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Establishment and Performance of a Magnetic Resonance Cardiac Function Clinic

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ABSTRACT

Our objective was to establish a cardiovascular magnetic resonance (CMR) cardiac function clinic to provide an assessment of cardiac volume, mass, and function in patients with heart failure on the same day as their cardiology outpatient clinic appointment. Sixty-four patients attended the CMR function clinic. The reproducibility, patient acceptability, and time efficiency of the CMR clinic were assessed and compared with radionuclide ventriculography (RNV) and echocardiography (echo). Reports were available in the cardiology outpatient clinic within 2 hr of the CMR appointment time. The reproducibility of volumes, ejection fraction, and mass in this heart failure population was good and comparable with CMR studies in the normal population. CMR was more acceptable to the patients than both RNV and echo ($p < 0.05$). The total time for CMR was less than that of RNV (42 ± 4 and 61 ± 4 min, respectively; $p < 0.001$) but more than that of echo (echo, 23 ± 2 min; $p < 0.001$). Comparison of ejection fractions revealed a correlation between CMR and RNV of 0.7, but Bland-Altman limits of agreement were wide (−10.5% to 18.9%). For CMR versus echo, the correlation was 0.6, and the limits of agreement were wider (−29.9% to 23.3%). The correlation between RNV and echo was 0.2 with wider limits of agreement (−29.8% to 24.9%). In conclusion, CMR can provide a rapid, reproducible, and patient acceptable assessment of cardiac function in heart failure patients, whereas other methods appear to have a wider variance. The high reproducibility of CMR lends itself to the follow-up of clinical progression and the effect of treatment in patients with heart failure.

KEY WORDS: *Cardiovascular magnetic resonance; Clinic; Heart failure; Ventricular function.*

INTRODUCTION

The accurate and reproducible assessment of cardiac volume, mass, and function is a fundamental aim of non-invasive cardiac imaging. A single assessment can provide important diagnostic and prognostic information (1–3). Much recent interest has centered on the process of cardiac remodeling, and reliable serial assessment may yield a greater understanding of this process and provide a more informed opinion on the progression of disease in individuals. Furthermore, a sufficiently accurate and reproducible imaging technique could monitor the re-

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sponse to therapeutic interventions designed to moderate or reverse remodeling, either in an individual or as part of a pharmaceutical trial. An ideal imaging technique would provide a noninvasive, accurate, and reproducible assessment of cardiac function without exposure to ionizing radiation. It would be widely available and time and cost effective. Echocardiography (echo) is a widely available but less than an ideal imaging technique because the image acquisition is operator and acoustic window dependent (4). Furthermore, the quantification of volumes and mass is limited by geometric assumptions that may provide a reasonable assessment in the normal ventricle but are less reliable in remodeled hearts (5,6).

Nuclear medicine can be used to measure ventricular function, but the need for repeated radionuclide doses, especially for research, is difficult to justify. This has led to a growing interest in cardiovascular magnetic resonance (CMR). CMR offers high spatial and temporal resolution and the ability to obtain three-dimensional tomographic images in any desired plane without the need for geometric assumptions. It is noninvasive and has been demonstrated to be highly accurate (7,8) and reproducible (9–13). Increasing interest has led to wider availability, leaving cost and patient acceptability as the major clinical factors to be examined. With the advent of faster more cost-effective imaging sequences, CMR may now offer a realistic alternative to other imaging modalities (14–16). Despite this, there have been few studies using a fast acquisition technique in patients and, to our knowledge, no reports of a routine CMR function clinic. In this study we establish and assess a same-day CMR function clinic for heart failure patients attending a cardiology outpatient clinic and compare ejection fraction, scanning time, and patient acceptability with previously performed investigations (echo and radionuclide ventriculography [RNV]).

MATERIALS AND METHODS

Sixty-four patients (55 men and 9 women aged 56 ± 11 yr) were invited to attend the CMR function clinic on the same day as their cardiology outpatient clinic appointment. CMR images were analyzed and the results sent to the clinic to allow the physician to see the patient with the results.

CMR

Subjects were imaged with a 1.5-T scanner (Picker, Cleveland, OH) using the body coil and electrocardiogram (ECG) triggering. The cardiac short axis was determined from three scout images: transverse, vertical long axis, and breathhold diastolic horizontal long axis (Fig. 1). The basal short-axis slice was positioned just forward of the atrioventricular ring, and all subsequent breathhold cines were acquired in 1-cm steps toward the apex. A breathhold segmented gradient echo fast low-angle shot sequence was used for each of the contiguous short-axis slices. Parameters were as follows: TE 3.8 msec, TR = RR interval, slice thickness 10 mm, field of view 35 × 35 cm, read matrix 256, phase matrix 128, frames 16, flip angle 35 degrees, and phase encode group 6–10. An average of 10 short-axis segments was needed to encompass the entire left ventricle. The average scanning time was 18 min.

Image Analysis

This was performed on a personal computer using in-house developed software (RGBwin). End-diastolic and end-systolic images were chosen as the maximal and minimal cross-sectional areas in a cinematic display. Short-axis end-diastolic epicardial and endocardial borders were traced manually for each slice. From the area within the contours and the slice thickness, the epicardial and endocardial volumes were calculated, the difference representing myocardial volume. Mass (g) was derived from this volume and multiplied by the specific density of myocardium (1.05 g/cm^3) (17). End-systolic endocardial borders were also traced, the difference between end-diastolic and end-systolic endocardial borders representing the left ventricular (LV) stroke volume. Ejection fraction (%) was calculated as LV stroke volume/LV end-diastolic volume. Papillary muscles were included in the mass and excluded from the volume. Care was taken not to include atrial slices at end-systole secondary to apical movement of the base of the heart during LV contraction.

To provide information on intraobserver and interobserver reproducibility, analysis was performed twice on 10 subjects by one investigator (N.G.B.) and once by a second investigator (C.L.D.). To assess interstudy reproducibility, six patients underwent a second CMR scan. The same operator (N.G.B. or J. M.F.) performed the second scan within 1 week.

All analysis was performed with investigators blinded to the patient details and previous results, and the scans were presented in random order.

Time Efficiency

The time for preparation (from presentation of the patient to the patient being successfully positioned on the

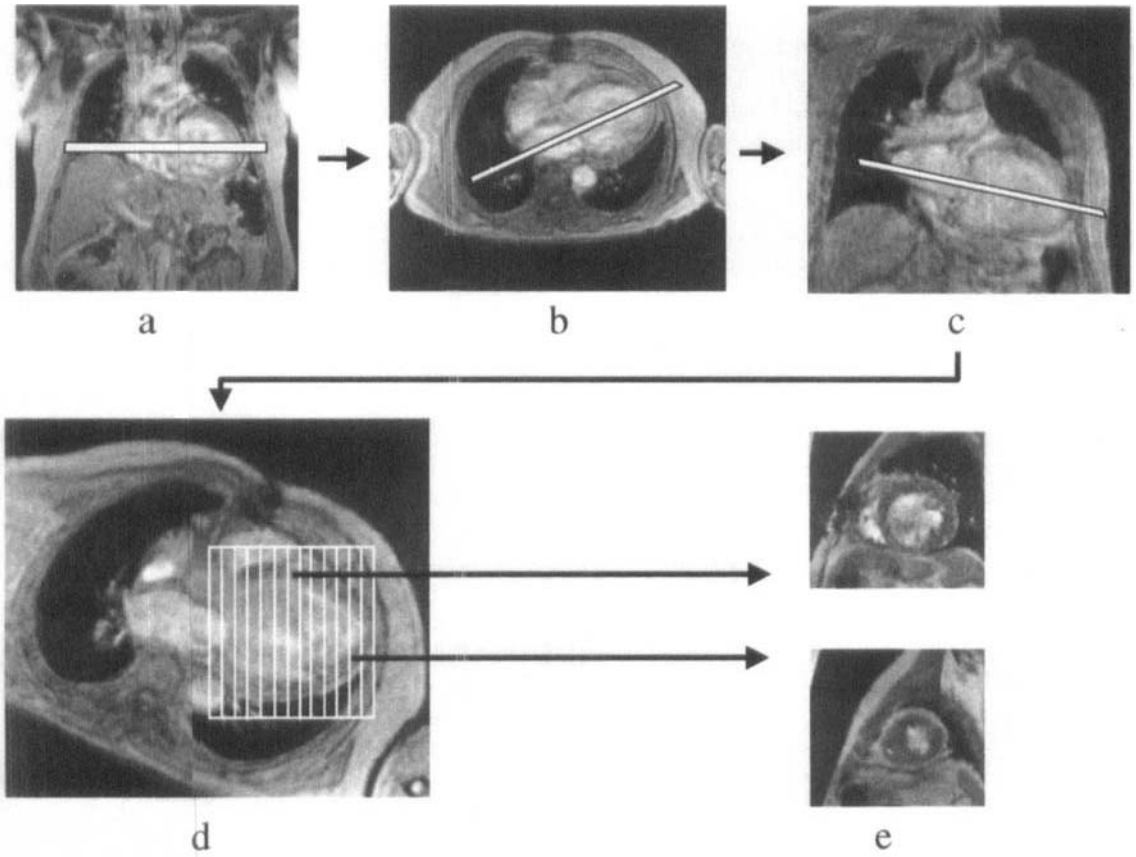


Figure 1. Method for obtaining the cardiac short axis. The transverse image (b) is obtained by placing the transverse imaging plane on a coronal image (a). An image plane connecting the mitral valve with the apex of the left ventricle on the transverse image (b) results in the vertical long axis (c). Connecting the mitral valve with the LV apex on the vertical long axis (c) results in the horizontal long axis (d). Two short-axis images are represented in e. These are obtained from a stack of contiguous slices imaged from the horizontal long axis. Each of these short-axis slices consists of a 16-frame cine.

couch), image acquisition, and analysis was assessed by timing 10 consecutive studies for echo, RNV, and CMR.

Patient Acceptability

Patients who had undergone echo, RNV, and CMR within 1 month were asked to retrospectively score their experience with each of these techniques from 1 to 9, where 1 was the worst experience they could imagine and 9 was a very pleasurable experience. They were also invited to comment on their experiences.

Comparison of RNV and Echo

The clinical reports on those patients who had undergone RNV or echo within 1 month of the CMR were examined. The RNV ejection fraction was noted and the echo ejection fraction calculated from M-mode dimensions using both the American Society of Echocardiology (ASE) (18) and Teichholz (6) recommendations.

Statistical Analysis

The intraobserver, interobserver, and interstudy reproducibilities were assessed by calculating the mean difference ± SD between results for end-diastolic and end-systolic volume, ejection fraction, and mass. Student's paired *t*-test was used to detect any significant difference between measurements. The correlation coefficient was calculated to assess the strength of the relation, but because good correlation does not necessarily represent agreement, the percentage variability (equal to the absolute value of the difference between two measurements over the mean of the two measurements) was also calcu-

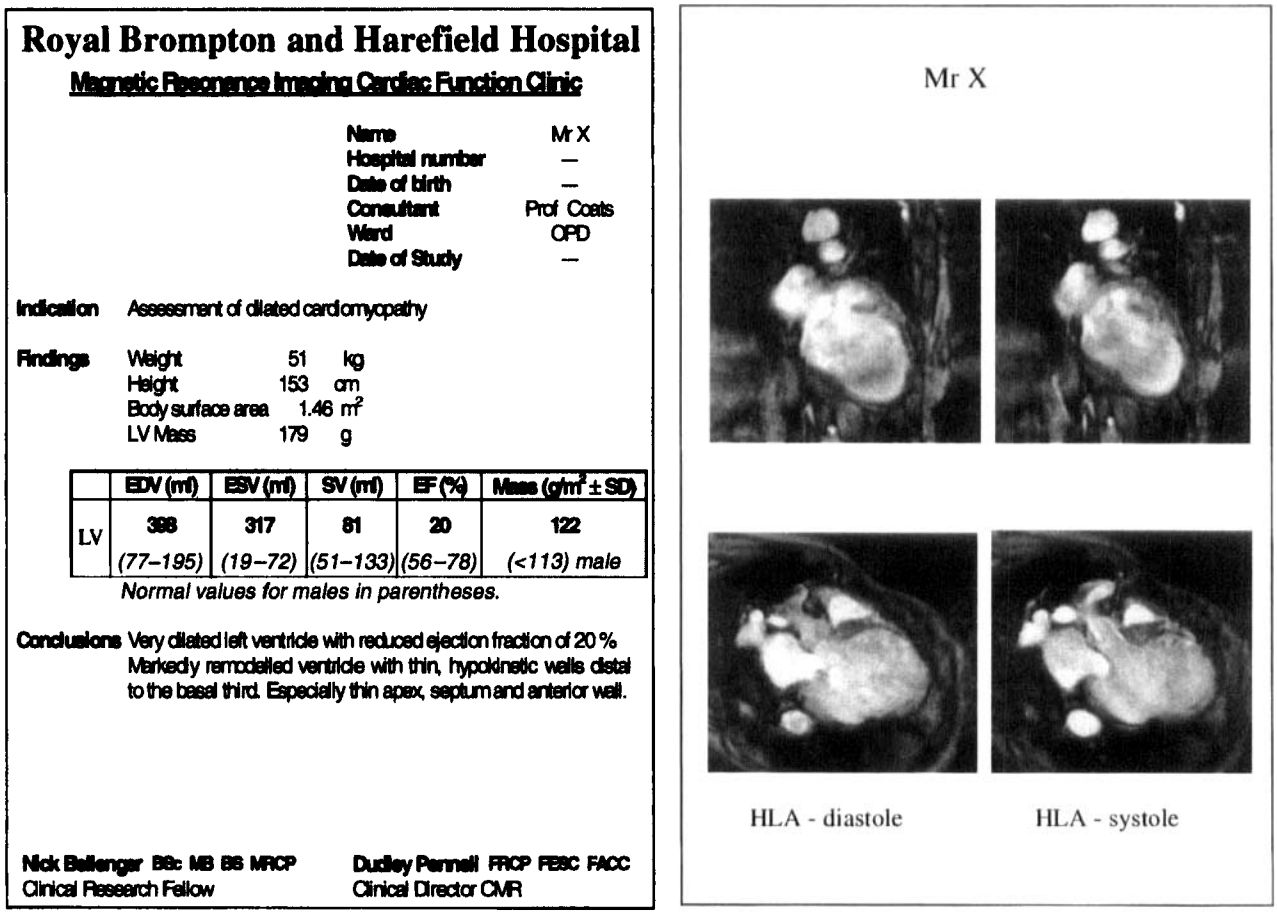
lated. Patient acceptability was scored from 1 to 9 and a nonparametric unpaired analysis of the results performed (Mann-Whitney test). The mean ejection fraction by CMR, echo (using both the ASE and Teichholz formulas), and RNV were compared using Student's *t*-test. Both correlation coefficient and Bland-Altman limits of agreement were calculated to provide a consistent measure of the difference in ejection fraction between techniques. Results are shown as means ± SD. $p < 0.05$ was regarded as significant.

RESULTS

An example of the report sent to the cardiology outpatient clinic is shown in Figure 2. The report includes the end-diastolic and end-systolic volumes, ejection fraction, mass and mass corrected for body surface area, and a comment on the cardiac structure and assessment of wall motion abnormality. HLA and VLA diastolic and systolic images were included in the report to allow a visual assessment of morphology and function.

Reproducibility

Table 1 shows the intraobserver, interobserver, and interstudy reproducibilities of CMR data. The mean difference is small in all groups, with a correlation (r) of 0.9, and no statistically significant difference between mean values in all but the intraobserver end-systolic volume analysis. The percentage variability ± SD was small and compared favorably with reproducibility studies from both our own and other centers (9,10,14). A full comparison of the reproducibility of this technique has previously been published (19).



Royal Brompton and Harefield Hospital

Magnetic Resonance Imaging Cardiac Function Clinic

Name	Mr X
Hospital number	—
Date of birth	—
Consultant	Prof Coats
Ward	OPD
Date of Study	—

Indication Assessment of dilated cardiomyopathy

Findings

Weight	51	kg
Height	153	cm
Body surface area	1.46	m^2
LV Mass	179	g

	EDV (ml)	ESV (ml)	SV (ml)	EF (%)	Mass (g/m^2 ± SD)
LV	398	317	81	20	122
	(77–195)	(19–72)	(51–133)	(56–78)	(<113) male

Normal values for males in parentheses.

Conclusions Very dilated left ventricle with reduced ejection fraction of 20 %
Markedly remodelled ventricle with thin, hypokinetic walls distal to the basal third. Especially thin apex, septum and anterior wall.

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Mr X

HLA - diastole HLA - systole

Figure 2. A CMR report sent to the cardiology outpatient clinic. This report includes end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), ejection fraction (EF), mass, surface area adjusted mass, and a clinical comment. HLA, horizontal long axis; VLA, vertical long axis.

Table 1

CMR Data for Intraobserver, Interobserver, and Interstudy Reproducibility

	EDV (ml)	ESV (ml)	EF (%)	Mass (g)
Intraobserver (n = 10)				
Mean ± SD	254 ± 95	154 ± 83	42 ± 17	196 ± 51
Mean difference ± SD	2.1 ± 5.0	1.8 ± 5.6	−0.4 ± 2.1	− 2.1 ± 4.9
Corr coef ($p < 0.001$)	0.99	0.99	0.99	0.99
t-Test p	ns	<0.05	ns	ns
% Variability	2.4 ± 2.5	2.8 ± 2.6	4.6 ± 2.7	2.1 ± 1.1
Interobserver (n = 10)				
Mean ± SD	267 ± 96	182 ± 91	35 ± 15	182 ± 45
Mean difference ± SD	10.6 ± 13.8	4.3 ± 15	1.4 ± 3.5	−3.8 ± 8.1
Corr coef ($p < 0.001$)	0.99	0.99	0.97	0.98
t-Test p	ns	ns	ns	ns
% Variability	5.1 ± 3.7	5.6 ± 4.9	9.3 ± 7.8	4.0 ± 3.5
Interstudy				
Mean ± SD	293 ± 92	195 ± 77	35 ± 11	231 ± 42
Mean difference ± SD	−1.8 ± 9.3	0 ± 8.2	−0.8 ± 2.4	−0.2 ± 10.1
Corr coef ($p < 0.001$)	0.99	0.99	0.99	0.98
t-Test p	ns	ns	ns	ns
% Variability	2.9 ± 1.2	4.1 ± 2.3	5.8 ± 2.3	−16.7 ± 16.3

Corr coef, correlation coefficient; EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction; mass, left ventricular mass; ns, not significant.

Time Efficiency

Table 2 shows the preparation, imaging, and analysis times for CMR, RNV, and echo. The total time for CMR was significantly less than RNV (42 ± 4 and 61 ± 4 min, respectively; $p < 0.001$). The total time for echo was significantly shorter than either CMR or RNV (echo time, 23 ± 2 min; $p < 0.001$).

Patient Acceptability

All 64 patients tolerated the CMR scan well with no cases of claustrophobia. Ten consecutive patients who had undergone echo, RNV, and CMR within 1 month were asked to fill in a questionnaire on patient acceptability. CMR was significantly more acceptable than echo (7 ± 0.9 and 5.1 ± 1.5; $p < 0.01$), with two patients commenting that the pressure from the echo probe was uncomfortable. CMR was also significantly more acceptable than RNV (7 ± 0.9 and 5.9 ± 0.7; $p < 0.02$), with patients commenting on the need for injections and long preparation time. There was no significant difference between echo and RNV.

Table 2

Preparation, Imaging, and Analysis Times for Echo, RNV, and CMR

Time (min)	CMR	RNV	Echo
Preparation time	3.5 ± 1.2	27.3 ± 2.4	2.3 ± 0.9
Imaging time	18.4 ± 2.0	27.2 ± 2.7	16.3 ± 1.9
Analysis time	20.5 ± 2.8	6.9 ± 1.5	4.6 ± 1.0
Total time	42.4 ± 3.7	61.4 ± 4.2	23.2 ± 1.8

n = 10.

Comparison with RNV and Echo

Of the 64 patients studied, 40% had undergone RNV within 1 month of the CMR. Similarly, 34% had undergone an echo and 25% all three (Table 3). There was a small but significant mean difference of ejection fraction between CMR and RNV ($p = 0.01$), with a correlation of 0.7. The range of the Bland-Altman limits of agreement provided a better comparison between the two ejection fractions, with a range of 29.4% for CMR verses RNV. The correlation between CMR and echo was 0.6 for both echo formulas, and the limits of agreement were wider (range of 47.5% and 43.9% for CMR vs. the ASE and Teichholz formulas, respectively). The correlation of

Table 3

Mean Difference ± SD, Student's t-Test, Correlation Coefficient, and Limits of Agreement for CMR–Echo (Both ASE and Teichholz Formulas), CMR–RNV, and RNV–Echo

	CMR–RNV (n = 26)	CMR–ASE Echo (n = 22)	CMR–Teichholz Echo (n = 22)	RNV–ASE Echo (n = 16)	RNV–Teichholz Echo (n = 16)
Mean difference ± SD (%)	4.1 ± 7.5	−6.1 ± 12.1	1.3 ± 11.2	−9.7 ± 14.7	−2.5 ± 13.6
p	<0.01	<0.05	ns	<0.05	ns
Correlation coefficient (r)	0.7	0.6	0.6	0.2	0.2
Limits of agreement (%)	−10.5 to 18.9	−29.9 to 17.6	−20.6 to 23.3	−38.6 to 19.1	−29.8 to 24.9
Range of agreement (%)	29.4	47.5	43.9	57.7	54.7

ns, not significant.

ejection fractions by RNV and echo was 0.2 for both echo formulas, and the limits of agreement were extremely wide (range, 57.7% and 54.7% for RNV vs. the ASE and Teichholz formulas, respectively).

DISCUSSION

An accurate and reproducible measure of cardiac function is required for both baseline and serial assessment of patients. This is particularly true of patients undergoing cardiac remodeling or those amenable to treatments designed to ameliorate this remodeling process. In this study we described the establishment of a cardiac function clinic in one such group of patients, those with dilated or ischemic cardiomyopathy. The remodeling process in these patients is characterized by progressive dilatation of the ventricle whereby it adopts a more spherical shape. In doing so, the geometric assumptions upon which the echo assessment of function are based no longer hold true. Nuclear medicine does not suffer the same limitations of geometric distortion but requires repeated exposure to ionizing radiation for follow-up. CMR provides three-dimensional tomographic images and a measure of cardiac function that is not dependent on geometric assumptions or ionizing radiation. Patients with dilated cardiomyopathy, however, present CMR with some technical challenges. Patients often suffer from arrhythmias, orthopnea, and the presence of slow-moving poor signal blood, all of which may degrade image quality. Despite these potential limitations, we have designed an imaging protocol that provided functional information that was both time efficient and acceptable to the patient while maintaining the high reproducibility of CMR.

Many patients in this group had already undergone RNV and echo, enabling a direct comparison of the day to day assessment of cardiac function by these methods. The correlation between CMR and RNV was 0.7, with RNV underestimating the ejection fraction (mean difference, 4.1%). However, the limits of agreement were wide (ejection fraction range, 29.4%) (Fig. 3). The correlation between echo and CMR was 0.6, with wider limits of agreement using both the ASE formula (ejection fraction range, 47.5%) and, to a lesser extent, the Teichholz formula (ejection fraction range, 43.9%). The correlation between RNV and echo assessment of ejection fraction was 0.2, with even wider limits of agreement (ejection fraction range, 57.7% for RNV vs ASE echo; 54.7% for RNV vs. Teichholz echo) (Table 3). These wide limits of agreement for RNV and echo are in agreement with other published studies (ejection fraction range, 40% for RNV vs. two-dimensional echo using an equation derived from Quinones et al. [20]; 43% for RNV vs. echo Simpson's rule method) (21).

The poor correlation between echo and both CMR and

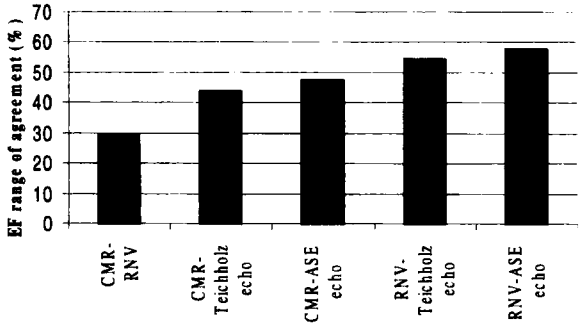

Figure 3. Range of Bland-Altman limits of agreement for the comparison of ejection fraction by CMR, RNV, and echo (both ASE and Teichholz formulas). EF, ejection fraction.

RNV may be explained by some of the fundamental and well-recognized limitations of the use of echo in patients with dilated ventricles. Echo relies on an adequate acoustic window and suffers from considerable interobserver variability. Furthermore, echo uses formulas that assume that the left ventricle is, for example, an ellipsoid with a fixed relation of length and diameter. This may be true for the normal LV, but as the LV volume increases, the LV becomes more spherical and the relation between length and diameter is altered (22). As a result, as the LV diameter increases, the 95% confidence interval of prediction of LV volume from the diameter increases (22). Furthermore, if the echo probe is off center, either too superior or inferior to the maximum diameter, the diameter will be underestimated. Echo is also unreliable in the presence of asynergy, because it assumes that the area where the echo measurements are taken is representative of the entire LV (6,23).

Study Limitations

The comparison of CMR, RNV, and echo was not part of a prospective trial but an observational study of current clinical practice. As such, the RNV and echo ejection fractions were derived from routine clinical reports. Furthermore, each investigation was not performed on the same day. The possibility of a change in the clinical condition of the patient occurring between investigations was minimized by only including patients who had all three scans within a 1-month period and who were due to attend a routine follow-up rather than a more acute heart failure clinic.

To reduce respiratory artifact, each short-axis cine image is performed during a breathhold. If the patient fails to hold their breath in the same place, overlap of the contiguous slices may occur, resulting in error in volume calculation. The effect of this is minimized with the use of end expiratory breathholds, which are more reproducible (24). Further errors may occur during the manual drawing of epicardial and endocardial borders. Faster sequences that allow all short-axis slices to be taken in one breathhold show much promise, as do automated border detection systems.

CONCLUSION

CMR can provide a rapid, reproducible, and patient acceptable assessment of cardiac function in heart failure, whereas other methods appear to have a wider variance in comparison. The high reproducibility of CMR lends itself to the follow-up of clinical progression and the effect of treatment in patients with heart failure.

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