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Right Ventricular Outflow-Tract Fractional Shortening: An Applicable Measure of Right Ventricular Systolic Function

P. Lindqvist[1,2], M. Henein[3] and E. Kazzam[2,4]

[1]*Department of Clinical Physiology, Sundsvall Hospital, Sundsvall, Sweden;* [2]*Department of Clinical Medicine, Umeå University Hospital, Umeå, Sweden;* [3]*Department of Clinical Cardiology, Royal Brompton Hospital, London, UK;* [4]*Department of Internal Medicine, Cardiology Division, Mälar Hospital, Eskilstuna, Sweden*

Aims: Assessment of right ventricular function is important. However, this is not easy to achieve due to the complex anatomy and geometry of the right ventricle, making the evaluation of its function limited. Therefore, a simple reliable and easy method is needed. This study was performed (1) to evaluate the use of right ventricular outflow tract fractional shortening obtained by M-mode echocardiography as a measure of right ventricular systolic function and (2) to determine the relationship between this parameter and other established measurements of right ventricular function such as long axis excursion.

Methods and Results: Ninety-two consecutive patients referred for echocardiographic assessment of left and right ventricular function, age mean $\pm$ SD was 68 ± 14 years, were investigated. Twenty healthy controls, age 46 ± 12 years were also studied. M-mode echocardiography was used to measure right ventricular outflow tract fractional shortening and right ventricular long axis excursion. Doppler echocardiography was used for the estimation of right ventricular–right atrial pressure drop and pulmonary artery acceleration time. Right ventricular outflow tract fractional shortening ($P<0{\cdot}0001$), right ventricular long axis excursion ($P<0{\cdot}0001$) and pulmonary acceleration time ($P<0{\cdot}0001$) were reduced in patients compared to controls. Right ventricular outflow tract fractional shortening correlated with long axis excursion ($r=0{\cdot}66$ $P<0{\cdot}0001$), pulmonary artery acceleration time ($r=0{\cdot}80$ $P<0{\cdot}0001$) and right ventricular–right atrial pressure drop ($r=-0{\cdot}53$ $P<0{\cdot}0001$). Right ventricular long axis excursion correlated with right ventricular–right atrial pressure drop though to a lesser significance ($r=-0{\cdot}27$ $P<0{\cdot}001$). Furthermore, right ventricular outflow tract fractional shortening was reduced in patients with pulmonary hypertension compared to patients without, this difference was not observed in the right ventricular systolic long axis excursion.

Conclusion: Right ventricular outflow tract fractional shortening provides a simple and non-invasive measure of right ventricular systolic function. In combination with long axis excursion and Doppler velocities they should provide comprehensive assessment of right ventricular function.
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Key Words: Echocardiography; right ventricular function; right ventricular outflow tract.

Introduction

Assessment of right ventricular function is important in many clinical conditions such as congestive heart failure[1], acute pulmonary embolism[2], valvular diseases[3] congenital heart disease and after cardiac surgery[4]. Non-invasive techniques such as radionuclide ventriculography[5], magnetic resonance imaging[6,7] and echocardiography[8–10] are used for the evaluation of right ventricular function. Two- and recently three-dimensional echo techniques have been applied for the calculation of ventricular volumes and ejection fraction but not without limitations[8,11–13]. Likewise, attempts using invasive angiography have been made to assess right ventricular function but again with their known

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Address correspondence to: Elsadig Kazzam, M.D., Ph.D., FESC., FACC., Department of Internal Medicine, Cardiology Division, Mälar Hospital, S-631 88 Eskilstuna, Sweden. Tel: +00-16-103000; Fax: +00-16-104876; E-mail: Elsadig.Kazzam@mse.dll.se

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difficulties. Due to the complex geometry of the right ventricle all these techniques have shown their inability to obtain an ideal amenable quantifying method[14,15]. Furthermore, the complex interaction between the right and left ventricles involves many anatomical and haemodynamic factors that affect the overall cardiac pump function[16].

Right ventricular long axis function measured as the extent of tricuspid annular excursion has been shown as a reliable method for assessing right ventricular systolic function even in patients with raised right-sided pressures[4,9,17–19]. Other studies have reported a possibility of using right ventricular infundibulum or outflow tract movement as a marker of right ventricular function[20–23]. Finally, acoustic quantification and border detection echocardiographic techniques have been used to automatically assess right ventricular systolic function[13,21,24].

M-mode technique, which is known for its objective advantage in quantifying wall motion, has received little attention in the field of right ventricular function. Therefore, we aimed in this study to assess the suitability and objectivity of such a simple technique in estimating regional right ventricular function and its relation to other established parameters for right ventricular function.

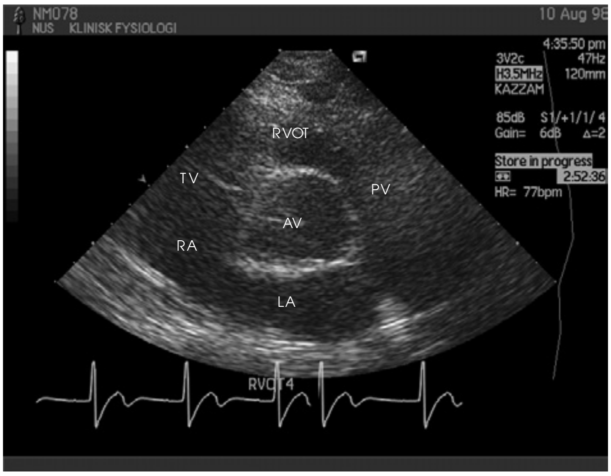

Figure 1. Two-dimensional view of the right ventricular outflow tract. RVOT: right ventricular outflow tract. PV: pulmonary valve. TV: tricuspid valve. RA: right atrium. LA: left atrium. AV: aortic valve.

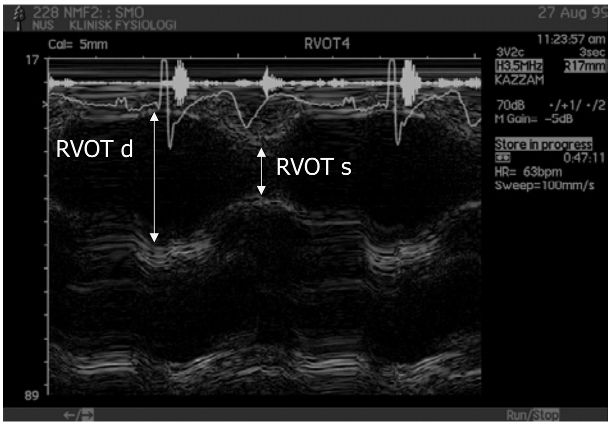

Figure 2. Right ventricular outflow tract M-mode recording from a normal. The estimated fractional shortening were 65%. EDD: end-diastolic dimension and ESD: end-systolic dimension.

Methods

Subjects

The study population consisted of 92 consecutive subjects referred to the laboratory for echocardiographic examination. No patient had more than a mild degree of tricuspid-regurgitation. On the basis of the echocardiographic presence of elevated right sided pressures (a peak tricuspid regurgitation pressure drop of >35 mmHg) the study population was divided into two groups: (1) patients with elevated right ventricular–right atrial pressure drop, 35 patients, mean age 72 ± 12 year (20 males) and (2) those with normal right ventricular–right atrial pressure drop, 57 patients, mean age 65 ± 14 year (36 males). For comparative purposes, 20 healthy controls mean age 46 ± 12 year (10 males) were also studied.

Echocardiographic Examination

Echocardiography was performed using the commercially available system (ATL HDI Ultramark 9) ultrasound imaging system, equipped with a 2·0–3·0 MHz phased array transducer. Patients were examined in the left lateral decubitus position. Two-dimensional echocardiograms of the parasternal short axis view at the level of the aortic root (Fig. 1) were obtained and the right ventricular outflow tract studied. M-mode recordings of the right ventricular outflow tract were obtained and dimensions were measured at end diastole (onset of the *Q* wave) and end-systole (end of T-wave) using endocardial leading edge methodology (Fig. 2). Right ventricular fractional shortening was calculated as the percentage fall in right ventricular outflow tract diameter in systole with respect to that in diastole. Right ventricular long axis function was recorded from the apical four-chamber view with the M-mode cursor positioned at the free wall angle of the tricuspid valve annulus (Fig. 3(a)). Total right ventricular long axis excursion amplitude (Fig. 3(b)) was taken from end-systole to end-diastole. Pulmonary valve Doppler flow velocities were recorded from the parasternal short axis view using pulsed wave Doppler technique. From the pulmonary valve flow recording, peak velocity was measured and pulmonary acceleration time, as the interval between the onset of flow and its peak. Transtricuspid peak retrograde velocities were recorded

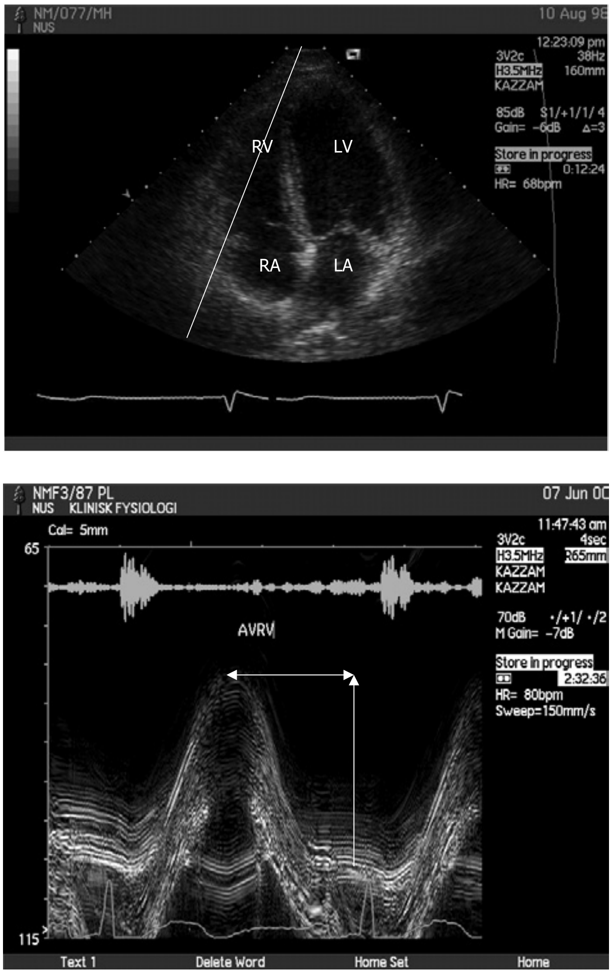

Figure 3. (a) The recording of 2–D echocardiography from the 4-chamber view. (b) The measurement of right ventricular atrioventricular plane displacement.

using the continuous wave Doppler technique and peak pressure drop was estimated using modified Bernoulli equation. All M-mode and Doppler velocity recordings were obtained with a superimposed ECG on a paper speed of 50–100 mm/s.

Statistical Analysis

Data is presented as mean ± standard deviation (SD). Student *t*-test was used to compare patients with controls. *P*-values <0·05 were considered significant. Pearson's correlation coefficients were calculated to illustrate certain relationships.

Results

Right Ventricular Outflow Tract Fractional Shortening and Right Ventricular Function

In patients right ventricular–right atrial pressure gradient was elevated (35 ± 14 vs 22 ± 7 mmHg, *P*<0·0001)

Table 1. Right ventricular outflow-tract fractional shortening and right ventricular function parameters.

	Controls (n=20)	Patients (n=92)
RVOT fs %	61 ± 13	37 ± 18*
RVLX (mm)	24 ± 4	17 ± 7*
TR RV–RA (mmHg)	22 ± 7	35 ± 14*
PACT (ms)	141 ± 23	87 ± 31*

RVOT fs %=right ventricular outflow-tract fractional shortening; RVLX =excursion; TR right ventricular–RA=tricuspid regurgitation pressure drop; RV=right ventricle; RA=right atrium; PACT=pulmonary acceleration time.
**P*<0·0001.

Table 2. Right ventricular function and pulmonary hypertension.

	Patients with TR RV–RA <35 mmHg (57)	Patients with TR RV–RV >35 mmHg (35)
RVOT fs %	43 ± 18	26 ± 10*
RVLX (mm)	18 ± 7	15 ± 7^{ns}
PACT (ms)	104 ± 31	66 ± 15*

**P*<0·0001; ns=not significant; RVOT fs %= right ventricular outflow-tract fractional shortening; RVLX=RV excursion; TR RV–RA=tricuspid regurgitation pressure drop; RV=right ventricle; RA=right atrium; PACT=pulmonary acceleration time.

Table 1 compared to healthy controls. The right ventricular outflow tract fractional shortening was less than healthy controls 37 ± 18 vs 61 ± 13%, *P*<0·0001 as was the long axis amplitude 17 ± 7 vs 24 ± 4 mm, *P*<0·0001. Pulmonary acceleration time was also shorter than healthy controls 87 ± 31 vs 141 ± 23 ms, *P*<0·0001. The right ventricular outflow tract fractional shortening correlated positively with right ventricular long axis amplitude (Fig. 4(a)) (r=0·66, *P*<0·0001), pulmonary artery acceleration time (Fig. 4(b)) (r=0·80, *P*<0·0001) and inversely with transtricuspid right ventricular–right atrial pressure drop (Fig. 4(c)) (r=–0·53, *P*<0·0001).

Right Ventricular Outflow Tract Fractional Shortening and Pulmonary Hypertension

In patients with elevated right ventricular–right atrial pressure drop >35 mmHg, right ventricular outflow tract fractional shortening was less 26 ± 10 vs 43 ± 18%, *P*<0·0001 and pulmonary artery acceleration time shorter 66 ± 15 vs 104 ± 31 ms, *P*<0·0001 compared with patients with normal right ventricular–right atrial pressures. However, right ventricular long axis amplitude did not differ between the two groups (15 ± 7 vs 18 ± 7 mm, *P*=0·07) Table 2. Figure 5 presents examples from right ventricular outflow tract in patients with

Table 3. Inter-, intra- and beat-to-beat observer variability in RVOT in 13 patients.

	Inter-observer variability				Intra-observer variability				Beat-to-beat variabilty			
	Mean	Mean difference	SD	CI, %	Mean	Mean difference	SD	CI, %	Mean	Mean difference	SD	CI, %
RVOTd (mm)	35·2	1·0	2·4	6·5	25·4	− 1·0	5·4	15·5	33·9	0·2	4·0	12·0
RVOTs (mm)	24·0	1·6	1·8	7·3	23·6	− 0·7	2·3	9·9	19·5	− 1·5	4·3	22·0
RVOT fs (%)	33·3	− 2·4	6·3	19·0	35·0	1·0	5·4	15·5	46·7	3·2	9·0	19·4

SD=standard deviation; RVOT fs=right ventricular outflow tract fractional shortening; d=diastole; s=systole; CI=coefficiant of variation.

pressure overloaded right ventricle due to (a) severe heart failure and (b) pulmonary embolism.

Reproduction of Measurements

Thirteen recording paper printouts were randomly selected for analysing offline intra- and inter-observer variability. Furthermore, another 13 curves were registered within approximately 20 min by two different observers to determine beat-to-beat inter-observer variation. The reproducibility analysis was done using paired *t*-test. Coefficient of variation (%) was calculated as the ratio of one standard deviation of difference (SD diff) to the mean value in percent (SDdiff/mean × 100). Intra-, inter- and beat-to-beat observer variability for right ventricular outflow tract fractional shortening were analysed in patients and the difference was mean ± SD: − 1·0 ± 5·4%, (r=0·98, $P<0{\cdot}0001$), − 2·4 ± 6·3%, (r=0·96, $P<0{\cdot}0001$) and 3·2 ± 9·0; (r=0·95, $P<0{\cdot}0001$) Table 3.

Discussion

Right Ventricular Anatomy

Myocardial fibre architecture of the left and right ventricles is fundamentally different[25–27]. Circumferential fibres are the predominant muscle layer in the left ventricle, particularly at the basal level, and are mounted on either side by longitudinally directed fibres in the subendo- and subepicardial layers[25,26]. In the right ventricle the fibres' orientation is different, in the infundibulum, both at the subepicardial and subendocardial level, the fibres are running longitudinally and they are overlain by fibres running at right angles to the outlet long axis, which can be traced to the crista supraventricularis and to the anterior sulcus serving to bind the ventricles together[25]. However, in the inlet part of the right ventricular, there are mainly spiral, circumferential fibres in the subepicardium and partially longitudinal in the subendocardium[25]. As inlet and outlet long axis of the right ventricular are approximately at right angles to each other, inlet long axis fibres are perpendicular to those on the diaphragmatic surface hence running parallel to the outlet infundibulum with little change in orientation[25]. Thus, global assessment of the right ventricle is difficult owing to the underlying complex anatomy with the two portions contracting perpendicular to each other: the proximal part longitudinally and the distal part circumferentially. In this study right ventricular function has been assessed using two conventional views, apical four-chamber and short axis, in order to obtain optimal analysis of the behaviour of the two right ventricular components. The function of these two parts of the right ventricle was assessed for their ability to identify patients with sign of pulmonary hypertension.

Findings

The present study demonstrates that right ventricular outflow tract fractional shortening is a technically easy measure of right ventricular systolic function, being obtainable in 95% of this study population. It can differentiate between patients and controls. In patients fractional shortening values are reduced compared to controls parallel to the reduced long axis excursion and the short pulmonary acceleration time. As part of the right ventricular body, right ventricular outflow tract function it closely correlates with other anatomical, long axis as well as functional parameters; pulmonary acceleration time and transtricuspid retrograde pressure gradient. Finally, right ventricular outflow tract fractional shortening correlates with echocardiographic signs of pulmonary hypertension more than right ventricular long axis excursion.

Data Interpretation

It is well known that the right and left ventricles are anatomically different. While the predominant shortening of the left ventricle is transversely that of the right ventricular is longitudinally. It is generally accepted that the systolic function of the ventricle is determined by its basal behaviour[20,28] particularly in absence of significant mid cavity or apical dysfunction. Although the two ventricles are different in the direction of maximum force production at the basal level, the stroke volume is expected to be similar. Left ventricular systolic function and clinical outcome are known to be determined by the

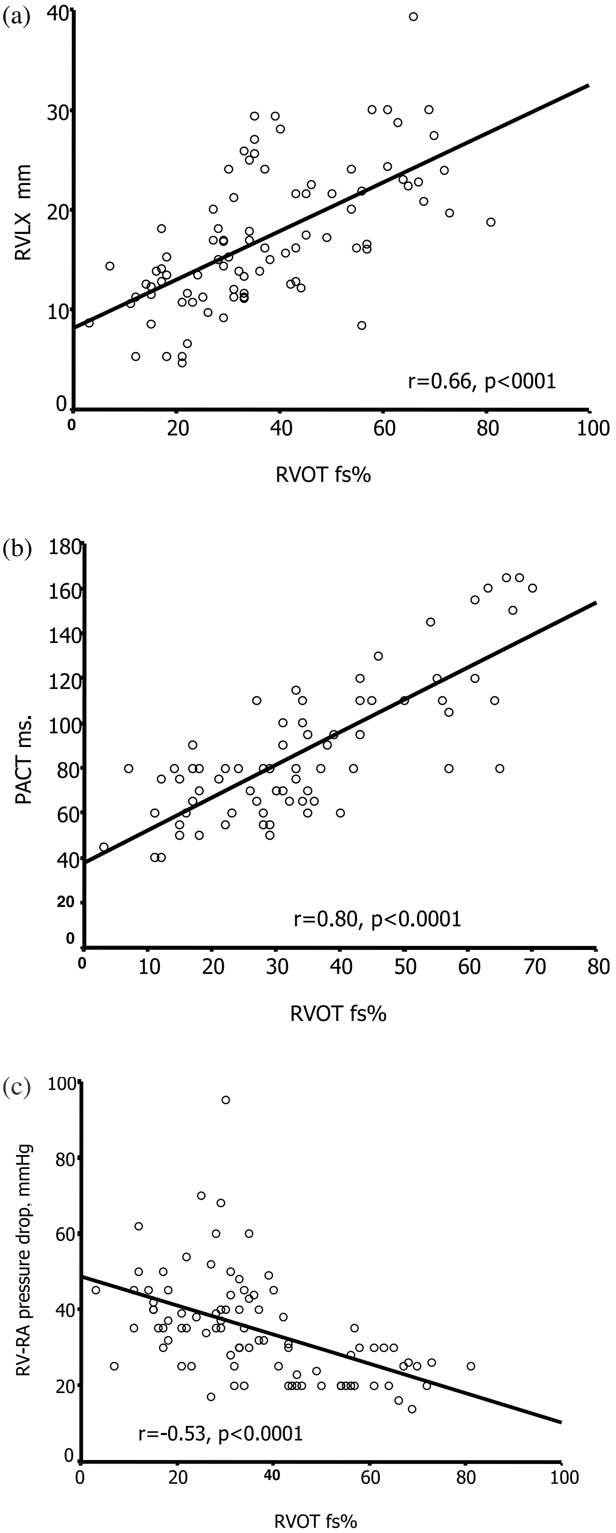

Figure 4. (a) The correlation between right ventricular outflow tract fractional shortening % and right ventricular atrioventricular plane excursion. (b) The correlation between right ventricular outflow tract fractional shortening % and pulmonary acceleration time. (c) The correlation between right ventricular outflow tract fractional shortening % and the right ventricular/right atrial pressure drop.

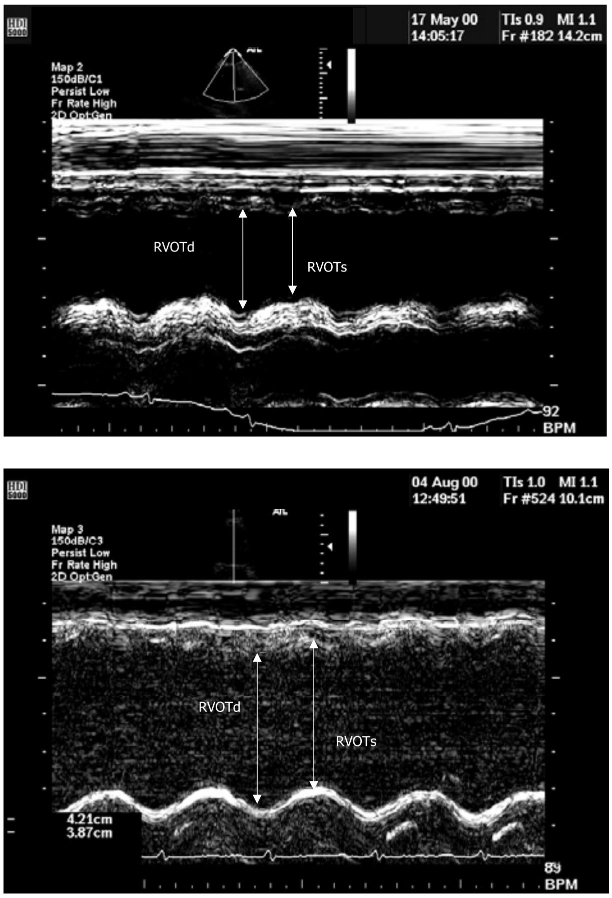

Figure 5. (a) Right ventricular outflow tract fractional shortening % from a patient with severe heart failure, right ventricular outflow tract fractional shortening=21%. (b) Right ventricular outflow tract fractional shortening % from a patient with pulmonary embolism. Right ventricular outflow tract fractional shortening=8%.

circumferential fibber-shortening fraction whereas that of the right ventricle is by the long axis amplitude of motion[29]. The latter has been shown to predict exercise tolerance in patients with dilated cardiomyopathy[30] as well as systolic and diastolic disturbances in patients with systemic sclerosis[31] and cystic fibrosis[32]. This should not underestimate the importance of the two other myocardial components. Left ventricular long axis function correlates closely with the estimated ejection fraction[33] and has also proved exquisitely sensitive in demonstrating early ischaemic disturbances in patients with coronary artery disease[34]. The function of the right ventricular infundibulum, as shown in this study correlates with the long axis values, being part of the same ventricle. More importantly, it closely correlates with the events happening near the outflow tract region, i.e. pulmonary acceleration time recorded at the cusp level. In fact, this demonstrates not only the anatomical relationship between the outflow tract and the pulmonary root but also the functional one. Furthermore, it was previously reported[35] that the right ventricular outflow tract has a peculiar embryological development arising from the circumvascular fibres, which are primarily circumconal in direction. Recently, we were able to demonstrate that although ACE-inhibitors treatment for congestive heart failure causes a fall in right atrial–right ventricular pressure drop it did not improve right ventricular long axis systolic function[19]. Finally, from this study, right ventricular outflow tract fractional shortening does correlate also with the right-sided pressures.

However when the overall right ventricular function is taken into account, it is important to mention that the inlet part of the right ventricular has a greater contribution compared with the infundibulum. This has been shown by using magnetic resonance imaging[21] and recently by Doppler Tissue Imaging[20] as well as STRAIN rate/strain technique[36].

Limitations

The aim of this study was not to obtain a global marker of right ventricular function but rather a regional one, which may be of practical use. M-mode recordings, although obtained with the highest possible quality remain subject to their known limitations. An oblique section at the level of right ventricular outflow tract may underestimate the fractional shorting value. This is why the observation by Kotler *et al.*[37] to visualize the outflow tract of the right ventricle, was taken into account to avoid pitfalls in M-mode recording due to transducer position.

We have no invasive data for pulmonary pressures and we relied on the estimated transtricuspid pressure drop as a guide for patients classification. Although this may have over- or underestimated right ventricular systolic pressures values it correlates closely with outflow tract function thus strengthening its accuracy. The analysis is relied on absolute values rather than volume calculations in order to avoid multiplication of any measurement error. A significant rise in pericardial pressures irrespective of its cause may affect right ventricular outflow tract fractional shortening values; none of our patients had pericardial effusion or raised central venous pressure. The main limitation of this study is the lack of a comparative golden standard technique for assessing right ventricular function, such as cardiac catheterization and/or cine magnetic resonance imaging. Such study is now under careful planning.

Conclusion

Right ventricular outflow tract fractional shortening is a non-invasive and easy applicable measure of function. It provides an objective value that can be used for follow up of patients who are prone to develop right ventricular dysfunction. Although it only assesses systolic performance of the outflow tract, its combination with long axis measurements and transtricuspid Doppler analysis should provide a comprehensive evaluation of the right ventricular performance.

Acknowledgement

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