A Practical Approach to Using Strain Echocardiography to Evaluate the Left Ventricle
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Left ventricular (LV) evaluation is the most important use of echocardiography. Speckle tracking strain echocardiography (SE) provides a quantitative regional and global LV assessment, an independent supplement to wall motion analysis and has been validated over the past 10 years. Despite these facts, SE is not being used routinely, especially in the United States. SE can generate longitudinal, radial, and circumferential strain measurements and LV twist. Although intriguing and potentially useful, these measurements also are confusing, complicated, time consuming, and frequently displayed as difficult-to-interpret wave forms. A pragmatic approach to SE simplifies the suggested method for strain calculation to reduce the time required and enhance reproducibility. With this modification the strain calculations take only 2–4 min. The yield is >80% in all patients. Reproducibility is at least as good as ejection fraction. Longitudinal strain is the most sensitive and reproducible of the various strain measurements, so it is the only strain we record. For simplicity, systolic strain is displayed as a positive number. Lastly, we primarily use a bullseye presentation for peak systolic strain. Many clinical examples are illustrated. However, as with all tests, SE is not perfect; there are limitations and potential false positives, but a practical approach to SE eventually should help make it a part of all echocardiographic examinations. (Circ J 2012; 76: 1550–1555)

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Evaluation of left ventricular (LV) systolic function is a critical component of the practice of cardiology and a fundamental function of the echocardiographic examination. Although LV systolic function is commonly defined by ejection fraction (EF), there are numerous technical and hemodynamic limitations to EF. A qualitative “eyeball” estimate has high variability, and quantitative measurements are subject to endocardial border definition and formulas that make assumptions in geometry of the LV. The EF denotes global LV function and does not convey any regional differences in function that may exist in patients with various cardiomyopathies. Hyperkinetic segments can distort a global measurement, leading to an underestimation of the significance of regional abnormalities. There are several alternative techniques that can either supplement or replace EF, including tissue Doppler recordings of the mitral annulus and measurements such as the TEI or myocardial performance index.

Doppler-Derived Strain Rate
The newest technique for evaluating the LV uses the concept of strain or strain rate. This technique assesses myocardial mechanics by measuring the relationship between 2 points within the myocardium as if they were connected by a rubber band. When the 2 points move away from each other (myocardial lengthening during diastole), strain values are positive. When the 2 points move toward each other (myocardial shortening during systole), strain is decreased, generating negative strain. Strain and strain rate can be derived from either tissue Doppler or speckle tracking 2- or 3-dimensional (D) echocardiography. Using tissue Doppler, which is a form of pulsed Doppler, specific points within the myocardium can be identified.1 Tracking these Doppler points enables measurement of strain rate. Because Doppler is velocity or distance divided by time, the initial measurement is strain rate. Integrating the strain rate gives strain.

There are limitations to the Doppler-based strain rate. As with all Doppler applications, the Doppler-derived strain rate is angle-dependent. The Doppler strain rate sample volume is also fixed while the myocardium is moving. Thus the sample volume may not stay within the myocardium throughout the cardiac cycle. Strain rate is a derivative of strain and tends to be noisy.

Figure 1 shows one way of recording strain rate using “curved M-mode”. A resting normal 4-chamber view shows yellowish-brown strain rate during ventricular systole. The strain rate recording of the apex is not reliable, because the apex is perpendicular to the ultrasonic beam, so there is no Doppler signal. With exercise the systolic strain rate turns reddish brown, indicating a higher degree of negativity or contraction in the basal segments. This patient has a blockage in the left anterior descending coronary artery. With exercise, there is a delay in the onset of contraction of the apical half of the septal and lateral walls, a failure of improvement of strain rate, systolic drop out and post-systolic contraction in early diastole, a valuable sign of ischemia. The strain rate curved M-mode display is only

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Figure 1. Curved M-mode displays of Doppler-derived strain rate studies before and after stress. (Left) Resting image. The septal portion of this 4-chamber view is uniformly yellowish-brown. The apex is green with no strain rate because of the angle dependency of Doppler. The lateral wall, in the lower half, is a broken-yellowish recording. (Right) Stress examination. The upper portion of the septal recording is now reddish brown, indicating normal stress hyperkinesis. The apical portion near the center of the recording is a delayed broken-yellowish early recording followed by a late brownish systolic contraction pattern. That same pattern is also noted in the apical portion of the lateral wall. Those abnormal strain rate findings are indicative of stress-induced ischemia.

Figure 2. Various ways of recording speckle tracking 2-dimensional strain. (Left) Parametric overlays superimposed on the 2-dimensional grayscale images. The upper parametric image shows the global strain. The regional strain measurements are displayed in the lower parametric image. (Right) Upper illustration shows the strain wave forms throughout the cardiac cycle of the 6 segments from this 4-chamber view. Lower illustration shows the M-mode recording, similar to that shown in Figure 1 with strain rate. Here, there is far less noise, a more homogeneous recording throughout systole, and no apical dropout because 2D strain is not angle-dependent.
Semi-quantitative, can be difficult to interpret and is not popular. However, strain rate imaging still may be a useful adjunct to conventional visual assessment of wall motion for detection of ischemia during stress echocardiography.

### Speckle Tracking 2D Strain

The other way of recording strain uses the principle of speckle tracking. The raw ultrasonic signal or radio frequency signal that creates the ultrasonic image consists of numerous random speckles. Any given point on an ultrasonic image can be identified by its unique speckle pattern. Using these speckle patterns (speckle tracking) to identify specific points in the myocardium, strain can be calculated and displayed. Because 2D echo is distance, the initial measurement is strain. The derivative of strain will give the strain rate. There is a variety of ways to demonstrate or present this strain information. One can overlay the 2D image with a parametric display and the segments can be assigned quantitative values (Figure 2). In addition, one can record wave forms from all of the various segments. There also is a curved M-mode display, similar to what is done with tissue Doppler. Only in this case the recording is less noisy and records the apex and the walls. A very convenient display uses a polar map or “bullseye” (Figure 3). Such a recording provides both a global and regional assessment of the entire LV. In this normal recording, all of the segments are red and have values in the 20s or high teens. The advantages of strain or strain rate are that they avoid some of the limitations of wall motion analysis, such as tethering, off-axis false positives and negatives and the difficulties in analyzing subtle wall motion. There are studies showing that strain is more sensitive than wall motion for detecting myocardial ischemia. The recordings are inherently quantitative. It is technically feasible to record strain with stress studies. The strain values are closer to assessing true regional contraction than either wall motion or tissue Doppler. There is evidence to suggest that strain may assist in assessing viability either at rest or with stress. Most importantly, strain represents an independent supplement to wall motion for evaluating LV mechanics.

There have been numerous articles over the past decade that have demonstrated the feasibility and potential clinical value of strain imaging, yet only a few academic centers have incorporated it into everyday practice of echocardiography and even then only on a limited basis. Studies demonstrating the validity of strain compared with magnetic resonance imaging have been published. There are studies showing the value of strain in identifying patients with hypertensive heart disease, system sclerosis, heart transplant rejection, chemotherapy, various cardiomyopathies and systemic muscular problems. There is literature indicating the superior diagnostic value of strain vs. EF inpatients with acute heart failure. A large multicenter study showed that strain assessment is both feasible and reliable in patients with LV dysfunction and allows for cardiovascular risk stratification in heart failure patients, with greater accuracy than LVEF. There is also a large study showing the prediction of all-cause mortality from global longitudinal speckle strain compared with EF and wall motion scoring. The conclusion was that longitudinal strain is a superior predictor of outcomes to either EF or wall motion score index and may become the optimal method for assessment of global LV systolic function.

With all this evidence of its clinical value in the literature, why isn’t strain echocardiography (SE) being more used clinically? One possible explanation could be that in most of the literature the strain measurement is used in time-consuming and complicated ways. There are longitudinal, radial, circumferential strain measurements and LV twist, all of which make clinical use complicated. The official word for strain is “deformation”, which may be scientifically accurate but is clinically confusing. Analyzing multiwave forms is also not appealing. And lastly, the fact that systolic strain or contraction is a negative number adds to the confusion. Is a strain of −10 more or less than −20? One needs to stop and think before giving the answer.

At Indiana, we have developed a simplified, practical approach to performing SE. We avoid manually adjusting the sampling segments to quicken the analysis and enhance the reproducibility of strain values. The bullseye presentation is the primary display for analysis. Systolic strain is stated as a posi-
tive number rather than a negative number. To simplify our strain examination, we only use longitudinal systolic strain, because it appears to be highly sensitive for myocardial disorders and more reproducible than either circumferential or radial strain. Because the LV shortens from base to apex with systole, the fixed short-axis tracking that is required for radial and circumferential strain is more difficult than longitudinal tracking, which moves with the base to apex motion.

Thus it is not necessary to label our measurement as “longitudinal” because it is the only form of strain that we routinely use. Global strain is therefore labeled global systolic strain (GSS) instead of global longitudinal peak systolic strain (or global longitudinal peak strain average), which are the labels used on the ultrasonic instrument, or global longitudinal strain used by some in the literature. We also calculate the average peak systolic strain values of the basal segments as basal systolic strain (BSS). The bullseye recording is analyzed by pattern recognition, as well as the quantization that it provides. Lastly we are primarily interested in assessing systolic strain, which is displayed on the echocardiographic instrument as a negative number. To avoid the confusion of communicating with negative numbers and wanting to refer to increased contraction as something positive, we manually convert the normally negative systolic strain numbers to positive numbers. Thus a systolic strain of 20 denotes greater contraction than a strain of 10.

We have introduced strain measurement into 3 different institutions on the Indiana University Health Center campus. To date we have performed approximately 3,000–4,000 studies. The success rate is still unclear, but is approximately 80–85% in an average patient weighing >200 pounds. We have modified the analysis so that it takes approximately 2–4 min to generate the strain data. Preliminary intra- and interobserver reproducibilities are probably not as good as what is stated in the literature, but appear to be as good if not better than EF.

Examples of Abnormal SE
Figures 4–8 are examples of bullseye patterns in certain diseases compared with a normal bullseye shown in Figure 3. A patient with concentric hypertrophy is shown in Figure 4.\textsuperscript{15,16}
The principal strain pattern with LV hypertrophy is that the basal strain segments are decreased and become light red or pink. The BSS value is <17 while the apical segments remain normal, thus providing the appearance of a bullseye “donut” with a red center and pink outer ring.

Strain bullseye patterns can help identify regional involvement with coronary artery disease. Figure 5A shows a typical example of abnormal basal inferior and posterior strain segments as a result of an obstruction within the right coronary artery. A bullseye showing the extensive regional strain abnormalities that occur with a left anterior descending coronary artery obstruction is shown in Figure 5B. There is a large number of segments that are pink and one that is slightly blue. The extremely low strain values suggest the non-viability of those segments. Non-ischemic cardiomyopathy shows a diffuse pattern of abnormal strain segments (Figure 6). The main strain feature is that the pattern of abnormal strain segments does not match any coronary artery perfusion. The severity of the abnormal strain can naturally vary. Although patients with lesser degrees of abnormal strain frequently have a normal EF, a patient with markedly abnormal strain (as in Figure 6) will undoubtedly have a reduced EF.

Possibly one of the most important uses of SE is proving to be in detecting cardiac toxicity of anticancer therapy. There is ongoing evidence that as patients are living longer, because of the advent of anticancer drugs, many are succumbing to the cardiac toxicity of these medications. There is a new organization known as the International Society of Cardioncology. Guidelines that use SE are being developed to help manage potential cardiac involvement in cancer patients undergoing therapy known to produce possible damage to the heart. Figure 7 shows an example of a patient undergoing chemotherapy whose cardiac strain deteriorates following chemotherapy with little change in EF. The post-chemotherapy GSS and BSS are below normal values while the EF remains in the normal range. There are preliminary data that strain may have the ability to predict mortality risk, as well as deterioration in LV function. The good news is that abnormal strain is potentially reversible. It is possible that monitoring chemotherapy cardiac toxicity may become the first common, and possibly required, use of SE.

False Positives
No test is perfect, and SE is not the first exception. False positives have been recognized. One of the false positives is an isolated, single abnormal segment that is surrounded by normal segments.
(Figure 8). Such an abnormal segment does not appear to be physiologic and clearly is a false positive. 2D speckle strain is also limited by heart rate, but this deficiency is being overcome.

**Speckle Tracking Strain Using 3D Echocardiography**

Speckle tracking strain can be obtained with 3D echocardiography and there are already instruments with this feature. There are theoretical reasons why 3D-derived strain could be advantageous, but presently the technical difficulties are probably still too great for routine use of the 3D approach. To obtain reliable strain information, a frame rate greater than 40 frames per second is required. Such a 3D frame rate or volume rate is not feasible currently. To achieve rapid frame or volume rates, the 3D sector angle must be reduced, and one cannot record the entire LV. For the foreseeable future, 2D strain will likely be the norm for SE.

**Conclusion**

SE is a sensitive indicator of myocardial dysfunction including ischemia, hypertrophy, infiltration, hypoxia, cardiotoxic drugs, myocardial rejection and severe systemic illness. Patients who potentially could benefit from SE include those with known or suspected coronary artery disease, hypertension, heart failure, significant mitral regurgitation, aortic stenosis, any kind of cardiomyopathy, diabetes, chemotherapy or cardiac transplant. SE should be a useful supplement to transthoracic echocardiography because wall motion analysis is subjective, with high interobserver variability, whereas strain is quantitative with ease of interpretation. Wall thickness measurements are difficult, again with high interobserver variability. Strain, on the other hand, is an independent indicator of hypertrophy. EF has significant limitations. Strain overcomes many of them. Speckle tracking is also possible with other cardiac chambers such as the right ventricle or left atrium.

Limitations with speckle tracking are still present. The quality of the 2D image is a factor and satisfactory recordings are not obtained for all patients. Poor speckle tracking can lead to false-positive results, which is a major concern. Although progress is being made, for the present, accurate strain is limited by frame rate and heart rate. With variable heart rates, the bullseye recording may not be generated. There is yet another major technical issue. To date, only one manufacturer seems to be producing reliable strain data that is similar in multiple laboratories and is responsible for the vast majority of strain data in the literature. This is a serious limitation. Efforts are being made by all of the manufacturers to correct this problem. It needs to be addressed before strain can become a commonly used component of routine echocardiography.

Although it is possible that strain could be considered to be separate, as with Doppler, it is questionable whether there will be an added reimbursement for strain. The major benefit will be to make echocardiography more objective and quantitative, thus producing a more accurate and complete cardiac examination. Multiple “complimentary” imaging studies are very costly. As a result, so-called “screening” examinations may be eliminated. To be cost effective and competitive, echocardiography must be a definitive examination. SE is a major step in this direction.

**References**