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# Exploration of the Utility of Speckle-Tracking Echocardiography During Mechanical Ventilation and Mechanical Circulatory Support

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**OBJECTIVE:** This narrative review aims to discuss the potential applicability of speckle-tracking echocardiography (STE) in patients under mechanical ventilation (MV) and mechanical circulatory support (MCS). Both its benefits and limitations were considered through critical analyses of the current available evidence.

**DATA SOURCES AND STUDY SELECTION:** A literature search was conducted in PubMed and Excerpta Medica Database indexed databases (2012–2021). In addition, the reference lists of all selected studies were manually scanned for further identification of potentially relevant studies.

**DATA EXTRACTION:** The terms "Speckle-Tracking Echocardiography," "Mechanical Ventilation," "Mechanical Circulatory Support," "Extracorporeal Membrane Oxygenation," "Ventricular Assist Devices," and "Left Ventricular Unloading Devices" were searched for the identification of relevant articles for narrative synthesis.

**DATA SYNTHESIS:** STE is a well-established post-processing method of analyzing myocardial function, with potentially greater clinical utility than conventional 2D echocardiography. STE has been incorporated into the guideline recommendations for both the diagnostic and prognostic evaluations of myocardial and valvular pathologies. However, the potential of STE application within critical care settings has not yet been fully realized. Its utility in the assessment of patients undergoing MV and MCS is substantial. Specifically, it may serve as an ideal modality in the assessment of subtle changes in cardiac function. In the limited number of studies reviewed, STE was consistently a more sensitive marker of myocardial functional change, compared with traditional markers of 2D and Doppler parameters during changes in MV and MCS.

**CONCLUSIONS:** Although current evidence is extremely limited, STE strain is suggested to be a more sensitive and reproducible parameter of myocardial function than conventional echocardiographic parameters and may have value in the assessment of patients undergoing MV and MCS in critical care settings. Further studies in larger populations are required to elucidate STE's prognostic capability and its value as a point-of-care tool in guiding clinical practice for subjects under MV and MCS.

**KEY WORDS:** critical care; mechanical circulatory support; mechanical ventilation; myocardial deformation; myocardial strain; speckle tracking echocardiography

Speckle-tracking echocardiography (STE) is a promising postprocessing tool for the quantitative analysis of myocardial function, which provides significant incremental value to conventional 2D echocardiography (1–4). Although conventional echocardiographic parameters, such as ejection fraction (EF), evaluate cardiac function based on blood volume in the cardiac chamber, STE can assess heart function based on the direct measurement and quantification of myocardial deformation (5). This unambiguous measurement of myocardial

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deformation improves the sensitivity of the assessment and allows detection of subtle changes in subclinical myocardial and valvular dysfunction. In addition, STE parameters can be assessed in a semiautomated manner, which improves its reproducibility by decreasing interobserver variability (6). The angle-independent strain measurement derived from STE has also overcome the flaw of the conventional tissue Doppler strain measurement and enabled evaluation of global and regional myocardial deformations in a multidirectional manner (1). As a result, STE can evaluate cardiac function with increased sensitivity, and higher reproducibility than conventional methods (6). The application of STE has gradually increased in clinical settings, such as ischemic heart disease (7), valvular heart disease (8), and cardiomyopathy (9–11). However, the utility of STE in critical care settings (12) remains extremely limited, especially during mechanical ventilation (MV) and mechanical circulatory support (MCS) (13). In this narrative review, we summarize the current evidence on the utility of STE in subjects undergoing MV and MCS, and discuss potential applicability of STE for these conditions by considering its benefits and limitations.

## BASICS OF STE

### Principle

STE is a common technique for measuring myocardial deformation in terms of strain, that is, the amount of lengthening, shortening, and thickening of myocardial fibers (13). Strain can be measured using dedicated software by tracking the dots called “speckles” in the gray-scale echocardiographic images, which represents the backscatters of myocardial fibers (14). Strain is expressed as a fractional length (L) change between systolic and diastolic phases (15) (**Fig. 1**).

### Different Types of Strain

There are several parameters for STE strain analysis depending on the cardiac chambers measured: left atrium (LA), left ventricle (LV), right atrium (RA), or right ventricle (RV), and the orientation of myocardial fibers. Since some strain parameters are denoted by negative values, there is often confusion in describing increases or decreases in strain. In order to overcome this, strain changes are described by either an “increase” or “decrease” in the “absolute value” of strain, as per the recommendations of the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI). Thus, increased strain indicates improved contraction, and vice versa.

***Left Ventricular Strain***. *Global longitudinal strain*. Global longitudinal strain (GLS) is the most widely used parameter in clinical practice. LV GLS is reflective of the length change of myocardial fibers in the longitudinal axis and acts as a measure of LV contraction (17). Echocardiographic images and normal value

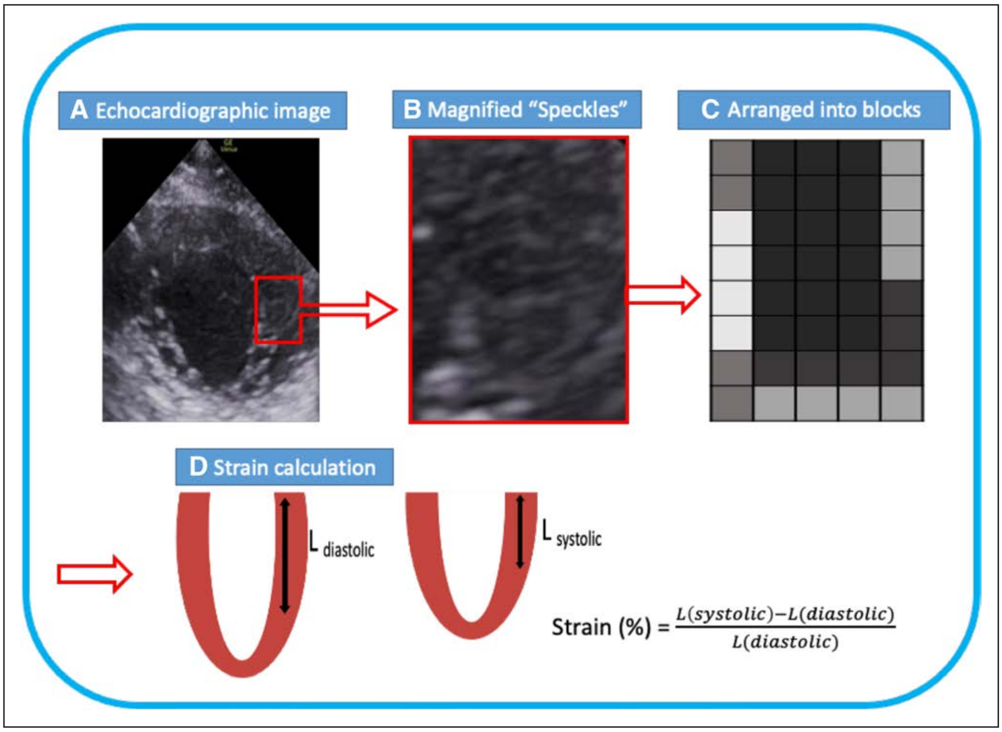

**Figure 1.** The mechanism of how to measure strain in speckle-tracking echocardiography. **A**, LV short-axis view taken by transthoracic echocardiography. **B**, A magnified view of image 1 (LV lateral wall), depicting “Speckles” as a group of dots. **C**, Speckles are arranged into blocks to be tracked frame-by-frame (1, 16). **D**, Speckles are tracked between end-diastolic and systolic phases, and the length (L) of myocardium is measured to calculate strain (15). LV = left ventricle.

of GLS (18) are shown in **Supplemental Figure 1** (http://links.lww.com/CCX/A957). The clinical applicability of GLS is supported by a strong body of evidence due to its high reproducibility and it reflecting the bulk of myocardial fibers. In particular, GLS has demonstrated superior prognostic value than LV EF in acute heart failure patients (19) and facilitates more prompt interventions in patients with non–electrocardiogram ST-segment elevation myocardial infarction (20). Fifty case-experiences have been demonstrated to be sufficient for novices to achieve expert-level competency in reporting GLS (21).

*Global circumferential strain and global radial strain*. LV global circumferential strain (GCS) and global radial strain (GRS) are both deformation parameters reflective of LV contraction mechanics but differ in that GCS reflects changes in length observed in the circumferential axis and GRS in thickness observed in the radial axis of myocardial fibers in the parasternal short-axis view. Echocardiographic images and normal values for LV GCS and GRS (18) are shown in Supplemental Figure 1 (http://links.lww.com/CCX/A957). Due to their limited reproducibility and greater normal ranges, GCS and GRS have had less clinical application than GLS (17, 18).

***Left Atrial Strain***. LA strain analysis evaluates three parameters based on the different phases of the cardiac cycle: reservoir, conduit, and contraction strains (3). LA reservoir strain is of clinical significance as studies have suggested that it has a greater accuracy and sensitivity in assessing LV diastolic function compared with the currently used parameter, LA volume index (22, 23). Echocardiographic images and normal ranges of LA strains (24) are shown in Supplemental Figure 1 (http://links.lww.com/CCX/A957). LA strain measured by novice observers has a high degree of intraobserver reproducibility (intraclass correlation coefficients for strain values greater than 0.88), with only a one-time, 30-minute education session on three consecutive patients (25). Furthermore, the LA strains of patients with atrial fibrillation or atrial flutter ($n = 56$) may potentially be a predictor of successful recovery following electrical cardioversion (26).

***Right Ventricular Strain***. RV longitudinal strain (LS) should be measured using the RV-focused apical four-chamber view to improve reproducibility (3). The ASE/EACVI/Industry Task Force recommends reporting RV free-wall strain without computing for the interventricular septum as the standardized measurement, while inclusion of the intraventricular septum in the computation of RV global longitudinal strain (GLS) is optional (3). The echocardiographic images and normal range of RV strains (27) are shown in Supplemental Figure 1 (http://links.lww.com/CCX/A957). Of significance, one study suggested RV LS to be a potentially superior predictor of 30-day mortality in acute pulmonary embolism than conventional echocardiographic parameters such as RV fractional area change (FAC) and tricuspid annular plain systolic excursion (28). At least 100 studies are required to achieve expert competency for independent RV strain reporting (29).

## Factors Affecting Strain Parameters

A clinical advantage of strain parameters over conventional echocardiographic measurements is its higher sensitivity to subtle functional changes, and it is important to understand factors affecting strain values in interpreting strain data (13).

***Effects of Hemodynamics on Strain***.

*Preload*. The effect of preload on strain values aligns with the Frank-Starling law, that is, prestretched myofibers may increase the maximal force of myocardial contraction in the absence of cardiac dysfunction (13). In the gravitational stress simulation study by Negishi et al (30), tilt-induced increases in gravitational stress were found to significantly reduce the absolute GLS and GCS in 13 healthy subjects (GLS: from −19.8% ± 2.2% to −14.7% ± 1.5%; GCS: from −29.2% ± 2.5% to −26.0% ± 1.8%; both $p < 0.001$), reflecting the reduced preload, whereas LV EF showed no significant change.

*Afterload*. An animal model study (16 pigs, weighting 28 ± 4 kg) that assessed the influence of an acute increase in afterload induced by aortic banding found a decrease in LV LS (31). In addition, several clinical studies demonstrated that in conditions of chronically elevated afterload, such as systemic hypertension, aortic stenosis, and pulmonary hypertension, LV LS was also reduced but not detected by conventional echo parameters (32–34).

*Heart rate*. Increased heart rate (HR) decreases ventricular filling time, leading to reduced stroke volume and reduced myocardial strain (13).

***Effects of Geometry, Tissue Characteristics, and Desynchrony on Strain***. Ventricular geometric factors in conditions such as cardiac dilatation and cardiac hypertrophy can decrease the absolute value of GLS (13). Myocardial tissue characteristics such as fibrosis and depositions may also decrease the absolute value of strain in condition of ischemic disease with scarring, cardiac amyloidosis, and hypertrophic cardiomyopathy (13). In addition, in homogeneous myocardial activation resulting from conduction delays, dyssynchrony can also reduce the absolute value of LS due to mismatched timing of each LV wall contraction (13).

## STE IN MECHANICAL VENTILATION

### Effects of Mechanical Ventilation on Hemodynamics and Cardiac Function

***Effects of MV on Preload***. MV changes the negative intrathoracic pressure into positive pressure for ventilation. This change can increase the RV surrounding pressure in the thoracic cavity, resulting in a reduction of venous return, hence decreasing RV preload (35, 36). Venous dilation caused by general anesthesia (GA) may also lead to further reduction of preload (37).

***Effects of MV on RV Afterload***. RV afterload is dependent on the extent of positive-pressure ventilation. During mechanical inspiration with an appropriate inflation pressure, the increased lung volume causes the pulmonary vasculature to distend, resulting in a decreased pulmonary vascular resistance (PVR), and thus a declined RV afterload (38). Reverse hypoxic vasoconstriction due to an improvement of oxygenation by MV will also reduce RV afterload. In contrast, if breathing pressure is excessive, the overinflated lung will compress the pulmonary capillaries and consequently increase PVR reflected as RV afterload (38).

***Effects of MV on LV Afterload***. LV afterload is the resistance against ventricular ejection and is dependent on the aortic elastance and the overall resistance of artery trees (39). During MV with positive-pressure inflation or positive end-expiratory pressure (PEEP), inspiration increases pleural pressure and decreases LV transmural pressure. This may lead to a decreased LV afterload, facilitating LV ejection. However, this increased LV ejection is limited by the decreased venous return mentioned above (effects of MV on preload) (40).

In summary, positive airway ventilation and PEEP induce various changes in cardiac output depending on preload, afterload, and the state of heart functioning. Therefore, physicians need to consider these factors to avoid misinterpreting data and making erroneous decisions.

### Available Literature on STE Application in Patients Under Mechanical Ventilation

Seven studies related to the application of STE for cardiac assessment under MV are summarized in **Supplemental Table 1** (http://links.lww.com/CCX/A958) (41, 42). All were conducted as single-center studies in a limited number of patients, with one being a preclinical study.

Franchi et al (43) reported that RA, RV, and LA strain values significantly decreased along with reduced cardiac output during PEEP titration (PEEP 0–15 mm Hg), whereas LV LS remained stable. This implies that the reduction in cardiac output that occurred with incremental PEEP was preload-related rather than contractility-related (43). In contrast, some reported that MV and GA were significantly associated with the lower absolute value of LV strain (37, 44). However, the interpretation of LV strain requires caution, as changes in LV preload or afterload frequently induce baroreceptor-mediated counterregulatory alterations in cardiac sympathetic activity. This may increase or decrease cardiac contractility depending on the hemodynamic conditions, thus affecting LV strain (44).

STE parameters have been applied in a small number of studies investigating subjects on MV. Ruiz-Bailén et al (45) reported that STE combined with dobutamine stress-echocardiography may discriminate weaning success from MV in heart failure patients during the recovery stage. In addition, Cameli et al (46) reported that LA strain may be a better predictor of LV filling pressure than the conventional echo parameter (E/e’), along with a better correlation with pulse pressure variation, which is a dynamic index of fluid responsiveness. Since both were merely pilot studies that aimed to explore novel applications of STE and involve numerous confounding factors, further investigations are warranted.

In summary, strain values under MV are strongly affected by preload and afterload, and the values should be interpreted with caution considering the loading conditions. There may be a potential for strain to detect latent cardiac dysfunction or fluid volume status under MV (**Fig. 2**). However, since available data surrounding this are limited, more evidence is warranted.

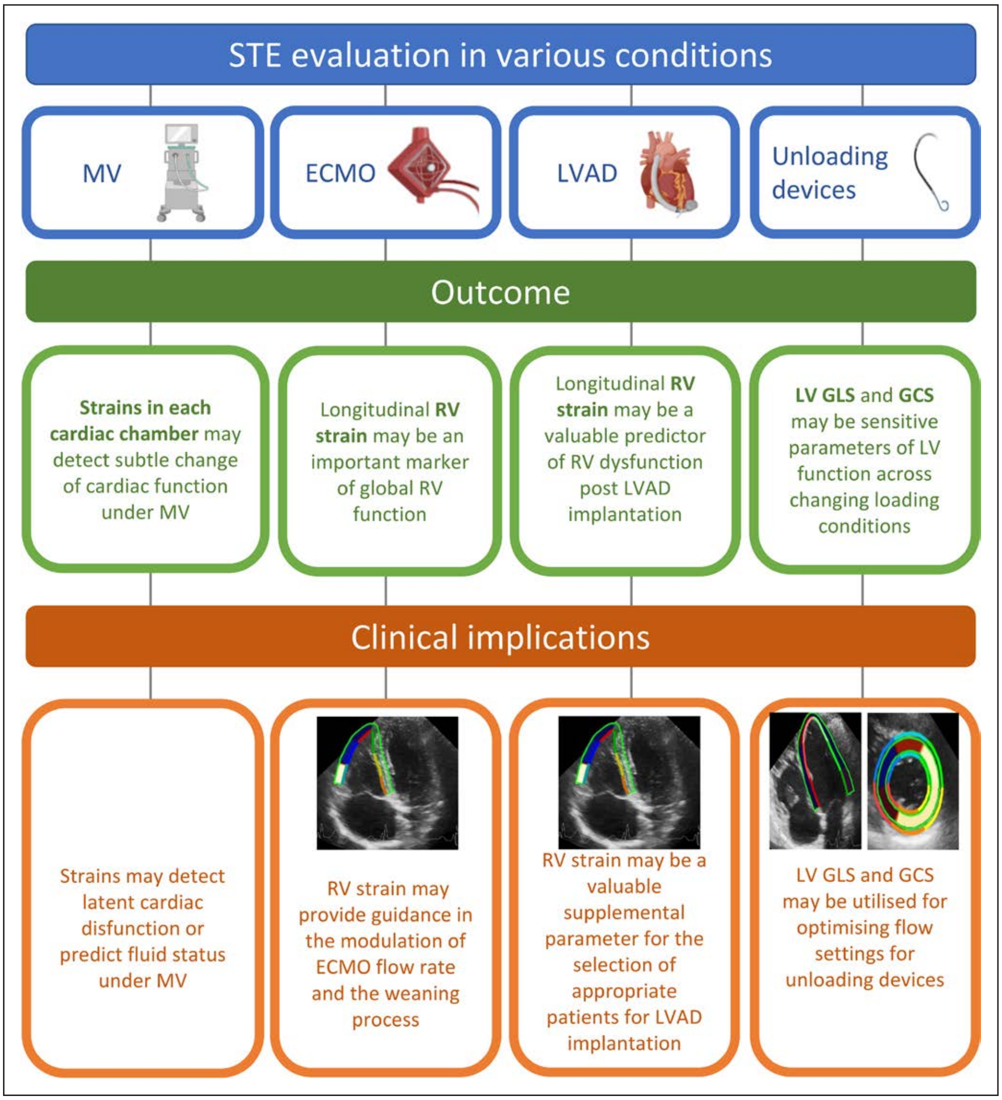

**Figure 2.** Clinical implications of cardiac strains based on speckle-tracking echocardiography under mechanical ventilation and mechanical circulatory support. Created with BioRender.com. ECMO = extracorporeal membrane oxygenation, GCS = global circumferential strain, GLS = global longitudinal strain, LV = left ventricle, LVAD = left ventricular assist device, MV = mechanical ventilation, RV = right ventricle, STE = speckle-tracking echocardiography.

## STE IN MECHANICAL CIRCULATORY SUPPORT (MCS)

### Venoarterial Extracorporeal Membrane Oxygenation

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) is one of the MCS device configurations for supporting cardiogenic shock patients (47, 48). Despite decades of clinical use, VA-ECMO weaning failure is still a significant problem, and the inhospital mortality following weaning is around 40% (49). The current lack of effective and reliable imaging techniques to indicate optimal timing for successful weaning may be a contributor to weaning failure (50). Hence, STE strain parameters may facilitate a more accurate cardiac assessment to aid weaning success from VA-ECMO.

***Effects of VA-ECMO on Hemodynamics and Cardiac Function***. VA-ECMO decreases RV preload by draining blood directly from the RA. The drained blood returns to the artery, resulting in an increased arterial blood pressure and LV afterload.

***Available Literature on STE Application in Patients on VA-ECMO***. Four included studies explored the application of STE in patients under VA-ECMO. All were conducted at a single-center and in a limited number of patients (**Supplemental Table 2**, http://links.lww.com/CCX/A958) (51).

At the commencement of VA-ECMO, the increased circuit flow rate decreases cardiac preload and increases afterload, and vice versa during VA-ECMO weaning (52). The resultant change in strain values in response to the modified preload and afterload by VA-ECMO flow is complex, as discussed the *Effects of Hemodynamics on Strain* section. Therefore, the utility of STE strains for patients under VA-ECMO remains controversial.

In a cohort of adult patients undergoing VA-ECMO support postcardiovascular surgery ($n$ = 111), Bartko et al (53) reported that RV free-wall strain was a powerful predictor of mortality risk, including that of 30-day mortality (adjusted HR, 0.41; 95% CI, 0.24–0.68; $p = 0.001$) and long-term mortality (adjusted HR, 0.48; 95% CI, 0.33–0.71; $p < 0.001$) for a 1-SD

(SD = −6%) change in RV free-wall strain. The authors suggest that the right heart and pulmonary circulation are of high prognostic value in predicting outcomes, with RV strain being an ideal indicator of RV function.

Furthermore, the study by Punn et al (54) on echocardiographic predictors of mortality in children weaning from VA-ECMO support ($n$ = 21) reported that strain parameters, LV GLS and GCS, were not associated with mortality or requirement for heart transplant, unlike conventional echo parameters such as LV outflow tract velocity-time integral. However, the authors postulated that the suboptimal frame rate and acoustic image quality in STE analyses may have hindered the detection of subtle dysfunctions, consequently influencing the outcomes.

In another study of 22 cardiogenic shock adult patients supported by VA-ECMO, Aissaoui et al (52) reported that LV LS was affected by stepwise decrements of ECMO flow and, thus, was unable to predict the success of weaning from VA-ECMO. However, the investigators also observed that significant improvements in LV systolic parameters (including strain values) during stepwise ECMO flow reduction were strongly associated with weaning success. Further studies are required to ascertain whether the observed variations in systolic measurements signified the presence of a load-dependent contractile reserve that follows the Frank-Starling law (52).

In summary, VA-ECMO has significant influences on cardiac preload and afterload; thus, strain parameters are significantly affected by its circulation flow. Certain strain parameters may be superior predictors for successful weaning compared with conventional echocardiographic parameters such as LV EF (Fig. 2). However, due to the paucity of evidence surrounding this, further studies are required.

## Ventricular Assist Device

The left ventricular assist device (LVAD) constitutes a more durable support device as opposed to temporary MCS and has significantly improved the mortality of patients with severe heart failure. However, right ventricle failure (RVF) has been reported to occur after LVAD implantation in approximately 30% of patients and remains a major cause of mortality following LVAD surgery (55). It is important to evaluate the RV reserve prior to LVAD implantation so that any existing latent RV dysfunctions are detected, and the treatment plan is revised as appropriate, such as a modification from LVAD alone to biventricular assist or direct heart transplantation.

***Effects of LVAD on Hemodynamics and Cardiac Function***. LVAD drains blood from the LV apex and returns it to the aorta, thereby decreasing intra-LV pressure, LV unloading, increasing arterial blood pressure, and improving systemic blood perfusion (56). In addition, LVAD decreases RV afterload by reducing LA and pulmonary artery occlusion pressure, thereby improving both pulmonary and systemic circulations, resulting in potentially improving metabolic milieu and LV contractility (56). In the case of damaged RV, the increased preload may cause the RV septum to shift toward the LV. This deformation can impair RV contractility and relaxation, exacerbating RVF (57).

***Available Literature on STE Application for Patients Requiring LVAD***. Seven included studies investigated the application of STE on patients who required LVAD support, as shown in **Supplemental Table 3** (http://links.lww.com/CCX/A958) (58–61). Most were conducted at a single center and within a limited number of patients.

One study investigated the relationship between STE strains and LV/RV functions following an implantation of pulsatile LVAD in children ($n$ = 18, median age, 9 mo) (62). In this study, Iacobelli et al (62) reported that LV function, measured by LVEF and GLS, and RV function, measured by FAC and free-wall strain, improved within the first and third months of implantation, respectively. However, both functions were reported to progressively decrease over time. Iacobelli et al (62) also suggest that both STE and conventional echo parameters may capture biventricular interactions during LVAD support. Further studies are needed to verify whether STE measurements can facilitate the detection of earlier recovery or persistent dysfunction, which would be useful in guiding clinical decision-making.

In another study, Kato et al (55) prospectively investigated 68 patients that underwent elective LVAD surgery and suggested preoperative RV strain as a predictor for those that developed RVF at 14 d following the operation, with an accuracy of 76.5%. This concurs with findings from the meta-analysis conducted by Barssoum et al (63), which investigated the role of RV strain for the assessment of RV function following LVAD implantation (Fig. 2).

In summary, STE strains may reflect subtle changes in cardiac function before and during LVAD support. In order to validate whether this facilitates patient selection for LVAD and other decision-making processes, in particular whether initiating biventricular support or cardiac transplantation are required, further validation studies are required.

### Temporal LV Unloading Devices (Impella)

***Effects of LV Unloading Devices on Hemodynamics and Cardiac Function***. MCS such as VA-ECMO can cause an overload on the LV, leading to LV distention and attendant complications such as LV clotting and thromboembolism. LV unloading devices, such as Impella (Abiomed, Danvers, MA), are used to temporally decrease the LV interventricular pressure and reduce myocardial oxygen consumption (64).

***Available Literature on STE Under Temporal LV Unloading Devices***. Two included studies investigated the application of STE on patients under temporal LV unloading devices, specifically whether STE strains can evaluate how much the device can unload LV interventricular pressure. Both studies were conducted at single centers, in a limited number of patients (**Supplemental Table 4**, http://links.lww.com/CCX/A958).

In an acute myocardial infarction model (pigs, $n$ = 24) with reduced LV EF (mean, SD; 38.5 ± 9.2%), Hammoudi et al (65) reported that the absolute values of LV LS and circumferential strain significantly decreased after LV unloading by Impella (Abiomed). Linear relationships between LV LS and stroke work were found, calculated by an invasive pressure-volume (PV) catheter. Similarly, Montisci et al (66) reported that LV GLS has the potential to assess the extent of LV unloading, whereas LVEF has been suggested to be insufficient for this purpose.

In summary, STE parameters may provide more precise estimates for the degree of LV unloading compared with conventional echo parameters, while being less invasive than PV catheters (Fig. 2). However, the limited evidence available warrants further validation studies.

***Limitation of STE in ICU Settings***. First, the evidence surrounding the utility of STE strain analysis in the presence of MV and MCS is extremely limited. Most of the available findings are based on individual single-center studies, thus may be prone to publication bias. Therefore, a cautious approach is required for the interpretation of findings.

Second, the impact of preload/afterload on STE strain parameters is comparable with or more significant than that of conventional echo parameters such as EF. However, the key difference between STE strains and conventional measurements is the higher sensitivity and reproducibility observed in STE. To effectively utilize this advantage in ICU settings, further studies are required.

Since there are technical requirements to enable the acquisition of quality images and accurate measures using STE, technology availability remains one of the limitations to its utility in critical care settings. With future technological advancements, there is potential for an increased uptake of STE in clinical settings.

*High dependency on image quality*. The accuracy of STE analysis is highly dependent on the obtained image quality. ICU settings are challenging to obtain the optimal image quality within a limited timeframe, frequently due to suboptimal acoustic windows of patients. As transesophageal echocardiography (TOE) imaging has been suggested as an effective technique for strain analysis (67, 68), STE analysis based on TOE may potentially increase its feasibility. In addition, contrast echocardiography may be incorporated to delineate endocardial borders, thereby increasing the accuracy of strain measurements and reducing interobserver variations under ECMO (69).

*Time-consuming nature*. As current STE predominantly uses offline software systems, the time required for acquisition of data and analysis is time-consuming. This process may be a deterrent to uptake in critical care settings. The emergence of advanced echo machines that have embedded software packages for real-time GLS measurements may further increase the feasibility of STE in clinical settings (70).

*Dependency on frame rate*. In critical care settings, patients commonly exhibit tachycardia due to conditions such as shock or hyperthermia. The quality of STE analysis is dependent on frame rate, which needs to be increased in higher HR but consequently compromises image resolution. Frame rate settings between 40 and 80 frames/s are required to obtain precise strain values with STE (13).

## CONCLUSIONS

There is currently insufficient evidence to support the utility of STE in subjects under MV and MCS. However, STE may provide more sensitive and reproducible measures of myocardial function than conventional echocardiographic parameters, which is valuable in the assessment of cardiac performance in subjects under MV and MCS, provided that its aforementioned limitations are considered. Further studies on larger cohorts are required to explore the diagnostic and prognostic value of STE in guiding clinical decisions for subjects under MV and MCS.

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