Advantage and validation of vendor-independent software for myocardial strain analysis compared to vendor-specific software

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Abstract

Introduction: One of the main limitations incorporating strain imaging into widespread clinical practice is inter-vendor incompatibility. This poses a problem when serial strain measurements are required in a multi-vendor echocardiography laboratory.

Methods: This study sought to compare the variability of two-dimensional speckle-tracking global and regional longitudinal strain using vendor-specific software and vendor-independent software from images acquired by two different commercially available ultrasound systems. Forty subjects underwent two sequential echocardiographic acquisitions using different ultrasound systems (GE Vivid E9 and Philips iE33). Global longitudinal strain and regional peak longitudinal strain were derived using vendor-specific software (EchoPAC BT 13 v201 and QLAB version 10.3) and vendor-independent software (TomTec Image Arena version 4.6). Agreement and reproducibility of global and regional strain between vendor-specific and vendor-independent software were assessed by independent blinded observers.

Results: Global longitudinal strain derived from vendor-independent software was comparable to global longitudinal strain derived from vendor-specific software, whilst regional strain was lower in agreement compared to global longitudinal strain. There was good overall agreement and high inter- and intra-observer reproducibility using vendor-independent software for global longitudinal strain and regional strain.

Conclusions: Vendor-independent software provides good agreement with vendor-specific software for global longitudinal strain. However, minor variability exists for regional strain measurements between vendor-independent and vendor-specific software. Good agreement of strain measurements derived by vendor-independent software suggests vendor-independent software could potentially be useful for serial follow-up of global longitudinal strain.

Keywords: strain imaging, speckle-tracking, variability, vendor difference.

Introduction

Left ventricular (LV) longitudinal strain by 2D speckle-tracking echocardiography allows quantification of myocardial function with increasing clinical application especially serial follow-up of sub-clinical myocardial disease.^{1–6} One known limitation of strain analysis is inter-vendor variability and lack of agreement

among different commercial vendors^{7–9} preventing widespread use in routine clinical practice especially for serial strain measurements of the same patient. The European Association of Cardiovascular Imaging (EACVI) and American Society of Echocardiography (ASE) Joint Task Force recommend the use of the same commercial ultrasound system and vendor-specific software for serial comparison of strain measurements to minimise potential errors from inter-vendor incompatibility. Comparing serial strain measurements at different time points to monitor disease progression^{10–12} may pose a problem of

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practicality and feasibility in a busy, high volume, multi-vendor echocardiography laboratory. The diversity of vendors providing strain analysis is increasing with the most common vendor-specific software (VSS) EchoPAC (GE Vigmed Ultrasound AS, Horten, Norway) used in research and clinical practice. Vendor-independent software (VIS) such as TomTec (Image Arena; Tom Tec Imaging Systems, Munich, Germany) is commercially available allowing strain analysis of Digital Imaging and Communications in Medicine (DICOM) images acquired from different ultrasound systems.^{12–18} The use of VIS may overcome limitations for retrospective strain analysis from previously acquired images on different ultrasound systems stored in DICOM format and multicenter studies using different ultrasound systems. However, validation and use of VIS for strain analysis have not been extensively investigated.

The purpose of this study was to:

- 1 Compare strain measurements obtained by VIS with those derived from VSS.
- 2 Investigate the agreement of strain measurements obtained using VIS on different images from different ultrasound systems.
- 3 Assess the reproducibility of strain measurements by VIS.

Methods

Forty adult subjects underwent routine clinically indicated transthoracic echocardiography were included in this study. Exclusion criteria were the presence of atrial fibrillation, pacemaker implantation or inadequate image quality defined as suboptimal endocardial definition in two or more segments, precluding strain analysis.

All subjects underwent transthoracic echocardiography on the same day using different cardiac ultrasound systems. Every echocardiographic study was performed by the same experienced cardiac sonographer using two different ultrasound systems (GE Vivid E9, GE Vigmed Ultrasound AS, Horten, Norway and Philips iE33, Philips Medical Systems, Andover, MA) with a 3.5-MHz ultrasound probe. The transthoracic echocardiograms were performed sequentially on the same subject within the same hour minimising variability of measurements. LV apical 4-chamber, 2-chamber and long-axis views for strain analysis were acquired over three cardiac cycles in the left lateral decubitus position. Images were optimised to allow visualisation of the whole LV. All images were acquired at frame rates of 50–80 frames/sec.

Strain analysis

Strain analysis was retrospectively performed on the stored echo images using VSS by two experienced observers in global and regional strain analysis (GE EchoPAC version BT13 v201 and Philips QLAB version 10.3) and VIS (TomTec Auto Strain, Image Arena version 4.6; Tom Tec Imaging Systems, Munich, Germany) using raw data acquired at the acquisition frame rate (Figure 1). GE strain analysis was performed using Automated

Functional Imaging (AFI). AFI requires the user to identify and place two basal markers and one apical marker which allows the software to generate a semi-automated region of interest (ROI) around the myocardium which can be manually adjusted. Philips strain analysis was performed in a similar manner to GE AFI, incorporating a ROI after basal and apical markers were placed. TomTec strain analysis uses a more automated approach requiring the user to identify the relevant apical image for analysis before an endocardial border is placed on the myocardium. The user can adjust the border placement and check tracking throughout the cardiac cycle to ensure accurate myocardial tracking is achieved. EchoPac AFI software performs strain analysis by tracking the entire myocardial wall within the defined ROI which ensures robust analysis and the strain value presented represents an average strain within that ROI.¹⁹ QLAB strain uses a defined ROI to track strain across the entire myocardium and strain values can be presented according to the endo, mid-wall or epicardial layers. The endocardial strain layer is reported in this study. TomTec AutoStrain uses an endocardial layer to define strain values which is the myocardial layer reported.

Strain analyses were performed in all three apical views. End diastole was defined as the peak of the R-wave and/or the frame at mitral valve closure. The timing of peak systolic strain was determined by end systole at the time of aortic valve closure. Timing of aortic valve closure was defined by pulsed-wave Doppler signals in the LV outflow tract. The different software generate a bull's eye map of global longitudinal strain and regional strain results. Regional strain according to segmental distribution by coronary artery territories (left anterior descending (LAD), left circumflex (LCX) and right coronary artery (RCA)) and three levels of strain (basal, mid and apical) by VSS and VIS were also recorded. Each coronary territory was divided into LV segments by the ASE 17 segment model of classification for VSS analysis,²⁰ whilst LV is divided into 16 segments for VIS analysis. GLS and regional strain measurements were obtained by two independent blinded observers. Inter-vendor software agreement and intra-observer variability were assessed by the observer one (K.S.), who analysed both sets of images from different ultrasound systems using VIS and VSS. Interobserver variability for VIS was assessed by observer two (R.C.), who analysed both sets of images from different ultrasound systems by VIS alone. Two observers were blinded to clinical background and other's results.

Statistical methods

Continuous data are expressed as mean $\pm$ standard deviation (SD). Agreement between VSS and VIS was assessed using Bland–Altman analysis, including bias, the limits of agreement (LOA) and intra-class correlation coefficients (ICC). Pearson's correlation coefficients (r) were used to calculate the associations between measurements. Student's t -test was used to compare heart rate of subjects, time consumption for strain analysis

Figure 1: Flow diagram highlighting the methodology used for strain analysis between vendor-specific and vendor-independent software.

between VIS and VSS and mean longitudinal strain values. P values < 0.05 were considered statistically significant.

Ethical approval

This study was approved by The Human Research and Ethics Committee at The Prince Charles Hospital, Brisbane, Australia and complies with the Helsinki Declaration.

Results

A total of 40 subjects were included in the cohort. Clinical and echocardiographic characteristics of subjects are summarised in Table 1. There were five subjects who were healthy, 14 subjects had valvular disease, 12 subjects had LV hypertrophy, 11 subjects had ischaemic heart disease, eight subjects had hypertension and two subjects had diabetes. The average heart rate for GE acquired images was 65 ± 15 bpm and for Philips images 66 ± 15 bpm ($P = 0.15$). The average frame rates for GE images were significantly higher compared with Philips images (56.8 ± 4.6 frames/sec vs. 51.8 ± 4.3 frames/sec, $P < 0.0001$).

Comparison of strain analysis

Tables 2 and 3 show the results between VSS and VIS applied to GE and Philips Images (VSS GE vs. VIS GE and VSS Philips vs. VIS Philips). There was no significant difference seen for GLS measurements when analysed by VIS (TomTec strain analysis on GE images; -18.6 ± 4.8 vs. TomTec strain analysis on Philips images; -19.2 ± 4.8 , $P = 0.09$).

Analysis of regional longitudinal strain according to segment distribution by coronary artery territories by VIS Philips showed a small but significant increase in regional longitudinal strain for LCX (GE; -19.2 ± 5.9 , Philips; -20.3 ± 5.1 , $P = 0.03$) and RCA territories (GE; -17.1 ± 4.9 , Philips; -18.3 ± 5.5 , $P = 0.02$). There was no significant difference for LAD territory (GE; -18.7 ± 4.7 , Philips; -18.9 ± 4.8 , $P = 0.65$). Analysis of regional longitudinal strain according to segmental levels of the LV strain by VIS showed a small, non-significant difference for basal and apical levels (Basal: GE;

Table 1: Clinical and echocardiographic characteristics

Age, years	54 ± 19
Height, cm	169 ± 10
Weight, kg	77 ± 18
Diabetes	5% (n = 2)
Hypertension	20% (n = 8)
Ischaemic heart disease	28% (n = 11)
Valvular heart disease	33% (n = 13)
Left ventricular hypertrophy	30% (n = 12)
Heart rate, bpm (GE)	65 ± 15
Heart rate, bpm (Philips)	66 ± 15
Systolic blood pressure, mmHg	124 ± 16
Diastolic blood pressure, mmHg	70 ± 9
Ejection fraction, %	59 ± 11 (range 15–80%)
LV End diastolic-volume, ml	120 ± 48
LV End systolic-volume, ml	54 ± 40

Values are mean $\pm$ standard deviation.

-18.6 ± 4.8 , Philips; -19.1 ± 4.7 , $P = 0.05$, Apical: GE; -19.5 ± 4.7 , Philips; -19.6 ± 4.8 , $P = 0.06$).

Agreement of GLS

GLS by VIS showed excellent correlation and agreement although a small bias was observed (mean bias 0.62 LOA -2.7 to 3.9) (Figure 2) with LOA ranging from -2.70 to 3.94 (Figure 2) (Tables 2 and 3). Agreement for regional longitudinal strain by coronary artery territory revealed a strong correlation showing LCX and RCA strain were not superior to LAD strain (Figure 3). Agreement for segmental longitudinal strain also revealed strong correlations and good level of agreement ($r = 0.87$ – 0.96) (Figure 4).

Table 2: Comparison of global and regional strain values using VIS (Tom Tec) versus VSS (GE)

	TomTec	GE	P	R	Bias	95% LOA
GLS	-18.6 ± 4.8	-17.7 ± 4.7	0.01	0.92	-0.91	-4.75 to 2.94
LAD	-18.7 ± 4.7	-18.7 ± 5.0	0.83	0.89	-0.08	-4.55 to 4.40
LCX	-19.2 ± 5.9	-18.1 ± 5.3	0.02	0.86	-4.29	-10.29 to 1.70
RCA	-17.1 ± 4.9	-16.8 ± 5.8	0.63	0.76	-0.30	-7.87 to 7.27
Basal	-18.6 ± 4.8	-16.9 ± 4.8	0.004	0.89	-3.17	-7.65 to 1.31
Mid	-18.2 ± 4.8	-17.7 ± 4.8	0.52	0.93	-1.43	-4.95 to 2.08
Apical	-19.5 ± 4.7	-20.4 ± 6.1	0.01	0.89	1.78	-5.63 to 9.18

LOA, Limits of agreement.

Table 3: Comparison of global and regional strain values using VIS (Tom Tec) versus VSS (Philips)

	TomTec	Philips	P	R	Bias	95% LOA
GLS	-19.2 ± 4.8	-19.2 ± 4.8	0.95	0.89	-0.02	-4.43 to 4.39
LAD	-18.9 ± 4.8	-19.7 ± 4.7	0.12	0.87	1.83	-2.97 to 6.64
LCX	-20.3 ± 5.1	-20.2 ± 5.4	0.87	0.76	-0.10	-7.29 to 7.10
RCA	-18.3 ± 5.5	-19.5 ± 6.4	0.12	0.70	1.16	-8.04 to 10.35
Basal	-19.1 ± 4.7	-19.1 ± 5.2	0.98	0.79	-0.01	-6.38 to 6.35
Mid	-19.1 ± 4.8	-19.8 ± 5.5	0.15	0.84	0.70	-5.21 to 6.61
Apical	-19.6 ± 4.8	-21.5 ± 5.2	0.003	0.71	3.41	-4.10 to 10.93

LOA, Limits of agreement.

Inter and intra-observer agreement

There was excellent interobserver agreement for GLS between observers using VIS for analysis of GE images (ICC = 0.92, CI, 0.63 to 0.97) and of Philips images (ICC = 0.96, CI 0.91 to 0.98); however, LOA were wider for GE GLS data (GE = 0.63–0.97, Philips = 0.91–0.98) (Table 4). There was good interobserver agreement for regional strain by coronary artery territories using VIS regardless of the ultrasound system; however, LOA were relatively wide. Regional strain measurements by coronary artery territories had better agreement using Philips images (Table 4). ICC showed there was good interobserver reproducibility for regional strain by LV segmental level with Philips images and revealed a lower bias using Philips images compared to GE images (Table 4).

There was excellent intra-observer agreement for GLS analysed by VIS (GE: ICC = 0.96, CI, 0.91–0.98; Philips: ICC = 0.96, CI, 0.82–0.98) with very similar LOA (GE: LOA = 0.91–0.98; Philips: LOA = 0.82–0.98) (Table 5). There was good intra-observer agreement for VIS analysis for regional strain by coronary artery territories with narrow LOA with better agreement for GE images than Philips images (Table 5).

There was excellent intra-observer agreement for VIS for regional strain by LV segmental level with GE images demonstrating better reproducibility with lower bias and LOA (Table 5).

Comparison of analysis time

The analysis time by VSS strain analysis (GE vs Philips) was significantly different with Philips strain analysis being significantly longer (GE; 96 ± 17 s, Philips; 270 ± 66 s, $P < 0.0001$). However, analysis time by VIS strain analysis showed no significant difference between different images by different ultrasound systems (GE images; 43 ± 12 s, Philips images; 46 ± 13 s, $P = 0.16$) (Figure 5).

Discussion

Speckle-tracking echocardiography is an accurate and reproducible method for assessing global and regional left ventricular myocardial function. However, one of the known limitations for widespread clinical use is the presence of inter-vendor variability. Recently, standardisation of the EACVI ASE Industry Task Force has improved variability of GLS measurements between VSS but regional strain still shows increased

Figure 2: Linear correlation and Bland–Altman plots for GLS measurements between GE and Philips images analysed using VIS software.

Figure 3: Linear Correlation and Bland–Altman plots for regional longitudinal strain measurements according to coronary artery territory (a: Left Anterior Descending artery, b: Left Circumflex artery and c: Right Coronary Artery) between GE and Philips images analysed using VIS software.

Figure 4: Linear Correlation and Bland–Altman plots for regional longitudinal strain measurements according to LV segments (a: Base, b: Mid and c: Apex) between GE and Philips images analysed using VIS software.

variability.^{10–12,15} Discrepancies may be due to differences in spatial and temporal resolution, image line densities, region of interest sizes and post-processing speckle-tracking analysis algorithms. To date, EACVI ASE Joint Task Force recommends the use of the same ultrasound system and the same strain analysis software for serial strain measurements.^{10,15} However, using a single vendor is impractical preventing prospective and retrospective clinical follow-up assessing temporal variations in strain resulting from changes in medical therapy or intervention. Recent studies show reproducibility of longitudinal strain by VSS and VIS was better compared with previous studies^{15,17} which highlights the clinical utility of the neutral software when multiple ultrasound vendors are being used in large echocardiography laboratories. This study is one of the first studies to assess the utility of new VIS compared with two popular widespread VSS in clinical use.

The findings of this study were represented as follows:

- 1 Comparisons of GLS measurements using VIS were comparable with VSS, whilst a wide agreement was observed for regional strain measurements.
- 2 A wide agreement was observed for LV longitudinal strain analysis between VIS and VSS (Philips) than VIS and VSS (GE) for same images.
- 3 GLS measurements by VIS on the same image acquired on different ultrasound systems showed excellent reproducibility. Regional strain measurements of LV showed good reproducibility.
- 4 Time consumption was significantly faster by VIS than VSS.

In this study, GLS measurement by VIS was performed using fully automated AutoStrain (Tomtec Image Arena 4.6) software which uses a validated machine-learning algorithm to facilitate endocardial border detection. Validation of this software has recently been undertaken with good correlation and agreement observed between manual and automated strain measurements²¹ and shows the potential benefits VIS has on serial strain measurements across differing cardiac ultrasound vendors.

Results of the current study show there was good agreement and strong correlations for GLS between VIS and VSS regardless of ultrasound system. Koopman et al.⁹ reported good agreement for GLS between VSS (GE Bias = 0.8 and Philips Bias = 0.02), however, wider LOA were reported compared to the current study and VIS analysis was performed using only tissue Doppler imaging not 2D speckle-tracking analysis. Risum et al.¹³ used VIS and VSS and reported excellent agreement and strong correlations for GLS at acquisition frame rates (GE Bias = 0.6, $r = 0.96$). The current study analysed images in raw format at the acquisition frame rate which increases the amount of information available for the strain analysis as spatial resolution is improved. This shows GLS analysed from DICOM or raw data acquisitions by VIS allows reproducible assessment across different ultrasound vendors improving accurate follow-up of patients in multi-vendor echo labs. Farsalinos et al.¹⁵ showed excellent agreement for GLS between VIS and VSS (GE $r = 0.92$, Philips $r = 0.83$) whilst Negishi et al.¹⁰ reported moderate to good correlation for GLS using VIS on echo images acquired on different ultrasound machines ($r = 0.73$).

Table 4: Interobserver variability using VIS (TomTec) for GE and Philips images

	Observer 1 (GE) (Mean $\pm$ SD)	Observer 2 (GE) (Mean $\pm$ SD)	R	Bias (95% LOA)	ICC (95% CI)	Observer 1 (Philips) (Mean $\pm$ SD)	Observer 2 (Philips) (Mean $\pm$ SD)	R	Bias (95% LOA)	ICC (95% CI)
GLS	-18.6 $\pm$ 4.8	-19.9 $\pm$ 4.9	0.96	1.29 (-15.1 to 4.10)	0.92 (0.63–0.97)	-19.2 $\pm$ 4.8	-18.7 $\pm$ 4.9	0.96	-0.56 (-3.21 to 2.10)	0.96 (0.91–0.98)
LAD	-18.7 $\pm$ 4.7	-19.8 $\pm$ 4.9	0.96	1.10 (-1.62 to 3.83)	0.93 (0.73–0.98)	-18.9 $\pm$ 4.8	-18.3 $\pm$ 4.7	0.94	-0.59 (-3.94 to 2.76)	0.93 (0.87–0.96)
LCX	-19.2 $\pm$ 5.9	-20.4 $\pm$ 5.8	0.93	1.21 (-3.65 to 6.07)	0.88 (0.77–0.95)	-20.3 $\pm$ 5.1	-19.7 $\pm$ 5.4	0.94	-0.59 (-4.07 to 2.90)	0.94 (0.88–0.97)
RCA	-17.1 $\pm$ 4.9	-18.2 $\pm$ 5.4	0.87	1.03 (-5.86 to 7.92)	0.75 (0.58–0.86)	-18.3 $\pm$ 5.5	-17.3 $\pm$ 5.6	0.92	-1.00 (-5.33 to 3.32)	0.91 (0.81–0.95)
Basal	-18.6 $\pm$ 4.8	-19.8 $\pm$ 4.9	0.94	1.20 (-1.54 to 3.94)	0.93 (0.68–0.98)	-19.1 $\pm$ 4.7	-18.3 $\pm$ 4.7	0.93	-0.81 (-4.17 to 2.55)	0.92 (0.83–0.96)
Mid	-18.5 $\pm$ 4.8	-19.5 $\pm$ 4.9	0.96	0.97 (-3.03 to 4.98)	0.88 (0.78–0.95)	-19.1 $\pm$ 4.8	-18.5 $\pm$ 4.9	0.96	-0.56 (-3.20 to 2.08)	0.96 (0.91–0.98)
Apical	-18.6 $\pm$ 4.7	-19.8 $\pm$ 4.9	0.95	1.21 (-1.69 to 4.11)	0.92 (0.69–0.97)	-19.1 $\pm$ 4.8	-18.5 $\pm$ 4.9	0.96	-0.61 (-3.32 to 2.09)	0.95 (0.90–0.98)

CI, Confidence Interval; ICC, Intra-Class Correlation coefficient; LOA, Limits of agreement.

Table 5: Intra-observer variability using VIS (TomTec) for GE and Philips images

	VIS 1 (GE) (Mean $\pm$ SD)	VIS 2 (GE) (Mean $\pm$ S-D)	R	Bias (95% LOA)	ICC (95% CI)	VIS 1 (Philips) (Mean $\pm$ S-D)	VIS 2 (Philips) (Mean $\pm$ SD)	R	Bias (95% LOA)	ICC (95% CI)
GLS	-18.6 $\pm$ 4.8	-19.1 $\pm$ 4.8	0.96	0.52 (-2.10 to 3.13)	0.96 (0.91–0.98)	-19.2 $\pm$ 4.8	-18.3 $\pm$ 4.9	0.96	-0.92 (-3.66 to 1.83)	0.94 (0.82–0.98)
LAD	-18.7 $\pm$ 4.7	-19.1 $\pm$ 4.7	0.96	0.41 (-2.03 to 2.85)	0.96 (0.93–0.98)	-18.9 $\pm$ 4.8	-18.1 $\pm$ 4.9	0.95	-0.75 (-3.80 to 2.30)	0.94 (0.86–0.97)
LCX	-19.2 $\pm$ 5.9	-19.5 $\pm$ 6.1	0.93	0.28 (-4.10 to 4.67)	0.93 (0.87–0.96)	-20.3 $\pm$ 5.1	-18.9 $\pm$ 5.3	0.91	-1.37 (-5.79 to 3.06)	0.88 (0.69–0.94)
RCA	-17.1 $\pm$ 4.9	-17.7 $\pm$ 5.2	0.87	0.59 (-4.39 to 5.57)	0.87 (0.77–0.93)	-18.3 $\pm$ 5.5	-17.3 $\pm$ 5.5	0.95	-1.00 (-4.41 to 2.42)	0.94 (0.84–0.97)
Basal	-18.6 $\pm$ 4.8	-18.9 $\pm$ 4.9	0.94	0.31 (-2.85 to 3.47)	0.94 (0.90–0.97)	-19.1 $\pm$ 4.7	-18.2 $\pm$ 4.8	0.96	-0.96 (-3.68 to 1.76)	0.94 (0.80–0.98)
Mid	-18.5 $\pm$ 4.8	-19.0 $\pm$ 4.8	0.96	0.46 (-2.16 to 3.07)	0.96 (0.92–0.98)	-19.1 $\pm$ 4.8	-18.1 $\pm$ 4.9	0.96	-0.98 (-3.64 to 1.68)	0.94 (0.80–0.98)
Apical	-18.6 $\pm$ 4.7	-19.1 $\pm$ 4.7	0.96	0.49 (-2.34 to 3.33)	0.95 (0.90–0.97)	-19.1 $\pm$ 4.8	-18.2 $\pm$ 4.9	0.96	-0.88 (-3.46 to 1.69)	0.95 (0.84–0.98)

CI, Confidence Interval; ICC, Intra-Class Correlation coefficient; LOA, Limits of agreement.

Figure 5: Time consumption for strain analysis by VSS and VIS.

investigating combinations of two different ultrasound vendors and two different VIS. Weak correlations, however, were seen when the ultrasound machine was kept the same and strain analysis was performed using two different VIS ($r = 0.31$ – 0.33).¹⁰ This finding highlights advantages of single vs multiple VIS to analyse strain from different ultrasound systems. The current study showed there was a tendency for higher strain values for Philips images versus GE images analysed by VSS and VIS. A source of this observation may be attributed to differences in tracking sight as GLS derived by GE VSS uses an averaged, mid-myocardial layer whilst GLS by Philips VSS and TomTec VIS use an endocardial layer. It is known that longitudinal myocardial fibres are found within the endocardium and epicardium whilst the mid-myocardial layer has more circumferential orientation.²² This heterogenous fibre orientation and differences in tracking sight could explain why Philips strain was higher vs. GE and why small differences were seen for regional strain. This observation has been reported by Nelson et al.²³ who adjusted the region of interest from endocardial/epicardial to endocardial only using VIS and found GLS increased from 13% to 16% which was more in line TomTec image arena VIS.

In our study, a good correlation of regional strain between VIS and VSS was demonstrated. Reliable regions were LAD strain between VIS and Philips ($r = 0.87$), and mid-level strain between VIS and GE ($r = 0.93$). LCX and RCA showed less reproducibility with wider LOAs which have been confirmed previously.^{12,24} Possible reasons why LAD territory strain yielded better results versus LCX and RCA territories are due to prominent overlying lung tissue in the posterolateral and anterolateral walls mainly supplied by the LCX and RCA.¹⁰ Location of the LCX and RCA territories with respect to the ultrasound beam may also explain the reduced agreement and wide LOA; as the posterolateral wall is positioned more oblique compared to the interventricular septum, which lies in the middle of the sector

(for apical 4 and long-axis views), and its longitudinal motion is not as parallel aligned to the ultrasound beam.¹⁰

Our results show excellent agreement for GLS and moderate agreement for regional strain between two VSS. They are better than previous reports before the latest standardisation^{9,13} and discrepancies between GLS and regional strain was analogous to previous reports.^{7,11,21,25} A comparison of GLS and regional strain by VIS showed good to excellent agreement revealing an improvement compared to previous studies.^{10,16} Interestingly, Nagata et al.¹⁴ reported when the same images from the same ultrasound vendors were analysed using an upgraded version of VSS, all GLS values were significantly reduced compared to older VSS. This variation is hazardous in the clinical setting therefore, VIS strain analysis may improve inter- and intra-vendor variability in the future.

This study showed a better agreement and reproducibility of LV longitudinal strain than previous studies and the utility of fully automated VIS and an un-compressed frame rate when stored as the RAW format could have attributed to this. However, regional strain measurements showed higher variability compared to GLS. The results suggest strain measurements by VIS can be used for longitudinal follow-up, retrospective analysis and for prospective research between multi-site institutions.

Limitations

There are several limitations; first, we did not investigate all commercially available VSS but limited to two of the most common ultrasound vendors in research and clinical practice. Second, our study was limited to longitudinal strain because it is the most reliable and sensitive method for the early detection of myocardial dysfunction with the greatest clinical application. Third, this study was performed in a relatively small population which may limit the clinical implication. However, we included subjects with a wide range of LV ejection fraction and cardiac pathologies.

Conclusions

In conclusion, agreement of GLS by VIS and VSS was excellent, with moderate agreement for regional strain. Reproducibility of strain measurements analysed by VIS was excellent regardless of the observers and ultrasound system. VIS is potentially useful and has the advantage over VSS to accurately analyse images acquired from multi-vendor systems for serial strain measurements.

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Conflict of interest

None declared.

Author contributions

Robert Chamberlain: Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Software (equal); Validation (equal); Writing-original draft (lead); Writing-review & editing (equal). **Kenji Shiino:** Conceptualization (lead); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Software (equal); Validation (equal). **Gregory M Scalia:** Project administration (equal); Resources (equal). **Surendran Sabapathy:** Supervision (equal). **Jonathan Chan:** Conceptualization (lead); Methodology (lead); Project administration (equal); Supervision (lead); Writing-review & editing (lead).

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