RESEARCH

Two-dimensional global and segmental longitudinal strain: are the results from software in different high-end ultrasound systems comparable?

Alexandros P Patrianakos MD, Aggeliki A Zacharaki MD, Antonios Kalogerakis MD, Georgios Solidakis MD, Fragiskos I Parthenakis MD and **Panos E Vardas MD PhD**

Cardiology Department, Heraklion University Hospital, PO Box 1352, Stavrakia, Heraklion 71410, Crete, Greece

Correspondence
should be addressed
to A P Patrianakos
Email
apatrianakos@yahoo.gr

Abstract

To compare the peak global longitudinal myocardial strain (PGLS) and peak segmental longitudinal myocardial strain (PSLS) values by speckle-tracking echocardiography (STE) obtained using two different echocardiography devices. STE is an emerging quantitative ultrasound technique that allows an accurate evaluation of global and segmental myocardial function. However, there is a lack of standardization of the acquired data among different manufacturers. Sixty-three subjects, mean age 56.2 ± 10.4 years, underwent complete echocardiographic studies with two different devices (Philips IE33 and General Electric VIVID E9) performed by the same operator. Thirty-one of them had known cardiac disease, with estimated left ventricular ejection fraction $<50\%$, while 32 were free of any cardiovascular disease (control subjects). All images were digitally stored and analyzed using off-line post processing with QLAB 9 and EchoPAC 11 Software packages. PSLS and PGLS were calculated. A strong relationship between QLAB and EchoPAC was found for PGLS ($r=0.91$, $P<0.001$), PSLS-4 chamber (CH; $r=0.79$, $P<0.001$), PSLS-2CH ($r=0.73$, $P<0.001$), and PSLS-3CH ($r=0.78$, $P<0.001$) QLAB. Bland–Altman analysis showed absolute differences vs average of -0.16, -0.37, -0.21, and -0.16 for PGLS, PSLS-4CH, PSLS-2CH, and PSLS-apical long-axis views respectively. Segmental analysis showed a good agreement between the apical segments, whereas poor correlations were found for the basal segments. Receiver operating characteristic curve analysis showed that cutoff values for PGLS of -17.5 and -17.75% with Philips or GE systems gave a sensitivity and specificity of 93.5 and 87.5%, and 90 and 87.5%, respectively, in the discrimination of the patients from the controls. Both Philips and GE echo stations were found to give comparable results for PGLS, with approximately the same cutoff values, suggesting that their PGLS results may be interchangeable.

Introduction

Speckle-tracking echocardiography (STE) is an almost new imaging technique that is used for the evaluation of myocardial deformation, expressed in terms of segmental and global longitudinal myocardial strain. STE is a mostly angle-independent technique and overcomes most limitations of strain measurements based on tissue Doppler imaging. The development of STE and its introduction into daily clinical practice have allowed a comprehensive

and quantitative assessment of left ventricular (LV) systolic function in a variety of myocardial diseases (1, 2, 3, 4, 5, 6, 7, 8).

However, a significant limitation of the current implementation of STE is the variation among vendors, driven by the fact that STE analysis is performed post-processing and cannot, currently, make use of other vendors' software products.

Therefore, in a recent joint initiative, the American, European, and Japanese Societies of Echocardiography stated that standardization among manufacturers is essential, as clinicians should be able to interpret data generated by different equipment, irrespective of vendor, before their use in daily clinical practice.

The aim of this study was to compare values of peak global longitudinal strain (PGLS) and peak segmental longitudinal strain (PSLS) values obtained by STE using two different commercially available ultrasound machines and analyzed post-processing by vendor-specific software products.

Methods

Initially, 72 consecutive subjects, >18 years old, in sinus rhythm, who were admitted to our echo laboratory, were screened for eligibility in this study. Among these, 36 had known cardiovascular disease, with estimated LV ejection fraction (EF) <50%, and 36 were free of any cardiovascular disease (control subjects). Five patients with known cardiovascular disease were excluded because of poor image quality and four of the control subjects were also excluded for suboptimal echogenicity. Speckle tracking was considered to be not achievable if more than one LV segment had inadequate tracking quality. Finally, 63 subjects, mean age 56.2 ± 10.4 years, were included in the study.

The study conformed to the principles outlined in the Declaration of Helsinki and was approved by the Institutional Ethics Committee. All patients gave written, informed consent.

All subjects underwent complete transthoracic echocardiographic (TTE) studies with two different ultrasound systems located in adjacent echocardiography rooms. The devices used were the Philips IE33 system (Phillips Medical Systems, Andover, MA, USA) and the General Electric Vivid E9 (GE Health Medical, Horten, Norway). The respective post-processing analysis software was QLAB 9 (cardiac motion quantification (CMQ); Phillips Medical Systems) and EchoPAC 11 (automated function imaging (AFI); GE Health Medical). The examinations were performed on both machines by the same operator, as follows. First, TTE

was acquired using the Vivid E9 with an M5S 1.5/4.6 MHz transducer; then, immediately after the first study, a second TTE was performed using the iE33 with an S5-1 1.5/3.6 MHz transducer. All studies were performed by two experienced echocardiography specialists (A P Patrianakos and A A Zacharaki, >10 years in echocardiography) both of whom are accredited for performing adult TTE by the European Association of Cardiovascular Imaging (EACVI).

Three consecutive cardiac cycles of the three apical views were acquired at a frame rate of 40–80 MHz and stored digitally as raw data, for subsequent post-processing analysis. LVEF was calculated using the modified Simpson's biplane method. PSLS, using AFI and CMQ, was automatically calculated from the saved data. Apical views were scanned with special care, because foreshortening affects the results of STE and therefore should be avoided.

Speckle-tracking analyses were performed for each image using the two different dedicated automated software products. For each of the apical views (two-chamber (2CH), 3CH, and 4CH), three sampling points were placed manually at the septal and lateral mitral annulus and at the apical endocardium. A region of interest (ROI) was then generated by the software to cover the entire thickness along the LV myocardium. The ROI was adjusted manually to provide optimal tracking. Longitudinal 2D speckle-tracking strain values were obtained from one representative cycle, avoiding premature beats. We chose to analyze the cardiac cycle with the best tracking and visually most satisfactory strain curves. The GE Health Medical software has an algorithm for assessing tracking quality. In both systems, we assessed the tracking quality visually and corrections were made if necessary. In rare cases (estimated at <5%), a segment was excluded by the software algorithm, but was approved manually when the investigator considered the tracking to be sufficient.

The PGLS values were estimated after the aortic valve closure had been identified visually, frame-by-frame, in the apical long-axis (APLAX) view. When a segment had a great difference in PSLS compared with a similarly contracted neighbored segment, PSLS was recalculated; if the problem could not be resolved, the segment was excluded (problem mainly with the QLAB Software).

To estimate PSLS, three apical views were analyzed off line by investigators blinded to the patient's underlying characteristics, using the two different specific software products mentioned above. Segmental LS values were based on the American Society of Echocardiography's 17-segment LV model. PGLS was calculated as the average of regional strains.

The results of all three planes were represented in a single bull's-eye summary as PSLS along with segmental
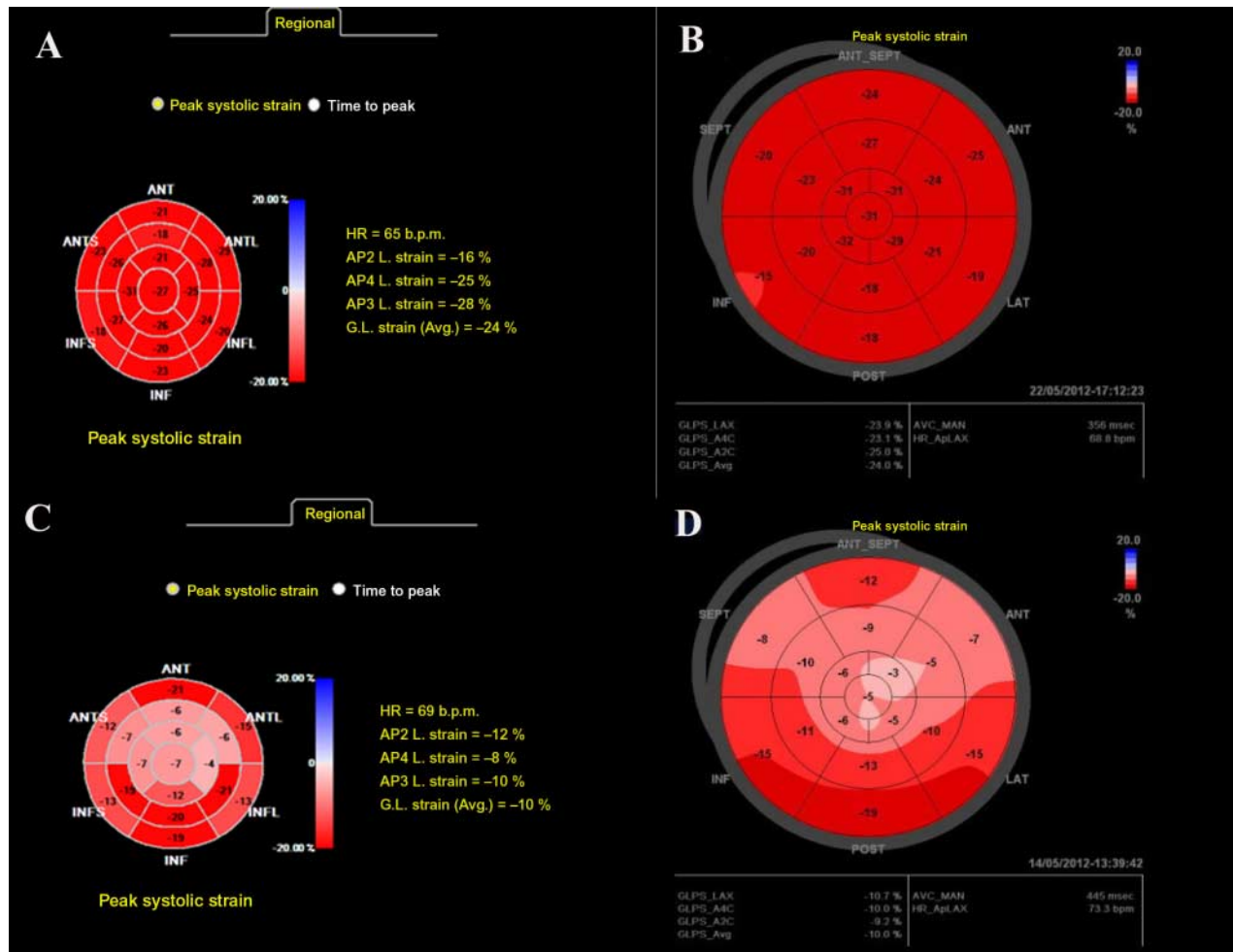
Figure 1

Bull's-eye summary of peak segmental longitudinal strain (PSLS) along with segmental and global peak strain values from a control subject (A and B) and from a patient (C and D), as generated by the CMQ (A and C) and AFI (B and D) methods in a 17-segment left ventricular model.

and PGLS. Figure 1 shows the examples of such a summary in a control subject and in a patient, as generated by CMQ and AFI methods for a 17-segment model.

The EchoPAC Software (AFI method) allowed the calculation of PGLS only when tracking quality was adequate in at least five of six segments in each apical view. However, only patients with all segments tracked sufficiently with both software packages were finally included in the study. Finally, intraobserver and inter-observer reproducibility data were evaluated for the echocardiographic methods used.

Statistical analysis

The mean differences were tested using Student's *t*-test. A *P* value of <0.05 was considered to be significant.

Pearson's correlations were calculated as measures of raw associations between measurements. Inter- and intraob-server variability, as well as inter-method repeatability and agreement between the measurements obtained from the two systems were calculated according to Bland & Altman's (9) method. Lower and upper limits of agreement (LOA) (95% LOA of the mean bias) and coefficients of variation (CV) were calculated as the within-subject S.D. divided by the mean of the observations. The differences (difference between paired measurements divided by the average of the two measurement times) were calculated for all Bland–Altman's plots.

Receiver operating characteristic (ROC) curves were constructed, and areas under the curves were measured to determine cutoff values for optimal sensitivity and specificity.

All statistical analyses were performed using SPSS for Windows (version 20.0, SPSS, Inc.) and Analyze-it for Microsoft Excel.

Results

Among the 63 subjects included in this study, 1067 segments were eventually analyzed using both software packages.

The 36 patients with known cardiovascular disease suffered from a variety of different diseases: 13 had ischemic cardiomyopathy with previous myocardial infarction, 21 had nonischemic dilated cardiomyopathy, three had myocarditis, two had hypertensive cardiomyopathy had, and one had amyloidosis.

Study population measurements in both systems is shown in Table 1. There were no significant differences in arterial blood pressure, heart rate, or age between the patients and controls. There was a strong correlation between LV end-diastolic volume (LVEDV; $r=0.91$, $P<0.001$) and LV end-systolic volume (LVESV; $r=0.93$, $P<0.001$), as well as between LVEDV and LVEF ($r=0.91$, $P<0.001$) measured with both systems. Bland–Altman analysis showed absolute differences vs average for LVEDV, LVESV, and LVEF of 0.21, 0.37, and 0.22, respectively, with corresponding 95% CIs −2.7 to 4.8, −2 to 3.4, and −2.3 to 0.3; 95% LOA −28.2 to 30.3, −20.4 to 21.8, and −11.4 to 9.4; and s.D.s of differences between single measurements 14.9, 10.8, and 5.3 respectively.

The correlation and Bland–Altman analysis results for LVEF measured by the two systems are shown in Fig. 2. Measurements of global and segmental values of PGLS are shown in Tables 1 and 2.

A strong relationship between CMQ and AFI was found for PGLS ($r=0.91$, $P<0.001$), PGLS-4CH ($r=0.79$, $P<0.001$), PGLS-2CH ($r=0.73$, $P<0.001$), and PGLS-APLAX ($r=0.78$, $P<0.001$) views (Fig. 3).

Bland–Altman analysis showed absolute differences vs average for PGLS, PGLS-4CH, -2CH, and -APLAX of −0.16, −0.37, −0.21, and −0.16, respectively, with corresponding 95% CI 0.72 to 2.48, −2 to 3.4, −1.18 to 0.74, and −1.4 to 0.37; 95% LOA −5.27 to 8.47, −20.4 to 21.8, −7.71 to 7.27, and −7.58 to 6.5; and s.D.s of differences between single measurements 2.01, 3.51, 3.82, and 3.59 respectively.

The correlation and Bland–Altman analysis results for the above measurements by the two systems are shown in Figs 3 and 4. The subgroup analysis showed that similar results were obtained in the patients group.

Table 1 Study population characteristics.

	Entire study population (n=63)				Controls (n=32)				Patients (n=31)			
	QLAB	EchoPAC	s.D. of Dif	95% LOA	QLAB	EchoPAC	s.D. of Dif	95% LOA	QLAB	EchoPAC	s.D. of Dif	95% LOA
Age (years)	56.2±10.4				50.9±16.9				54.3±13.8			
Heart rate (/min)	73.6±14.6	72.4±13.8			71.8±12.9	70.9±12.6			75.4±16.1	74±14.9		
SBP	121±12.1	120±9.8			118±9.1	117±7.9			125±13.8	123±10.5		
LVEDV (ml)	110±37	105±34	14.9	−28.2 to 30.3	95.2±26.8	89.3±20.8	13.3	−29.3 to 23	125.6±40.7	122±38.3	16.3	−33.1 to 30.9
LVESV (ml)	55±28	53±27	10.8	−20.4 to 21.8	38.4±12.7	36.2±10.4	8.7	−17.2 to 17	73.6±29.1	70.6±28.7	12.6	−23.2 to 36.4
LVEF (%)	50±13	51±12	5.3	−11.4 to 9.4	59.4±8.9	59.7±6.8	5.7	−10.6 to 11.6	41.7±10.2	43.3±10.4	4.5	−11.3 to 6.2
PGLS average (%)	−16.7±5	−16.5±4.8	2	−3.69 to 4.1	−20.4±2.2	−19.9±2.8	2.3	−4 to 5.1	−12.8±4	−13.1±3.9	1.5	−3 to 2.9
PGLS-4CH (%)	−17.4±5.6	−15.8±4.7	3.5	−5.2 to 8.4	−20.9±3.7	−18.9±3	3.9	−5.8 to 9.7	−13.9±5	−12.5±3.9	2.9	−4.5 to 7
PGLS-2CH (%)	−16.2±5.1	−16.6±5.4	3.8	−7.7 to 7.2	−19.5±2.8	−19.9±3.7	4.4	−9 to 8.3	−12.9±4.8	−13.2±4.8	3.1	−6.2 to 6
PGLS-APLAX (%)	−16.4±5.9	−17.2±5	3.5	−7.5 to 6.5	−20.8±3.8	−20.6±3.1	4.1	−7.8 to 8.3	−11.9±3.9	−13.6±3.9	2.7	−6.8 to 4.1

LVEDV, left ventricular end-diastolic volume; LVESV, LV end-systolic volume; LVEF, LV ejection fraction; PGLS, peak global longitudinal strain; CH, chamber; APLAX, apical long axis; s.D. of Dif, s.D. of differences between single measurements; LOA, limits of agreement.
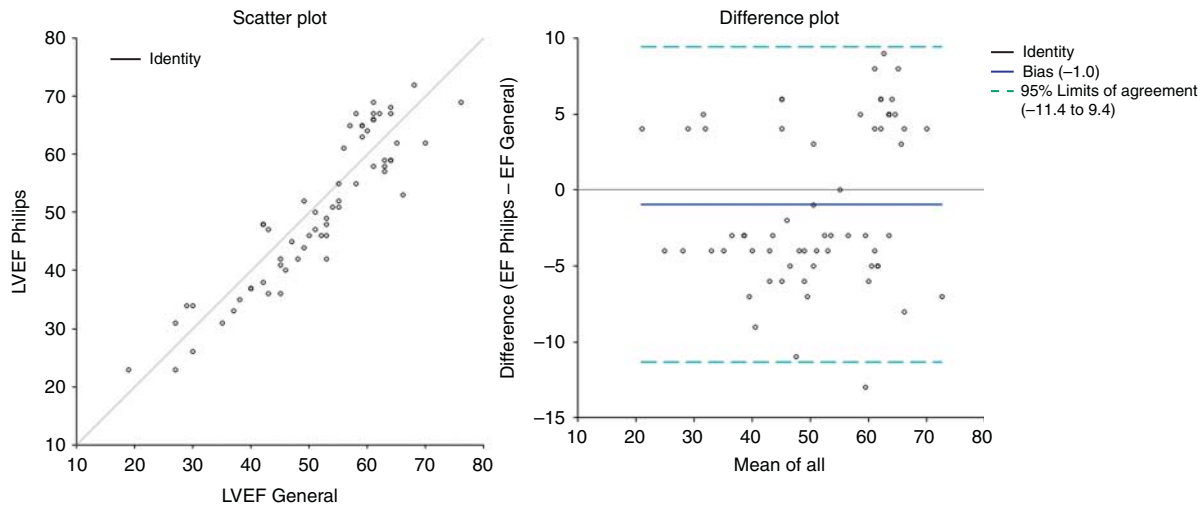
Figure 2
Results of the Bland–Altman analysis for left ventricular ejection fraction (LVEF) measured using Philips (IE 33, QLAB 9) and General Electric (Vivid E9, EchoPAC 11) echo devices.

The Bland–Altman analysis showed that PGLS, PGLS-4CH, PGLS-2CH, and PGLS-APLAX had absolute differences vs average of 0.25, −0.19, −0.15, and 0.16; 95% CI −0.37 to 1.36, 0.53 to 3.4, −2.01 to 1.19, and −1.35 to 1.68; 95% LOA −4.21 to 5.19, −5.83 to 9.75, −9.1 to 8.28, and −8.09 to 8.42; and s.D.s of differences between single measurements 2.4, 3.51, 3.97, and 4.21 respectively.

Segmental analysis (Table 1) showed good agreement between the apical segments, but less so for the basal segments, with the major disagreement observed in basal inferior, inferolateral, anterolateral, and anterior segments. However, the discrepancies in the measurements of segmental longitudinal strain were observed mainly in the controls, whereas a better agreement was observed in patients (Table 2). Figure 5 gives an example where, despite agreement in PGLS, segmental analysis showed great variability.

ROC curve analysis (Fig. 6) showed that the cutoff values of −17.5 and −17.75% for PGLS, measured using QLAB (area under the curve 0.98) or EchoPAC (area under the curve 0.94) Software, had a sensitivity and specificity of 93.5 and 87.5%, and 90 and 87.5%, respectively, for the discrimination between patients and normal subjects.

For PGLS-4CH, -2CH, and -APLAX (area under the curve 0.87, 0.89, and 0.97, vs 0.90, 0.89, and 0.91, for Philips and GE respectively) cutoff values of −18.5, −17.5, and −16.5% and −17.2, −17.75, and −18.25%, respectively, had 87–75%, 87–75%, and 96.8–87.5% and 90–66.64%, 90–82%, and 87–82.2% sensitivity and specificity respectively.

Intraobserver analysis was performed in 16 cases after the two experienced operators reviewed the stored images 1 week later. A slightly better interobserver variability was observed for AFI than for CMQ as Bland–Altman analysis shows as follows:

i) for PGLS the cor-absolute differences vs average were −0.16 and −0.53 respectively; 95% CI were −0.4 to 1.5 and −0.34 to 0.83; 95% LOA were −2.3 to 3.4 and −1.91 to 2.4; and s.D.s of differences between single measurements were 1.4 and 1.1 respectively.

ii) For PGLS-4CH the cor-absolute differences vs average were 0.1 and −0.25 respectively; 95% CI were −0.1 to 3.2 and −0.22 to 1.38; 95% LOA were −3.2 to 6.3 and −2.37 to 3.53; and s.D.s of differences between single measurements were 2.4 and 1.51 respectively.

iii) For PGLS-2CH the cor-absolute differences vs average were 0.08 and −0.6, respectively; 95% CI were −1.1 to 2.1 and −1.1 to 1.27; 95% LOA were −4.2 to 5.1 and −3.77 to 3.94; and s.D.s of differences between single measurements were 2.4 and 1.97 respectively.

iv) For PGLS-APLAX the cor-absolute differences vs average were 0.38 and 0.14, respectively; 95% CI were −3 to 2.2 and −0.76 to 0.74; 95% LOA were −8 to 7.2 and −2.45 to 2.43; and s.D.s of differences between single measurements were 3.9 and 1.24 respectively.

After working with two recently introduced software packages for the semiautomatic measurement of 2D strain,

Table 2 Segmental peak systolic longitudinal myocardial strain in the study population.

	All study population (n=63)				Controls (n=32)				Patients (n=31)			
	QLAB	EchoPAC	s.D. of Dif	95% LOA	QLAB	EchoPAC	s.D. of Dif	95% LOA	QLAB	EchoPAC	s.D. of Dif	95% LOA
Bas infs (%)	−13.2±6.1	−13.4±5.2	5.4,	−11 to 10.3	−16.3±5.1	−16.4±4.3	6.1,	−12.1 to 12	−9.9±5.4	−10.3±4	4.7,	−9.8 to 8.5
Mid infs (%)	−19.1±8.3	−16±5.3	5.6,	−7.9 to 14.2	−23.5±6	−19±3.6	4.9,	−5.3 to 13.9	−14.7±8	−12.8±5	6.1,	−10.1 to 13.9
Aps (%)	−22.8±8.3	−19.5±9.3	6.5,	−9.9 to 15.5	−26.9±5.4	−24.2±4.5	6,	−9.1 to 14.5	−18.6±8.8	−15.5±7.1	7,	−10.9 to 16.7
Bas ants (%)	−13.7±6.8	−15.3±6.1	7.1,	−15.2 to 12.8	−16.8±6.3	−17.9±4.6	7.6,	−16 to 13.7	−10.6±5.9	−12.6±6.4	6.8,	−14.6 to 12.1
Mid ants (%)	−20.4±8.4	−18.5±6.3	7.3,	−12.2 to 16.4	−24.6±6.4	−21.8±4.6	7.3,	−11.3 to 17.3	−16.1±8.1	−15±6	7.3,	−13.2 to 15.5
Bas ant (%)	−13.7±6.8	−15.8±6.3	8,	−13.4 to 17.9	−16.8±6.3	−17.5±4.4	8,	−12.3 to 19	−10.6±5.9	−14±7.4	7.9,	−14.4 to 16.7
Mid ant (%)	−20.4±8.4	−14.9±7.8	9.2,	−16.4 to 19.7	−24.6±6.4	−19.1±4.4	7.7,	−16.1 to 14.1	−10.6±5.9	−10.6±8.2	9.9,	−15 to 23.9
Ap ant (%)	−14.8±6.7	−17.5±8.5	6.7,	−15.5 to 10.6	−23±5.7	−19.4±5.1	7.5,	−18.2 to 11.1	−10.1±4.6	−11.9±7.2	5.7,	−12.6 to 9.7
Bas infl (%)	−17.2±9.1	−18.5±5.8	8.2,	−17.1 to 14.9	−21.5±7.9	−20.9±4.4	8,	−15 to 16.4	−12.7±8.1	−16±6	8.1,	−18.7 to 12.9
Mid infl (%)	−20.1±7.3	−16.3±5.6	7.5,	−10.7 to 18.6	−22.4±6.9	−19.1±3.1	6.9,	−10.1 to 16.9	−17.7±7.1	−13.4±6	8.1,	−11.4 to 20.4
Bas antl (%)	−19.5±8.1	−13.9±9	9.7,	−13.3 to 24.6	−21.9±6.7	−16±9.9	10.7,	−15 to 26.9	−17±8.8	−11.9±7.5	8.7,	−11.7 to 22.3
Mid antl (%)	−18.4±8.8	−14.3±5.3	8.2,	−11.8 to 20.2	−22±7.8	−17±4.2	7.8,	−10.5 to 20.1	−14.7±8.2	−11.6±5.1	8.6,	−13.3 to 20.4
Ap antl (%)	−15.2±6.4	−17.2±6.9	5.3,	−12.2 to 8.4	−19.1±4.8	−21.2±3.8	5.6,	−12.9 to 8.9	−11.2±5.4	−13.1±7	5,	−11.6 to 8
Bas inf (%)	−17.3±7.7	−16.9±6.2	8.6,	−15.2 to 17.4	−20.3±7.9	−19.2±4.9	9.7,	−17.8 to 20.4	−14.2±6.2	−14.5±6.6	7.2,	−14.2 to 14
Mid inf (%)	−18.9±7.3	−17.3±5.6	6,	−10.6 to 13.1	−21.8±5.4	−19.8±4.8	5.9,	−9.8 to 13.3	−16±8	−14.8±5.3	6.3,	−11.6 to 12.9
Ap inf (%)	−21.2±7.6	−18.7±7.6	5.9,	−9.1 to 14	−24.7±5.5	−23.5±4.8	6,	−10.2 to 13.2	−17.5±7.8	−13.8±6.7	5.7,	−7.7 to 14.7
Apex (%)	−17.2±6.3	−18.2±7.3	4,	−8.6 to 7	−21.3±3.9	−23±4.1	4.4,	−10.2 to 7.2	−12.9±5.4	−13.2±6.5	3.4,	−6.8 to 6.5

s.D. of Dif, s.D. of differences between single measurements; LOA, limits of agreement; Bas, basal; ap, apical; infs, inferior septum; ants, anterior septum; ant, anterior; infl, inferolateral; antl, anterolateral; inf, inferior.

we recognized that both systems are quite simple and user-friendly, but we observed the following differences:

CMQ is more time-consuming than AFI. We measured the time needed to complete the measurements using AFI with EchoPAC or CMQ with QLAB in 15 subjects. The time required with EchoPAC compared with QLAB was 117 ± 17 s vs 477 ± 43 s, $P<0.001$.

We prefer to begin the PGLS measurements from the APLAX view in order to set the aortic valve closure by seeing it from 2D views and not from pulsed-wave Doppler envelope or automatically. This is a prerequisite for AFI but not for CMQ. Furthermore, it is necessary to make changes in the basal segments as CMQ frequently does not track these segments reliably.

AFI shows the tracking quality of each segment every time in each view, while in CMQ it is necessary to determine the tracking quality manually.

An advantage of the CMQ is that the operator can manually adjust the endocardial and epicardial borders, as well as the thickness in the whole myocardium and each segment separately, while in AFI one can adjust only the myocardial thickness as a whole, and not segment by segment. This can gain prominence after a myocardial infarction with co-existing dyskinetic areas where the relative thickness of each segment can be adjusted with CMQ.

An advantage of AFI, according to our experience, is that an appropriate cardiac cycle can be selected if there are problems with the electrocardiogram recording or with image quality (we preset three cardiac cycles for measurement, because we believe this to be much better for evaluation and calculation and it follows the current recommendations), but this is not the case with CMQ.

Discussion

Semiautomatic methods for the calculation of global and segmental longitudinal 2D strain represent an encouraging and very promising technique that has been proved to possess diagnostic and prognostic information in a different variety of myocardial diseases ([1], [2], [3], [4], [5]). However, before these methods are put into use in daily clinical practice, we must know whether the results obtained using different ultrasound machines are comparable with each other.

Our study was designed to compare two different commercially available ultrasound machines, the Philips IE33 system (Phillips Medical Systems) and the General Electric Vivid E9 (GE Health Medical), for measuring
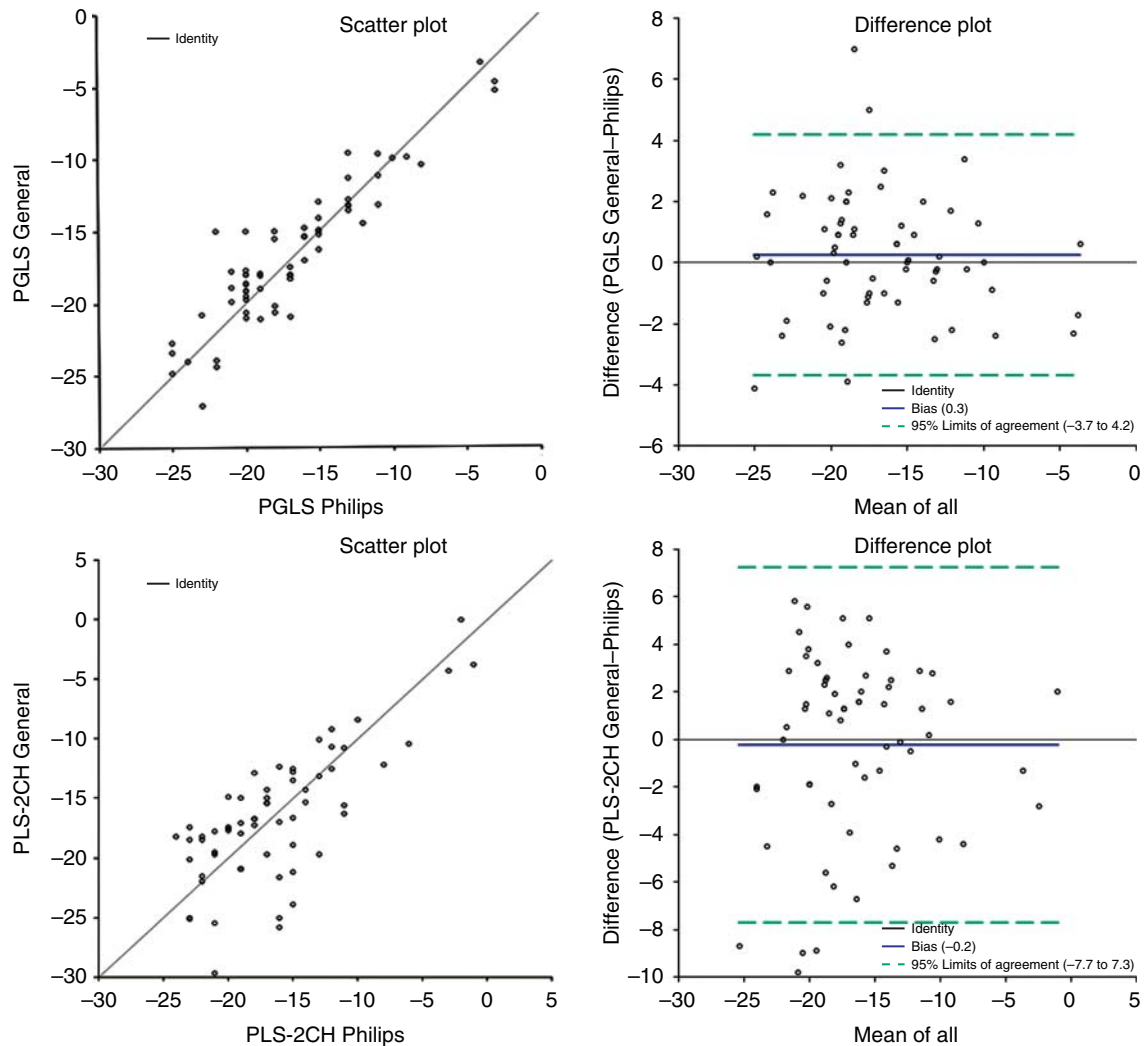
Figure 3

Results of the Bland–Altman analysis for peak global longitudinal strain (PGLS) and peak segmental longitudinal strain (PSLS) in the apical two-chamber view (PLS-2CH) measured using Philips (IE 33, QLAB 9) and General Electric (Vivid E9, EchoPAC 11) echo devices.

global and segmental myocardial longitudinal strain using STE analysis.

PGLS and PSLS values was obtained and analyzed post-processing using vendor-specific software, the QLAB 9 (CMQ method) and EchoPAC 11 (AFI method) respectively.

In a recent study using older dedicated automated software (EchoPAC 6 and QLAB 7), Sun *et al.* (10) have found that longitudinal strains measured by the two different echo machines had good correlations, but the Phillips-assessed strains were 10% greater in magnitude than the GE measurements (-26.7 ± 3.9 vs -24.3 ± 3.4). This difference was not observed in our study and the explanation may be due to the different software used or

the different population, as Sun *et al.* evaluated a mixed Caucasian and Asian population and reported that the values obtained from Asians were higher than those of Caucasians. Indeed, the values obtained from the use of EchoPAC in Caucasians were about the same as our measurements in controls ($-19.7\pm2.4\%$ vs $-19.9\pm3.7\%$). A second explanation may be that we also found better agreement in patients than in healthy controls.

Takigiku *et al.* (11) also compared the peak longitudinal myocardial strain in healthy people by using devices from the same two vendors (EchoPAC PC version 110.1.3, GE and QLAB, version 7.1, Philips) and although they achieved results similar to ours (-18.9 ± 2.51 and $-21.3\pm2\%$ respectively), they found a weaker intraclass CV (0.63).
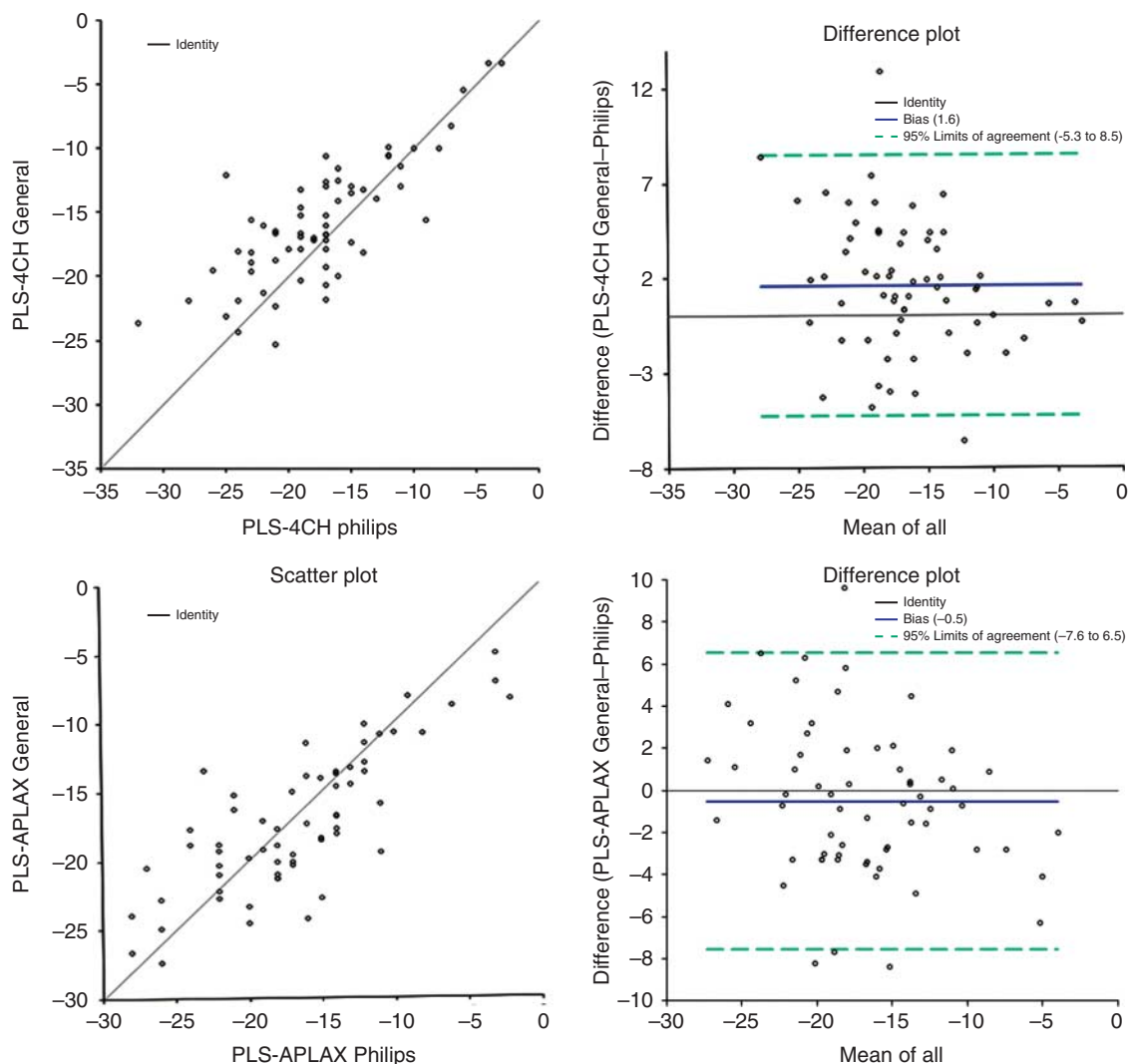
Figure 4

Results of the Bland–Altman analysis for peak global longitudinal strain in the four-chamber (PLS-4CH) and apical long-axis (PLS-APLAX) view measured by Philips (IE 33, QLAB 9) and General Electric (Vivid E9, EchoPAC 11) echo devices.

They did not report values from each apical view or segmental strain. This, again, can be explained by the different software used (QLAB 7.1 vs QLAB 9) and by the fact that their study was multicenter, with different echo-machines (VIVID 7 or E9) and different operators obtaining the images. Our study, although a single-center study, had the advantage of using echo studies by the same two echocardiography experts each time, ensuring homogenous data. Furthermore, the earlier investigators used an 18-segment model, while EchoPAC and QLAB use a 17-segment model; finally, they excluded subjects who had unreliable tracking quality in >9 of the 18 segments, rather than in one segment, as in our study.

We found a significant relationship between the two systems in terms of PGLS, especially in cardiac patients, a finding that allowed the results of one system to be considered interchangeable with those of the other. In addition, this finding should not be inferior to the classical measurements of LV volumes and EF, which are the cornerstone of echocardiography in daily practice.

The variation that we found in LVEF and volumes was in agreement with all previous studies reported in the literature (12, 13).

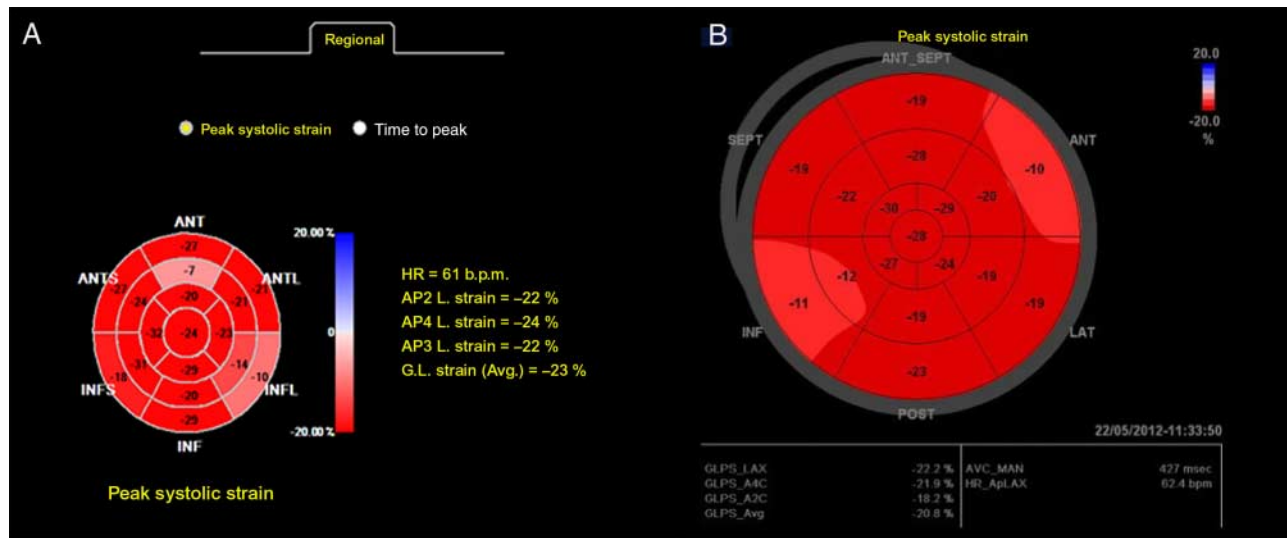The values that we found for PGLS and PSLS from both machines for each apical view were very close to the

Figure 5

An example of a control subject in whom, despite an agreement in PGLS, segmental analysis showed great variability between the segmental peak longitudinal strain evaluated by the CMQ (A) and AFI (B) methods.

reported normal values obtained using a GE or non-GE echo system (14, 15, 16, 17). Specifically, in a recent meta-analysis (15) of 28 studies investigating PGLS in normal adults, the authors concluded that the use of devices from different vendors was not significantly associated with mean absolute GLS, or GLS in normal patients. The measurements obtained using the EchoPAC Software (GE Healthcare, Milwaukee, WI, USA) were not different from the measurements obtained using non-EchoPAC Software ($19.65 \pm 1.78\%$ vs $19.67 \pm 1.80\%$).
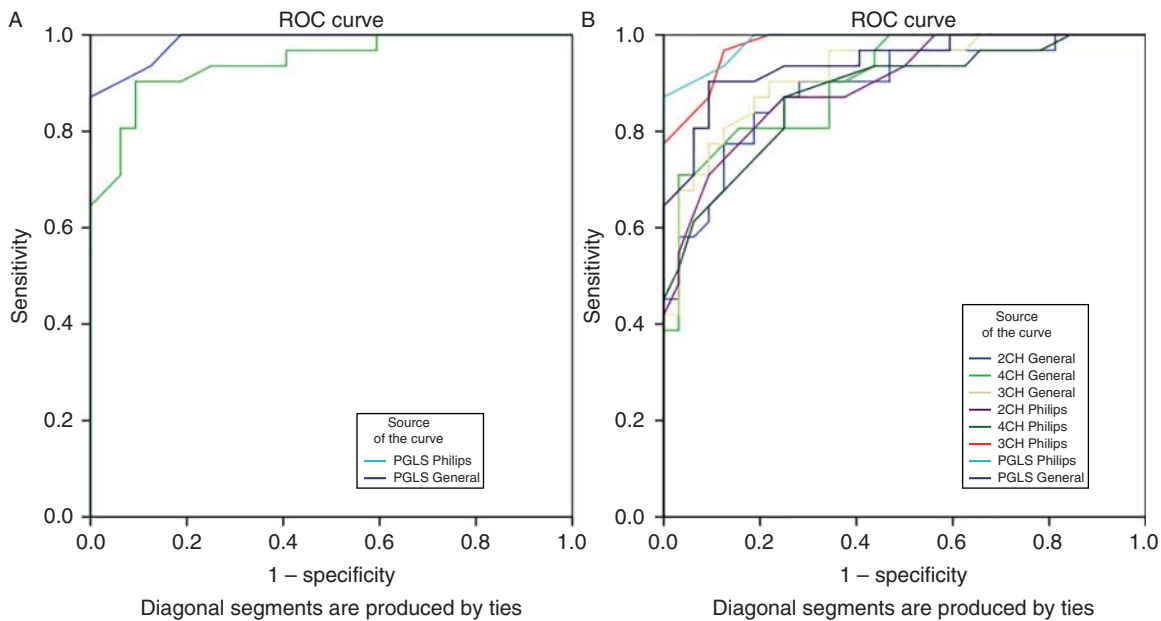

Figure 6

(A) ROC analysis showing cutoff values for peak global longitudinal strain (PGLS) of -17.5 and -17.75%, with QLAB (area under the curve 0.98) or EchoPAC (area under the curve 0.94) Software respectively, had 93.5 and 87.5%, and 90 and 87.5% sensitivity and specificity, respectively, for the discrimination of patients from controls. (B) ROC analysis of PGLS and peak longitudinal strain for each of the apical views (four-, two-, and three-chamber) for the differentiation between patients and controls.

Although these results and the peak reported values are about the same as our results obtained in controls, it is necessary to point out the variation in the segmental PGLS found in controls. Furthermore, while we found a very good agreement in the measurements of PGLS, segmental strain should be viewed with caution for the basal segments, as in some cases major deviations were found between the analysis in the two studies. This difference was even more pronounced in normal subjects. The basal inferior, inferolateral, and lateral wall are anatomically the most distant from the transducer's position in TTE. As such, they are subject to distance-related echo dropout, incomplete endocardial visualization, and myocardial thickening. This problem may also be amplified by parallel visualization of these segments and also by the fact that these segments are juxtaposed on the fibrous skeleton of the heart and may be tethered by the annular movement. This problem with the basal segments was also an early recognized problem in the interpretation of stress echocardiography [18, 19].

In accordance with our study, Castel *et al.* [20] have recently reported almost the same results. In the direct comparison of PGLS values, using QLAB 9 and EchoPAC 12 Software, they reported an agreement in the global and the territorial strain, but not for basal regional or segmental longitudinal strain, further supporting our findings.

Overall, we believe that our results show that the measurements of PGLS using each system correspond sufficiently closely. Furthermore, we believe that in the near future, in addition to LVEF, a second number will accompany every patient's echo report: namely, the PGLS value, as this has been shown to possess prognostic and diagnostic information and has less variability than the LVEF. It may be used for the follow-up of patients and finally it can help in the differentiation between patients and healthy subjects in marginal cases.

Study limitations

Our study avoided the apical foreshortening which, in our opinion, is the major drawback of STE, along with the image quality and the severely dilated ventricles (thus the apex is located outside the image width). This may be a problem in inexperienced operators, but in our study the images were obtained by two expert echocardiographers. The aim was the comparison of two echo systems and we needed the best possible optimization of the images. The post-processing analysis was quite simple and has

shown a high level of agreement, even in nonexperienced operators.

The analysis of the longitudinal strain of the lateral and anterior walls was technically more challenging than that of the other segments. This was presumably because of the suboptimal image quality due to rib artifacts or proximity to non-myocardial structures, such as the posterior mitral annulus. Thus, care must be taken and we believe that it is important for the tracking quality to be indicated by the software.

We did not examine the radial and circumferential strain but only the longitudinal strain, as it is more easy to use in daily clinical practice and has been shown to have a prognostic and diagnostic role. However, previous studies have shown greater variability in the radial and circumferential than in the longitudinal strain [21].

Another limitation is that the differences between vendors were only studied in 63 subjects, which was a relatively a small sample size. However, we strongly believe that the study was large enough to allow the drawing of conclusions, especially as the vast majority of studies carried out to determine the normal values of PGLS had an even smaller sample size.

In addition, comparing only two commercially vendor-specific speckle-tracking software packages is obviously another clear limitation of the study. However, there are currently no more such software products available for study in our hospital.

Conclusions

Both Philips and GE echo stations were found to give comparable results for global longitudinal systolic strain, with almost the same normal cutoff values. Segmental analysis showed a strong relationship between the values of apical myocardial segments, but a weak relationship for the basal segments. Therefore, although the values of PGLS obtained with Philips and GE devices appear to be interchangeable, the evaluation of segmental systolic strain, especially in the basal segments, must be viewed with caution.

References

1 Mor-Avi V, Lang RM, Badano LP, Belohlavek M, Cardim NM, Derumeaux G, Galderisi M, Marwick T, Nagueh SF, Sengupta PP et al. 2011 Current and evolving echocardiographic techniques for the quantitative evaluation of cardiac mechanics: ASE/EAE consensus statement on methodology and indications endorsed by the Japanese Society of Echocardiography. European Journal of Echocardiography 12 167–205. (doi:10.1093/ejechocard/jer021)

2 Geyer H, Caracciolo G, Abe H, Wilansky S, Carerj S, Gentile F, Nesser HJ, Khandheria B, Narula J & Sengupta PP 2010 Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. Journal of the American Society of Echocardiography 23 351–369 (quiz 453–455). (doi:10.1016/j.echo.2010.02.015)

3 Biswas M, Sudhakar S, Nanda NC, Buckberg G, Pradhan M, Roomi AU, Gorissen W & Houle H 2013 Two- and three-dimensional speckle tracking echocardiography: clinical applications and future directions. Echocardiography 30 88–105. (doi:10.1111/echo.12079)

4 Cho GY, Marwick TH, Kim HS, Kim MK, Hong KS & Oh DJ 2009 Global 2-dimensional strain as a new prognosticator in patients with heart failure. Journal of the American College of Cardiology 54 618–624. (doi:10.1016/j.jacc.2009.04.061)

5 Nahum J, Bensaid A, Dussault C, Macron L, Clémence D, Bouhemad B, Monin JL, Rande JL, Gueret P & Lim P 2010 Impact of longitudinal myocardial deformation on the prognosis of chronic heart failure patients. Circulation. Cardiovascular Imaging 3 249–256. (doi:10.1161/CIRCIMAGING.109.910893)

6 Fontana A, Zambon A, Cesana F, Giannattasio C & Trocino G 2012 Tissue Doppler, triplane echocardiography, and speckle tracking echocardiography: different ways of measuring longitudinal myocardial velocity and deformation parameters. A comparative clinical study. Echocardiography 29 428–437. (doi:10.1111/j.1540-8175.2011.01618.x)

7 Amundsen BH, Crosby J, Steen PA, Torp H, Slørdahl SA & Støylen A 2009 Regional myocardial long-axis strain and strain rate measured by different tissue Doppler and speckle tracking echocardiography methods: a comparison with tagged magnetic resonance imaging. European Journal of Echocardiography 10 229–237. (doi:10.1093/ejechocard/jen201)

8 Sjøli B, Ørn S, Grenne B, Vartdal T, Smiseth OA, Edvardsen T & Brunvand H 2009 Comparison of left ventricular ejection fraction and left ventricular global strain as determinants of infarct size in patients with acute myocardial infarction. Journal of the American Society of Echocardiography 22 1232–1238. (doi:10.1016/j.echo.2009.07.027)

9 Bland JM & Altman DG 1999 Measuring agreement in method comparison studies. Statistical Methods in Medical Research 8 135–160. (doi:10.1191/096228099673819272)

10 Sun JP, Lee AP, Wu C, Lam YY, Hung MJ, Chen L, Hu Z, Fang F, Yang XS, Merlino JD et al. 2013 Quantification of left ventricular regional myocardial function using two-dimensional speckle tracking echocardiography in healthy volunteers – a multi-center study. International Journal of Cardiology 167 495–501. (doi:10.1016/j.ijcard.2012.01.071)

11 Takigiku K, Takeuchi M, Izumi C, Yuda S, Sakata K, Ohte N, Tanabe K, Nakatani S & JUSTICE investigators 2012 Normal range of left ventricular 2-dimensional strain: Japanese Ultrasound Speckle Tracking of the Left Ventricle (JUSTICE) study. Circulation Journal 76 2623–2632. (doi:10.1253/circj.CJ-12-0264)

12 Malm S, Frigstad S, Sagberg E, Larsson H & Skjaerpe T 2004 Accurate and reproducible measurement of left ventricular volume and ejection fraction by contrast echocardiography: a comparison with magnetic resonance imaging. Journal of the American College of Cardiology 44 1030–1035. (doi:10.1016/j.jacc.2004.05.068)

13 Thomson HL, Basmadjian AJ, Rainbird AJ, Razavi M, Avierinos JF, Pellikka PA, Bailey KR, Breen JF & Enriquez-Sarano M 2001 Contrast echocardiography improves the accuracy and reproducibility of left ventricular remodeling measurements: a prospective, randomly assigned, blinded study. Journal of the American College of Cardiology 38 867–875. (doi:10.1016/S0735-1097(01)01416-4)

14 Marwick TH, Leano RL, Brown J, Sun JP, Hoffmann R, Lysyansky P, Becker M & Thomas JD 2009 Myocardial strain measurement with 2-dimensional speckle-tracking echocardiography: definition of normal range. JACC. Cardiovascular Imaging 2 80–84. (doi:10.1016/j.jcmg.2007.12.007)

15 Yingchoncharoen T, Agarwal S, Popović ZB & Marwick TH 2013 Normal ranges of left ventricular strain: a meta-analysis. Journal of the American Society of Echocardiography 26 185–191. (doi:10.1016/j.echo.2012.10.008)

16 Dalen H, Thorstensen A, Aase SA, Ingul CB, Torp H, Vatten LJ & Stoylen A 2010 Segmental and global longitudinal strain and strain rate based on echocardiography of 1266 healthy individuals: the HUNT study in Norway. European Journal of Echocardiography 11 176–183. (doi:10.1093/ejechocard/jep194)

17 Reckefuss N, Butz T, Horstkotte D & Faber L 2011 Evaluation of longitudinal and radial left ventricular function by two-dimensional speckle-tracking echocardiography in a large cohort of normal probands. International Journal of Cardiovascular Imaging 27 515–526. (doi:10.1007/s10554-010-9716-y)

18 Carstensen S, Ali SM, Stensgaard-Hansen FV, Toft J, Haunsø S, Kelbaek H & Saunamäki K 1995 Dobutamine–atropine stress echocardiography in asymptomatic healthy individuals. The relativity of stress-induced hyperkinesia. Circulation 92 3453–3463. (doi:10.1161/01.CIR.92.12.3453)

19 Bach DS, Muller DW, Gros BJ & Armstrong WF 1994 False positive dobutamine stress echocardiograms characterization of clinical, echocardiographic and angiographic findings. Journal of the American College of Cardiology 24 928–933. (doi:10.1016/0735-1097(94)90851-6)

20 Castel AL, Szymanski C, Delelis F, Levy F, Menet A, Mailliet A, Marotte N, Graux P, Tribouilloy C & Maréchaux S 2014 Prospective comparison of speckle tracking longitudinal bidimensional strain between two vendors. Archives of Cardiovascular Diseases 107 96–104. (doi:10.1016/j.acvd.2014.01.007)

21 Manovel A, Dawson D, Smith B & Nihoyannopoulos P 2010 Assessment of left ventricular function by different speckle-tracking software. European Journal of Echocardiography 11 417–421. (doi:10.1093/ejechocard/jep226)