WHITE PAPER

HeartAssist™: Automatic View Classification and Measurement Tool for Adult Transthoracic Echocardiography

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

Hyuk-Jae Chang, MD, PhD

CONNECT-AI Research Center,
Yonsei University College of Medicine
Division of Cardiology, Severance Cardiovascular Hospital,
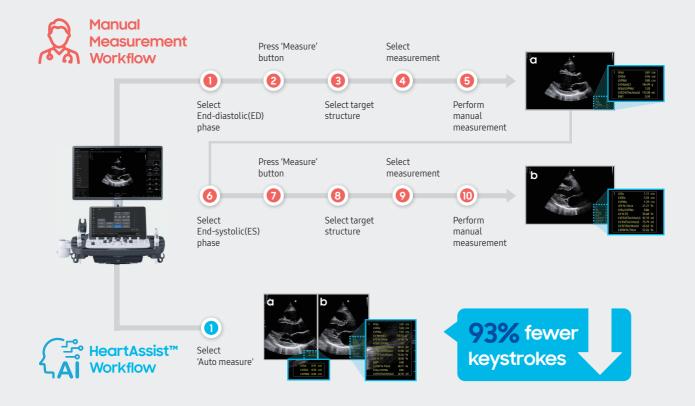Seoul, South Korea.

Introduction

Echocardiography plays a crucial role in the diagnosis and management of patients with cardiovascular disease. Accurate quantitative assessment of cardiac structure and function is essential for initial evaluation, treatment planning and follow-up. However, while quantitative echocardiographic evaluation has undoubtedly improved patient care, the current manual measurements of echocardiographic parameters require time-consuming tasks even for the experienced clinician. In addition to strong dependence on the level of experience, the procedures are prone to intra- and inter-observer variability.

Artificial intelligence (AI) is rapidly evolving in the field of diagnostic medical imaging including echocardiography. Of importance, deep learning (DL), which has dramatically improved the accuracy of AI algorithms, enables efficient, accurate and consistent automated measurement in echocardiography.[1] HeartAssist™ is a DL-powered AI software based on a SONIX HEALTH™ algorithm developed by ON:TACT HEALTH, and is commercially available as a built-in feature on the V7/V8 (Samsung Medison Co., Ltd., Seoul, Korea). By eliminating observer-dependent manual intervention, HeartAssist™ is expected to reduce variability which in turn can allow reproducible measurements without repetitive and tedious tasks. Considering the increasing burden of cardiovascular disease and the parallel growth in demand for echocardiographic studies, fully automated quantitative echocardiographic evaluation can be extremely advantageous in reducing workload for the examiner and making echocardiographic laboratory sustainable.
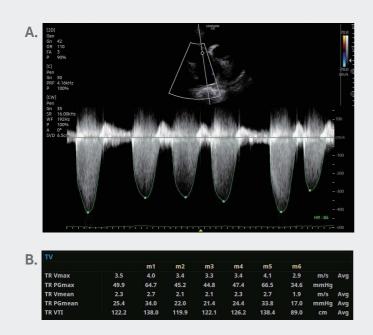
Workflow Comparison

Conventional quantitative echocardiographic evaluation requires the following steps: 1) view identification, 2) appropriate phase selection including end-diastole (ED) and end-systole (ES), 3) target structure selection, 4) measurement selection and 5) manual measurement (Figure 1). To complete an echocardiographic examination of one patient, it is generally necessary to perform 20-30 measurements. In addition, guidelines recommend performing each measurement in two or more cardiac cycles to account for inter-beat variability; three beats for patients in normal sinus rhythm and a minimum of five beats in patients with atrial fibrillation.[2] However, in daily clinical practice, this recommendation is not well implemented as the process is inevitably time-consuming and tedious.

HeartAssist™ aims to fully automate every step of echocardiographic measurements while avoiding step-by-step operation. Each part of the automated steps is integrated into a single pipeline; thus, all of the processes are performed automatically (Figure 1). HeartAssist™ automatically segments the electrocardiogram (ECG) and selects the appropriate cardiac phase for the measurements, eliminating the need for the operator to select the appropriate cardiac phase prior to measurement. Even when the ECG is unavailable, it automatically detects ED and ES using other indicators. Furthermore, the auto-measurement provided by HeartAssist™ for adult is not limited to one cardiac cycle but can be applied to multiple cycles, thereby reducing concerns about inter-beat variability without time-consuming, repetitive work by providing fast and accurate measurements in each echocardiogram view (Figure 2). Therefore, HeartAssist™ can offer a sustainable solution for the reduction of the workload of the echocardiography laboratory through automated echocardiography quantification. In this white paper, we provide an overview of how HeartAssist™ for adult works and tips for appropriate use.

The comparison of workflow in B-mode

Figure 1. Automated echocardiographic measurements in B-mode by HeartAssist™ for adult.
HeartAssist™ reduces the workload by integrating multiple keystrokes of manual measurements in B-mode into a single pipeline. For example, while 14 keystrokes are required for the manual measurements of left ventricular parameters in parasternal long axis left ventricle view, only a single touch is required (93% keystroke reduction). HeartAssist™ automatically identifies the acquired B-mode image, detects the appropriate phase such as ED and ES, and provides corresponding measurements.

A.

B.

TV		m1	m2	m3	m4	m5	m6		
TR Vmax	3.5	4.0	3.4	3.3	3.4	4.1	2.9	m/s	Avg
TR PGmax	49.9	64.7	45.2	44.8	47.4	66.5	34.6	mmHg	Avg
TR Vmean	2.3	2.7	2.1	2.1	2.3	2.7	1.9	m/s	Avg
TR PGmean	25.4	34.0	22.0	21.4	24.4	33.8	17.0	mmHg	Avg
TR VTI	122.2	138.0	119.9	122.1	126.2	138.4	89.0	cm	Avg

(A) patient with atrial fibrillation and tricuspid regurgitation. Maximum velocity is measured from all available beats.
(B) Averaged tricuspid regurgitation maximal velocity is displayed. Although current guidelines recommend performing each measurement in two or more cardiac cycles to account for inter-beat variability (three beats for patients in normal sinus rhythm and a minimum of five beats in patients with atrial fibrillation), this recommendation is not being well implanted in our daily clinical practice, since the process is inevitably time consuming and tedious. However, automated measurements provided by HeartAssist™ is not limited to the single cardiac cycle. It is possible to proceed with auto-measurements on as many cardiac cycles as the user wants. Therefore, users can get the average value from multiple consecutive beats as recommended in the guidelines without time consuming tedious-process.

Figure 2. Auto-measurement of multiple cardiac cycles using HeartAssist™ for adult.

* Currently, only one cardiac cycle measurement can be displayed at a time but the next version(VI.03) will allow simultaneous display of multiple cardiac cycle measurements.

View Identification

Automatic view identification is a fundamental step for automatic analysis of echocardiographic images.[1] Correct view identification is necessary to ensure subsequent accurate evaluation of the echocardiogram. Previous studies on automatic view classification models have reported accuracies of 84-92% for 15 views.[3, 4] Most of the previous studies focused on view classification of B-mode images and only one study was found that aimed to specifically classify Doppler images, which demonstrated an overall classification accuracy of 96%.[5] To our knowledge, automatic view classification performance for M-mode has not yet been reported. HeartAssist™ for adult does not specifically work for each image mode but instead provides automatic view identification of frequently acquired echocardiographic views including 7 B-mode images as well as 2 M-mode and 11 Doppler images (Table 1). HeartAssist™ view classification algorithm has been validated on 1,237 images encompassing a wide range of cardiovascular diseases such as abnormal chamber morphophysiology and arrhythmia, and thus outperforms all previous studies reported so far. The average accuracy for HeartAssist™ for adult was 98%. Table 1 summarizes the accuracy for each view.

Table 1. Accuracy of automatic view identification

Mode	View	Accuracy(%)
B-mode	Parasternal Long Axis Left Ventricle	100
	Apical Four Chamber	98
	Apical Four Chamber Zoomed Left Ventricle	95
	Apical Two Chamber	98
	Apical Two Chamber Zoomed Left Ventricle	100
M-mode	Left Atrium and Aorta	100
	Left Ventricle	100
Doppler	CW Doppler Mitral Stenosis	100
	CW Doppler Mitral Regurgitation	88
	PW Doppler Mitral Valve	100
	CW Doppler Aortic Valve	99
	CW Doppler Aortic Regurgitation	100
	CW Doppler Tricuspid Regurgitation	99
	CW Doppler Pulmonary Valve	93
	CW Doppler Pulmonary Regurgitation	100
	PW Doppler Right Ventricular Outflow Tract	98
	PW Doppler Left Ventricular Outflow Tract	100
	Tissue Doppler Imaging Mitral Valve Annulus	100

The accuracy of automatic view identification for 18 views was evaluated in 1,201 views. Views which the experts were unable to classify were excluded from the analysis. The accuracy of view recognition is defined as;

$$\text{Accuracy}(\%) = \frac{\text{Number of correctly recognized image}}{\text{Total number of images with each view}} \times 100$$

CW = Continuous Wave; PW = Pulsed Wave

Auto Measurement

After view identification, HeartAssist™ proceeds to auto-measurements of required parameters corresponding to each view. To evaluate the auto-measurement performance of HeartAssist™ for adult, we calculated the acceptance rate, which is defined as the percentage of measurements that was accepted by two experts (22 years of experience, 6 years of experience).

1) B-mode

The essential step of transthoracic echocardiography is the measurement of the cardiac chamber size and function, which requires accurate delineation of the endocardium. Currently, identification of the endocardial border is performed manually, thus the procedure suffers

from time-consuming tasks that are prone to intra- and inter-observer variability, soliciting the need for a fast, accurate, and automated analysis of echocardiogram.[1, 6] HeartAssist™ provides linear measurements of the left ventricle (LV), including interventricular septum, LV cavity and posterior wall in the parasternal long-axis view as well as the left atrium (LA), sinus of Valsalva of aorta and proximal right ventricular outflow tract diameter (Table 2).[2] In apical four chamber and two chamber views, LV and LA volumes are provided. HeartAssist™ automatically identifies the acquired B-mode image, detects the appropriate phase such as ED and ES, and then provides corresponding measurements (Figure 1). Since the detection of ED and ES is determined by the LV area rather than the ECG, HeartAssist™ for adult works even in the absence of ECG. It is expected to be helpful in situations where an ECG cannot be used. The performance of B-mode auto-measurements is summarized in Table 2.

Table 2. Acceptance rates for B-mode auto-measurements

View	Phase	Measurement	Acceptance rate(%)
Parasternal Long Axis	ED	Interventricular Septum Diameter	98
		LV Diameter	98
		Posterior Wall Diameter	96
		Aorta Diameter	100
	ES	Interventricular Septum Diameter	98
		LV Diameter	98
		Posterior Wall Diameter	96
		LA Diameter	96
Apical Four Chamber	ED	LV Volume	100
	ES	LV Volume	95
		LA Volume	98
Apical Four Chamber Zoomed LV	ED	LV Volume	100
	ES	LV Volume	95
Apical Two Chamber	ED	LV Volume	100
	ES	LV Volume	98
		LA Volume	100
Apical Two Chamber Zoomed LV	ED	LV Volume	100
	ES	LV Volume	95

Auto-measurements for parasternal long axis view and apical views were evaluated in 47 patients and 44 patients, respectively. Acceptance rates were calculated at the level of patient. Views which the experts found not possible for manual measurement were excluded from the analysis.

ED = End-Diastole, ES = End-Systole, LA = Left Atrium, LV = Left Ventricle, RV = Right Ventricle

To obtain accurate B-mode auto-measurements, it is necessary to acquire the image as follows.

• The depth of the image should be set to maximize the size of the display within the limits that include all the structures of interest.[2] For instance, setting the depth of parasternal long-axis view leaving about 1 cm of depth beyond the pericardium would fulfill the above recommendation (Figure 3A).[2] If the depth is inappropriately set, the possibility of error in measurements increases or auto-measurements do not proceed normally (Figure 3B, 3C).

Figure 3. Optimal image depth for B-mode auto-measurement.
(A) The depth of parasternal long-axis view is set leaving about 1 cm of depth beyond the pericardium. (B, C) If the depth is inappropriately set, the possibility of error increases or auto-measurements do not proceed normally.

• For accurate segmentation of LV and LA in an apical four-chamber view, left-sided structures are preferred to appear on the right side of the displayed sector and right-sided structures on the left as current guidelines recommend (Figure 4A).[2] Similarly, the anterior wall of LV is preferred to be on the right side in an apical two-chamber view (Figure 4B) and the anteroseptal wall and aorta on the right side in an apical three-chamber view (Figure 4C). Segmentation is possible even when an image is conversely acquired (Figure 4D, 4E, 4F), but the accuracy is likely to be low. In this case, taking auto-measurements again by inverting the image left to right is recommended.
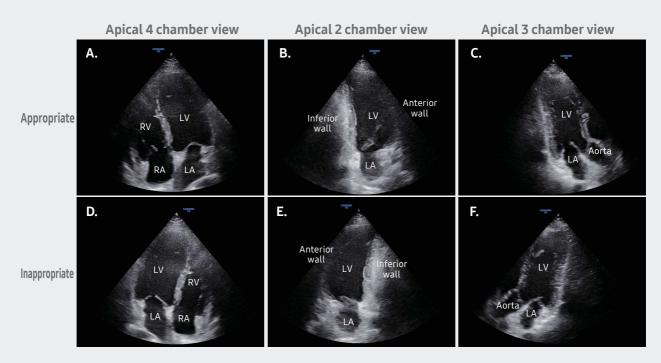
	Apical 4 chamber view	Apical 2 chamber view	Apical 3 chamber view

Figure 4. Optimal image positioning for segmentation of LV and LA.
(A) Apical four-chamber view. Left-sided structures are preferred to appear on the right side of the displayed sector and right-sided structures on the left. (B) The anterior wall of LV is preferred to be on the right side in an apical two-chamber view and (C) the anteroseptal wall and aorta on the right side in an apical three-chamber view. (D, E, F) Even when an image is conversely acquired, segmentation is possible, but the accuracy is likely to be low. In that case, you can try again by inverting the image left and right.

• For accurate measurement of LV volume, the LV apex should be centered in the sector and the long axis of the LV chamber maximized (Figure 5A).[2] If the imaging plane is missed, the true apex foreshortening of the ventricle results and LV volumes are underestimated (Figure 5B).
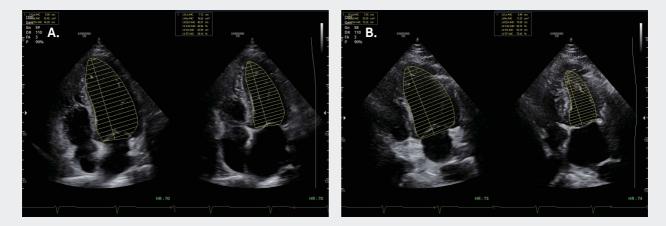

Figure 5. Optimal image positioning for LV volume measurement.
(A) LV apex should be centered in the sector and the long axis of the LV chamber maximized. (B) Imaging plane is missed, resulting in the true apex foreshortening of the ventricle and underestimation of LV volume.

2) M-mode

Current guideline does not recommend routine linear M-mode measurements for quantification, with two-dimensional imaging being the preferred method over the M-mode technique.[2] However, as measurement of M mode through aorta and LA and M mode through LV are still used in many laboratories, HeartAssist™ for adult provides automatic measurements for these two views (Table 3). HeartAssist™ automatically identifies the given view and provides measurements with a single touch (Figure 6). Importantly, measurements are not limited to a single cardiac cycle but instead, users can proceed with auto-measurements as many cardiac cycles as desired. Therefore, users can obtain the average value from multiple consecutive beats as recommended in the guidelines without the tedious, time-consuming process.[2] When we evaluated the performance of auto-measurement for M-mode images, acceptance rates by clinical experts ranged from 97.5% to 100% (Table 3).

Table 3. Acceptance rates for M-mode auto-measurements

View	Phase	Measurement	Acceptance rate (%)
M-mode through aorta and LA	ED	Aorta	97.8
	ES	LA	98.4
M-mode through LV	ED	Interventricular septum	97.7
		LV	100
		Posterior wall	100
	ES	Interventricular septum	97.5
		LV	100
		Posterior wall	100

Auto-measurements for M-mode through Aorta and LA and M-mode through LV were evaluated in 55 patients (267 cardiac cycles) and 44 patients (221 cardiac cycles), respectively. Cardiac cycles which the experts found not possible for manual measurement were excluded from the analysis. Acceptance rates were calculated at the level of cardiac cycle.

ED = End-Diastole, ES = End-Systole, LA = Left Atrium, LV = Left Ventricle

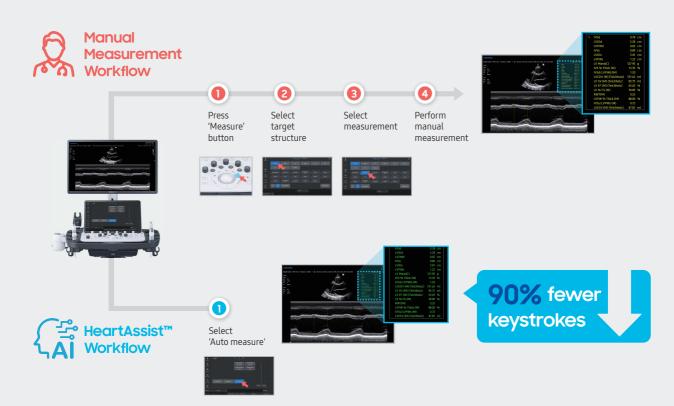# The comparison of workflow in M-mode

Figure 6. Automated echocardiographic measurements in M-mode by HeartAssist™ for adult.
HeartAssist™ reduces the workload by integrating multiple keystrokes of manual measurements in M-mode into a single pipeline. For example, 11 keystrokes are required for the manual measurement of M-mode through Left Ventricle. However, HeartAssist™ automatically identifies the acquired B-mode image and provides required measurements with a single touch. (90% keystroke reduction)

Below are tips for accurate image analysis in M-mode:

• Although M-mode can be analyzed without an ECG based on the change in diameter, if there is arrhythmia or even a small change in diameter during cardiac cycles, the accuracy of ED and ES detection may decrease (Figure 7A, 7B). Therefore, use of ECG is preferred for more accurate evaluation (Figure 7C, 7D).
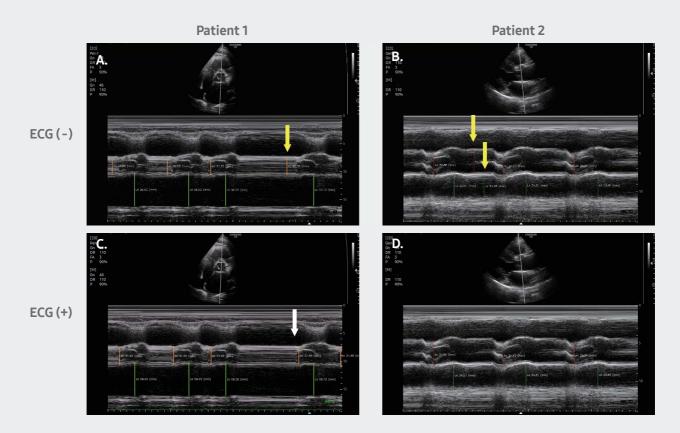

Figure 7. Analysis of M-mode using an electrocardiogram (ECG).
(A) When the M-mode image of an arrhythmia patient was analyzed without ECG, the ED of the fourth cardiac cycle was incorrectly detected as a time point earlier than the actual ED (yellow arrow). (B) In a normal sinus rhythm, little changes in the diameters during the cardiac cycle resulted in false detection of ED and ES (yellow arrows). Whereas, when the same M-mode image was analyzed with ECG, (C) the ED of all the cardiac cycles were correctly detected as a time point of QRS (white arrow). (D) In the presence of ECG, accurate ED and ES detection was possible for all the given cardiac cycles.

* Currently, only one cardiac cycle measurement can be displayed at a time but the next version will allow simultaneous display of multiple cardiac cycle measurements.

• M-mode image should include all of the target structures. M-mode through aorta and LA should include both the aorta and LA, especially the LA posterior wall (Figure 8A). M-mode through LV should include all of the LV structures, especially the LV posterior wall (Figure 8B). Otherwise, auto measurement may not proceed (Figure 8C, 8D).
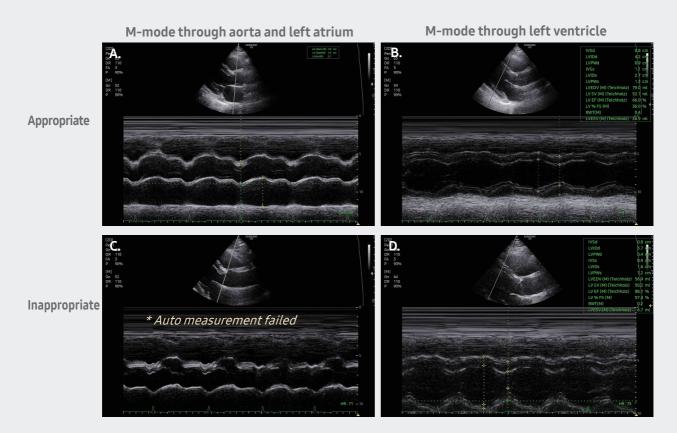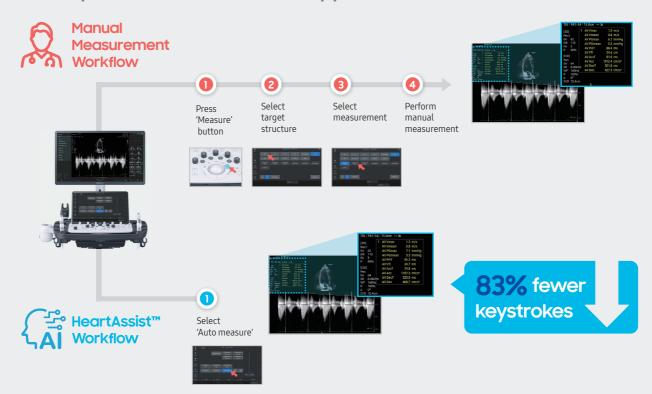

Figure 8. M-mode image should include all the target structure. (A) M-mode through aorta and LA should include both aorta and LA, especially the LA posterior wall. (B) M-mode through LV should include all LV structures, especially the LV posterior wall. If not, (C) auto-measurement may not proceed or (D) may provide inaccurate measurements.

3) Doppler

  Conventionally, the operator must measure each value manually after selecting the target valve and the type of Doppler parameter to measure (Figure 9). HeartAssist™ simplifies these complicated steps by automatically recognizing the acquired Doppler image and providing the required measurements with a single touch. For instance, if a continuous wave (CW) Doppler aortic valve image is given, the algorithm recognizes and identifies the image, measures the maximal velocity (V_{max}) and velocity time integral (VTI) from the Doppler envelope, and then calculates and provides clinical values such as maximal and mean pressure gradient along with V_{max} (Figure 9).

The comparison of workflow in Doppler

Figure 9. Automated echocardiographic measurements in Doppler-mode by HeartAssist™ for adult.
HeartAssist™ reduces the workload by integrating multiple keystrokes of manual measurements in Doppler-mode into a single pipeline. For example, 6 keystrokes are required for the manual measurements of CW Doppler aortic valve. Whereas, HeartAssist™ automatically identifies the acquired Doppler image and provides required measurements with a single touch. (83% keystroke reduction)

HeartAssist™ automatically identifies 11 Doppler views including PW, CW and TDI, and provides 25 measurements (Table 4). The acceptance rate by clinical experts ranges from 97% to 100% (Table 5). Importantly, as in M-mode measurements, users can proceed with auto-measurements as many cardiac cycles as desired. Therefore, it is expected to resolve the issue related to beat to beat variability without requiring additional effort and time.

Table 4. Supported views and measurements

Valve	Doppler View	Measurements		
Mitral Valve (MV)	PW Doppler Mitral Valve	E Velocity	A Velocity	Deceleration Time
	Mitral Annulus TDI	e' Velocity	a' Velocity	s' Velocity
	CW Doppler Mitral Stenosis	V_{max}	VTI	Pressure Half Time
	CW Doppler Mitral Regurgitation	V_{max}	VTI	
Aortic Valve (AV)	PW Doppler Left Ventricular Outflow Tract	V_{max}	VTI	
	CW Doppler Aortic Valve	V_{max}	VTI	
	CW Doppler Aortic Regurgitation	V_{max}	Pressure Half Time	
Valve	CW Doppler Tricuspid Regurgitation	V_{max}	VTI	
Pulmonic Valve (PV)	PW Doppler Right Ventricular Outflow Tract	V_{max}	VTI	
	CW Doppler Pulmonic Valve	V_{max}	VTI	
	CW Doppler Pulmonic Regurgitation	V_{max}	End-Diastolic Velocity	

CW = Continuous Wave; PW = Pulsed Wave; V_{max} = Maximal Velocity; VTI = Velocity Time Integral

Table 5. Acceptance rates for Doppler Auto-measurements

View	Measurement	Acceptance rate(%)
PW Doppler Mitral Valve	E Velocity	100
	A Velocity	99
	Deceleration Time	100
Tissue Doppler Imaging Mitral Valve Annulus	e' Velocity	100
	a' Velocity	100
	s' Velocity	100
CW Doppler Mitral Stenosis	V_{max}	100
	VTI	97
	Pressure Half Time	97
CW Doppler Mitral Regurgitation	V_{max}	100
	VTI	100
PW Doppler Left Ventricular Outflow Tract	V_{max}	100
	VTI	100
CW Doppler Aortic Valve and Pulmonary Valve	V_{max}	100
	VTI	100
CW Doppler Aortic Regurgitation and Pulmonary Regurgitation	V_{max}	100
	Pressure Half Time	100
	End-Diastolic Velocity	100
PW Doppler Right Ventricular Outflow Tract	V_{max}	100
	VTI	100
CW Doppler Tricuspid Regurgitation	V_{max}	100
	VTI	100

Auto-measurements for Doppler images were evaluated in 115 patients. Acceptance rates were calculated at the level of cardiac cycle and cardiac cycles which the experts found not possible for manual measurement were excluded from the analysis.; PW Doppler Mitral Valve E Velocity in 247 cycles, A Velocity in 226 cycles and Deceleration Time in 225 cycles; Tissue Doppler Imaging Mitral Valve Annulus e' Velocity in 254 cycles, a' Velocity in 237 cycles and s' Velocity in 265 cycles; CW Doppler Mitral Stenosis V_{max} in 90 cycles, VTI in 90 cycles and Pressure Half Time in 89 cycles; CW Doppler Mitral Regurgitation V_{max} in 20 cycles and VTI in 20 cycles; PW Doppler Left Ventricular Outflow Tract V_{max} in 259 cycles and VTI in 259 cycles; CW Doppler Aortic Valve and Pulmonary Valve V_{max} in 213 cycles, and VTI in 213 cycles; CW Doppler Aortic Regurgitation and Pulmonary Regurgitation V_{max} in 77 cycles, Pressure Half Time in 77 and End-Diastolic Velocity in 77 cycles; PW Doppler Right Ventricular Outflow Tract V_{max} in 256 cycles and VTI in 256 cycles CW Doppler Tricuspid Regurgitation V_{max} in 142 cycles and VTI in 142 cycles.

CW = Continuous Wave; PW = Pulsed Wave; V_{max} = Maximal Velocity; VTI = Velocity Time Integral

• Acquiring Doppler images in compliance with the guidelines enables more accurate Doppler auto-measurement.[2] The spectral Doppler baseline should be positioned to optimally display the flow of interest. By convention, flow toward the transducer is displayed above the zero-velocity baseline and flow away from the transducer below the baseline on transthoracic echocardiographic images. When a Doppler image is given, the position of the baseline is recognized and the Doppler signal below the baseline is analyzed when it is located above the center, while the Doppler signal above the baseline is analyzed when it is located below the center. If the baseline is centered, the algorithm automatically finds the dominant flow. However, if significant Doppler signals are identified on both sides except for mitral annulus tissue Doppler imaging, the algorithm may fail to capture the correct target flow. In this case, the operator can re-adjust the baseline according to the target Doppler signal, and then the auto-measurements will identify the target Doppler and provide corresponding auto-measurements.

• The operator must properly adjust the scale to display the spectral Doppler trace as large as possible without aliasing occurring. The operator also needs to adjust sweep speed not to display too many beats in a single image; a sweep speed of 100 mm/sec is usually recommended (Figure 10A).[2] Otherwise, a small Doppler envelope due to a poorly adjusted scale and too many beats in the image due to improper sweep speed can cause significant differences in the resulting values (Figure 10B, 10C).
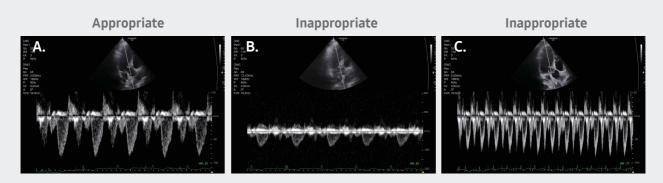
Appropriate	Inappropriate	Inappropriate

Figure 10. Measurement optimization of Doppler images using HeartAssist™ for adult.
(A) The operator must adjust the scale to display the spectral Doppler trace as large as possible without aliasing. The operator also needs to adjust sweep speed not to display too many beats in a single images; a sweep speed of 100 mm/sec is usually recommended. (B) If the Doppler signal is too small due to poorly adjusted velocity scale or (C) too many beats are included in the image, small variability in the measurement can cause significant difference in the time-related measurements.

- HeartAssist™ works well without ECG information in all Doppler views except the PW Doppler mitral valve view. Even for the PW Doppler mitral valve view, the algorithm still works well if patients have sinus rhythm and typical E and A shapes (Figure 11A). However, in patients with arrhythmia, the detection of E and A waves can be incorrect in the absence of ECG. For instance, in patients with atrial fibrillation which results in loss of A wave, or in patients with tachycardia which can cause EA summation, the algorithm may misidentify the E wave for A wave (Figure 11B, 11C), whereas in the presence of ECG, the algorithm automatically identifies the cardiac phase and correctly detects both the E and A waves (Figure 11D, 11E, 11F).
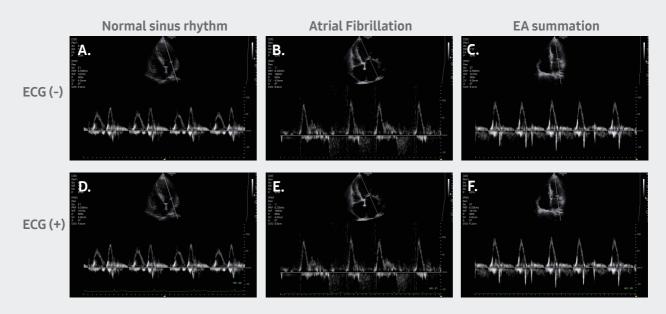

Figure 11. Measurement of Doppler images without ECG using HeartAssist™ for adult.
(A) In the evaluation of PW Doppler mitral valve, the algorithm still works well without ECG if patients have sinus rhythm and typical E and A shapes. However, in patients with arrhythmia, the detection of E and A waves can be incorrect in the absence of ECG. (B) In patients with atrial fibrillation which results in loss of A wave, or (C) in patients with tachycardia which can cause EA summation, the algorithm may misidentify the E wave as A wave. (D, E, F) In the presence of ECG, the algorithm automatically identifies the cardiac phase and detects both the E and A waves.

The AI-based HeartAssist™ provides quick and comprehensive automatic view-identification and measurement in adult transthoracic echocardiography by reducing the number of keystrokes required for measurement by 88% and measurement time by 90% on average, thereby relieving the operator of excessive physical stress from repetitive, time-consuming measurements and allowing efficient workflow to improve the quality of patient care.

Conclusions

HeartAssist™ fully automates each step of the transthoracic echocardiographic measurement process, thus reducing the time and effort required during manual measurements. Furthermore, by enabling M-mode and Doppler measurements in multiple consecutive beats without extra effort, it is expected to increase accuracy and reduce beat to beat variability. The echocardiographic specialist will benefit from the use of HeartAssist™ for adult which will greatly reduce time and effort.

Supported system - V8

HeartAssist™ for Adult is available in the following systems - V7(v1.01)/V8(v1.02)

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