Estimate of global radial, circumferential, and longitudinal strain from SSFP cines: a study in controls and patients with low to normal ejection fraction

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Introduction: Left ventricular (LV) ejection fraction (EF) cannot distinguish contributions from longitudinal and circumferential function, and furthermore, is preserved in some cardiac conditions despite abnormalities in LV morphology and function. Longitudinal, circumferential, and radial strains have been studied as more sensitive markers of dysfunction than EF, particularly in the early stages of disease[1–3]. However, quantitative strain analysis with tissue tagging is not part of most clinical studies due to added data acquisition times and onerous post-processing. We propose surrogates for global longitudinal, circumferential, and radial strains measured from SSFP cine images based on the change in endocardial and epicardial borders over the entire LV. Here, these metrics are measured in controls and patients with a wide range of EFs and compared with literature values.

Methods: 19 healthy subjects (28±3 yrs) and 52 patients (13 systolic and 18 diastolic heart failure, 3 at risk for heart failure, 7 coronary artery disease, 11 inflammatory heart disease, 57±18 yrs) were studied with standard SSFP exams (1.5/3.0 ms TE/TR, 60° flip angle, 8 mm slice thickness, 2 mm gap between slices, 256 points resolution, ~10 short axis and 3 long axis slices). Patients were divided into groups based on EF: >55%, 40–55%, and <40%. The LV was manually traced at end systole and end diastole. Method of disks combined with long axis information was used to calculate EF, longitudinal (LS) and circumferential shortening (CS), radial thickening (RT), and long axis shortening (LAS) using the average lengths over the entire LV in the directions indicated in Fig. 1. These percent changes in average length were used as surrogates for strain. The average of endocardial and epicardial shortening was measured to represent mid-wall strain.

In addition to estimates of linear strains, longitudinal and circumferential contributions to EF were evaluated using a model[4]: volume = constant × length × (circumference)^2, yielding the following estimate of EF: $EF_M = 1-(1-LAS)\times(1-CS_{endo})^2$. $EF_L = 1-(1-LAS)$ is the approximate longitudinal contribution to EF, holding circumference constant, and $EF_C = 1-(1-CS_{endo})^2$ is the equivalent circumferential contribution. The fractional longitudinal contribution to EF is: $EF_L/(EF_L+EF_C)$.

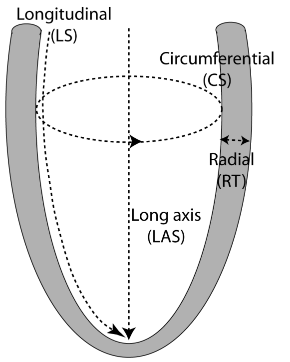

Fig. 1. Radial, circumferential, longitudinal, and long axis directions are shown.

Results: RT, CS, and LS in the control group were similar to average ultrasound speckle tracking and MRI tagging literature strain values in equivalent populations (35–67% radial, 13–43% circumferential, and 14–22% longitudinal strain[1,5,6]). 17 patients had >55% EF, 16 had 40–55% EF, and 19 had <40% EF. Fig. 2 shows the correlation of the EF model with measured EF. Bland-Altman analysis of the model (Fig. 3) yielded a bias of −0.8% and 95% confidence intervals of ±4.4%. Table 1 shows RT, CS, LS, and LAS values. Longitudinal function was reduced in all patient groups, including the preserved EF group where the EF measured was identical to controls.

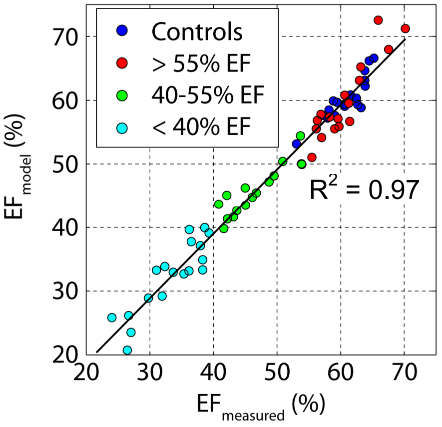

Fig. 2. Correlation between the EF model and measured EF.

Table 1. Parameters of left ventricular deformation

	Controls	>55% EF	40–55% EF	<40% EF
EF, %	60.9 ± 3.1	60.7 ± 4.2	46.7 ± 4.6*	32.7 ± 5.5*
Radial thickening (RT), %	59.0 ± 9.4	55.5 ± 12.1	38.6 ± 8.8*	25.8 ± 8.9*
Longitudinal shortening (LS)				
Endocardial, %	23.1 ± 2.1	21.7 ± 2.7	14.7 ± 2.9*	9.8 ± 3.8*
Average, %	20.9 ± 1.9	19.1 ± 2.3*	13.2 ± 2.3*	9.0 ± 3.6*
Circumferential shortening (CS)				
Endocardial, %	31.3 ± 2.6	31.0 ± 5.2	21.8 ± 2.2*	14.2 ± 3.0*
Average, %	22.1 ± 2.3	21.0 ± 2.9	15.8 ± 1.7*	10.7 ± 2.2*
Long axis shortening (LAS), %	18.3 ± 1.6	16.3 ± 3.4*	11.6 ± 3.4*	7.2 ± 3.6*
Fractional longitudinal contribution to EF	0.26 ± 0.02	0.24 ± 0.04*	0.23 ± 0.05*	0.21 ± 0.09*

* represents $p < 0.05$ compared to controls

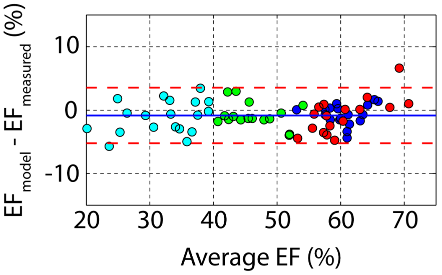

Fig. 3. Bland-Altman plot of measured EF and the EF model.

Conclusions: Radial thickening and longitudinal and circumferential shortening can be determined from conventional cines with minimal additional post-processing. In the patients with preserved EF, longitudinal function was lower than controls despite no measured difference in EF, circumferential, or radial function; however, a lack of age-matched controls limits the interpretation of this finding. The fractional longitudinal contribution to EF declines with impaired EF.

References: 1) J Am Soc Echocardiogr. 2008;21:1309-17. 2) J Am Coll Cardiol. 1995;26:195-202. 3) J Am Soc Echocardiogr. 2007;20:298-306. 4) Clin Cardiol. 1979;2:257-63. 5) Radiology. 2000;214:453-66. 6) Am J Physiol Heart Circ Physiol. 2001;280:H610-20.