

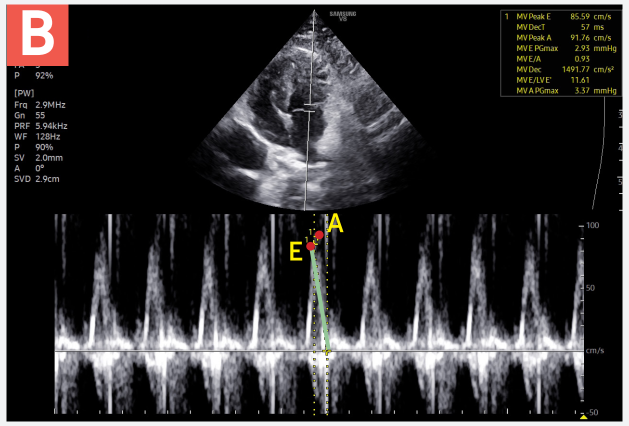
LV = Left Ventricle (with Teichholz method), LVOT = Left Ventricular Outflow Tract, MV = Mitral Valve, RVOT = Right Ventricular Outflow Tract, AR = Aortic Regurgitation, MR = Mitral Regurgitation, PR = Pulmonic Regurgitation TR = Tricuspid Regurgitation, Vmax = Maximal Velocity, VTI = Velocity Time Integral, M-mode = Time motion mode, PW-mode = Pulse wave spectral Doppler mode, CW-mode = Continuous wave spectral Doppler mode, TDI = Tissue Doppler Imaging

Figure 5. Analysis of PW Doppler MV inflow view with/without EA fusion

EA fusion (+), Feline

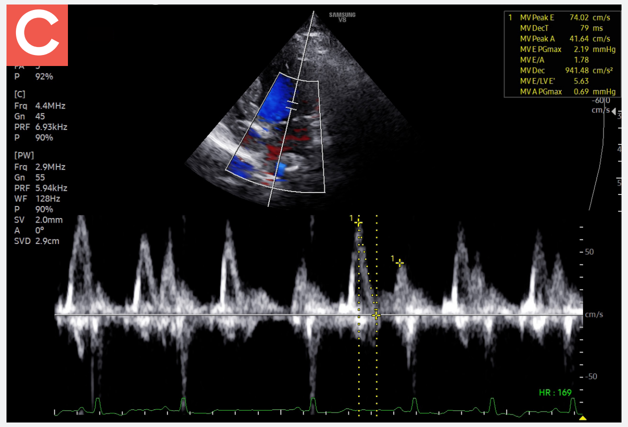


A) In patients with tachycardia which can cause EA fusion, the algorithm may misidentify the E wave as A wave.
EA fusion can be seen in both canine and feline, with tachycardia. In our study, EA fusion was detected only in feline.



B) In EA fusion, the E and A (red dots) and the line for MV deceleration time (green line) should be manually distinguished.

EA fusion (-), Canine



C) In patients with normal sinus rhythm, The algorithm correctly detects both E and A wave.

Conclusion

HeartAssist™ is a comprehensive automated solution that streamlines every aspect of the echocardiographic measurement procedure, significantly cutting down on time and effort when compared to manual measurements. The advantages of opting for HeartAssist™ over manual methods are plentiful.

For veterinarians specialized in veterinary imaging or sonographers, HeartAssist™ can reduce the workload of manual echocardiographic flow measurements including drawing the line of the flow, whereas for novice veterinarians or sonographers, HeartAssist™ can be a useful additional guideline of how to measure echocardiographic flow, on each view.

Also, due to similar acceptance rate between ECG availability, HeartAssist™ can reduce the inconvenience of attaching ECG pad to the patient.

Many veterinarians and sonographers will benefit from the use of HeartAssist™ for canine and feline, which will greatly reduce time and effort without significant difference in species.

HeartAssist™ is clinically beneficial and recommendable to the veterinary medicine.

References

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* HeartAssist™ is an AI software based on a SONIX HEALTH™ algorithm developed by ON:TACT HEALTH

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