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Reliability and feasibility of longitudinal AFI global and segmental strain compared with 2D left ventricular volumes and ejection fraction: intra- and inter-operator, test–retest, and inter-cycle reproducibility

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Aims Echocardiographic evaluation of 2D longitudinal peak systolic strain (LPSS) can detect initial impairment of left ventricular (LV) function in heart disease. Global LPSS (GLPSS) variability has been assessed in small groups and segmental LPSS has not been determined. We compared variability of GLPSS and segmental LPSS with that of 2D LV volumes and ejection fraction (EF) in patients with and without heart diseases.

Methods and results 2D speckle tracking analysis was performed on LV apical views using automated function imaging (AFI) software (GE Healthcare). Intra-operator, inter-cycle, and test–retest variability (bias and CR, coefficient of reproducibility; MPE, mean percent error; CV, coefficient of variation) was assessed for GLPSS, 18 segments of LPSS, and LV volumes and EF in 40 patients (720 segments), and inter-operator variability in 250 patients (4500 segments). Feasibility of segmental tracking was 93.1%. Variability of GLPSS increased from a minimum intra-operator CV = −2.6% to a maximum test–retest CV = −5.4% and was lower than that assessed for volumes and EF. Segmental intra-operator LPSS CV ranged from −5.6 to −14.7%, and test–retest from −8 to −22%, and was at worst similar to variability of end-systolic volume. In the 8.3% of segments with the highest variability, this was related to suboptimal imaging, minor changes in scan angulation, and insufficient ROI width.

Conclusion Overall, reproducibility of GLPSS is excellent and superior to that of 2D EF, whereas segmental LPSS reproducibility is good and similar to that of LV volumes. Both are suitable for diagnosis and follow-up of LV global and regional systolic function.

Keywords echocardiography • ventricular • strain • volumes • reproducibility • ejection fraction

Introduction

One of the main clinical indications for echocardiography is to gain knowledge about global and regional left ventricular (LV) myocardial function. Traditional assessment has relied upon qualitative and quantitative analysis of ejection fraction (EF), and pulsed Doppler tissue imaging (assuming a tight correlation between longitudinal and global function). The recently introduced speckle-tracking strain technique tracks semi-automatically on greyscale images the cyclic myocardial deformation separately in the radial, circumferential, and longitudinal directions, and has been proposed as a relatively effortless method to obtain both global and regional longitudinal LV function.[1] Notwithstanding concerns about inter-vendor variability secondary to the different proprietary algorithms being used,[2] one

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of these, automated function imaging (AFI, GE Vingmed Ultrasound AS, Horten, Norway), appears better suited for clinical echocardiography since it allows on-board analysis (limited to longitudinal strain) and has been validated[3] and tested in different clinical settings,[1] but data on reproducibility are few.

The aim of this study was to analyse reproducibility and feasibility of AFI-based LV longitudinal global, regional, and segmental strain analysis, to compare it with that accepted for 2D LV volumes and EF,[4] and to establish the usability of longitudinal strain evaluation in daily practice. Although a tracking algorithm possesses an intrinsic reproducibility, our purpose was to measure the *extent* of this reproducibility while tracking operator-dependent LV imaging. Standard 2D echo served as benchmark given that its reproducibility is easily appreciated by most operators in routine diagnostics.

Methods

Study design

We studied prospectively 335 consecutive patients undergoing diagnostic echocardiography (single experienced operator, P.B.) between August and September 2013 with either a GE Vivid 7 (186 patients) or a Vivid 9 (149 patients) scanner (GE Vingmed Ultrasound AS). Inclusion criteria were age >16 years, sinus rhythm, no arrhythmias, and visualization (not necessarily optimal) on greyscale imaging of all LV myocardial segments. Thus, 45 patients were excluded because of incomplete LV visualization, and 290 were included in the study and underwent AFI analysis (*Figure 1*). The study protocol was approved by the institutional review board, and written informed consent was obtained.

Echocardiographic examination

Patients were examined in the left lateral decubitus position with a multi-frequency phased array transducer (M4S, 1.9/4.0 MHz or M5S, 1.7/3.3 MHz) during quiet respiration at constant heart rate. Three consecutive 2D cycles were saved for offline analysis. All variables were measured by an experienced operator (P.B.) for intra-operator and test–retest variability; two additional experienced operators measured conventional 2D (CC) and strain variables (OM) for inter-operator variability. Operators were blinded to each other's results and to patient's data. Greyscale images were acquired in the apical four-, two-, and three-chamber views, using the shortest depth and the narrowest sector including the LV apex and walls in the different views (30–60°), with 45–70 frame rates (means, Vivid 7 = 61 fps; Vivid 9 = 53.8 fps), as optimal balance between spatial and temporal resolutions. Pulsed Doppler LV stroke volume (in the apical five-chamber view), M-mode end-diastolic hypertrophy index and LV mass index, 2D biplane LV end-diastolic volume (EDV) and end-systolic volume (ESV) (Simpson's rule), including end-diastolic and end-systolic long axis, and EF were measured as recommended.[5,6]

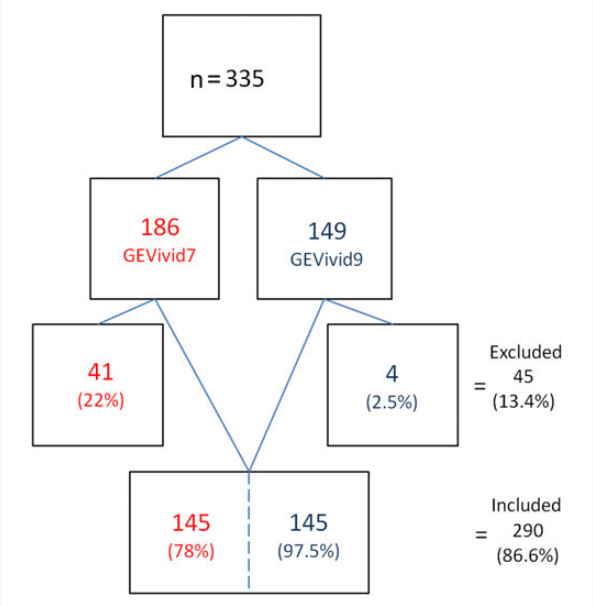

Figure 1: Patient enrolment flow chart.

Strain analysis

Speckle tracking was performed using the semi-automatic AFI algorithm (Automated Function Imaging, Version 112, GE Healthcare, Horten, Norway) that analyses myocardial motion by tracking frame-to-frame speckle changes in 2D images.[7] When necessary, automatic endocardial recognition was manually adjusted to ensure correct 'anchorage' of the algorithm to the mitral annulus, exclude papillary muscles and chordae from tracking, and correctly include the LV apex. The region of interest (ROI) was eventually adjusted to ensure tracking of the whole myocardial thickness. Systolic myocardial deformation is presented with negative and systolic lengthening with positive values; LV outflow pulsed Doppler was used to time end-systole. The algorithm calculated average longitudinal peak systolic strain (LPSS) for each of the LV 18 segments, displaying segmental strain plots in each apical view, computed average peaks for each view, and global LPSS (GLPSS), displayed in bull's eye format (*Figure 2*). Peak systolic values were unequivocally identified for each segment in all patients.

Feasibility and reproducibility analysis

A set of images was defined as the cine-loops of the three LV apical views. Strain feasibility in included patients was reported for each of the 18 LV segments as exclusion rate (%) = (number of segments with failed or unsatisfactory AFI tracking/patients studied) × 100. Intra-observer reproducibility was assessed on measurements repeated in random order after 1 month by the same operator on the same image set. Inter-observer reproducibility was assessed on measurements performed by two different operators at different times, in random order, on the same image set. Test–retest reproducibility was assessed on measurements performed in random order by the same operator on two image sets recorded at beginning and end of an examination (20′ time interval) to avoid physiologic changes in LV filling/size. Inter-cycle reproducibility was assessed on measurements performed in random order by the same operator comparing the first and the third of three stored cycles for each patient. Strain feasibility was assessed in all 290 patients, whereas 2D and strain variables test–retest, inter-cycle, and intra-operator reproducibility, and 2D variables inter-operator reproducibility were assessed in a subgroup of 40 patients (Group 1), and inter-operator reproducibility was assessed in a subgroup of 250 patients (Group 2).

Statistical analysis

All values are expressed as mean ± SD. Intra-operator and inter-operator, test–retest, and inter-cycle reproducibility were tested for LV long axis, volumes, and EF; segmental, view and base, papillary and apex LPSS; GLPSS. To facilitate comparisons with other studies, we assessed reproducibility using four methods: (i) Bland–Altman (BA)

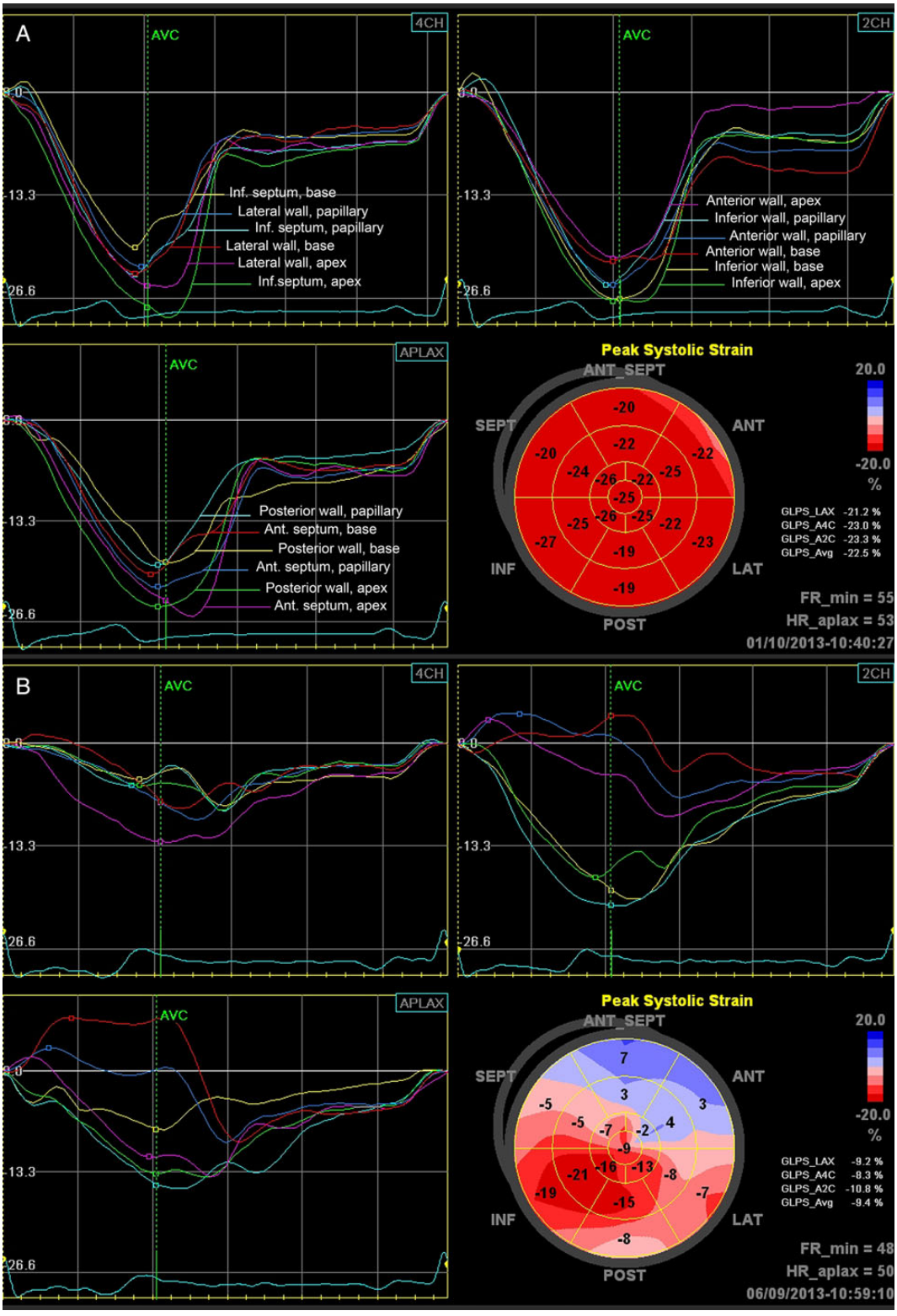

Figure 2: Analysis of longitudinal strain using AFI. (*A*) Normal subject. (*B*) Ischaemic dilated cardiomyopathy and wall dyssynergy. The AFI algorithm calculates the % strain peak negative value (small squares, maximum segmental contraction) between the ECG R wave and end-ejection (green dotted line). Positive values (segmental distension) are calculated when 75% greater than negative peak systolic contraction along the same segment. In each view, six wall segment lines are analysed (total = 18 segments), whereas the bull's eye graphs show a LV 17-segment model averaging apical segments and extrapolating the true apex. 2CH, apical two-chamber view; 4CH, apical four-chamber view; ANT, anterior wall; ANT_SEPT, anterior septum; APLAX, apical long-axis (three-chamber) view; AVC, aortic valve closure; Avg, average; FR, frame rate; GLPS, global longitudinal peak systolic (strain); HR, heart rate; INF, inferior wall; LAT, lateral wall; POST, posterior wall; SEPT, inferior septum.

analysis; (ii) standard deviation of replicate measurements (SDRM); (iii) intra-class coefficient of correlation (ICC); and (iv) mean percent error (MPE). For BA, bias = average of the differences between two sets of measurements, and the coefficient of repeatability (CR) = 1.96 × SD of bias, with its 95% limits of agreement. For SDRM, the coefficient of variation (CV) = SD of the mean variances divided by the mean value of the two sets of measurements. For ICC, a two-way random-effects model was used with absolute agreement type analysis. The MPE was calculated as the absolute average difference between measurements divided by the mean value of the measurements × 100. In Group 2 patients, MPE differences between Vivid 7 and 9 scanners were analysed with an independent *t*-test, and the χ^2 test was used for segmental feasibility analysis. Multiple regression analysis was used to identify independent predictors of MPE of 2D and strain measures, including ultrasound equipment, age, sex, body surface area (BSA), heart rate, end-diastolic hypertrophy index, LV mass index, stroke volume, and EF. All 2D and strain images of segments with MPE ≥ 40% at test–retest analysis were reviewed by two operators (P.B. and O.M.) to agree on the mechanisms responsible for the high variability, and coded = 1, suboptimal 2D imaging; 2, differences in transducer angulation within the same view (papillary muscles = position markers); 3, differences in ROI (myocardium not fully included, either on subendocardial or subepicardial side); 4, unexplained. SPSS software version 20 (IBM SPSS, Inc., Armonk, NY, USA) was used.

Results

Included exams represented a wide range of LV volume indices, EF (*Table 1*), GLPSS, and segmental LPSS (between +10% in apical anterior wall systolic distension and −39% in apical anterior septum hyperkinesis). Population characteristics are presented in *Table 1*.

Table 1 Patients and exam characteristics

		***n* = 290**
Age (range)	years	54 ± 18 (14–88)
Sex	m : f	206 : 79
BSA	m^2	1.81 ± 0.2
Heart rate (range)	bpm	65 ± 12 (42–115)
Vivid 7 : 9	*n*	145 : 145
LV EDV index (range)	mL	75 ± 36 (26–222)
LV ejection fraction (range)	%	52 ± 16 (14–80)
LV EDHI (range)		0.37 ± 0.1 (0.17–0.92)
LV mass index (range)	g/m^2	111 ± 45 (45–313)
GLPSS (range)	%	−17 ± 5.8 (−4.6/−27.1)
Diagnosis		
Normal	*n*	96
Coronary artery disease	*n*	85
Dilated cardiomyopathy	*n*	38
LV hypertrophy[a]	*n*	42
Aortic or mitral valve regurgitation	*n*	29

EDHI, end-diastolic hypertrophy index; EDV, end-diastolic volume; GLPSS, global longitudinal peak systolic strain; LV, left ventricular.
[a]Arterial hypertension, aortic stenosis, and hypertrophic cardiomyopathy.

Feasibility

Positioning of the ROI, and AFI processing with curve display in the three apical views, required ∼5 min when no manual repositioning was required by the algorithm and 5–15 min with manual adjustments, prevalently in the basal segments. Overall, AFI feasibility was 93.1% (Vivid 7: 93.3%; Vivid 9: 92.4%) with no difference (1%) between operators: 360/5220 segments were excluded because of unsatisfactory tracking. Regionally, 8.7% of segments were excluded at base, 5.3% at papillary level, and 7.3 at the apex. At wall level, 4% of segments were excluded in the septum, 6% in the inferior, 8% in the anterior, 9.5% in the lateral, and 11% in the posterior walls. Segmental feasibility is reported in *Figure 3* for both Vivid 7 and 9 machines (no differences between operators).

Variability of 2D measures

Intra-operator variability was lowest for four-chamber end-diastolic long axis and highest for two-chamber ESV, with an intermediate value for biplane EF (Supplementary data online, *Table S1*: MPE and CV); CR was, respectively, 10 mL and 9% for biplane EDV and EF. Inter-operator, inter-cycle, and test–retest variability showed similar patterns (Supplementary data online, *Tables S2–S4*). Overall, inter-operator was 2 times higher than intra-operator variability; the former was similar to test–retest, whereas inter-cycle variability was somewhat lower. Global and segmental ICC values are also reported (Supplementary data online, *Tables S1–S4*). At test–retest, measurements obtained at first and second acquisitions were superimposable (Supplementary data online, *Table S4*), and four- and two-chamber end-diastolic (>0.93, $P < 0.001$) and end-systolic (>0.89, $P < .001$) long-axis correlations were very high. The BA analysis showed in the optimal setting (intra-operator variability: no change in ultrasound equipment, operator, or reader) a measurement uncertainty of 10 mL for LV volumes and 9% for EF, whereas for both inter-cycle measurements and repeat acquisitions (same operator and reader) measurement variability was within 17 and 20 mL for, respectively, EDV and ESV and within 11% for EF (*Table 2*).

Variability of strain measures

Globally, variability of GLPSS was lowest for intra-operator analysis, with a CR of only 1.3% and a CV half of that calculated for biplane EF (*Tables 1* and *3*). Variability increased progressively from intra- to inter-operator, to inter-cycle with a maximum MPE for test–retest of 6.8% (but lower than EF MPE) and a CR of 2.7% (*Table 3* and Supplementary data online, *Tables S5–S8*). At the regional level, overall variability was slightly lower in the four-chamber view, higher at the base level, lowest for intra-operator, and highest for test–retest (*Table 3* and Supplementary data online, *Tables S6–S8*). At the segmental level, intra-operator and inter-cycle variability were lowest, and test–retest was highest (*Figures 4–6*).

The BA analysis suggested in the optimal setting (intra-operator variability: no change in ultrasound equipment, operator, or reader) a measurement uncertainty ≤1.4% (absolute value) for GLPSS, ≤2% at regional, and ≤4% at the segmental level (*Table 3*, *Figure 6*) (respectively 1.8, 2.8 and 5.1% for inter-cycle variability). Maximum variability (test–retest) was ≤2.7% for GLPSS, ≤4.1% for regional (*Table 3*), and ≤7.2% for mean segmental strain (*Figure 6*). Global

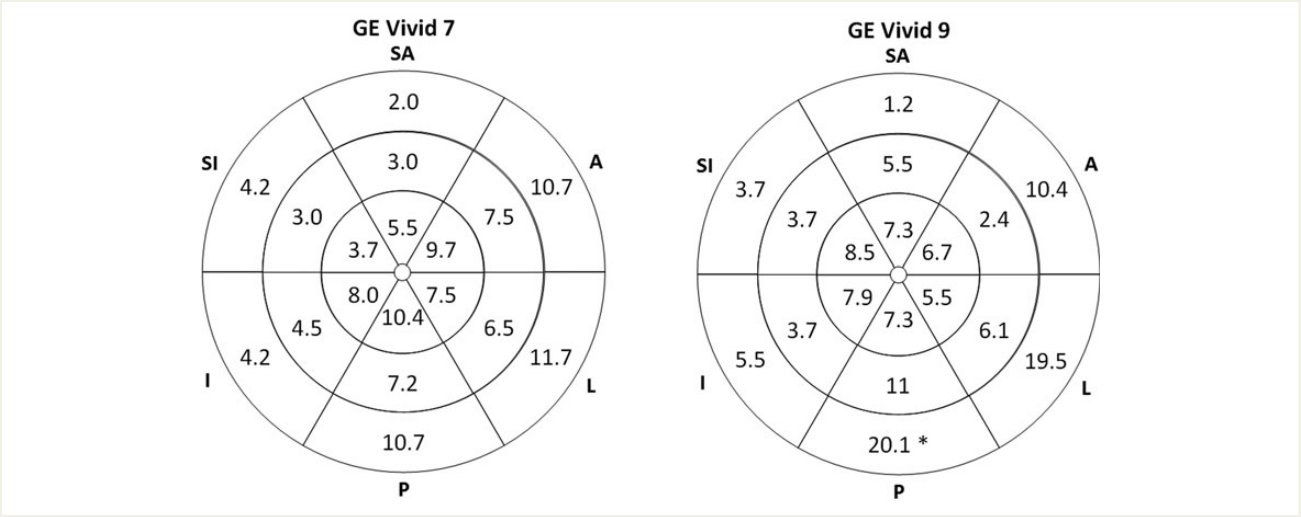

Figure 3: Segmental AFI feasibility analysis. Segment exclusion rates (%) are reported separately for the two ultrasound equipments used (GE Vivid 7 and 9). *$P = 0.03$, χ^2 test vs. GE Vivid 7.

Table 2 Coefficient of variation (%) for variability of 2D biplane variables

	Intra-operator	Inter-operator	Inter-cycle	Test–retest
Intra-operator				
EDV (mL)	3.1	7.9	5.9	6.5
ESV (mL)	7	10.7	10.9	11.9
EF (%)	5.3	9.1	7.4	6.8

Table 3 Global and regional variability of strain variables

	Intra-operator	Inter-operator	Inter-cycle	Test–retest
Coefficients of variation (%)				
Global				
GLPS	−2.6	−4.8	−3.8	−5.4
Regional				
Four chamber	−3.3	−6.6	−5.5	−8.5
Two chamber	−4.8	−7.5	−6.5	−7.3
Three chamber	−4.3	−7.5	−5.3	−9.7
Base, mean	−11.1	−14.2	−13.2	−17.7
Papillary, mean	−6.9	−10.1	−8.9	−12.4
Apex, mean	−8.5	−13.8	−9.2	−13.9
Bias (%)/coefficient of repeatability (%)				
Global				
GLPS	0.1/1.3	−0.4/2.4	0.3/1.8	0.01/2.7
Regional				
Four chamber	−0.03/1.7	−0.4/3.1	0.3/2.7	0.1/4.3
Two chamber	−0.03/2.3	−0.5/3.8	0.4/3.1	−0.4/3.5
Three chamber	0.1/2.1	−0.2/3.5	0.01/2.6	0.5/4.6
Base, mean	−0.1/4.4	−0.5/6.2	0.08/5.5	−0.2/7.4
Papillary, mean	−0.03/3.4	−0.7/4.7	0.1/4.4	0.2/6.1
Apex, mean	−0.04/5	0.2/7.3	0.5/5.4	−0.1/8.1

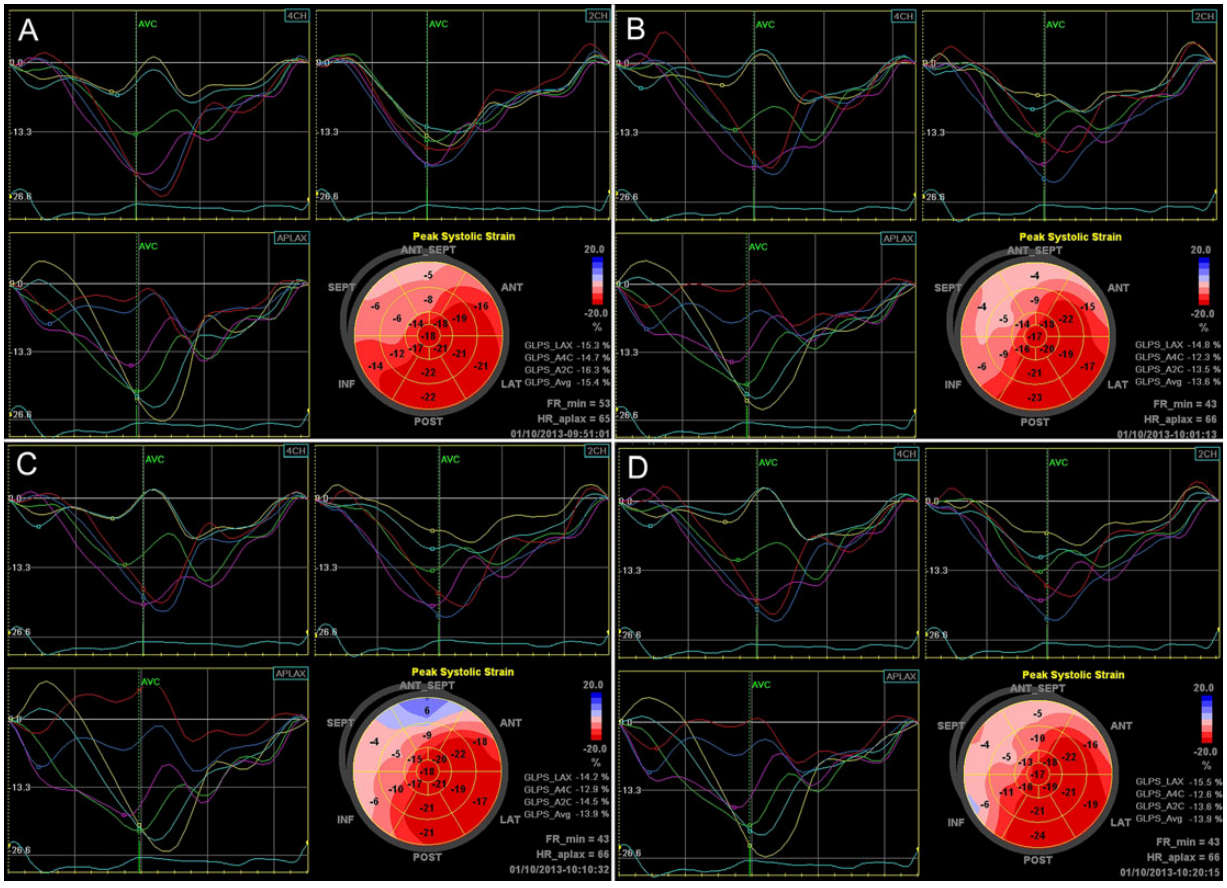

Figure 4: Examples of AFI test (*A*)–retest (*B*), inter-cycle (*C* vs. B), and intra-observer variability (*D* vs. B) in a patient with left bundle branch block and mild reduction of LV ejection fraction (42%). Abbreviations as in *Figure 1*. Overall, segmental strain appears highly reproducible, whereas regional and segmental variations may occur: (i) note the basal anterior septum segment (red line, APLAX view) that shifts from an akynetic (A, B, and D) to a dyskinetic profile only in C; (ii) a slight shift of the transducer at test–retest (B vs. A) produces a different segmental profile in the two-chamber view: more abnormal in *B* with higher dispersion of segmental peak strain, producing a lower (−13.5 vs. −16.3%) regional longitudinal peak systolic strain.

and segmental ICC and MPE values are also reported (Supplementary data online, *Tables S5–S8*).

Variability of global GLPSS was half of that of EF for intra-operator, inter-operator, and inter-cycle analysis, and similar to EF for test–retest. At regional level, overall strain variability was similar to that of four- and two-chamber EDV. At segmental level, overall strain variability was similar or lower to that of ESV.

Determinants of variability

No determinants were found for intra- and inter-operator GLPSS variability (MPE), whereas lower stroke volume and EF were associated, respectively, with higher inter-cycle ($B = -0.12$, $r^2 = 0.24$, $P = 0.018$) and test–retest ($B = -0.18$, $r^2 = 0.15$, $P = 0.031$) variability. Baseline EF influenced also EF inter-cycle variability (MPE) ($B = -0.37$, $r^2 = 0.13$, $P = 0.008$), whereas no determinants were found for intra-operator, inter-operator, and test–retest variability. Scanner type and frame rate had no influence.

When segments with MPE $\geq$ 40% (8.3% of total) were reviewed, three causes were identified (*Figures 7 and 8*) with a (not significant) pattern of regional differences in their distribution; 40% of these segments were equally distributed between the base anterior septum and inferior wall, and the papillary lateral and the apical inferior walls. The highest MPE was found in the base anterior septum and wall. No differences in heart rate or frame rate were observed between segments with MPE above or below 40%.

Discussion

This is the first study to analyse both global and segmental LPSS feasibility and variability in patients with heart diseases. We report that overall feasibility is high, and that reproducibility of global and regional/segmental measures of LV longitudinal deformation is, respectively, excellent and good, and higher than previously assessed. Reproducibility of global strain (GLPSS) was better or similar to that of EF; reproducibility of segmental strain was similar to that found (and generally accepted) for 2D volumes.

Variability of 2D measures

We compared variability of longitudinal strain with that of 2D LV volumes and EF, because the latter are the most frequently

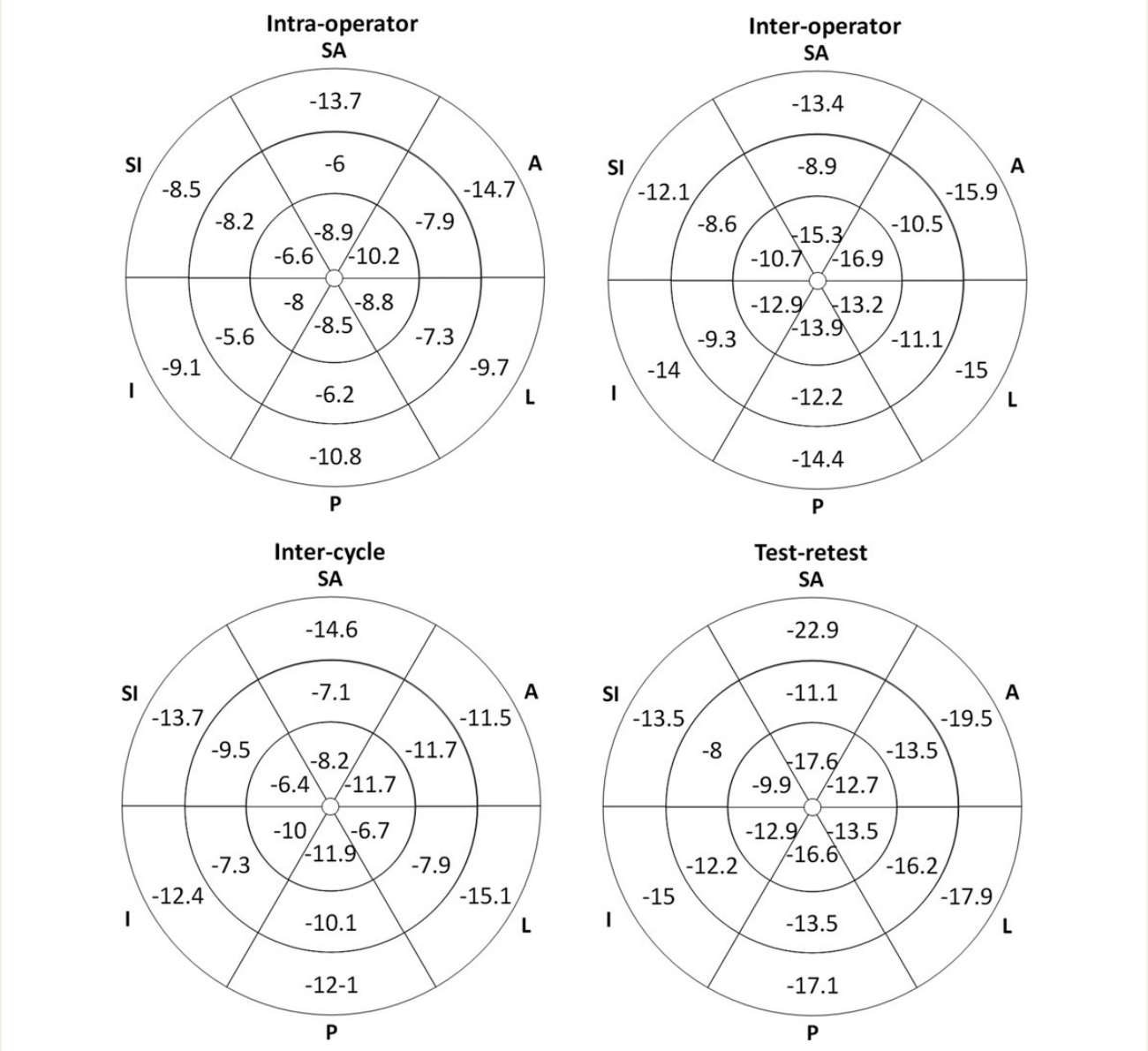

Figure 5: Bull's eye representation of left ventricular segmental (18-segment model) variability with coefficient of variation (%) analysis. A, anterior wall; I, inferior wall; L, lateral wall; P, posterior (postero-lateral) wall; SA, septum, anterior; SI, septum, inferior.

performed measures in cardiology, with known and accepted (for clinical use) variability. In contrast, variability of GLPSS and especially segmental LPSS, which are emerging new methods to measure LV mechanics,[1,8] has only been assessed in small groups, using different statistical methods.[2,7,9–14] Strain analysis evaluates separately longitudinal, radial, and circumferential deformations to quantitate early systolic dysfunction in heart diseases, in relation to myocardial fibrosis or regional ischaemia.[15] Among the different vectors, longitudinal strain has gained popularity because of higher feasibility and reproducibility,[2] and on-board availability.

Different authors have analysed variability of LV volumes and EF,[4,16–23] which was generally higher[18,21,23] or much higher[22] compared with our study; interestingly, in one instance, inter-observer variability using contrast was comparable.[21] Echocardiographic imaging is dependent on both operator skill and experience, the main pitfall for LV volume acquisition being long-axis foreshortening:[24] in this respect, end-diastolic and end-systolic long axes were identical in our study between test–retest acquisitions (Supplementary data online, *Table S1*). Although improved spatial and temporal resolutions over time explained most of the observed reduction in measurement variability, other factors—variable technical skills and the attention to foreshortening—must be taken into account.

Variability of GLPSS

Our study demonstrates that across a large spectrum of LV geometrical and functional alterations, reproducibility of GLPSS is excellent: highest for intra-operator, lowest for test–retest, and intermediate for inter-operator and inter-cycle assessments. The test–retest

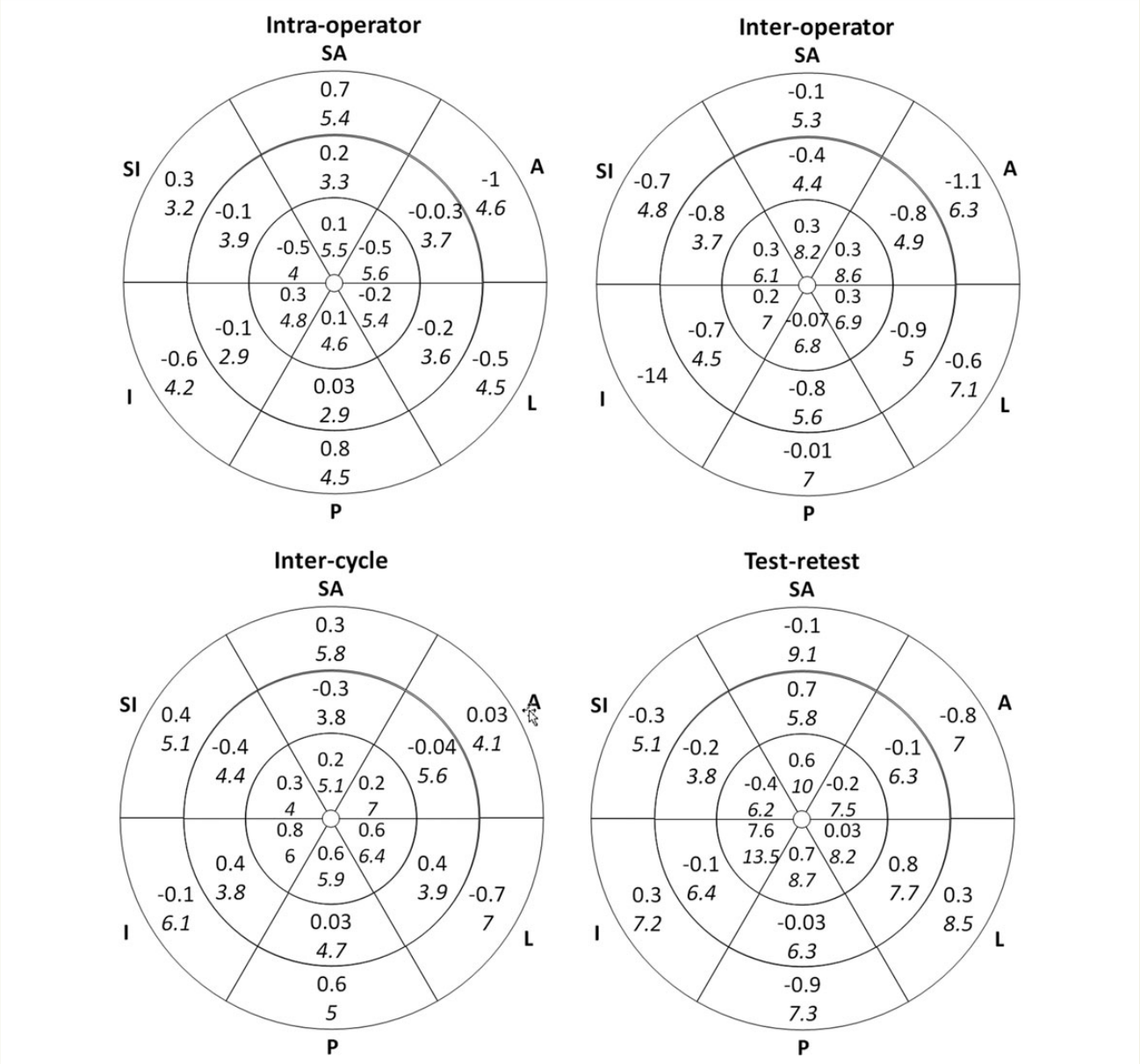

Figure 6: Bull's eye representation of left ventricular segmental (18-segment model) variability with Bland–Altman analysis (bias and coefficient of repeatability, %). A, anterior wall; I, inferior wall; L, lateral wall; P, posterior (postero-lateral) wall; SA, septum, anterior; SI, septum, inferior.

absolute 95% limits of agreement (−2.6–2.7%) and relative MPE (6.8 ± 6.6%) define the accuracy of GLPSS changes both in early diagnosis of LV systolic dysfunction and during follow-up. Interestingly, these limits are narrower than those of EF, and this difference is partly explained by the semi-automated method used to measure strain. Variability was also low in inter-cycle testing, which may obviate the 'three-cycle average' custom: since AFI software does not allow automated averaging, avoiding this tedious task may foster its routine use.

Our data show an overall improvement in GLPSS variability compared with previous studies (EchoPac software): from 7.9 to 3.3% MPE for intra-observer and from 7.9 to 6% for inter-observer variability in 10 patients with non-obstructive hypertrophic cardiomyopathy;[9] from 0.95 to 0.996 ICC for intra-observer, and from 0.92 to 0.99 for inter-observer variability (similar bias) in 25 patients with coronary artery disease or heart failure;[7] from 6 to 3.3% MPE for test–retest variability in 10 normals, with comparable intra-observer and inter-observer MPE;[11] from 0.807 to 0.996 ICC in 20 normals;[12] from 5.5 to 2.6% CV for intra-observer, and from 7 to −4.8% for inter-observer variability in 30 patients.[2] Finally, both inter- and intra-observer variability (ICC and bias) were similar in a recent study in 50 patients with different heart diseases.[14] As noted,[2] type of scanner and the range of frame rate used did not influence overall variability.

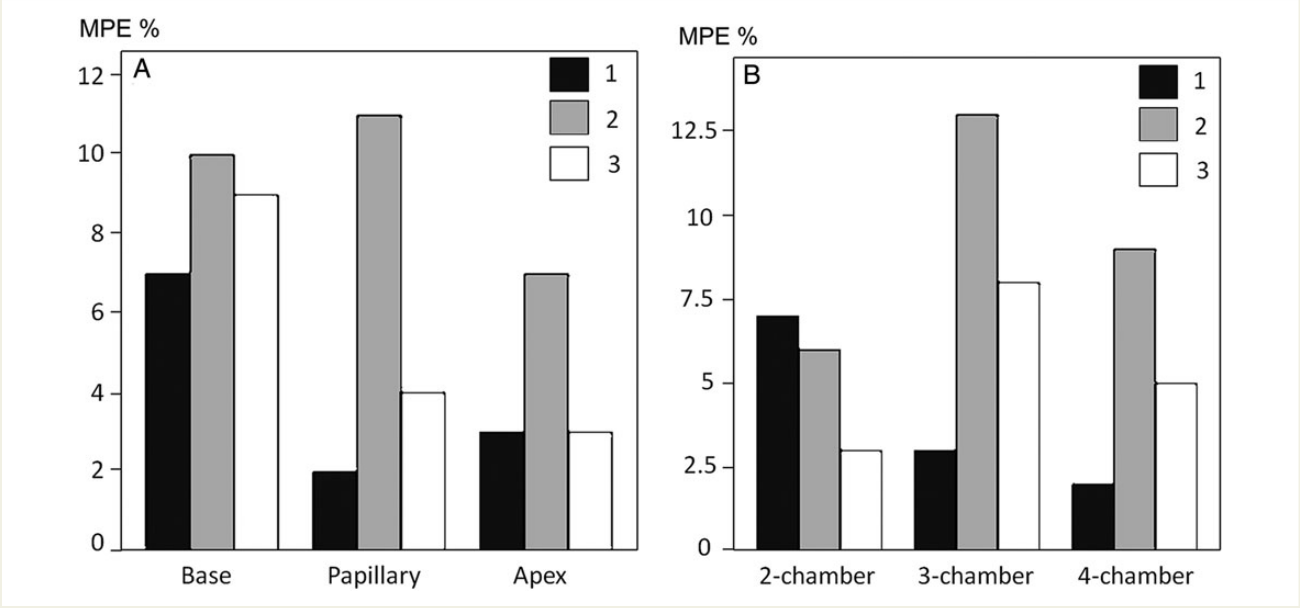

Figure 7: Causes of high segmental strain MPE (≥40%) at test–retest analysis. (*A*) Analysis by region and (*B*) analysis by view. (i) Suboptimal 2D imaging; (ii) minor changes in transducer angulation; (iii) insufficient ROI width. Suboptimal 2D imaging prevails at the base and in two-chamber view; and minor changes in transducer angulation within the same view are the main cause and appear uniformly distributed; insufficient ROI width prevails at the base and in three-chamber view.

Feasibility and variability of segmental strain

Feasibility

Average feasibility was very high (93%), best at papillary level, and lowest at the base lateral and posterior walls. Although lower lateral scanning resolution in the far field was consistent with the latter finding, the apparent lower feasibility in these segments with the Vivid 9 was unexplained. However, it must be stressed that the use of newer technology (higher penetration and resolution) increased dramatically feasibility of 2D wall imaging (*Figure 1*). No operator-related differences were found. Time required to obtain AFI data prolonged the examination, the main issue being the algorithm difficulty to automatically 'hook-up' the mitral annulus in the basal segments. Further, the time required to obtain the apical views suitable for AFI analysis was longer than that necessary to obtain the same apical views for ejection fraction analysis.

Variability

Segmental variability was previously analysed only in a small normal group:[10] four-chamber intra- and inter-observer ICC ranges (0.79–0.92 and 0.58–0.87) were much lower than in our study (Supplementary data online, *Tables S5 and S6*). Variability in the two-chamber segments was unacceptably high, an unexplained finding at variance with the good feasibility and reproducibility of our measurements.

In our study, only 8% of segments had a high MPE (≥40%, in the 'worst case scenario' of test–retest variability), prevalently in the base anterior septum and anterior wall segments. The high segmental MPE occasionally found at test–retest were secondary to amplification of small (clinically insignificant) differences between positive and negative values of LPSS around the zero strain line, which resulted in MPE > 100% (*Figure 5* and Supplementary data online, *Figures S1 and S2*). Thus, MPE may overestimate variability of LPSS in abnormal segments and in this respect is less useful than bias ± CR or CV (Supplementary data online, *Figure S2*).

As expected, reduced EF (increased volumes and segmental dyssynchrony) was associated with increased variability. More noticeable were the effects of lower imaging quality, minor changes in transducer scan angulation, and insufficient ROI width (*Figures 7 and 8*, and Supplementary data online, *Figures S1 and S2*). The main explanation for the observed higher test–retest variability were the minor changes in scan angulation occasionally occurring between same view acquisitions, given that the algorithm appears to track (accurately) a different portion of the same wall segment (*Figure 7* and Supplementary data online, *Figure S1*). Consequently, side-by-side use of previous imaging using papillary muscles as view markers should reduce variability consistently.

Although reproducibility of segmental LPSS was not as good as that of GLPSS, it was nonetheless similar to that generally accepted for ESV (currently used in trials to monitor LV remodelling and outcome). We suggest that segmental measures of LPSS are as acceptable for clinical use as GLPSS, but that regional differences in variability must be taken into account when evaluating regional function. Segmental strain analysis has important clinical applications for analysis of LV regional function in coronary heart disease and various cardiomyopathies.

Limitations

Variability analysis of this study was limited to a single vendor software. Since differences are known to exist between vendors, our

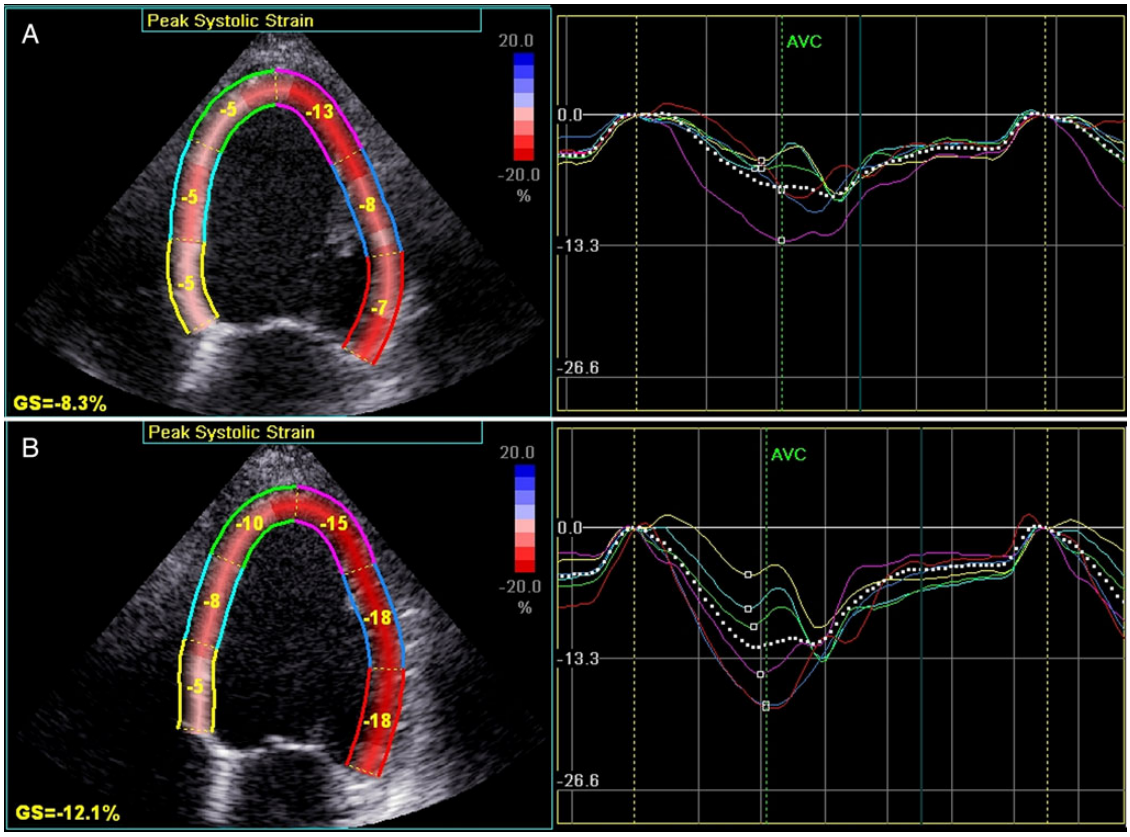

Figure 8: Example of four-chamber test (*A*)–retest (*B*) variability, secondary to minor modification of scanning plane angulation. Compared with B, more posterior portions of the base and mid-lateral wall segments are visualized in A (demonstrated by partial visualization of the lateral papillary muscle) with calculated different segmental (red and blue segments) and regional (GS) peak systolic strains. In this example, test–retest variability is caused by differences in transducer position, whereas the algorithm tracks accurately different (contiguous) portions of the same wall.

results cannot be immediately extended to other strain analysis packages.

Conclusion

This is the largest study to compare measurement variability of both global and segmental longitudinal strain with that of standard 2D LV volumes and EF for intra-operator, inter-operator, inter-cycle, and test–retest differences. Reproducibility of GLPSS and segmental LPSS are, respectively, excellent and good, better or similar than that of 2D LV volumes and EF, and thus suitable for clinical use for both diagnosis follow-up studies of LV global and regional systolic function. However, 7% of segments were excluded because of sub-optimal tracking.

Conflict of interest: None declared.

Supplementary data

Supplementary data are available at *European Heart Journal – Cardiovascular Imaging* online.

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