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Impact of apical foreshortening on deformation measurements: a report from the EACVI-ASE Strain Standardization Task Force

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Aims Foreshortening of apical views is a common problem in echocardiography. It results in an abnormally thick false apex and a shortened left ventricular (LV) long axis. We sought to evaluate the impact of foreshortened (FS) on LV ejection fraction (LVEF) and layer-specific 2D speckle tracking based segmental (S) and global (G) longitudinal strain (LS) measurements.

Methods and results We examined 72 participants using a GE Vivid E9 system. FS apical views were collected from an imaging window one rib-space higher than the optimal images. Ejection fraction as well as layer-specific GLS and SLS measurements were analysed by GE EchoPAC v201 and TomTec Image Arena 4.6 and compared between optimal and FS images. On average, LV long axis was 10% shorter in FS images than in optimal images. FS induced a relative change in LVEF of 3.3% and 6.9% for GE and TomTec, respectively (both, $P < 0.001$). Endocardial GLS was 9.0% higher with GE and 23.2% with TomTec ($P < 0.001$). Midwall GLS measurements were less affected (7.8% for GE and 14.1% for TomTec, respectively, both $P < 0.001$). Segmental strain analysis revealed that the mid-ventricular and apical segments were more affected by foreshortening, and endocardial measurements were more affected than midwall.

Conclusion Optimal image geometry is crucial for accurate LV function assessment. Foreshorhening of apical views has a substantial impact on longitudinal strain measurements, predominantly in the apex and in the endocardial layer. Our data suggest that measuring midwall strain might therefore be the more robust approach for clinical routine use.

Keywords foreshortening • speckle • strain • tracking

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Introduction

Foreshortening of apical views is a common problem in routine two-dimensional echocardiography (2DE). Foreshortened (FS) echocardiographic views are characterized by an imaging plane that usually transects the heart above and anterior of the true apex leading to a geometric distortion of the image of the left ventricle. As a result, the long axis of the left ventricle appears shorter and the false apex is thicker and apparently hyper-contractile resulting in an overestimation of both global and regional left ventricular (LV) function and an underestimation of LV volume and length. Furthermore, assessment of apical geometry and function are hindered.

LV ejection fraction (LVEF) is the most frequently reported parameter to describe global systolic LV function,[1] but global longitudinal strain (GLS) measured by speckle tracking 2DE has now emerged as a clinically valuable complementary parameter which is both robust and sensitive to subtle functional changes.[2,3] Several vendors of speckle tracking software allow to measure strain in different layers of the myocardium as this has been suggested to add clinically useful information.[4] Little is known, however, how foreshortening affects global and regional longitudinal strain measurements in different myocardial layers.[5,6] We, therefore, investigated the effects of foreshortening on speckle tracking based functional measurements using software packages from two different vendors which are representatives of two different technical approaches for strain measurements.

Methods

Study population

The study population consisted of 72 volunteers and patients with a wide range of cardiac conditions to represent a real-world clinical situation. Participants were enrolled from the echocardiography unit of the University Hospital Leuven and its Medical Imaging Research Centre. Inclusion criteria were: (i) being older than 18 years of age, (ii) having good echocardiographic image quality with an apical image window covering at least two intercostal spaces, (iii) being in sinus rhythm, and (iv) being able to give informed consent.

Study protocol

Patients were scanned in a left supine position using a commercially available Vivid E9 echocardiography machine (GE Vingmed, Horten, Norway). A set of optimized 2D grey scale apical four-, three-, and two-chamber views were recorded, followed by a set of deliberately FS views which were acquired from an imaging window one rib-space higher than that used for optimized views. Care was taken that the mitral valve annulus and the valve opening was still properly displayed (*Figure 1* and Supplementary material online, *Video S1*). At least three consecutive cardiac cycles were recorded during breath hold. Pulsed-wave Doppler tracings from both aortic and mitral valve were used to identify LV time intervals. Average frame rate for grey scale images was 60 frames/s. All recordings were stored in proprietary raw-data and standard Digital Imaging and Communications in Medicine (DICOM) format at the original frame rate to allow post-processing with different software packages.

Data analysis

Strain was measured in the endocardial and midwall layer in all three apical views using EchoPAC BT 201 (GE Vingmed Ultrasound, Horten, Norway) and Image Arena 4.6. (TomTec Imaging Systems, Unterschleissen, Germany). These two software packages were chosen since they represent two different approaches to measure longitudinal strain based on speckle tracking: According to personal communication with the vendors, EchoPAC software performs tracking for the entire myocardial wall thickness as defined by the region of interest borders. To ensure robust measurements, the estimates are then filtered in the longitudinal and radial direction. Strain is then presented for the desired layer in a way that midwall strain is derived as the average over the full wall thickness, while the endo- and epicardial strain values represent the deformation of the respective inner and outer contour of the region of interest. TomTec communicated, that their software performs tracking around a sub-endocardial, midwall, and sub-epicardial line with subsequent calculation of layered strain from the weighted measurements. The width of the myocardial region around the line which is used for tracking is not disclosed.

With both software packages, identical images were analysed (proprietary Raw-DICOM data format for GE, full frame rate Standard-DICOM data format for TomTec). Tracking was performed as recommended by the vendors. The electrocardiogram R-wave trigger served as definition of end-diastole. End-systole was defined according to the time of aortic valve closure in the PW-Doppler traces of the LV outflow tract. Tracking quality was visually checked by comparing the motion of the tracking points with the motion of the underlying myocardium. We used an 18-segment model of the left ventricle.[1,2] Apical views with more than two poorly tracked LV segments were rejected from the global strain analysis. The average GLS was calculated from at least two apical views. All strain measurements were performed by a single reader (S.U.), who has a long experience with echocardiography and strain analysis and had been personally trained by a software application specialist prior to start analysing the images.

LV volumes and ejection fraction (EF) were calculated from apical four- and two-chamber views, using the same echo data sets as indicated above with the auto EF function of EchoPac and the automated EF measurement function of Image Arena, respectively.

Statistical analysis

Normality of distribution was tested by a Kolmogorov–Smirnov test. Categorical data are presented as percentages and continuous variables are presented as mean ± standard deviation or median and interquartile range. The change in strain values due to foreshortening is described as percentage. Paired *t*-test or Wilcoxon test was used to assess differences between layers, optimal and FS images and companies. A P-value of <0.05 was considered statistically significant. All data were analysed using SPSS (IBM, Chicago, IL, USA) version 23.0.

Results

Study population

The study population comprised 44 healthy volunteers, 13 patients with reduced LV systolic function and 15 patients with LV hypertrophy with an average age of 41 ± 18.0 years. The EF ranged from 20% to 77% and the end-diastolic volume from 38 mL to 312 mL.

Conventional echocardiographic parameters

LV long-axis appeared on average 9.8% shorter in FS images compared with optimized views ($P < 0.001$). End-diastolic and end-systolic volumes were significantly lower in FS images (both, $P < 0.001$). The median relative difference in LVEF was 3.3% for GE

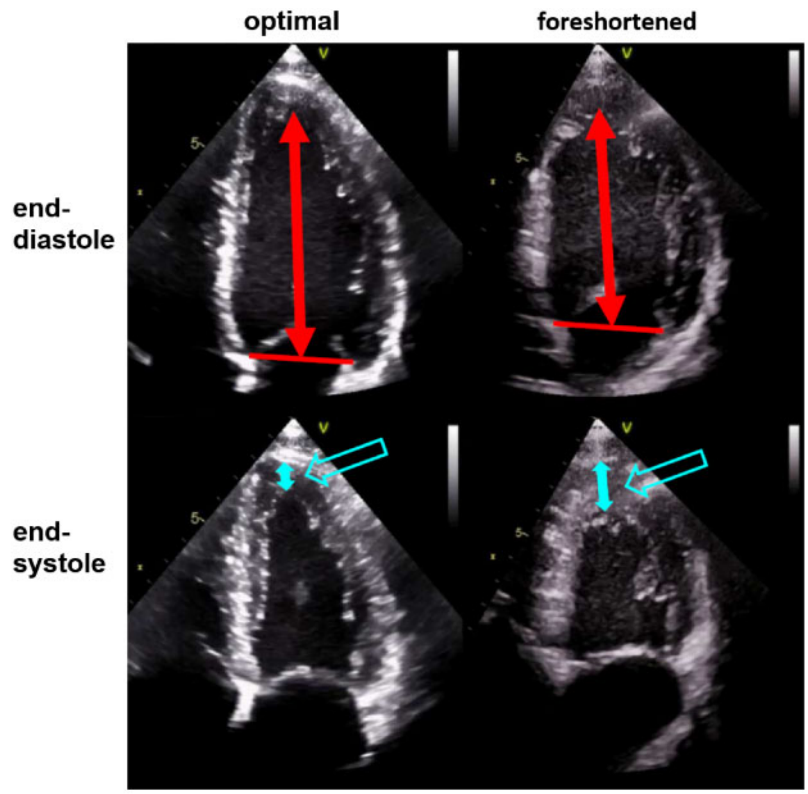

Figure 1 Image geometry in optimal and foreshortened images. Compared with optimal images (left panels), foreshortened images (right panels) have a reduced LV length (red arrow) and show an apparent thickening of the apex (light blue arrows).

and 6.9% for the TomTec software package (non-significant between vendors, *Figure 2*). An overview of the influence of foreshortening on conventional echocardiographic parameters is presented in *Table 1*.

2D layer-specific global longitudinal strain measurements

With both software packages, foreshortening resulted in a significant increase in the measured endocardial and midwall GLS (all $P < 0.001$). Endocardial GLS in FS images showed a significant relative increase by 9.0% with GE and by 23.2% with TomTec software ($P < 0.001$ between vendors). The relative increase in midwall GLS was 7.8% and 14.1% with GE and TomTec, respectively (*Figures 2* and *3*, *Table 2*).

2D layer-specific segmental peak systolic longitudinal strain measurements

In similarity to GLS, foreshortening resulted also in an increase of segmental strain measurements (Supplementary material online, *Videos S2* and *S3*). The apical segments were the most affected and the basal segments the least (*Figure 3*). Endocardial segmental strain measurements were more affected by foreshortening than midwall layer measurements (*Figures 3* and *4*). The susceptibility to foreshortening was significantly different between the two software packages (*Figure 4*). Numeric details are provided in *Table 3*.

Discussion

Main findings

In this study, we investigated the impact of foreshortening on speckle tracking 2DE derived layer-specific global and segmental strain measurements using two different software packages to represent different approaches to LV tracking. The main findings can be summarized as follows: (i) speckle tracking 2DE derived endocardial strain is more affected by foreshortening than midwall strain measurements, (ii) apical and mid-ventricular segments of the left ventricle are more affected than basal segments, and (iii) software packages of different vendors can show significant differences in susceptibility to foreshortening.

Software selection

The two software packages (GE EchoPac 201, TomTec Image Arena 4.6) were chosen as they represent two different approaches to myocardial functions assessment by 2D speckle tracking. The software of GE tracks all myocardial features within a defined region of interest that is intended to cover the entire thickness of the myocardium. The default output is the average full wall strain which approximately represents tracking the middle of the wall. Layer-specific strains of the endocardium and epicardium are calculated from the filtered full wall data. While this approach has the advantage of using all available myocardial features

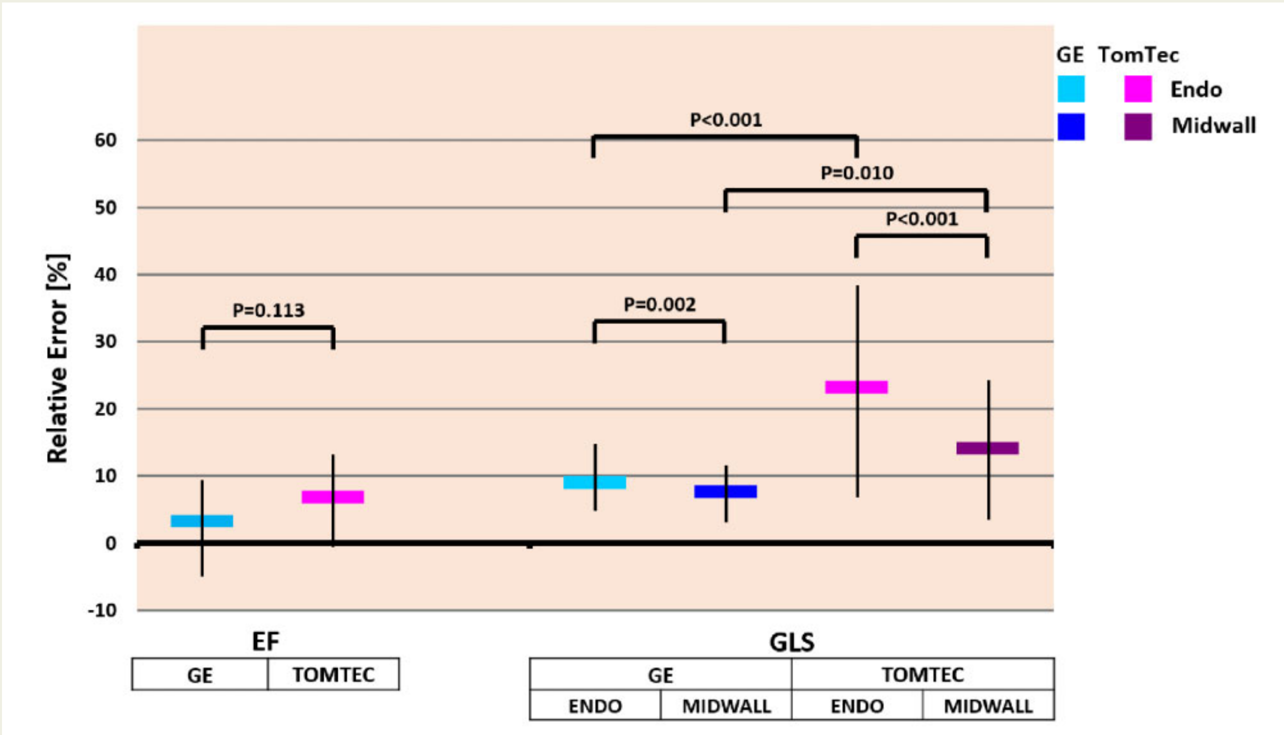

Figure 2 Relative error in EF and GLS measurements caused by foreshortening. The median of the relative differences of EF as well as endocardial and midwall GLS measurements between optimal and foreshortened images are presented per vendor. Light colours are used for endocardial, dark colours for midwall measurements. See *Tables 1* and *2* for numeric values.

Table 1 Conventional echocardiographic parameters in optimal and foreshortened images per vendor

Parameters	GE			TomTec			*P*-value[b]
	Opt. image	FS image	*P*-value[a]	Opt. image	FS image	*P*-value[a]	
LVEF (%)	59.8 ± 10.6	62.1 ± 9.2	<0.001	58.1 ± 10.7	62.2 ± 12.3	<0.001	
Relative change in LVEF (%)	3.3 (-5 to 9.4)			6.9 (-1 to 13.2)			<0.001
ESV (mL)	43.3 ± 42.8	38.6 ± 38.4	<0.001	42.7 ± 41.8	37.8 ± 32.7	<0.001	
EDV (mL)	101.2 ± 52.8	92.5 ± 49.0	<0.001	95.1 ± 46.1	88.7 ± 39.3	<0.001	
Systolic length of LV (mm)	6.9 ± 0.8	6.6 ± 0.8	<0.001				
Diastolic length of LV (mm)	8.3 ± 0.9	7.6 ± 0.7	<0.001				

EDV, end-diastolic volume; ESV, end-systolic volume; FS, foreshortened; GE, General Electric; LV, left ventricle; LVEF, left ventricular ejection fraction; Opt., optimal.
[a]Comparison between optimal and foreshortened images within a vendor.
[b]Comparison between vendors for relative changes.

(speckles) in the region of interest for tracking, which increases robustness, it might be less susceptible in case of layer-specific differences.

TomTec software is a representative of a tracking software that defines the region for tracking around a line. This line is usually the endocardial border with in addition a certain myocardial region around it, the thickness of which is usually not disclosed. While endocardial strain is the typical default output, other lines (midwall, epicardial) can be added to the analysis and their values can be provided as well. This line tracking approach seems to use less myocardial features which might increase the noise level, but might result, on the other hand, in a more layer-specific measurement.

Foreshortening in conventional echocardiography

Foreshortening of apical views is a frequent problem in routinely performed 2DE examinations. The most common cause of foreshortening is an inadequate imaging window due to the anatomical characteristics of the patient, but it can also occur more frequently in acquisitions obtained from less experienced sonographers. Foreshortening results not only in an apparently shorter long axis of

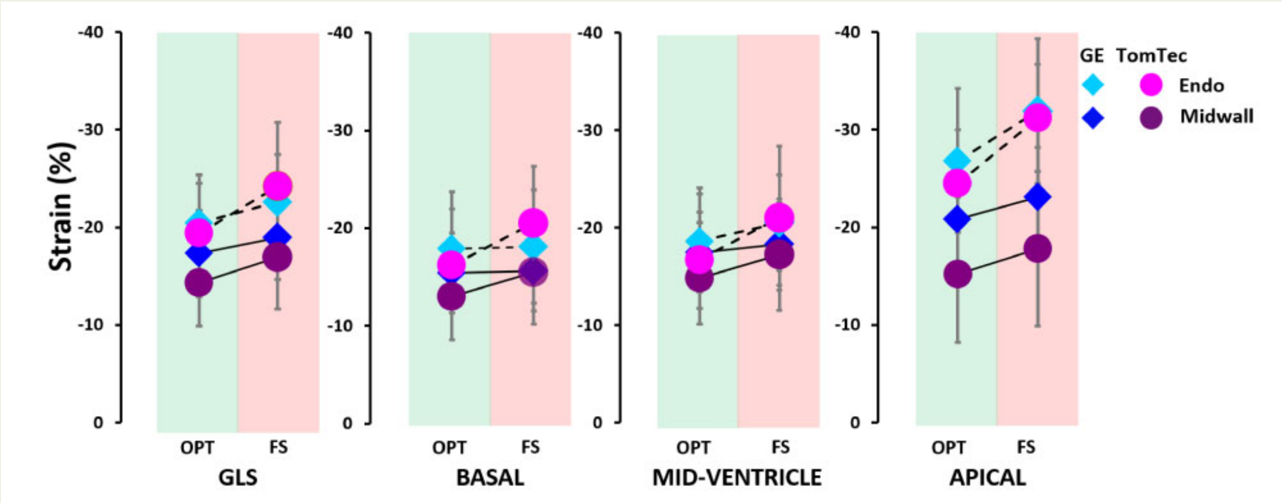

Figure 3 Global and segmental strain and its changes due to foreshortening. Average left ventricular global and segmental longitudinal strain per vendor and layer in optimal and foreshortened images. FS, foreshortened images; OPT, optimal images. Colours as in *Figure 2*.

Table 2 Layer-specific global longitudinal strain measurements and relative errors for optimal and foreshortened images per vendor

Parameters		GE			TT			*P*-value[b]
		Opt. image	FS image	*P*-value[a]	Opt. image	FS image	*P*-value[a]	
Endocardium	GLS (%)	-20.4 ± 5	-22.6 ± 4.9	<0.001	-19.4 ± 5.1	-24.2 ± 6.5	<0.001	
	Relative error (%)	9.0 (4.8–14.8)			23.2 (6.8–38.3)			<0.001
Midwall	GLS (%)	-17.3 ± 4.4	-18.9 ± 4.3	<0.001	-14.3 ± 4.4	-16.9 ± 5.3	<0.001	
	Relative error (%)	7.8 (3.2–11.6)			14.1 (3.5–24.3)			<0.001

FS, foreshortened; GE, General Electric; GLS, global longitudinal strain; Opt., optimal; TT, Tomtec.
[a]Comparison between optimal and foreshortened images within a vendor.
[b]Comparison between vendors for relative changes.

the left ventricle, but—most importantly—in an apparent thickening of apical regions which can impair assessment of global and regional LV function.[7,8] In the present study, we used images with mild (albeit significant) foreshortening which might have been accepted in a routine clinical scan. Consequently, the end-diastolic and end-systolic volumes were measured smaller as volume estimations are largely dependent on LV length,[1] while systolic LV function, described by EF, was significantly overestimated (*Table 1*). Since volume estimates with both software packages were based on comparable automatic endocardial border delineations controlled by the same observer, we found no significant difference between the two software packages regarding the susceptibility of conventional measurements to foreshortening (*Figure 2*).

Impact of foreshortening on global longitudinal layer-specific strain measurements

Foreshortening resulted in higher absolute GLS measurements. This effect was more apparent with TomTec than with GE software, although the image data sets used with both software solutions had identical image geometry. One might speculate that a full wall tracking approach is less influenced by the extreme changes in endocardial behaviour in FS images than an approach that relies on tracking endo- and epicardial myocardium along a line. This would indicate that the two tracking approaches which were compared in this study differ in their susceptibility for distorted image geometry (*Figure 2*).

The effect of foreshortening was significantly more pronounced in endocardial GLS and less in midwall GLS estimates as the endocardial contour is most affected by the impaired image geometry (*Figure 2*). Given that we provoked only mild foreshortening in our study, such as it may occur in difficult to scan patients in the clinical routine, our results suggest that the more robust midwall strain measurements should be preferred for clinical routine use.

In this study, differences in GLS measurements among the vendors differ slightly from previous comparisons where different software versions were used.[9] In concordance with our previous publications, however, we found again for endocardial strain measurements a slightly better agreement among vendors than midwall measurements.[10]

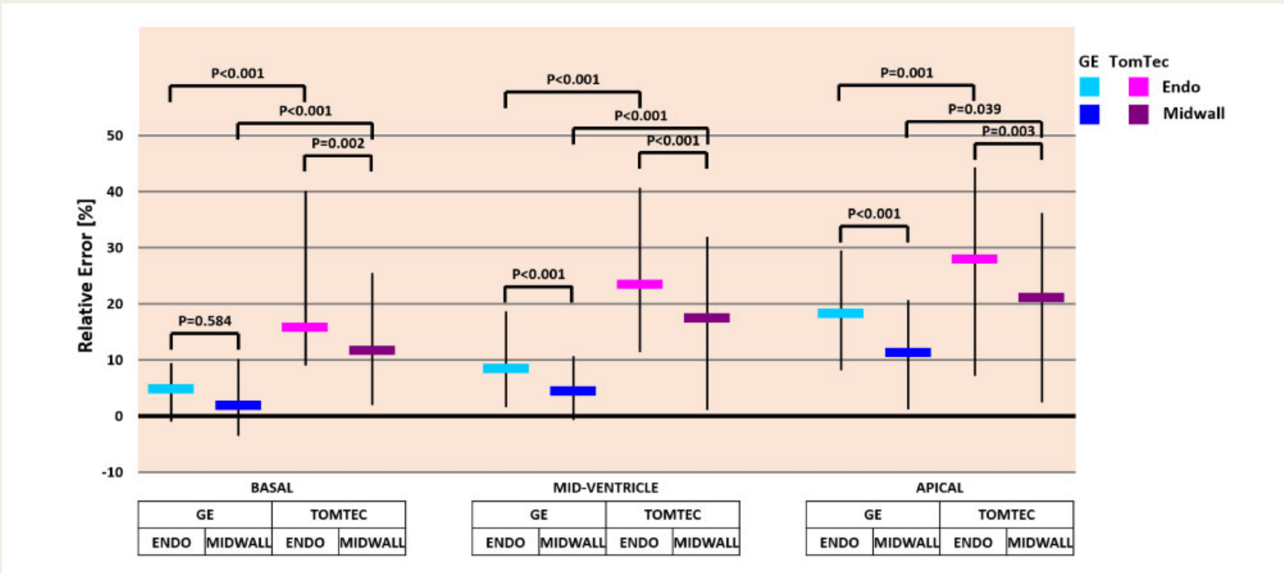

Figure 4 Relative error in segmental strain measurements caused by foreshortening. The relative differences of segmental longitudinal strain measurements between optimal and foreshortened images for basal, mid-ventricular, and apical levels of the left ventricle are presented per vendor. Colour coding as in *Figure 2*. See *Table 3* for numeric values.

Table 3 Layer-specific peak-systolic segmental longitudinal strain measurements and relative errors for optimal and foreshortened images per vendor

Parameters		GE			TT			*P*-value[b]
		Opt. image	FS image	*P*-value[a]	Opt. image	FS image	*P*-value[a]	
Endocardium								
Basal segments	$PSLS_{endo}$ (%)	-17.9 ± 4.9	-18.1 ± 5.8	0.488	-16.2 ± 4.9	-20.5 ± 5.8	<0.001	
	Relative error (%)	4.9 (-1 to 9.4)			15.8 (9.1 to 40.1)			<0.001
Mid-ventricular segments	$PSLS_{endo}$ (%)	-18.6 ± 4.3	-20.5 ± 4.9	<0.001	-16.7 ± 5	-21 ± 7.4	<0.001	
	Relative error (%)	8.5 (1.6–18.7)			23.5 (11.4–40.7)			<0.001
Apical segments	$PSLS_{endo}$ (%)	-26.8 ± 6.8	-31.9 ± 7.4	<0.001	-24.5 ± 5	-31.2 ± 5.5	<0.001	
	Relative error (%)	18.3 (8.1–29.5)			28 (7.2–44.3)			<0.001
Midwall								
Basal segments	$PSLS_{midwall}$ (%)	-15.4 ± 4.1	-15.6 ± 4.1	0.316	-13 ± 4.4	-15.5 ± 5.3	<0.001	
	Relative error (%)	2 (-3.5 to 10.2)			11.7 (1.9 to 25.5)			<0.001
Mid-ventricular segments	$PSLS_{midwall}$ (%)	-17.4 ± 4.0	-18.3 ± 4.2	<0.001	-14.8 ± 4.7	-17.2 ± 5.7	<0.001	
	Relative error (%)	4.5 (-0.6 to 10.7)			17.5 (1.1 to 32)			<0.001
Apical segments	$PSLS_{midwall}$ (%)	-20.8 ± 5.3	-23.1 ± 5.1	<0.001	-15.2 ± 7	-17.8 ± 7.9	<0.001	
	Relative error (%)	11.3 (1.2–20.6)			21.1 (2.5–36.1)			<0.001

FS, foreshortened; GE, General Electric; Opt., optimal; PSLS, peak-systolic longitudinal strain; TT, Tomtec.
[a]Comparison between optimal and foreshortened images within a vendor.
[b]Comparison between vendors for relative changes.

Impact of foreshortening on segmental longitudinal layer-specific strain measurements

In general, the effect of foreshortening was highest close to the apex and least at the base of the left ventricle. These findings differ from a previous publication which also aimed at investigating the impact of foreshortening on segmental strain measurements and which found that basal segments are the only affected part of the myocardium.[6] In this study, however, apical five-chamber views were regarded as a FS version of apical four-chamber views which might be questioned as an apical five-chamber view requires tilting the image plane anteriorly from a stable apical point while foreshortening occurs due to an inappropriate position of the probe with largely unaffected basal parts of the image.

We observed relevant differences in segmental strain measurements between the two software packages (Supplementary material online, *Videos S2* and *S3*). The differences ranged from not relevant in basal midwall measurements to very pronounced overestimation in some apical endocardial measurements. Apical endocardial longitudinal deformation was overestimated up to almost 30% which renders such measurements useless for clinical purposes. But also the least affected midwall apical strain estimate showed an overestimation of over 10% which is not acceptable for clinical use and which underlines the importance of correct image acquisition for accurate functional measurements.

Limitations

Our study population has only a moderate size and may not cover all possible geometric distortions that might occur on clinical practice. We believe, however, that the wide range of LV shapes and function included in this study is sufficient to allow general conclusions about the impact of foreshortening on longitudinal strain measurements with different software solutions.

Our study compared only two software packages. It cannot be excluded that using other software might give slightly other results. Our design allowed, however, to compare the two most frequently used approaches to LV tracking (endo/epi and full wall) and this with even the same images, thus reducing inter-observer variability.

Clinical relevance of foreshortening

Echocardiographic measurements are significantly affected by distorted image geometry due to foreshortening. Echocardiographers should therefore aim at recognizing inappropriate images and strictly reject such data from further use. When feasible, 3D volumetric acquisitions might help to explore the actual image geometry in order to avoid foreshortening. Recent advances in machine learning have led to an automated recognition of the key aspects of echocardiographic images including the appropriateness of views. This emerging technology is likely to reduce the problem of distorted data sets as it can guide the less experienced user. Machine learning could therefore play an important role in the standardization of image acquisitions and analysis.[11–13]

Conclusion

Given the significant effect of foreshortening on conventional and strain measurements, the paramount relevance of good image quality for proper functional measurements cannot be overestimated. Images with distorted geometry should not be used for further processing.

Foreshortening affects the results from different software packages differently which might be a result of differing concepts about how to perform tracking in the myocardial wall. Regardless of the software used, however, midwall measurements were in all circumstances less affected by foreshortening than endocardial measurements. Accordingly, our data support the notion that midwall strain measurements are more robust and should therefore be preferred in the clinical routine.

Supplementary data

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

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Conflict of interest: none declared.

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