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CLINICAL RESEARCH

The role of echocardiography in the assessment of right ventricular systolic function in patients with transposition of the great arteries and atrial redirection

Place de l'échocardiographie transthoracique dans l'évaluation du ventricule droit systémique chez les patients porteurs d'une transposition des gros vaisseaux opérés par switch atrial

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Abbreviations: 2D, two-dimensional; IVS, interventricular septum; LV, left ventricular; MRI, magnetic resonance imaging; MRI-RVEF, RVEF assessed by MRI; NYHA, New York Heart Association; RV, right ventricle/ventricular; RVEDV, right ventricular end-diastolic volume; RVEF, right ventricular ejection fraction; RVESV, right ventricular end-systolic volume; RVFS, right ventricular fractional shortening; S', peak systolic velocity; S' TDI, peak systolic velocity at the junction of the RV free wall and the tricuspid annulus, assessed with pulsed TDI; TDI, tissue Doppler imaging; TGA, transposition of the great arteries.

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KEYWORDS
Echocardiography;
Transposition of the great arteries;
Atrial switch;
Mustard-Senning;
Systemic right ventricle

Summary
Background. — Although dysfunction of the systemic right ventricle (RV) in patients with complete transposition of the great arteries (TGA) after atrial redirection by Mustard or Senning procedures is well recognized, there are few data on systemic RV geometry and function. Echocardiography is a widely available imaging technique that is particularly suitable for clinical follow-up because of its non-invasive nature, low cost and lack of ionizing radiation.
Aim. — To examine the feasibility and variability of transthoracic echocardiography variables in the assessment of the systemic RV.
Methods. — Multivariable transthoracic echocardiographic analysis, including assessment of global function variables (RV ejection fraction [RVEF; Simpson's method], RV fractional shortening [RVFS] and dP/dt), longitudinal function variables (tricuspid annular plane systolic excursion [TAPSE], peak systolic velocity at the junction of the RV free wall and the tricuspid annulus, assessed with pulsed tissue Doppler imaging [S' TDI]), tricuspid regurgitation and asynchrony, was performed in 35 consecutive patients with TGA after atrial redirection. Functional variables were compared with magnetic resonance imaging (MRI). Inter- and intraobserver echocardiographic analysis variability was assessed in ten randomly selected cases.
Results. — Global and longitudinal function variables were not correlated with RVEF calculated by MRI, except for S' TDI, which was weakly correlated ($P = 0.02$, $r = 0.37$). Asynchrony assessment was feasible in all patients. Inter- and intraobserver echocardiographic analysis variability was high for RVEF, RVFS and dP/dt (> 10%), and low for TAPSE and S' TDI (5%).
Conclusion. — Owing to geometric changes, presumed contractility pattern shift and retrosternal position, conventional echocardiographic variables are not relevant for RV function assessment. Assessment of asynchrony and tricuspid regurgitation is easily feasible in routine practice and highly reproducible. Echocardiography does not permit complete assessment of the systemic RV after atrial redirection but is fully complementary with MRI and should not be abandoned. Future improvements in transducers and dedicated software should permit major improvements in the near future.

MOTS CLÉS
Échocardiographie ;
Transposition des gros vaisseaux ;
Mustard-Senning ;
Ventricule droit systémique

Résumé
Contexte. — Bien que la dysfonction du ventricule droit systémique soit connue chez les patients porteurs d'une transposition des gros vaisseaux (TGV) opérés par technique de Senning ou Mustard, il existe peu de données sur sa géométrie et ses paramètres fonctionnels. L'échocardiographie transthoracique (ETT) est la modalité d'imagerie la plus utilisée dans l'exploration cardiaque en raison de son caractère non invasif, non irradiant, accessible et peu couteux.
Objective. — Notre étude a pour but d'évaluer la corrélation entre l'imagerie par résonance magnétique et l'échocardiographie cardiaque transthoracique dans l'approche du ventricule droit systémique.
Méthodes. — Trente-cinq patients porteurs d'une TGV opérée par Senning/Mustard ont bénéficié d'une IRM et d'une ETT au repos. Une analyse échographique mutiparamètrique de la fonction systolique du VD a été effectuée : fraction d'éjection du ventricule droit par méthode Simpson, fraction de raccourcissement de surface, dP/dt, index de Tei, TAPSE, S'TDI), ainsi qu'une quantification de l'insuffisance tricuspide et une analyse de l'asynchronisme inter et intraventriculaire. Les marqueurs de la fonction systolique ont été comparés avec le fraction d'éjection du ventricule droit à l'IRM, considéré comme le gold standard dans l'évaluation du ventricule droit systémique. Une étude de la variabilité intra- et interobservateur à également été réalisé sur dix patients randomisés.
Résultats. — De tous les différents paramètres de la fonction systolique du ventricule droit (FEVD, FR, dP/dt, index de Tei, TAPSE, S' TDI) seul le S' TDI est corrélé avec la FEVD à l'IRM ($p = 0,02$, $r = 0,37$). L'étude de l'asynchronisme a été faisable chez tous les patients. Pour l'analyse de la variabilité en inter- ou intraobservateurs, on retrouve une variabilité importante (10 à 20 %) pour la fraction d'éjection du ventricule droit (RVEF), et la dP/dt mais faible pour le TAPSE ou le S' TDI (< 5 %).
Conclusion. — L'ETT présente donc des avantages et des inconvénients dans l'exploration des TGV opérées par switch atrial. En effet, les phénomènes adaptatifs du ventricule droit en position systémique, telles que l'hypertrophie ou les modifications supposées de la mécanique contractile au profit de la composante radiale, ainsi que la position rétrosternale, rendent son approche plus difficile. Néanmoins, elle présente des avantages indéniables comme l'étude de la

fuite tricuspide et de l'asynchronisme. L'ETT apparaît donc comme complémentaire de l'IRM et ne doit pas être abandonnée. De nouvelles techniques échocardiographiques à l'étude devraient améliorer des améliorations dans un futur proche.

Introduction

Despite excellent surgical results, atrial switch operations (Mustard or Senning procedures [1]) in patients with complete transposition of the great arteries (TGA) are associated with increased late mortality, mainly because of heart failure [2] and sustained ventricular tachycardia [3] secondary to failure of the morphologic right ventricle (RV) in the systemic (subaortic) position. Evidence is accumulating that deterioration of right ventricular (RV) function and clinical status is progressive [4]. Hence, accurate assessment of RV function is mandatory to anticipate the need for heart failure treatment in these patients.

Various imaging modalities have been used to evaluate the systemic RV, including angiography, radionuclide imaging and magnetic resonance imaging (MRI) [5]. Nevertheless, in clinical practice, echocardiography is still used predominantly for the assessment of RV function, as it is non-invasive, widely available, relatively inexpensive and has no adverse side effects. However, because of complex geometry, the assessment of systemic RV function by echocardiography has remained mostly qualitative.

Advances in digital echocardiography allow for a more refined assessment of the RV, as demonstrated in patients with pulmonary arterial hypertension [6] or other clinical conditions. These novel echocardiography variables may also be valuable in the functional assessment of the systemic RV [7].

To redefine the role of echocardiography in the functional assessment of the systemic RV, we investigated the feasibility and variability of standard and novel echocardiographic variables in the assessment of the systolic function of the systemic RV, compared with MRI. Additional variables involved in heart failure physiopathology, such as inter- and intraventricular asynchrony and tricuspid regurgitation, were also studied.

Methods

Patients

We enrolled 35 clinically stable patients with TGA who had undergone atrial redirection by the Senning or Mustard procedures in childhood, attended the Adult Congenital Heart Disease Clinic at the University Hospital of Bordeaux and were in sinus or regular junctional rhythm. The institutional review board approved the study and all subjects gave informed consent. Transthoracic echocardiography and MRI at rest were performed on the same or on the subsequent day, according to the following protocols.

Echocardiography

Standard echocardiography

Transthoracic echocardiography was performed using Vivid 7® (GE Vingmed Ultrasound A.S., Horten, Norway) by two experienced cardiologists (A.H., I.X.). All echocardiographic recordings were stored on digital versatile discs for offline analyses. Measurements were made in three cardiac cycles and average values were used for statistical analyses. Intra- and interobserver variability was analysed on the basis of two consecutive results from ten randomly selected patients.

Fig. 1 gives an overview of common echocardiographic variables for RV function, which were also used in the current study. In the apical four-chamber view, RV end-diastolic and end-systolic diameters and areas were assessed. From these measurements, we calculated RV fractional shortening (RVFS) and we estimated RV ejection fraction (RVEF) by Simpson's one-plane method [8]. Tricuspid annular plane systolic excursion (TAPSE) was assessed in M-mode. Using colour Doppler, tricuspid valve regurgitation was semi-quantitatively graded as mild, moderate or severe. Peak systolic velocity (S') at the junction of the RV free wall and the tricuspid annulus was assessed with pulsed tissue Doppler imaging (TDI) (S' TDI). RV dP/dt_{max} was estimated from regurgitation along the tricuspid valve using echo Doppler. RV myocardial performance index, also known as the Tei index and defined as the sum of the isovolumic contraction and the isovolumic relaxation time divided by the ejection time, was also assessed by Doppler echocardiography [9].

Two-dimensional longitudinal strain assessment of the RV

Myocardial deformation imaging by two-dimensional (2D) strain, as an index of contractile function, is based on frame-by-frame tracking of acoustic markers within the myocardial region of interest on greyscale echocardiographic images [10]. In the apical four-chamber view, the myocardium was automatically tracked and divided into six segments (Fig. 3). Global systolic strain was assessed in the longitudinal direction.

Asynchrony

To measure inter- and intraventricular dyssynchrony, regional longitudinal strain was assessed in the basal and mid segments of the RV free wall, the interventricular septum (IVS) and the left ventricular (LV) free wall. The average time from the onset of QRS to peak strain of the basal and mid segments ($T\varepsilon$) was calculated for the RV free wall, the IVS and the LV free wall. Right intraventricular mechanical delay was defined as the difference in $T\varepsilon$ between the RV free wall and the IVS ($\Delta T\varepsilon RV-IVS$); the interventricular mechanical

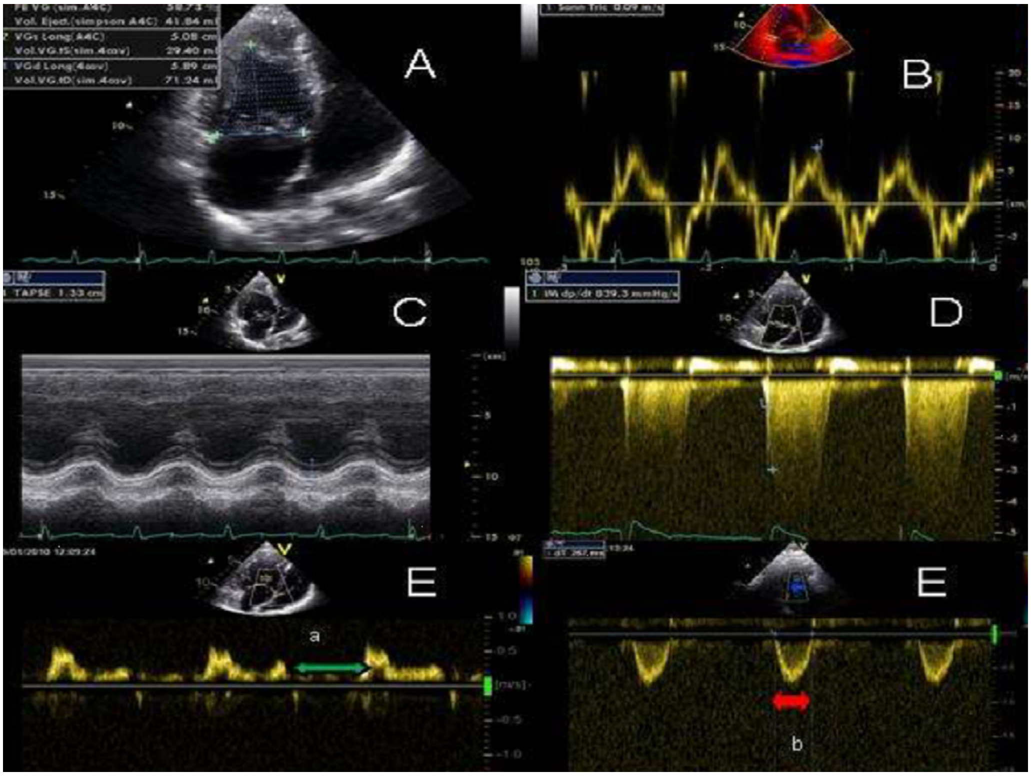

Figure 1. Common parameters of right ventricular systolic function. Parameters commonly used for assessment of right ventricular systolic function are displayed in the panels A—E. A. Right ventricular ejection fraction (RVEF) using monoplane Simpson's method as calculated by dividing the difference between the RV end-diastolic volume and the RV end-systolic volume by the RV end-diastolic volume in two-dimensional and apical four-chamber (A4C) view. B. S' Tissue Doppler Imaging (TDI) to the tricuspid ring in lateral A4C window. C. Tricuspid annular plane systolic excursion (TAPSE) in lateral A4C view and M-mode. D. dP/dT in continuous Doppler in A4C at the level of Tricuspid Regurgitation (TR). E. Tei index (a—b)/a, in which a = (isovolumic contraction time + isovolumic relaxation time + ejection time) and b = ejection time.

delay was defined as the difference in $T\varepsilon$ between the RV and LV free walls ($\Delta T\varepsilon$RV—LV).

We also used the TDI technique for the assessment of intraventricular asynchrony with different delays in apical four-chamber view, in Doppler pulsed on the free wall and on the interventricular septum. We studied electromechanical and electrosystolic delays.

MRI acquisition and data postprocessing

MRI was performed in 35 patients on a 1.5T system (Sonata; Siemens, Erlangen, Germany) with a phased-array radiofrequency receiver coil placed on the chest. All images were gated to the electrocardiogram. Double oblique long-axis and four-chamber scouts were acquired to obtain true short-axis reference. Steady-state free-precession prospective electrocardiogram-gated breath-hold images, encompassing the whole RV, were then acquired in short-axis orientation with no gap between slices (TrueFISP sequence; slice thickness 7 mm; TE 1.53 ms; TR 33.6 ms, depending on the R—R interval; matrix 256 × 256 mm; field of view 38 cm). RV end-systolic and end-diastolic volumes (RVESV and RVEDV, respectively) and RVEF were measured on a postprocessing workstation (Leonardo, Siemens) using commercially available software (Syngo Argus; Siemens) by a radiologist with 15 years' experience in cardiac MRI and blinded to the results of echocardiographic evaluation.

Statistical analysis

Data are presented as mean ± standard deviation. Agreement between RVEF assessed by echocardiography and by MRI (''gold standard''; MRI-RVEF) was evaluated using the Bland-Altman analysis. Relationships between other echocardiographic variables and MRI-RVEF were evaluated by Pearson's correlation coefficient. A P value < 0.05 was considered statistically significant. Statistical analyses were performed using Stata 8.0 (StataCorp, College Station, TX, USA).

Results

Study population

Thirty-five patients were included, all of whom had had atrial redirection for TGA; of these, 31 had undergone the Senning procedure and four had undergone the Mustard procedure. Nine patients had associated ventricular septal defect and are therefore referred to as 'complex TGA'; in these patients, the ventricular septal defect was closed at the time of the atrial redirection surgeries, without residual leaks. Patient characteristics at study inclusion are presented in Table 1. Mean age at examination was 23 ± 8 years. Most patients were in New York Heart Association (NYHA) function class I (88%).

Echocardiographic results

Echocardiography was performed in all patients. Table 2 shows the overall results for the echocardiographic variables. The numbers of patients in whom the respective variables could be assessed are indicated in Table 2. The assessment of standard variables was feasible in the large majority of patients. Tricuspid regurgitation assessment was possible in all patients. Asynchrony assessment was feasible in 34 patients using the pulsed Doppler technique and in 30 patients using 2D strain. In 28 patients (80%), the lateroapical and septoapical segments were ''out of measurement'', so these data were excluded from statistical analysis. The 2D strain technique was used as a marker of longitudinal function and intraventricular RV asynchrony. Inter- and intraobserver variability for systolic function variables was assessed in ten randomly selected cases. The results are presented in Table 3.

MRI results

MRI results are shown in Table 4. We found a mean RVEF of 52 ± 11%, a mean RVEDV of 96 ± 31 mL/m^2 and a mean

Table 1 Patient characteristics (*n* = 35).

Age (years)	23 ± 8
Men/women	26/9 (74/26)
Body mass index (kg/m^2)	21.4 ± 3.5
Simple/complex TGA	26/9 (74/26)
Senning/Mustard	31/4 (89/11)
NYHA classification	
I	31 (88)
II	2 (6)
III	2 (6)
IV	—
Pharmacological treatment	
Beta-blockers	5 (14.2)
ACE inhibitors	5 (14.2)
Platelet-suppressive agents	4 (11.4)
Vitamin K antagonists	4 (11.4)
Diuretics	2 (5.7)
Antiarrhythmic agents	6 (17.1)

Data are mean ± standard deviation or number (%). ACE: angiotensin-converting enzyme; NYHA: New York Heart Association; TGA: transposition of the great arteries.

Table 2 Echocardiography results.

Echocardiography variable	Mean ± SD or number of patients	Number of patients in whom the variable was assessed
RVEF (Simpson's method) (%)	44 ± 10	33
RVFS (%)	33 ± 10	34
TAPSE (mm)	13 ± 3	35
S' TDI (cm/s)	8 ± 2	34
RV diameter/LV diameter	1.8 ± 0.5	32
RV Tei index	0.5 ± 0.2	29
dP/dt$_{max}$ (mm Hg/s)	1024 ± 318	
Asynchrony (TDI)		
Atrioventricular delay (%)	46 ± 7	33
Interventricular delay (ms)	31 ± 17	34
Intraventricular ES delay (ms)	23 ± 11	34
Intraventricular EM delay (ms)	10 ± 12	34
Longitudinal 2D strain		
2D global longitudinal strain (%)	−13.5 ± 4.0	30
Tricuspid regurgitation		33
Mild	22	
Moderate	8	
Severe	3	

2D: two-dimensional; EM: electromechanical; ES: electrosystolic; LV: left ventricular; RV: right ventricular; RVEF: right ventricular ejection fraction; RVFS: right ventricular fractional shortening; SD: standard deviation; S' TDI: peak systolic velocity (S') at the junction of the RV free wall and the tricuspid annulus, as assessed with pulsed TDI; TAPSE: tricuspid annular plane systolic excursion; TDI: tissue Doppler imaging.

Table 3 Inter- and intraobserver variability for echocardiography, assessed in ten randomly selected cases.

Echocardiographic variable	Interobserver variability (%)	Intraobserver variability (%)
RVEF (Simpson's method)	16	13
RVFS	14	10
TAPSE	6	4
S' TDI	5	4
dP/dt_{max}	17	19
RV Tei index	8	7

RV: right ventricular; RVEF: right ventricular ejection fraction; RVFS: right ventricular fractional shortening; S' TDI: peak systolic velocity (S') at the junction of the RV free wall and the tricuspid annulus, as assessed with pulsed TDI; TAPSE: tricuspid annular plane systolic excursion; TDI: tissue Doppler imaging.

Table 4 MRI results.

MRI variable	
RVEF (%)	52 ± 11
LVEF (%)	58 ± 9
RVEDV (mL)	171 ± 71
RVEDV (mL/m^2)	96 ± 31
RVESV (mL)	86 ± 59
RVESV (mL/m^2)	47 ± 33
Late raising	
Present	10 (29)
Absent	25 (71)

Data are mean ± standard deviation or number (%). LVEF: left ventricular ejection fraction; MRI: magnetic resonance imaging; RVEDV: right ventricular end-diastolic volume; RVEF: right ventricular ejection fraction; RVESV: right ventricular end-systolic volume.

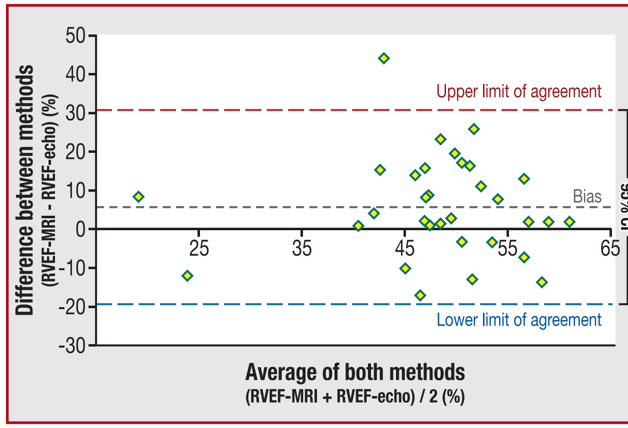

Figure 2. Agreement between right ventricular ejection fraction at MRI and echocardiography by Bland-Altmann analysis. CI: confidence interval; RVEF-echo: right ventricular ejection fraction assessed by echocardiography; RVEF-MRI: right ventricular ejection fraction assessed by magnetic resonance imaging.

RVESV of 47 ± 33 mL/m^2. Late gadolinium enhancement was present in ten patients and absent in 25 patients.

Agreement between echocardiographic variables and RVEF-MRI

Comparisons between RVEF assessed by echocardiography and MRI were performed using the Bland-Altman analysis (Fig. 2); agreement was low, indicated by the broad 95% confidence interval of disagreement of 50 percentage points (i.e. with 95% certainty the difference between echocardiography and MRI in the assessment of RVEF is less than 50 percentage points). Furthermore, the bias of +6 percentage points indicates that echocardiography systematically ''underestimates'' RVEF by 6 percentage points compared with MRI.

Comparisons between echocardiography variables and MRI-RVEF were analysed using Pearson's correlation (Fig. 3). The Tei index, TAPSE, RV systolic function, dP/dt and 2D longitudinal strain were not well correlated with MRI-RVEF ($P = 0.08$, $r = -0.31$; $P = 0.3$ $r = 0.17$; $P = 0.16$, $r = 0.25$; $P = 0.59$, $r = -0.11$; $P = 0.2$, $r = 0.25$, respectively). Only S' TDI was moderately correlated with MRI-RVEF ($P = 0.02$, $r = 0.37$).

Discussion

The aim of the study was to determine the role of echocardiography in the evaluation of the systemic RV, by evaluating the strength and weakness of echocardiographic variables compared with MRI, which is considered the ''gold standard''. Assessment of the RV using 2D echocardiography has been done for decades but remains challenging because of the complex anatomy of the RV. Although assessment of the various conventional systolic function variables is relatively easy to perform, accuracy has been shown to be poor in our study. Various points have to be discussed.

Correlation between echocardiographic and MRI variables for RV systolic function assessment in patients with TGA and atrial redirection

In contrast to the study of Lissin et al. [11], we did not find acceptable correlation between global and longitudinal functional variables compared with MRI, except for lateral tricuspid annulus S'. Several hypotheses can be discussed: our cohort was larger than that in the study by Lissin et al. and our population was more heterogeneous in terms of

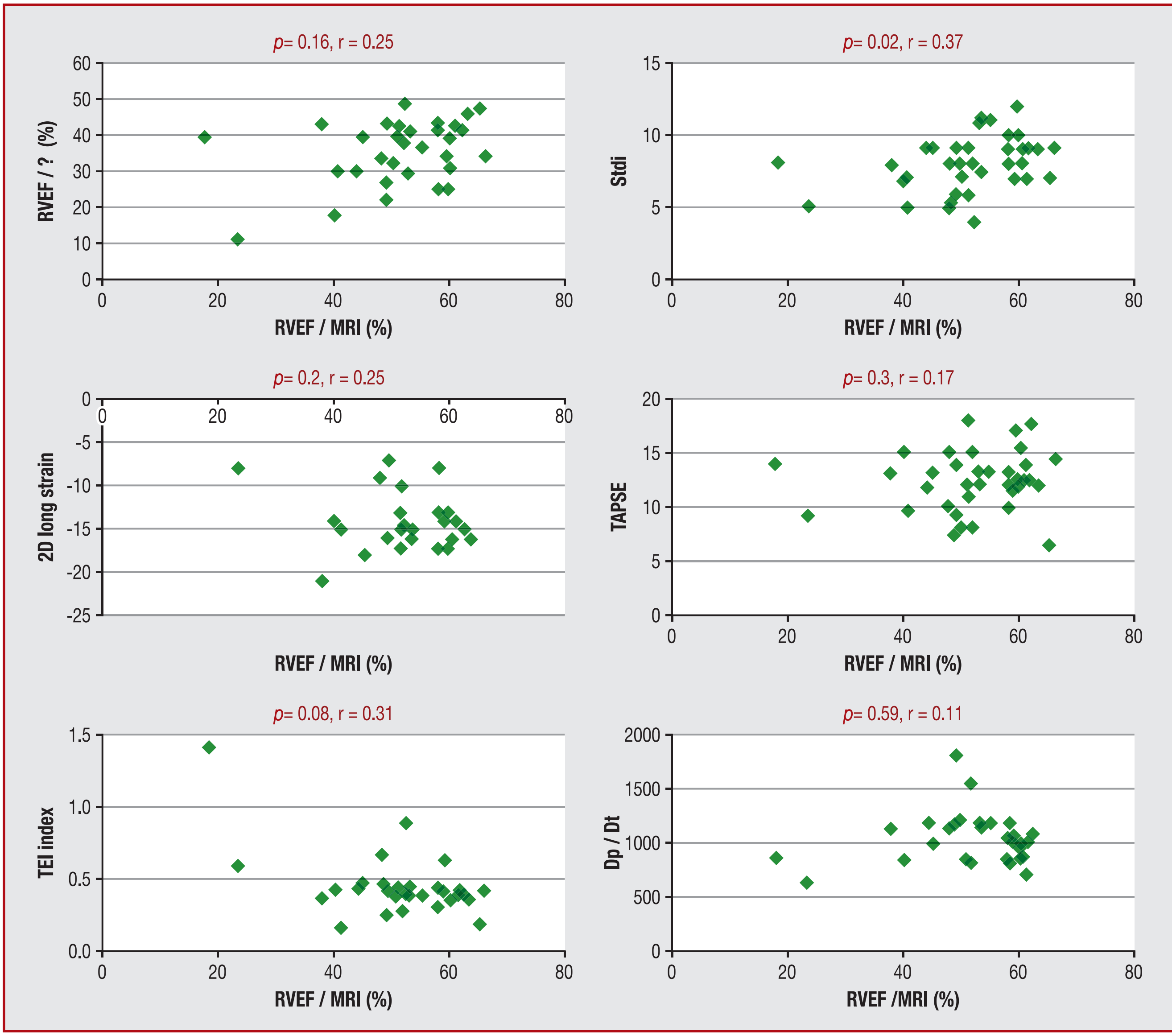

Figure 3. Correlations between the various echocardiographic parameters of right ventricular systolic function and estimation of right ventricular ejection fraction by MRI (r = correlation coefficient and P = probability). 2D: two-dimensional; MRI: magnetic resonance imaging; RVEF: right ventricular ejection fraction; RVSF, right ventricular systolic function; S' TDI: peak systolic velocity at the junction of the RV free wall and the tricuspid annulus, assessed with pulsed tissue Doppler imaging; TAPSE: tricuspid annular plane systolic excursion.

anatomical distribution between complex and simple TGA. Furthermore, as demonstrated by MRI measurements, RVEDV was larger in our population, resulting in a larger RV diameter, which may complicate echocardiographic assessment of the RV.

For patients with a systemic RV, reference values are lacking [12]. Standard variables (TAPSE, tissue velocities) reflect mainly the long-axis function of the basal RV free wall, whereas RVEF using Simpson's method and RVFS reflect global systolic function. Overall RVEF assessed by echocardiography using Simpson's method was 44 ± 10%. Kalogeropoulos et al. [13] reported a slightly lower RVEF of 37 ± 11% using Simpson's method in 27 patients. However, it has to be mentioned that 11 of these patients were receiving pacing and the population was slightly older (mean age 30 ± 6 years). In a cohort of 28 patients, Chow et al. [14] reported an RVFS of 32 ± 5%, which is in line with the mean RVFS in our study population (33 ± 11%). It might be interesting, concerning the problem of lacking ''reference values'', to see what the mean values (echocardiography and MRI) are for patients among their NYHA class.

Kalogeropoulos et al. reported good feasibility and reproducibility for the assessment of RV 2D longitudinal strain in patients with TGA and atrial redirection [13]. Moreover, it was recently demonstrated that reduced global longitudinal strain of the systemic RV is associated with an increased risk of clinical events among patients with TGA and atrial redirection by the Senning or Mustard procedures. Global longitudinal peak systolic strain greater than −10% optimally predicted future events (C = 0.83, 95% confidence interval 0.71—0.91, P < 0.001) [15]. Our results are consistent with the study by Kalogeropoulos and Becker, with longitudinal

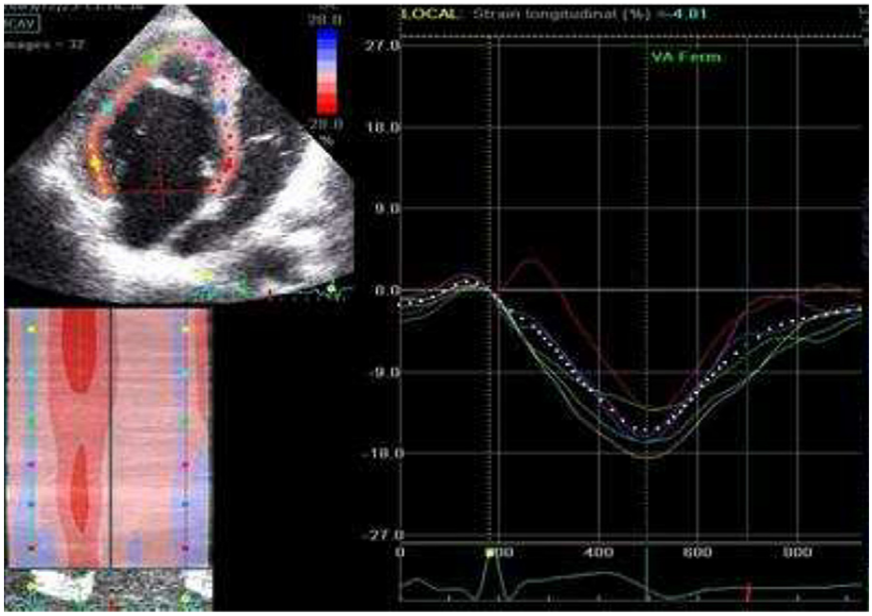

Figure 4. Two-dimensional strain in apical four-chamber view.

middle strain of $-13.2 \pm 3.8\%$ (in a cohort of 27 patients). Despite the absence of correlation with MRI, our results are consistent with clinical status regarding NYHA classification and might predict a good outcome regarding the cutoff established by Kalogeropoulos et al. [15].

Similar to Kalogeropoulos et al., we assessed RV deformation only in the longitudinal direction from a single apical view. This approach supports evaluation of only one aspect of myocardial deformation and leaves deformation in other dimensions undefined. Indeed, a recent study using TDI and cardiac MRI demonstrated that there is a shift in the contraction pattern of the systemic RV from longitudinal to circumferential shortening [16]. In addition to these important RV findings, Becker et al. [17] reported that in the systemic free RV wall, circumferential strain was greater than longitudinal strain.

In patients with complete TGA, the RV is enlarged and anteriorly placed, which makes it very difficult to meaningfully encompass the ventricle in the short-axis view. Therefore, speckle-tracking echocardiographic interrogation of the short-axis for circumferential and radial strain would not be reliable.

Two-dimensional strain imaging needs an excellent echocardiographic window. As echocardiographic imaging may be hampered by the retrosternal position of the RV, strain measurements are more difficult to perform for the systemic RV than for the systemic left ventricle. In our experience, only apical four-chamber views were accessible in 30 patients (86%) but remained limited for lateroapical and septoapical segment analysis (unusable in 80%) (Fig. 4).

The previously mentioned anatomical limitations explain the rather high inter- and intraobserver variabilities for evaluation of global function echocardiographic variables, in our experience, (Table 3). Inter- and intraobserver variability for S' TDI at the lateral tricuspid annulus was 5%, which is similar to the variability usually observed for MRI [18,19].

Asynchrony of the systemic RV

We have studied intraventricular asynchrony using two echocardiographic methods: by measuring electromechanical and electrosystolic intraventricular delays using TDI; and by using 2D longitudinal strain. To our knowledge, no studies have demonstrated an equal delay measurement using 2D longitudinal strain and TDI so far. However, the difference in the delays between these two methods may be explained by technical reasons. The strain delay index is of limited interest here, because it is calculated on limited RV walls (septomedial, septobasal, laterobasal, lateromedial). Although it is promising and agreed upon (notably in the exploration of the resynchronization of the left ventricle by Lim et al. [20]), this technique is currently under uncertain application for the systemic RV and needs to be further investigated.

The presence of asynchrony between the ventricles and within the systemic RV in patients with TGA after atrial redirection has been reported by Chow et al. [14]. Within the population with TGA and atrial redirection surgery, ventricular asynchrony is more dominantly present in patients receiving ventricular pacing in the non-systemic (i.e. left) ventricle [21]. Asynchronous electromechanical activation may be one cause of RV dysfunction [22]. Favourable effects of cardiac resynchronization therapy have been reported in a small series of patients with dextro-TGA [23]. Echocardiography has a certain value in the management of the resynchronization, especially in patients with a pacemaker.

Limitations of echocardiography

The assessment of RV function remains difficult, partly due to its complex geometry. Measurements of RVEF, RV systolic function and TAPSE revealed great variability in normal and pathological hearts. Studies in patients with overload subpulmonary RV showed very poor correlation with MRI [24]. In Senning- or Mustard-operated patients, MRI is the only reference method for calculating RV volume and function. Technical difficulties in visualizing the RV, which is situated behind the sternum, must be taken into account. Furthermore, RV hypertrophy, as found in patients with a systemic RV, complicates ''contouring'' of the RV for volume assessment.

Clinical implications

Echocardiographic assessment of systolic function of the systemic RV in patients with TGA after atrial redirection surgery is difficult and does not well correlate with RVEF measured by MRI. Nevertheless, echocardiography remains clinically important, as it comes with better accessibility and a lower cost compared with MRI. Besides, MRI is not available for patients with a pacemaker and up to 50% of patients who have undergone atrial redirection surgery for TGA may have pacemakers. Furthermore, echocardiography is an excellent and irreplaceable investigation for evaluating the presence of RV mechanical dyssynchrony and tricuspid regurgitation, which are important features in the physiopathological process of systemic RV failure. To make a valuable estimation of RV systolic function using echocardiography, a combination of multiple variables should be assessed, as our study suggests that single variables are neither very reliable nor reproducible (RVEF [Simpson's method], RVFS or dP/dt_{max}), except for S' at the junction of the RV free wall and the tricuspid annulus or TAPSE.

Conclusion

In this paper, we describe the strengths and weaknesses of current non-invasive echocardiographic techniques in the assessment of the systemic RV after atrial redirection in TGA patients. Due to geometric changes, presumed contractility pattern shift and retrosternal position, conventional echocardiographic variables remain limited for RV function assessment compared with MRI. Nevertheless, echocardiography remains the technique of first choice for asynchrony and tricuspid regurgitation assessment. Although echocardiography does not permit complete assessment of the systemic RV after atrial redirection, it is fully complementary with MRI and should not be abandoned. Accessibility is wide and it is not cost limited compared with MRI. New echocardiographic techniques, although promising for the assessment of systemic LV function, are not yet recognized for assessment of systemic RV function but deserve broader investigation. Larger multicentre studies should be performed to allow a better echocardiographic approach of the systemic RV and thus enable recognition of its dysfunction in advance.

To make a valuable estimation of RV systolic function using echocardiography, a combination of multiple variables should be performed, as our study suggests that single variables are neither very reliable nor reproducible.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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