Estimation of Left Ventricular Systolic Function by Nonvolumetric Echocardiographic Analysis in Subjects with Poor Left Ventricular Visualization: A Pilot Study

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Summary

Background: Accurate assessment of left ventricular (LV) systolic function is an essential requirement in clinical cardiology. Several echocardiographic methods provide quantitative analysis of LV volumes and ejection fraction (EF) based on the precise tracing of endocardial borders. Often, however, technically limited studies prohibit such direct analysis, and alternative techniques must be applied.

Hypothesis: Nonvolumetric echocardiographic methods which do not require endocardial edge definition and tracing may accurately provide quantitative LV systolic function data.

Methods: A pilot study was conducted to validate and compare two recently described indirect echocardiographic methods of LV systolic function analysis, with LVEF by radionuclear cardiac angiography (RNCA). Thirty-two consecutive patients undergoing RNCA for clinical indications also underwent echocardiography within 24 h, with LV analysis performed by the techniques of (1) atrioventricular plane displacement (AVPD) and (2) mitral valve leaflet coaptation point to interventricular septum distance at end-systole (MVC-IVS).

Results: Thirteen patients had an echocardiogram with poor two-dimensional visualization of LV endocardial borders. One patient could not be evaluated by the MVC-IVS method and two others by the AVPD method because of technical limitations. Chi-square analysis to compare how each method could discriminate between an RNCA LVEF of $<$ or $\geq 50\%$ demonstrated high correlations for the AVPD method ($r =$

0.6530 , $p < 0.0005$) and the MVC-IVS method ($r = -0.7029$, $p < 0.0001$). Sensitivity, specificity, positive and negative predictive values, and test accuracy for the AVPD and MVC-IVS methods were 85 and 80%, 88 and 94%, 85 and 92%, 82 and 83%, and 83 and 87%, respectively.

Conclusion: This pilot study demonstrates that both alternative echocardiographic methods may be useful in the assessment of LV systolic performance, even in the setting of poor LV endocardial border visualization. A larger study is warranted to apply and contrast these methods in different patient subsets.

Key words: radionuclide angiography, echocardiography, left ventricular systolic function, nonvolumetric analysis

Introduction

The evaluation of left ventricular (LV) systolic performance is crucial in the assessment of patient symptoms and conditions that affect the heart. This is usually performed using radionuclear ventriculographic and echocardiographic techniques. The latter is less invasive and generally more cost effective and has been shown to quantitate LV volumes and ejection fraction (EF) accurately when LV endocardial borders can be carefully delineated and traced. At times, however, the left ventricle is poorly visualized on standard two-dimensional (2-D) echocardiography, and alternative techniques must be applied. In this pilot study we validate and compare two such recently described echocardiographic methods for LV systolic function assessment which do not require visualization of larger segments of LV endocardium. These are the methods of (1) atrioventricular plane displacement (AVPD)¹ and (2) mitral valve leaflets coaptation point to interventricular septum distance at end-systole (MVC-IVS).²

The AVPD method attempts to correlate the descent of the mitral annular ring, a reflection of the longitudinal shortening of the left ventricle, with global LV systolic function. The MVC-IVS method is based on the observation that the distance between the mitral valve coaptation point and the ven-

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tricular septum at end-systole is a reflection of LV end-systolic volume and indirectly LVEF. Left ventricular performance indices from both the AVPD and the MCV-IVS method are directly compared with the LVEF obtained from standard radionuclear cardiac angiography (RNCA) performed in patients within 24 h of echocardiography examination.

Subjects and Methods

Study Population

The study population (Table I) consisted of 32 patients referred to the nuclear laboratory at St. Vincent's Medical Center of Richmond for RNCA for clinical indications [13 men, 19 women, ages 39–89 years (mean age 68 years)]. Coronary disease was present in 13 patients, congestive heart failure in

16, angina pectoris in 7, essential hypertension in 15, transient ischemic attack in 2, diabetes mellitus in 6, non-Q myocardial infarction in 3, acute transmural myocardial infarction in 1, renal insufficiency in 3, pulmonary disease in 2, and pericarditis in 1 patient. All patients were in normal sinus rhythm at the time of evaluation. All underwent echocardiography specifically for this protocol ≤ 24 h after RNCA, with most echocardiographic examinations performed immediately thereafter. Thirteen patients had an echocardiogram with inadequate 2-D visualization of the left ventricle, defined as the inability to recognize and trace at least 75% of the LV endocardial borders. This definition of inadequate LV visualization has been suggested in previous studies in which the LV endocardial borders were traced manually³ or semi-automatically (acoustic quantification).⁴ One patient could not be evaluated by the MVC-IVS method and two could not be evaluated by the AVPD method because of patient technical limitations.

TABLE I Demographic, radionuclear, and echocardiographic data in all 32 study population patients

Patient	Age	Sex	Adm. Dx	RNCA EF%	AVPD mm	MCV-IVS mm
1	80	Female	HTN, TIA	52	11.0	Unable
2	78	Female	PLE	26	4.5	51.0
3	71	Female	HTN, BBB	54	Unable	25.0
4	67	Female	HTN, CHF	34	9.0	17.5
5	54	Male	PLE, NQI	61	7.0	27.0
6	86	Female	CHF	19	3.0	37.0
7	51	Female	USA	56	11.0	13.0
8	54	Male	PLE, NQI	61	9.5	20.5
9	42	Female	CHF	41	12.0	25.0
10	58	Female	NQI, AFL	30	8.0	29.5
11	57	Male	USA	27	8.0	33.0
12	81	Male	NQI, CHF	57	10.5	26.5
13	65	Female	USA, HTN	71	15.0	20.5
14	81	Male	CHF	30	9.5	31.0
15	71	Male	USA, PER	48	10.5	31.5
16	73	Male	AFIB, CHF	49	10.0	30.0
17	82	Female	TIA, HTN	50	10.0	30.5
18	83	Female	CHF	25	9.0	30.0
19	74	Male	HTN, CHF	43	10.5	22.5
20	39	Female	USA	25	7.0	36.5
21	70	Male	HTN	53	Unable	26.0
22	60	Male	HTN, DM	54	18.5	15.0
23	72	Male	HTN, CHF	25	8.0	51.0
24	86	Male	ASHD	24	6.5	30.0
25	89	Female	CHF	61	7.0	22.0
26	53	Female	COPD	58	12.5	24.0
27	69	Male	CHF, CRF	21	7.5	46.5
28	75	Female	AC.MI	38	5.0	39.5
29	66	Female	CAD, CRI	34	7.5	30.0
30	58	Female	HTN, CRI	76	13.5	12.0
31	65	Female	CHF, USA	24	9.0	31.0
32	64	Female	COPD	72	14.0	22.0

Abbreviations: HTN = hypertension, TIA = transient ischemic attack, PLE = pulmonary edema, BBB = bundle branch block, CHF = congestive heart failure, NQI = non-Q infarction, USA = unstable angina, AFL = atrial flutter, PER = pericarditis, AFIB = atrial fibrillation, DM = diabetes mellitus, ASHD = atherosclerotic heart disease, COPD = chronic obstructive pulmonary disease, CRF = chronic renal failure, AC.MI = acute myocardial infarction, CAD = coronary artery disease, CRI = chronic renal insufficiency.

Echocardiography

Echocardiography was performed in the semi-recumbent left lateral decubitus position with a Hewlett-Packard 77020AC ultrasound system with appropriate use of power, reject, and gain controls. The methods of AVPD and MVC-IVS were applied as described in previous studies.^{1,2} Briefly, in the AVPD method, the motion of the AV plane (as measured by the mitral annular ring) was determined during 2-D echocardiography of apical 4-chamber and 2-chamber views. In the 4-chamber view, the M-mode cursor was placed in the septal portion of the mitral ring (at the junction of the base of the anterior mitral leaflet and ventricular septum), and subsequently in the lateral portion (at the junction of the base of the posterior mitral leaflet and the lateral LV wall), such that the AV plane moved along the M-mode cursor (Fig. 1). In a similar fashion the anterior and posterior wall AV plane displacement was recorded from the apical 2-chamber view. The mean magnitude (four consecutive beat average) of mitral ring displacement along the M-mode line was determined by M-mode echocardiography for each of the four possible sites (septal, lateral, anterior, and posterior) by measuring the maximal distance between the leading edge of the highest and lowest echoes during each cardiac cycle. By averaging the mean magnitude of mitral ring displacement obtained from each of the four recording sites, the mean AVPD was calculated and used as a measure of global LV systolic function.

In the MVC-IVS method, the left ventricle was imaged in the left parasternal long-axis view. The image was frozen at the end of systole (defined as the point of smallest LV minor axis dimension during mitral leaflet coaptation), and a measurement was taken by electronic caliper to determine the shortest distance between the mitral leaflet coaptation point and the interventricular septum by the internal edge method. The mean of four beats was used for each determination (Fig. 2).

Radionuclide Cardiac Angiography (RNCA)

All patients underwent standard RNCA evaluation in the left anterior oblique position. Images were acquired with a Picker Dynamo (Picker International, Cleveland, Ohio) scintillation camera and a Picker computer, PCS II, with a general purpose collimator. Counts of 6×10^6 were obtained for 16-frame gated R-R intervals. The calculation of EF uses the best end-diastolic and end-systolic regions of interest and automatic background positioning and correction.

Results

The observed RNCA EFs ranged from 19 to 76% (mean 43.7%), the AVPD values from 3.0 to 18.5 mm (mean 9.7 mm), and MVC-IVS values from 12.0 to 51.0 mm (mean 28.7) (Table I).

Chi-square analysis was performed to determine how each method could discriminate between an RNCA LVEF of $<$ or $\geq$ 50%. For the AVPD method there was a strong correlation ($r =$

FIG. 1 Two-dimensional echocardiogram (4-chamber view) and corresponding cursor-derived M-mode echocardiogram showing the recording of the atrioventricular plane displacement through the septal-anterior mitral leaflet junction.

FIG. 2 Two-dimensional echocardiogram (parasternal long-axis view) demonstrating derivation of the mitral valve leaflets coaptation point to interventricular septum distance during end-systole (explanation in text).

0.6530, $p < 0.0005$) between the degree of mean AV plane displacement and LVEF. Using an AVPD measurement of ≥ 10 mm to define an RNCA LVEF $\geq 50\%$, the sensitivity, specificity, positive predictive value, negative predictive value, and test accuracy were 85, 88, 85, 82, and 83%, respectively.

For the MVC-IVS method, there was again a strong correlation ($r = -0.7029$, $p < 0.0001$) between the mean shortest distance between the mitral valve coaptation point and the ventricular septum at end-systole and the LVEF. Using a MVC-IVS measurement of < 30 mm to define an RNCA LVEF $\geq 50\%$, the sensitivity, specificity, positive predictive value, negative predictive value, and test accuracy were 80, 94, 92, 83, and 87%, respectively (Fig. 3).

Observer Variability

To determine intraobserver variability, the AVPD and MVC-IVS distances were measured by one observer on two occasions in 23 patients selected at random from the study

		AV plane displacement				MVC-IVS distance	
		≥ 10 mm	< 10 mm			< 30 mm	≥ 30 mm
RNCA EF	$\geq 50\%$	11	2	RNCA EF	$\geq 50\%$	12	1
	$< 50\%$	3	14		$< 50\%$	3	15
N = 30 applicable patients				N = 31 applicable patients			

FIG. 3 Relationship between radionuclear cardiac angiography (RNCA) ejection fraction (EF) and echocardiographic indices of left ventricular systolic function in applicable study patients. AV = atrioventricular, MVC-IVS = mitral valve leaflets coaptation point to interventricular septum distance at end-systole.

population. To determine interobserver variability, a second independent observer measured the AVPD and MVC-IVS distance in those 23 patients. The intraobserver variability was 1% for both methods. The interobserver variability for the AVPD method was 4% and for the MVC-IVS distance method it was 2%.

Discussion

The common end point of a myriad of different processes which adversely affect the myocardium is a decrease in LV systolic function. Several methods are currently available to assess the function of the left ventricle, each with its own advantages and limitations. Echocardiography has the advantage of being commonly available, noninvasive, easily performed, reliable, and cost effective. At times, however, the left ventricle is poorly delineated echocardiographically, making quantitative measures of endocardial borders very difficult. Others have required a minimum of 75% of the endocardium to be definable before determining the assessment of LV systolic function by volumetric echocardiographic methods.^{3,4} Several methods for the indirect, nonvolumetric echocardiographic (M-mode, 2-D, and Doppler) determination of LV systolic function have been proposed, each with its own inherent difficulties and limitations. In 1977, Massie *et al.* reported the mitral-septal separation as a new index of LV systolic function.⁵ In their study, the minimal distance between the E point of the anterior mitral valve leaflet and the interventricular septum on M-mode echocardiography showed a strong negative correlation with biplane angiographic EF. Others have shown that such a relationship remains valid and useful in patients with acute and chronic coronary artery disease and in the presence of other wall motion abnormalities.^{6,7} The mechanism of such a relationship between the E point-septal separation, a diastolic event, and the LVEF, a systolic event, remains unclear. Thus, additional systolic echocardiographic indices have been sought. Two more recently introduced methods, AVPD^{1,8-10} and MVC-IVS,² have proved promising in early trials, each showing strong correlation with LVEF as determined by either radioisotopic¹ or contrast ventriculographic² techniques.

Ours is the first study to apply both of these two recent methods in the same patient in an attempt to establish their fea-

sibility, validity, and reproducibility. We found that the appropriate indices were easy to measure in most patients (AVPD 30 of 32, MVC-IVS 31 of 32), despite the fact the LV endocardial definition was not reliably obtainable in many (13/32). In fact, the echocardiographic structures used for these measurements (mitral annular ring points, mitral valve coaptation point, ventricular septal distance) are generally quite easily visualized by virtue of their being strong, mobile echo reflectors.

Our results confirm a strong relationship between each of the studied echocardiographic indices and the LVEF as determined by RNCA. Furthermore, each method could discriminate between normal and subnormal LVEF with a high degree of reliability. Even in the few studies whereby one index could not be determined because of technical limitations, the respective index by the alternative method proved reliable.

The implication of this finding is relevant to the daily practice of echocardiography, since it is common to encounter patients in whom echocardiographic studies are suboptimal and who are in need of evaluation of LV systolic function. Such patients may be too ill to be evaluated by other methods such as transesophageal echocardiography, RNCA, contrast ventriculography, or newer imaging techniques such as cine computed tomography or magnetic resonance imaging. Even if such tests could be performed, they would place an additional financial burden on the health care system.

Limitations

Our study has several limitations. The study population was selected as one undergoing RNCA for clinical indications, thus the results may not be applicable to all patient groups. Yet, even in this population, a wide range of LVEFs were represented. Also, echocardiographic and nuclear examinations were nonsimultaneous, and global LV systolic function could have differed somewhat between the studies because of transient alterations of loading conditions or myocardial contractility. However, most studies were, in fact, performed on the same day and under similar conditions.

An additional limitation is the relatively small number of patients in the study population. As a result we elected not to perform linear regression analyses which would have allowed for the correlation between echocardiographic and nuclear measurements along the full continuous range of LVEFs, thereby not limiting the correlation to a single EF value of $<$ or $> 50\%$. Also, such analyses would be expected to allow for the direct comparison between the two echocardiographic techniques. Likewise, our relatively low R values, $r = 0.6530$ for AVPD and $r = -0.7029$ for MVC-IVS, require confirmation in much larger studies. Also, these techniques need to be further evaluated in large subpopulations with various wall motion abnormalities and/or valvular pathologies.

There are also potential limitations of the echocardiographic methods themselves. The AVPD method is dependent on the ability to record a truly "apical" view to allow for the displacement of the AV plane to be recorded parallel to the long axis of the left ventricle. Furthermore, the effects of a variety of intracardiac and extracardiac factors, which may potentially

alter the relative motion of the AV plane, must be further elucidated. Likewise, the MVC-IVS is subject to inherent limitations. While the mitral leaflet coaptation point should be relatively easy to delineate in most cases, the demarcation of the ventricular septum may at times be problematic. Use of the apical long-axis view in conjunction with the parasternal long-axis view should help in a number of cases. There is also the need to obtain the long-axis plane through the "middle" of the mitral leaflets to assure that the correct MVC-IVS measurement is made. This can be readily accomplished by an experienced echocardiographer. In addition, there is further need to evaluate the effects of mitral valve pathology, LV volume loading conditions, ventricular septal wall motion abnormalities, and other potentially confounding variables on the relationship between LVEF and MVC-IVS.

For the MVC-IVS method, we defined end-systole as the point of smallest LV minor axis dimension during mitral leaflet coaptation, whereas others have defined end-systole as the point coincident with the second heart sound. Since phonocardiography is generally not performed during routine echocardiography, we felt that our surrogate definition would be more acceptable.

Since this was only a pilot study, we did not set out to compare the results of these two echocardiographic indices with others of LV systolic function, that is, E point-septal separation, fractional shortening or EF by M-mode techniques. Correlation with the E point-septal index would be of particular interest because of the relative simplicity of that method; however, proper technical attention must be given to its acquisition and measurement.

An extension of this study is planned to address these concerns.

Conclusion

This pilot study demonstrates that a useful estimate of global LV systolic function can be obtained by AVPD and/or MVC-IVS echocardiographic methods, even in situations where the left ventricle is not fully visualized. Further studies are needed to extend these results in additional patient populations.

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