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Echocardiographic assessment of systolic and diastolic left ventricular function using an automatic boundary detection system

Correlation with established invasive and non invasive parameters

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Abstract

Systolic and diastolic left ventricular function was assessed using an echocardiographic automatic boundary detection system (ABD) in 50 unselected patients undergoing left cardiac catheterisation. Automatic boundary detection system derived parameters (fractional area change [FAC], peak positive rate of area change [+ dA/dt] and peak negative rate of area change [- dA/dt]) were compared with invasively (left ventricular angiography and pressures) and non invasively (Doppler mitral filling velocities and isovolumic relaxation time) acquired conventional indices of ventricular function. Adequate detection of endocardial boundaries and subsequent measurements using the ABD system were achieved in 40/50 (80%) patients in the short axis parasternal view, in 41/50 (82%) in the apical four chamber view and in 34/50 (68%) in both views. For the whole group of patients the FAC (maximal left ventricular diastolic area – minimal left ventricular systolic area / maximal left ventricular diastolic area) estimated in the short axis view correlated with the angiographic ejection fraction (EF) measured in the right oblique projection ($r = 0.51$, $p < 0.001$). There was only a weak correlation of the FAC estimated in the apical four chamber view with the EF ($r = 0.36$, $p < 0.01$). The mean FAC (mean value of the FAC in the short axis and apical four chamber views) correlated reasonably with the EF ($r = 0.62$, $p < 0.0001$). There was no correlation between ABD derived parameters and left ventricular end diastolic pressure (LVEDP) in these patients.

In a subgroup of patients with normal coronary arteries and left ventricular function ($n = 17$), although there was no correlation between EF and FAC, there was a strong positive correlation between FAC (apical four chamber and mean) and LVEDP ($r = 0.77$, $p < 0.01$ and $r = 0.87$, $p < 0.01$ respectively). No correlation was found in these patients between EF and LVEDP. In a further subgroup of patients with angiographically abnormal left ventricular function (EF < 45%), there was a positive correlation between FAC (short axis, apical four chamber and mean) and EF ($r = 0.52$, $p < 0.05$, $r = 0.83$, $p < 0.0001$ and $r = 0.80$, $p < 0.001$ respectively) and a negative correlation between FAC (short axis and mean) and LVEDP ($r = -0.52$, $p < 0.05$ and $r = -0.60$, $p < 0.01$ respectively). There was also a negative correlation between LVEDP and EF in the same subgroup of patients ($r = -0.65$, $p < 0.01$).

None of the ABD derived parameters correlated with non invasively acquired indices of diastolic ventricular function (peak early left ventricular diastolic filling blood velocity [Emax], peak late diastolic velocity [Amax], E/A ratio and isovolumic relaxation time [IVRT], but there was a consistent positive correlation between - dP/dt and + dA/dt estimated in the four chamber view ($r = 0.5$, $p < 0.01$, all patients).

Therefore, although ABD derived parameters cannot be used in an interchangeable way with ejection fraction, they do provide a rapid, bedside method for the assessment of left ventricular function. FAC and dA/dt do appear to reflect left ventricular performance both in patients with normal ventricles and in patients with impaired left ventricular function.

Introduction

Off-line quantitative assessment of left ventricular function, using conventional two dimensional echocardiography, is time consuming when performed correctly using multiple sequential cardiac cycles [1].

However, new methods of echocardiographic signal processing based upon tissue characterisation methodology can facilitate automatic echocardiographic assessment of left ventricular function by detection of the endocardial boundary. A commercially available, echocardiographic method of automatic endocardial boundary detection (ABD) is now available and calculates in real time left ventricular area within every sequential echocardiographic image/frame. The system also calculates the fractional area change (FAC = maximal ventricular diastolic area-minimal left ventricular systolic area/maximal left ventricular diastolic area) and the rate of area change (dA/dt). These parameters may be displayed graphically against time permitting real time assessment over multiple cardiac cycles. This method can be used in the majority of the patients successfully, quickly and with acceptable interobserver and intraobserver variability (15%, 12% for ventricular areas, 16%, 11% for FAC and 13%, 11% for dA/dt) [2]. Results obtained with this system correlate well with those obtained with the manual, off-line, analysis systems both in experimental [3] and clinical studies [4]. Previous studies have suggested that ABD derived parameters correlated closely with cardiac output [5] and stroke volume [6], as well as with contractility [7] estimated with conventional methods. The ejection fraction calculated after applying the Simpson's rule to left ventricular areas measured by the ABD system has been demonstrated to correlate closely with radionuclide estimated ejection fraction [8]. Furthermore the ratio of left ventricular areas measured in the early and the atrial filling period correlated well with the E/A ratio (ratio of peak early left ventricular diastolic filling blood velocity [Emax] to peak atrial diastolic filling blood velocity [Amax], measured by pulsed wave Doppler [9].

There is however, no published data correlating on-line ABD parameters (FAC, peak positive and negative dA/dt) with traditionally accepted invasive (ejection fraction [EF], left ventricular end diastolic pressure [LVEDP], maximum positive dP/dt, maximum negative dP/dt) and non-invasive (Emax, Amax, E/A, isovolumic relaxation time) indices used for the assessment left ventricular systolic and diastolic function in unselected patients. Therefore, the aims of the present study were: a) to evaluate the relationship between parameters derived from an echocardiographic automatic boundary detection system and those obtained from left ventricular angiography, left ventricular pressure monitoring and Doppler assessment of left ventricular filling pattern and b) to establish if the automatic boundary detection system can be used to substitute for and/or complement these established but more complex and in part invasive methods in the assessment of left ventricular function.

Patients and methods

Patient population

Fifty patients (36 males, 14 females) undergoing routine cardiac catheterisation for different clinical indications were studied. Their age (mean $\pm$ SD) was 58.2 ± 16.1 years (range 30 to 81). The indications for catheterisation were; suspected ischaemic heart disease in 45 and dilated cardiomyopathy in 5 patients. The final diagnosis was ischaemic heart disease in 28 patients, normal coronary arteries and normal cardiac function in 17 and dilated cardiomyopathy in 5. The 17 patients with normal coronary arteries and cardiac function were being studied because of persistent chest pain. All of these patients either had an equivocal or negative exercise test, no valvular pathology and no pulmonary or systemic hypertension. All 50 patients underwent echocardiographic evaluation with ABD prior to, and within 1 hour of, cardiac catheterisation. No fluids or medications were administered to the patients in the interim period. Heart rate and blood pressure were measured prior to echocardiographic evaluation and were continuously monitored during cardiac catheterisation.

Echocardiographic automatic boundary detection system

Echocardiography was performed by 3 highly experienced echocardiographers. A Hewlett Packard Sonos 1500 system with a 2.5 MHz phased array transducer was used for the automatic echocardiographic assessment of left ventricular function. The above system has specialised software (trade name AQ), which enables automatic detection of the endocardial boundaries and subsequent real-time assessment of left ventricular area. Parameters of left ventricular function are derived simultaneously, and displayed on-line, from the calcu-

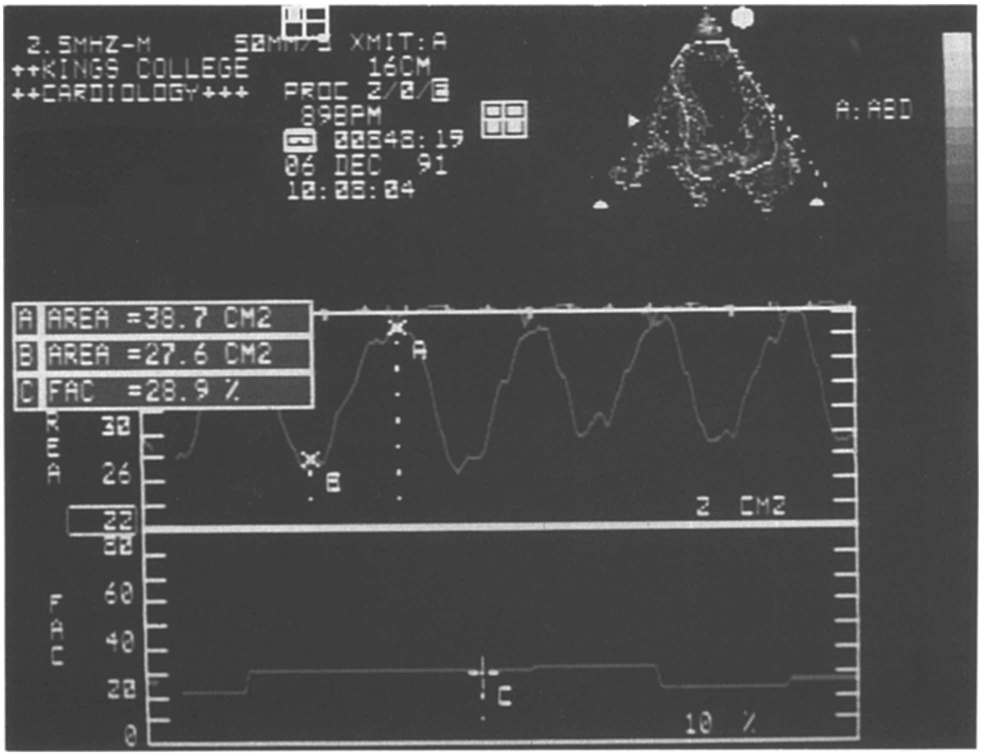

Fig. 1. Demonstrates the use of the ABD system in the apical 4 chamber view. Maximum (A) and minimum (B) areas are displayed and below this, the fractional area change (C). All parameters are displayed on-line.

lated area. The automatic boundary detection system is based upon methods of radiofrequency echocardiographic signal processing which allow automatic identification and separation of blood and myocardial tissue down each image scan line. Filtering and smoothening of the data cannot be adjusted, but it is seems likely to be incorporated in future versions of the software. Utilising this, the blood tissue interface is recognised over the entire image and used to create an endocardial boundary. Adjustment of transducer output power and gain controls which operate in both the conventional axial and, more recently, the lateral planes, allows control over endocardial detection. However, it is important to note that as gain settings are increased in order to try to identify endocardial borders, left ventricular areas may artefactually decrease producing an underestimation of left ventricular areas. It is therefore important to confirm adequate endocardial detection visually and if < 75% of the endocardial border is detected then the study should be rejected. Therefore the images were accepted for measurements only if at least 75% of the endocardial boundary appeared to be successfully detected against visual evaluation. Fine adjustements of the time gain compensation setting (axial gain), lateral gain and transmit (output power) controls were required to optimise endocardial detection. A region of interest is drawn around the left ventricle and the adjacent myocardium. The ventricular area is then continuously calculated for each image frame within the region of interest. A real time graphical display of ventricular area, FAC and dA/dt is displayed (Figs 1 and 2).

For the purpose of this study, echocardiographic images of the left ventricle at the parasternal short axis (level of the papillary muscles) and the apical four chamber views were obtained when possible. The FAC, peak positive dA/dt and peak negative dA/dt of the left ventricle both in the short axis and the apical four chamber views were measured on-line and averaged over a period of 5 consecutive beats. The mean value of the averaged FAC from both views was also calculated (mean FAC).

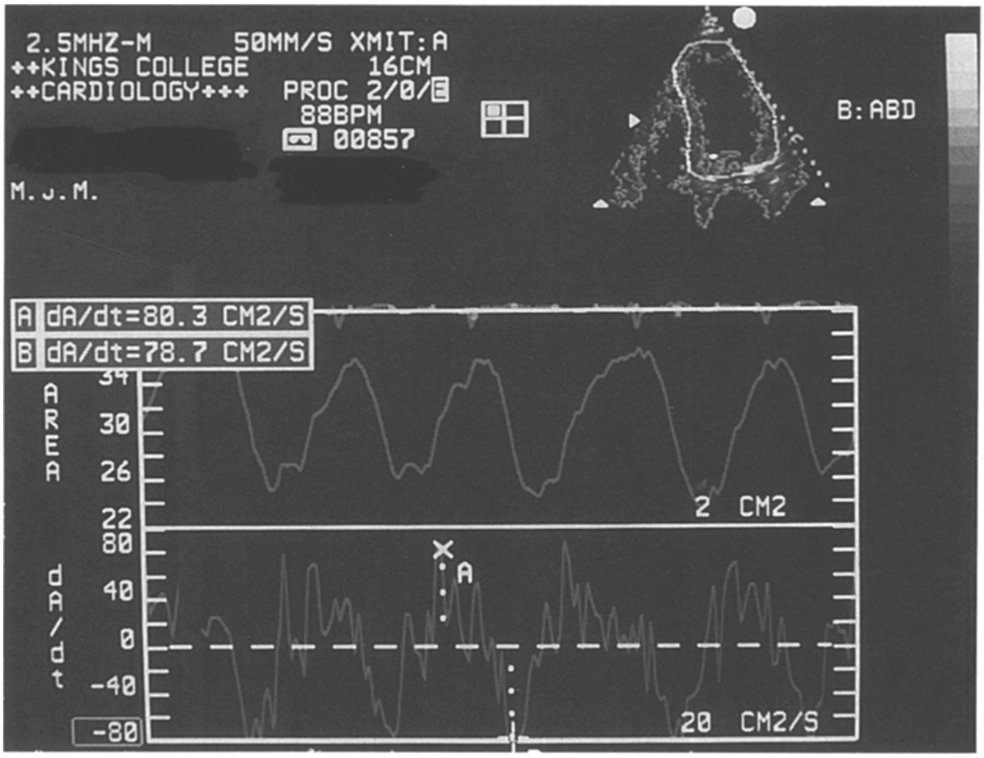

Fig. 2. Again demonstrates the use of the ABD system in the apical 4 chamber view. On this occasion maximum positive (A) and maximum negative (B) rates of area change (+ dA/dt and - dA/dt respectively) are displayed on-line.

Doppler measurements

After ABD imaging was completed, a spectral pulsed wave Doppler recording of the mitral inflow was recorded utilising the apical four chamber view with the pulsed wave sample volume positioned at the tips of the mitral valve. The precise sample volume position was adjusted to give the maximal transmitral velocities using both the audible signal and spectral velocity display [10]. The velocity profile was then recorded during passive end expiration at a paper speed of 100 $sm.s^{-1}$. An ECG and phonocardiogram were simultaneously displayed and recorded. The following parameters of left ventricular function were subsequently measured: peak early left ventricular diastolic filling blood velocity (Emax), peak late (atrial) velocity (Amax), E/A ratio and isovolumic relaxation time (IVRT). For the purposes of the present study IVRT was defined as the time interval between the first positive deflection of the aortic component of the second heart sound to the onset of transmitral flow. The measured parameters were averaged over 5 consecutive cardiac cycles.

Invasive assessment of left ventricular function

Left ventriculography was performed using a pigtail catheter. Ejection fraction was estimated angiographically in the right anterior oblique 30° projection using the modified area length ellipsoid method [11–13]. To measure LV ejection fraction, two sinus beats not preceded by an ectopic ventricular beat, were traced in end-diastole and end-systole. Ejection fraction was determined as the average of the two beats. Positive and negative rate of left ventricular pressure change was estimated automatically from the left ventricular pressure tracings using a high fidelity pressure transducer, whilst continuous monitoring of the left ventricular pressure prior to angiography allowed estimation of the left ventricular end diastolic pressure. The pressure parameters were averaged over 5 consecutive cardiac cycles.

Table 1. Correlation between ABD derived parameters and invasively acquired indices of left ventricular function in the total group of patients (n = 50). (Only statistically significant data is displayed.)

	EF
$FAC_{shortaxis}$	r = 0.51
(n = 40)	(p < 0.001)
$FAC_{ap\ 4\ ch}$	r = 0.36
(n = 41)	(p < 0.01)
FAC_{mean}	r = 0.62
(n = 34)	(p < 0.0001)
$- dA/dt_{ap\ 4\ ch}$	r = 0.33
(n = 41)	(p < 0.05)

$FAC_{shortaxis}$: Fractional area change estimated in the short axis view, $FAC_{ap\ 4\ ch}$: Fractional area change estimated in the apical four chamber view, FAC_{mean}: Mean value of the fractional area change estimated in short axis and apical four chamber views, $- dA/dt_{ap\ 4\ ch}$: peak negative rate of area change estimated in the apical four chamber view, r: Pearson's correlation coefficient, EF: ejection fraction.

Statistical analysis

The invasively and non-invasively obtained parameters of left ventricular function were correlated using the Pearson's correlation.

Results

Adequate endocardial detection, using the previously described criteria, was achieved in 40/50 patients (80%) in the short axis parasternal view, 41/50 (82%) in apical four chamber view and in 34/50 (68%) in both views. The mean ± SD time to acquire the ABD data was 4.4 ± 1.2 minutes. Phonocardiographic data, pulsed wave Doppler measurements and invasive data were obtained in all 50 patients. There were no statistically significant differences between systolic blood pressure, diastolic blood pressure and heart rate prior to echocardiographic assessment and during cardiac catheterisation.

Invasive parameters

The ABD derived parameters ($FAC_{short\ axis}$, $FAC_{apical\ 4\ chamber}$, FAC_{mean}, $+ dA/dt_{short\ axis}$, $- dA/dt_{short\ axis}$, $+ dA/dt_{apical\ 4\ chamber}$ and $dA/dt_{apical4chamber}$) were correlated with indices acquired invasively (EF, LVEDP, + dP/dt and - dP/dt) for the total group of patients. The significant correlations are displayed in Table 1. The $FAC_{short\ axis}$ and FAC_{mean} had a positive correlation with EF (r = 0.51, p < 0.001 and r = 0.62, p < 0.0001 respectively). The correlation between FAC_{mean} and EF, along with the regression equation, is shown in Fig. 3. Only a weak correlation was found between $FAC_{apical\ 4\ chamber}$ and EF (r = 0.36, p < 0.01). The only correlation found between positive or negative dA/dt and EF was that between $- dA/dt_{apical\ 4\ chamber}$ and EF (r = 0.33, p < 0.05). There was no correlation between any of the ABD derived parameters and either LVEDP or + dP/dt. The $+ dA/dt_{apical\ 4\ chamber}$ correlated with the - dP/dt (r = 0.5, p < 0.001). A possible explanation for the weak correlation between $FAC_{apical\ 4\ chamber}$ and EF was the lack of representation of the inferior wall in the echocardiographic plane and of the lateral wall in the angiographic view used. Therefore, the correlation between FAC and EF was studied in a subgroup of patients without posterior or inferior wall motion abnormalities on the left ventricular angiogram and normal left circumflex coronary artery (n = 25). Fractional area change was available in 24/25 in the short axis view, 22/25 in the apical 4 chamber view and 18/25 as a mean value. In this subgroup the correlation of the $FAC_{apical\ 4\ chamber}$ with the EF remained not significant statistically.

Two further subgroups, those with and those without left ventricular dysfunction, were analysed (Table 2 and Table 3). Seventeen patients had angiographically normal left ventricular function (defined as EF > 45% without any localised wall motion abnormality) and normal coronary arteries (all of these patients had suspicious clinical symptoms of ischaemic heart disease but equivocal or negative exercise tests), whilst another 17 had angiographically impaired left ventricular function (defined as EF < 45%). In the second subgroup, the final diagnosis was ischaemic heart disease in 12 patients and dilated cardiomyopathy in 5. Two out of twelve patients with ischaemic heart disease had anterior wall motion abnormalities, 5/12 anteroapical, 3/12 apical and 2/12 posterior. In the first subgroup of patients, the mean ± SD values of $FAC_{shortaxis}$, $FAC_{apical\ 4\ chamber}$ and FAC_{mean} were 35.0 ± 8.7, 28.1 ± 7.3 and 31.12 ± 8.34 respectively. Mean FAC values were available in 13/17 patients with normal left ventricular function and normal coronary arteries and in 12/17 patients with impaired left

Table 2. Correlation between ABD derived parameters and invasively acquired indices of LV function in patients with angiographically normal left ventricular function and coronary anatomy (n = 17). (Only statistically significant data is displayed.)

	LVEDP
$FAC_{ap\ 4\ ch}$	r = 0.77
(n = 14)	(p < 0.01)
FAC_{mean}	r = 0.87
(n = 13)	(p < 0.01)
+ $dA/dt_{shortaxis}$	r = 0.49
(n = 15)	(p < 0.05)
- $dA/dt_{shortaxis}$	r = 0.50
(n = 15)	(p < 0.05)
+ $dA/dt_{ap\ 4\ ch}$	r = 0.58
(n = 14)	(p < 0.05)
- $dA/dt_{ap\ 4\ ch}$	r = 0.79
(n = 14)	(p < 0.01)

$FAC_{ap\ 4\ ch}$: Fractional area change estimated in the apical four chamber view, FAC_{mean}: Mean value of the fractional area change estimated in short axis and apical four chamber views, + $dA/dt_{shortaxis}$: peak positive rate of area change estimated in the short axis view, - $dA/dt_{shortaxis}$: peak negative rate of area change estimated in the short axis view, + $dA/dt_{ap\ 4\ ch}$: peak positive rate of area change estimated in the apical four chamber view, - $dA/dt_{ap\ 4\ ch}$: peak negative rate of area change estimated in the apical four chamber view, r: Pearson's correlation coefficient, LVEDP: left ventricular end diastolic pressure.

Table 3. Correlation between ABD derived parameters and invasively acquired indices of left ventricular function in the subgroup of patients with angiographically abnormal left ventricle (n = 17). (Only statistically significant data is displayed.)

	EF	LVEDP
$FAC_{shortaxis}$	r = 0.52	r = - 0.52
(n = 14)	(p < 0.05)	(p < 0.05)
$FAC_{ap\ 4\ ch}$	r = 0.83	NS
(n = 14)	(p < 0.0001)	
FAC_{mean}	r = 0.8	r = - 0.6
(n = 12)	(p < 0.001)	(p < 0.01)
- $dA/dt_{shortaxis}$	r = 0.56	NS
(n = 14)	(p < 0.05)	
+ $dA/dt_{ap\ 4\ ch}$	NS	r = - 0.47
(n = 14)		(p < 0.05
- $dA/dt_{ap\ 4\ ch}$	r = 0.52	NS
(n = 14)	(p < 0.05)	

$FAC_{shortaxis}$: Fractional area change estimated in the short axis view, $FAC_{ap\ 4\ ch}$: Fractional area change estimated in the apical four chamber view, FAC_{mean}: Mean value of the fractional area change estimated in short axis and apical four chamber views, - $dA/dt_{shortaxis}$: peak negative rate of area change estimated in the short view, + $dA/dt_{ap\ 4\ ch}$: peak positive rate of area change estimated in the apical four chamber view, - $dA/dt_{ap\ 4\ ch}$: peak negative rate of area change estimated in the apical four chamber view, r: Pearson's correlation coefficient, EF: ejection fraction, LVEDP: left ventricular end diastolic pressure, NS: Statistically non significant.

ventricular function. In the subgroup of patients with normal LV function (mean EF = 72 ± 11%) and coronary arteries there was no correlation between any of the ABD derived parameters and EF. In contrast, there was a strong positive correlation between almost all ABD parameters (other than $FAC_{shortaxis}$) and LVEDP (Table 2 and Fig. 4). No correlation between angiographic EF and LVEDP was found in this subgroup of patients. A correlation between + $dA/dt_{apical\ 4\ chamber}$ and - dP/dt was noted again ($r = 0.54$, $p < 0.05$). In the patients with impaired LV function (mean EF = 32 ± 12%) there were positive correlations between most ABD derived parameters and EF. In this subgroup, in contrast to those patients with normal LV function, there were significant negative correlations between ABD derived parameters ($FAC_{shortaxis}$, FAC_{mean}, + $dA/dt_{apical\ 4\ chamber}$) and LVEDP (Table 3 and Fig. 4). A negative correlation was found between angiographic EF and LVEDP ($r = - 0.65$, $p < 0.01$) in these patients. There was again a positive correlation between + $dA/dt_{apical\ 4\ chamber}$ and - dP/dt ($r = 0.60$, $p < 0.05$) in the subgroup with impaired left ventricular function.

Non-invasive parameters (Table 5)

ABD derived parameters showed no correlation with any of the obtained non-invasive diastolic filling parameters.

Discussion

Previous studies have shown that this new echocardiographic automatic boundary detection system can be used in the majority of patients, quickly and with acceptable inter and intraobserver variability [2, 14]. In both experimental [3] and clinical studies [4] ABD derived parameters correlate well with results obtained

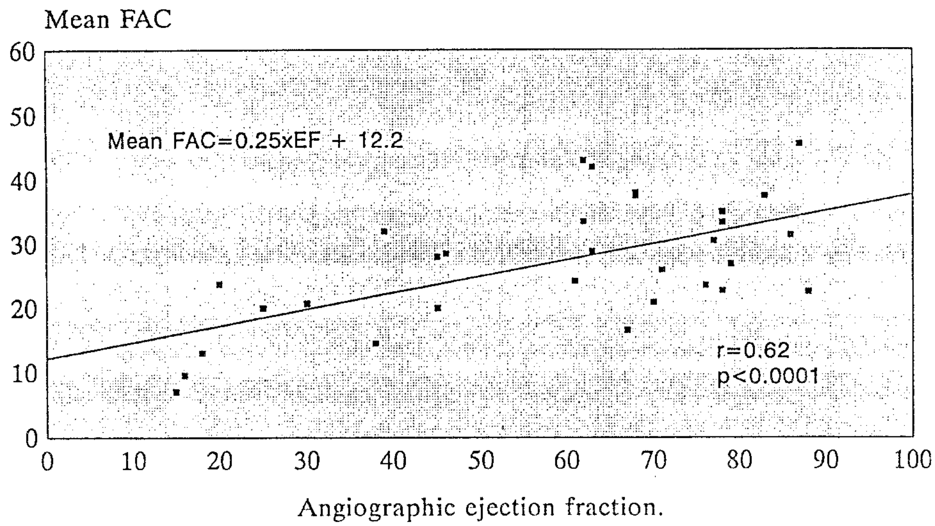

Fig. 3. Demonstrates the relationship between mean FAC and angiographic ejection fraction. The regression equation (x = 1.5y + 11.8) for the two parameters is also shown.

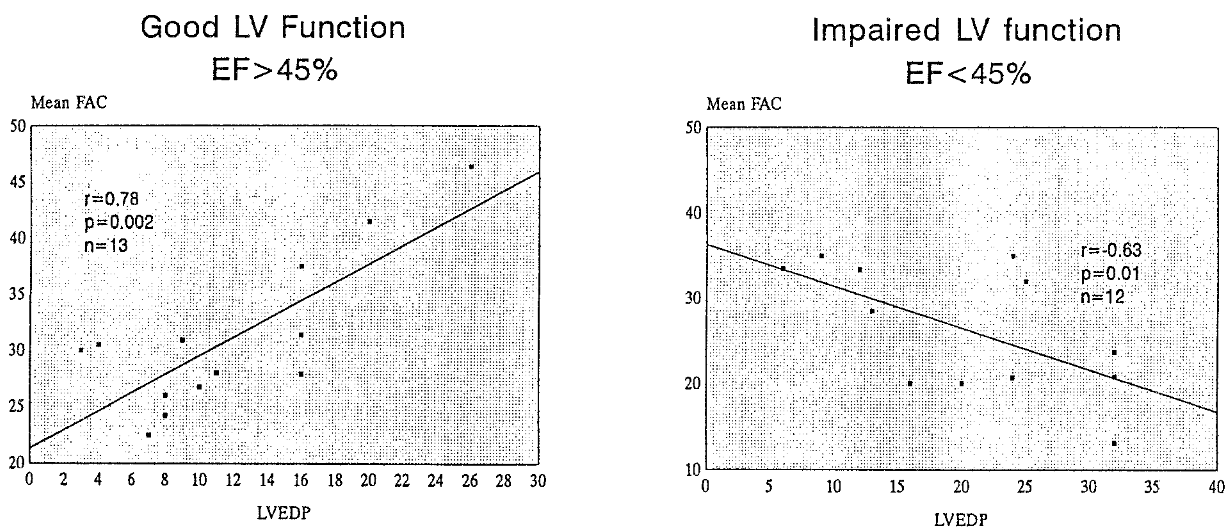

Fig. 4. Demonstrates the relationship between mean FAC and LVEDP in those patients with normal and impaired left ventricular function.

echocardiographically using manual off-line analysis systems. In particular, it has been shown that FAC correlates satisfactorily with EF estimated off-line manually using echocardiography [4]. Previous work using ABD in a small study of 8 patients undergoing bypass surgery demonstrated that cardiac output, measured by the incorporation of ABD derived area change into a mathematical algorithm, correlated well with similar measurements using thermodilution techniques [5]. Furthermore, in two small experimental studies, it has been shown that changes in left ventricular area, detected using ABD, correlate with changes in stroke volume ($r = 0.96$, $p < 0.001$) [6] and that changes in FAC reflect changes in ventricular contractility [7]. In another study, ejection fraction was calculated by applying the Simpson's rule to left ventricular areas measured by the ABD system and this correlated well with radionuclide estimated ejection fraction ($r = 0.91$, $p = 0 < 0.001$) [8]. However the previous studies have two main disadvantages: a) they compare echocardiographic data versus echocardiographic data [4, 15] and b) by incorporating ABD derived parameters into mathematical algorithms there may be potential for increasing error and prolonging study times.

The present study is the first to compare on-line ABD derived parameters with invasively and non-invasively acquired indices traditionally used to assess systolic and diastolic left ventricular function in a group of non-selected patients. Although the measurements (ABD versus invasive and non invasive assessment) were not taken simultaneously, precautions were taken to eliminate changes in factors that may affect left ventricular function (short period of time between echocardiographic and invasive assessment, no fluids or medications administered during this period, no difference between blood pressure and heart rate during echocardiographic and invasive assessment).

Fractional area change

Whilst previous studies [3, 4] have demonstrated satisfactory correlation between FAC and EF we found only a weak correlation when the total patient group was analysed [$FAC_{shortaxis}$ and EF ($r = 0.51$), $FAC_{apical\ 4\ chamber}$ and EF ($r = 0.34$), FAC_{mean} and EF ($r = 0.62$)].

We considered four possible explanations for the weak correlation between FAC and EF found in our patients. There may have been differences in our patient characteristics compared to a previous study [4] where the patient characteristics were not clarified. Also, in this study [4] the methodology used compared echocardiographic data with echocardiographic data and which may lead to stronger correlations. Conversely in the present study, where EF was estimated angiographically, separate problems related to each of the methodologies may have resulted in weaker instead of stronger correlation. An obvious problem with the different methodologies is that angiography is a shadowgram which truly shows the largest projected area whereas echocardiographic areas will be dependent on the given cross section displayed and, if anything, will tend to underestimate left ventricular areas especially at the end systole. Another possible explanation, was the disparity between the echocardiographic and the angiographic views utilised. In the apical four chamber view, the lateral wall is well visualised (whilst it is poorly represented in the angiocardiographic view) and in the right oblique angiographic projection the inferior wall is well visualised (whilst it is poorly represented in the echo apical 4 chamber view). Finally the disparity between echocardiographic and angiographic views in combination with the fact that echocardiography tends to underestimate cross-sectional areas significantly during end systole and only minimally during end diastole can account both for the generally weak correlation between FAC and EF and especially for the differences in correlation in different projections in our study.

In order to try and establish the significance of the incompatibility between echocardiographic and angiographic views, a subgroup of patients without posterior or inferior wall motion abnormalities was identified and the $FAC_{apical\ 4\ chamber}$ was compared with the EF in this subgroup. There was no correlation between the two parameters in these 25 patients suggesting that the representation of various myocardial regions in the echocardiographic and angiographic views was not the main cause of the weak correlation between FAC and EF.

In a further attempt to explain the overall weak correlation between FAC and angiographic EF we compared these parameters in two different subgroups of patients: those with normal (EF > 45%), normal coronary arteries and those with abnormal (EF < 45%) left ventricular function. In the subgroup with normal left ventricular function, there was no correlation between FAC and EF, whilst there was a strong correlation in the patients with left ventricular dysfunction (the strongest being in the $FAC_{apical\ 4\ chamber}$: $r = 0.83$, $p < 0.0001$ and the regression equation is represented by $FAC_{apical\ 4\ chamber} = 0.44 \times EF + 2.6$). The results in the subgroup of patients with impaired left ventricular function are similar with those previously reported [4] and may suggest that differences in overall patient populations could account for the disparity between the studies. In addition, our data suggest that although in an unselected population, FAC correlates only weakly with EF, there is a much stronger correlation in patients with impaired left ventricular function. Furthermore the good correlation of the $FAC_{apical\ 4\ chamber}$ and angiographic EF in patients with impaired left ventricular function, may relate to the high number of patients with apical wall motion abnormalities (8/17) in this subgroup (the apical region is well represented in the 4 chamber view).

The correlations between FAC, LVEDP and EF in patients with normal and abnormal ventricular function were of interest (Fig. 4). In patients with normal left ventricular function, the $FAC_{apical\ 4\ chamber}$ and FAC_{mean} correlated positively with the LVEDP, however there was no correlation between EF and LVEDP. Whilst in patients with abnormal ventricular function both the FAC (all views) and the EF correlated negatively with the LVEDP. These findings possibly simply confirm that in normal hearts LVEDP mainly reflects preload [16] and that moderate changes in preload although have little effect in the EF [17, 18] affect in a much sensitive way the FAC. However although it would be interesting to postulate that the positive correlation found between ventricular filling pressures and FAC reflects operation of the Frank-Starling principle [19] the only way for this to be proven would have been to obtain data from the same heart. Conversely, the significant negative correlation found between LVEDP and both FAC and EF in patients with abnormal left ventricular function possibly indicates that increased LVEDP is secondary to impaired left ventricular function and therefore FAC values reflect the functional status of the impaired myocardium.

The lack of correlation between FAC and EF in patients with normal left ventricular function may be due to close clustering of EF values (Fig. 3) with a narrow range which makes statistical correlation more difficult. In patients with poorly contracting dilated left ventricle, it is our impression, that because the heart lies closer to the thoracic wall and there is less superimposed lung tissue, they have less artefacts and are, as a group, better echocardiographic subjects.

Rate of area change

In the subgroup of patients with normal ventricles there was no correlation between positive or negative rates of area change (in any view) and angiographic EF. However, in the same patients there was a positive correlation between both positive and negative rates of area change (in all views) and LVEDP, similar to the relationship found between FAC and LVEDP.

Conversely, in the subgroup of patients with abnormal LV function there were negative correlations between rates of area change and LVEDP, so that in patients with abnormal ejection fraction, increased LVEDP tended to be associated with lower rates of both positive and negative area change. As with FAC, these results possibly suggest that dA/dt, in patients with normal ventricles, allows subtle changes in left ventricular performance due to increased filling pressures to be appreciated, whilst in patients with reduced ejection fraction, this parameter reflects the status of the failing myocardium. In the group as a whole, and in the subgroups with normal and abnormal left ventricular function, $+ dA/dt_{apical\ 4\ chamber}$ had a significant positive correlation with - dP/dt. This suggests that + dA/dt, being a parameter measuring rate of area change during diastole, may have a role to play in the assessment of left ventricular diastolic function and deserves further evaluation in this context.

Finally no correlation was found between - dA/dt and + dP/dt. However, + dP/dt has been shown to be of little value as a tool to assess basal levels of ventricular contractility or in comparing contractility between different patients [20] and this may explain this poor correlation.

ABD derived parameters and non invasively acquired indices

No correlation was found between any of the ABD derived parameters and the non invasively acquired indices (Emax, Amax, E/A and IVRT). However, this is not an unexpected result as: a) diastole itself is a complex set of separate but interrelated processes with several indexes of diastolic function describing different aspects of these processes [21] and b) the studied Doppler parameters, are dependent on a number of variables other than intrinsic left ventricular diastolic function [22] (including age, preload and afterload).

Study limitations

One of the limitations of the present study, which reflects the problems of echocardiographic automatic boundary detection systems, is the limited number of patients (68%) in whom adequate echocardiographic detection could be obtained in more than one view. This finding is in agreement with previous reports [4] and demonstrates the need for critical evaluation before accepting an image for quantitative analysis.

A second limitation is the different tomographic planes used during the echocardiographic and angiographic studies. This problem has been fully discussed above and it was shown that the correlation between ABD derived parameters and invasive indices did not improve in a subgroup of patients where the major source of error due to incompatibility between the different views was minimised. However a source of error due to different tomographic planes cannot be completely excluded.

Unfortunately, only small numbers of patients were in the subgroups with normal and poor left ventricular function. However, although greater patient numbers will be needed to confirm the results, the findings were consistent with almost all ABD parameters. The results suggesting that ABD derived parameters may be more sensitive indices than EF in the assessment of left ventricular performance need to be interpreted with some caution because the response of FAC and dA/dt to different preload conditions was not measured in the same subject.

A final limitation of the present study is that only peak rates of dA/dt were measured and correlated with Doppler indices of left ventricular diastolic function. It is possible that improved correlations would be found with Doppler parameters, if peak early and late filling rates of area change were measured. However, very high quality ABD traces are necessary for these values to be reliably identified. In our experience this may make this technique impractical in the majority of patients.

Conclusions

This first study comparing ABD parameters with invasive indices of LV function demonstrates encouraging results. It suggests that although ABD derived parameters can not be used in an interchangeable way with ejection fraction, they do provide a rapid, bedside method for the assessment of left ventricular function. FAC and dA/dt do appear to reflect left ventricular performance both in patients with normal ventricles and in patients with impaired left ventricular function. The role of these indices, in the assessment of changes in left ventricular function following various pharmacological and mechanical (eg revascularisation) interventions to the myocardium, deserves further evaluation.

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