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Speckle-tracking analysis of left ventricular systolic function in the intensive care unit

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Abstract

Speckle-tracking analysis is a new available tool in order to assess left ventricular function in cardiology. Its novelty relies on the technological ability to track natural acoustic markers (known as speckle) within the myocardium during the cardiac cycle. This technology allows the evaluation of myocardium strain during systole and diastole. To date, global longitudinal strain (GLS) has been extensively studied in cardiology. It is now well established that GLS is more sensitive than left ventricular ejection fraction with 2D echocardiography in detecting systolic function impairment. It is also superior to left ventricular ejection fraction in the prediction of major cardio-vascular events. In the intensive care unit (ICU) setting, data are scarce. In experimental model and human studies in septic shock, speckle-tracking analysis suggests that GSL is impaired along with preserved left ventricular ejection fraction. Recent data also suggest that GLS impairment could predict in-ICU mortality in septic shock. In severe subarachnoid haemorrhage patients, speckle-tracking analysis could be more sensitive in detecting stress cardiomyopathy. However, there are many gaps to fill in the critically ill patient. For instance, the influence of mechanical ventilation on GLS is not fully elucidated, and there are, to date, too few data to exactly assess potential GLS alterations on the patient's outcome. Nonetheless, this new tool provides objective and sensitive data with acceptable intra and inter-observer variability and may be of primary interest in the evaluation of left-ventricular systolic function in the ICU.

Key words: global longitudinal strain, shock, intensive care, mortality, speckle tracking echocardiography

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Left ventricular (LV) contraction during systole is a complex phenomenon. Owing to the myocardial muscular fibres' orientation, it is a combination of longitudinal, circumferential and radial contraction (Fig. 1). A 15% shortening of longitudinal myocardial fibres leads to a 40% radial LV thickening and to a 60% modification of LV ejection fraction (LVEF) in a normal heart [1]. Myocardial contraction in the circumferential-longitudinal plane, results in twist or torsional LV deformation during systole. Altogether, these specific dynamic modifications play a key role for the generation of blood suction in the LV chamber during diastole, as well as ejection fraction during systole. Thus, myocardial deformation is of major functional interest during the cardiac cycle [2].

Several echographic echocardiographic techniques have been developed in order to study myocardial deformations and strain. Although tissue Doppler-derived strain imaging was introduced several years ago, this technology suffers from few drawbacks, such as angle-dependency, noise interference, as well as intraobserver and interobserver variability [4]. Speckle-tracking echocardiography (STE) has more recently emerged as an alternative by studying natural acoustic markers within an ultrasonographic window of the LV. The image algorithm tracks these markers in several blocks of regions of interest of approximately 20 to 40 pixels. Speckles are tracked consecutively using a sum-of-absolute differences algorithm to resolve angle-independent sequences of tissue deformation or motion.

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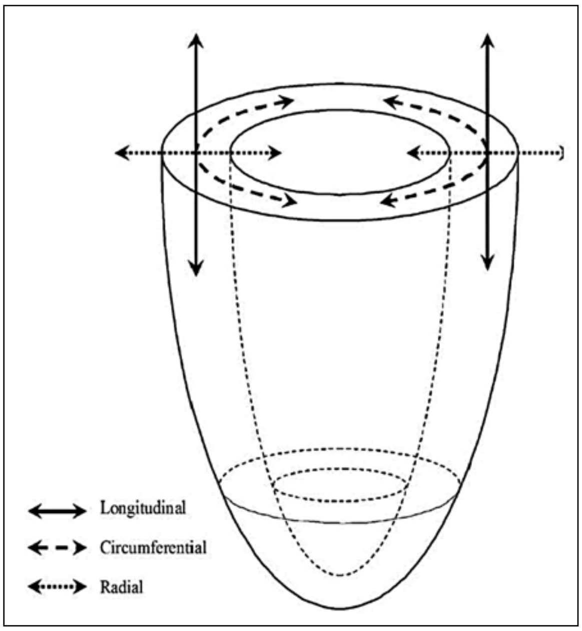


Fig. 1. Example of local heart coordinate system illustrating the 3 orthogonal axes: longitudinal, circumferential, radial [3]

Strain is therefore a dimensionless index and represents a fractional change in one dimension, typically length, and can be mathematically written as: $(L-L_0)/L_0$. In this formula, L is the myocardium length after deformation and L_0 is the original length. By convention, when the length is increasing, strain is expressed positively, while shortening is expressed negatively. When acquired at the apex with echocardiography, normal LV myocardium strain has a negative value during systole and a positive value during diastole, in the longitudinal direction. Other values can be retrieved with speckle-tracking acquisition such as strain rate, which is the rate of deformation. Mathematically, it is expressed as the change in velocity between two points divided by the distance between 2 points. The strain rate has a negative value during systole and a positive value during diastole, when acquired at the apex of a normal LV [3].

STE allows a frame-by-frame tracking of natural acoustic markers within the myocardium with standard echocardiography. Unlike Doppler-Tissue Imaging, STE is not a Doppler-based tracking method and is not angle-dependant. However, similar to Doppler-Tissue Imaging, a high frame rate is necessary to achieve STE (average 80–90 Hz), while high quality echocardiography is required to allow proper tracking of the myocardium during the cardiac cycle [3] (Fig. 2). Eventually, STE provides regional strain data in each LV segments (Fig. 3).

CLINICAL APPLICATIONS OF STE FOR MYOCARDIAL DEFORMATION ASSESSMENT

Longitudinal LV mechanics are predominantly governed by the sub-endocardial area, which is the most vulnerable component of LV mechanics and the most vulnerable area to myocardial disease. The midmyocardial and epicardial function may remain initially unaffected; therefore circumferential strain and twist may remain normal or even supranormal in order to preserve LV systolic performance [2]. The detection of early altered longitudinal

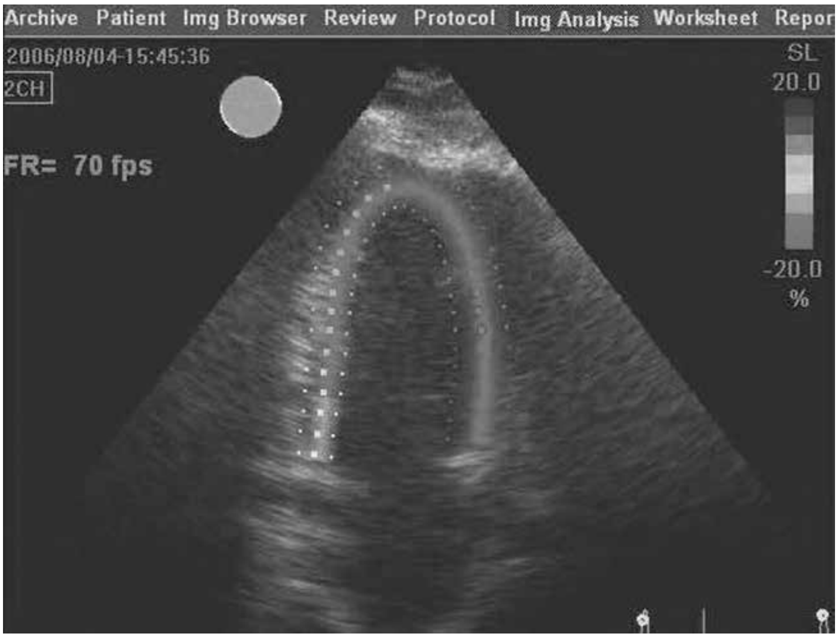
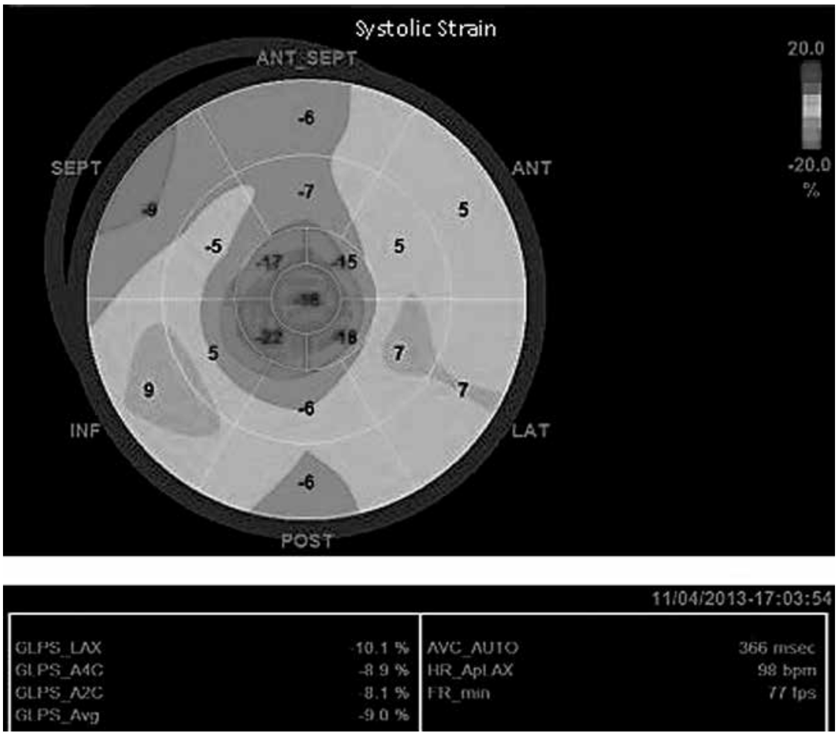


Fig. 2. Example of speckle-tracking analysis of a normal LV



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GLPS_LAX	-10.1 %	AVC_AUTO	366 msec
GLPS_A4C	-8.9 %	HR_ApLAX	98 bpm
GLPS_A2C	-8.1 %	FR_min	77 fps
GLPS_Avg	-9.0 %		

Fig. 3. Example of regional longitudinal strain and longitudinal peak strain. Basal and medio-ventricular strain are severely impaired. Apical segments display a preserved strain in this patient victim of a severe subarachnoid haemorrhage (personal data)

mechanics is, therefore, an early detector of myocardial disease and systolic function impairment. Thus, longitudinal strain has been mostly studied in cardiology in ischemic cardiomyopathy, valvular diseases, chronic hypertension, amyloidosis etc.

During aortic stenosis, LV progressively thickens, due to the increased afterload while LVEF remains preserved. STE showed that although longitudinal strain is impaired during aortic stenosis [5], it improves after aortic valve replacement [6]. In a cohort of 65 patients with aortic stenosis, longitudinal strain impairment was significantly associated with poorer exercise response and more cardiac events during a 12-month follow-up, in spite of a preserved LVEF [7]. During aortic insufficiency, strain rates are decreased and correlated to LV end-systolic and end-diastolic volumes [8]. After myocardial infarction, longitudinal strain is reduced in patients in correlation with the area of infarction and ejection fraction [9–11].

During stress cardiomyopathy, STE has helped in describing an LV failure pattern. Some authors have found the presence of hyperkinesis in the basal segments [12], attenuation of the longitudinal strain in the medio-ventricular segments [13] or dyskinesis in the apex [12]. Strain abnormalities in stress cardiomyopathy do not follow a unique coronary territory, which is helpful in distinguishing them from acute coronary syndromes. During stress cardiomyopathy, strain specifically improves over time [13–15].

In summary, strain provides robust, operator-independent data on LV systolic function, which can be more sensitive in detecting systolic function impairment than classical 2-dimension echocardiography. In a recent meta-analysis including 16 studies and 5,721 patients [16], global longitudinal strain impairment was more robust than LVEF in the prediction of death or major cardio-vascular events in cardiology, underlining the importance that STE will take in the next years.

SPECKLE-TRACKING IN THE INTENSIVE CARE UNIT

Owing to the growing interest of STE in cardiology, its superiority in the prediction of cardio-vascular events compared to standard LVEF, STE has been recently introduced in the Intensive Care Unit (ICU). In a recent experimental study, Hestenes *et al.* [17] studied strain in a porcine model of septic shock. They demonstrated that LV longitudinal strain was impaired along with preserved LVEF and cardiac output but that there was a decrease in the index of regional work. The first ICU-description of STE was in a paediatric population of septic shock [18]. The authors found that LV longitudinal strain and the strain rate were impaired in septic children compared with controls. At the same time, LVEF was preserved in both the septic children and controls. In adult septic shock, several authors found similar data. In a mono-centric study of 106 adult patients with septic shock, the authors found a severe longitudinal strain impairment along with preserved LVEF [19]. In 60 patients with septic shock, the authors found systolic function impairment in 69% of patients assessed with STE, whereas only 33% patients displayed LVEF alteration [20]. In another cohort of 50 patients with septic shock, the authors also described a preserved LVEF when LV global longitudinal peak strain was altered [21]. These findings were confirmed in 35 patients with septic shock [22]. Longitudinal strain worsens in the first hours following septic shock, when adjusting for the level of vasopressors and LV end-diastolic volume. However, in this study [22], 15 patients with severe sepsis did not display the same longitudinal strain alterations, suggesting a specific signature in septic shock. In another mono-centric study in patients with septic shock [23], the authors found a correlation between strain impairment and the level of hyperlactatemia and low central venous oxygen saturation. LV strain could, therefore, be used in septic shock as a surrogate marker of oxygenation deliverance inadequacy. To the best of our knowledge, one study pointed out that right ventricle strain impairment was associated with long-term mortality in septic shock [20] and a large mono-centric study of 111 patients pointed out that a GLS impairment ≥ –13% was the best marker of in-ICU mortality [24]. Our group published a mono-centric observational study about LV systolic function assessment with STE in patients with severe subarachnoid haemorrhage [25]. In this 46-patient cohort, we also found that while global longitudinal strain was altered, LVEF was preserved. All these data advocate the superiority of strain on classical LVEF in detecting mild systolic impairment.

LV SYSTOLIC FUNCTION ASSESSED WITH STE IN PATIENTS UNDERGOING MECHANICAL VENTILATION

There are currently no data in the literature regarding LV systolic assessment with STE in healthy patients undergoing mechanical ventilation. In a mono-centric study of 20 patients in the general ICU setting [26], the authors found that a PEEP elevation from 5 to 15 cm H_20 would not modify LV longitudinal strain but would alter left peak-atrial longitudinal strain. It is, therefore, difficult to evaluate the accurate effects of mechanical ventilation on strain parameters. Until now, authors have extrapolated from data in the cardiologic literature in an attempt to set a threshold for normal GLS values in ICU ventilated patients. In a large Norwegian multi-centric nation-wide study [27], the authors studied 1,266 healthy subjects. Although global longitudinal strain increases with age (implying strain impairment), the overall normal global longitudinal strain was -17.4%. In another multi-centric study of 250 volunteers without cardio-vascular diseases, the average global longitudinal strain was –18.6% [28]. However, numerous factors are susceptible to modify a patient's global longitudinal strain. Chronic hypertension can alter longitudinal strain. In a cohort of 56 patients, longitudinal strain was decreased along with increased LV torsion. The authors also found a correlation with serum levels of aminoterminal propeptide of procollagen I/III and tissue inhibitor of matrix metalloproteinase, suggesting a modification of the myocardial collagen turnover and fibrotic process which could alter LV systolic function [29].

WHAT COULD STE ADD IN THE ICU FIELD?

One of the major drawbacks of classical 2D echocardiography parameters the ICU setting is their high inter-observer variability. In a cohort of 50 patients undergoing mechanical ventilation with shock, LVEF evaluation with the Simpson technique displayed the worst intra and inter-observer variability [30]. STE is an operator-independent technique with low inter-observer variability (from 2 [31] to 13% [32]) regarding strain data but higher variability regarding strain rate [28]. In patients with mechanical ventilation, we found an inter-observer variability of 8% [25] while others [20, 24] have also found a good inter-observer agreement with a Bland-Altman analysis. STE could, therefore, provide objective data on systolic function with an acceptable variability.

CONCLUSION

STE is more sensitive in detecting mild systolic function impairment than classical LVEF. It is well-established in cardiology that STE is superior to standard echocardiography in order to predict major cardio-vascular events. However, there are, to date, too few data in the ICU to delineate the potential strain alterations on patient's outcome. However, further studies should definitely provide substantial data regarding cardio-vascular events in specific settings, such as septic shock or neuro-ICU.

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