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The utility of transthoracic echocardiographic measures of right ventricular systolic function in a lung resection cohort

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Abstract

Right ventricular (RV) dysfunction occurs following lung resection and is associated with post-operative complications and long-term functional morbidity. Accurate peri-operative assessment of RV function would have utility in this population. The difficulties of transthoracic echocardiographic (TTE) assessment of RV function may be compounded following lung resection surgery, and no parameters have been validated in this patient group. This study compares conventional TTE methods for assessing RV systolic function to a reference method in a lung resection population. Right ventricular index of myocardial performance (RIMP), fractional area change (FAC), tricuspid annular plane systolic excursion (TAPSE) and S′ wave velocity at the tricuspid annulus (S′), along with speckle tracked global and free wall longitudinal strain (RV-GPLS and RV-FWPLS respectively) are compared with RV ejection fraction obtained by cardiovascular magnetic resonance ($RVEF_{CMR}$). Twenty-seven patients undergoing lung resection underwent contemporaneous CMR and TTE imaging; pre-operatively, on post-operative day two and at 2 months. Ability of each of the parameters to predict RV dysfunction ($RVEF_{CMR}$ <45%) was assessed using the area under the receiver operating characteristic curve (AUROCC). RIMP, FAC and S′ demonstrated no predictive value for poor RV function (AUROCC <0.61, $P > 0.05$). TAPSE performed marginally better with an AUROCC of 0.65 ($P = 0.04$). RV-GPLS and RV-FWPLS demonstrated good predictive ability with AUROCC's of 0.74 and 0.76 respectively ($P < 0.01$ for both). This study demonstrates that the conventional TTE parameters of RV systolic function are inadequate following lung resection. Longitudinal strain performs better and offers some ability to determine poor RV function in this challenging population.

Key Words

- right ventricle
- speckle tracked strain
- cardiovascular magnetic resonance imaging
- lung resection

Introduction

Using cardiovascular magnetic resonance (CMR) imaging our group has demonstrated right ventricular (RV) dysfunction following lung resection (1). RV dysfunction in this group is associated with peri-operative morbidity and decreased long-term functional capacity (2, 3, 4, 5). Reliable assessment of RV systolic function in the peri-operative period would enable identification of patients developing RV dysfunction. Eventually this may allow targeted implementation of management strategies, ameliorating the burden of disease in this population.

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Despite being a reference method for assessment of the RV, CMR is not suitable for routine use in this patient group. CMR is not universally available, some patients are permanently excluded as a result of implantable devices, the requirement of transfer to isolated sites, and the need for breath holds to reduce respiratory artefact, mean it is not suitable in the acutely unwell post-operative patient. Transthoracic echocardiography (TTE) is the mainstay of assessment of RV structure and function in the majority of clinical settings.

Recommended TTE methods for assessing RV systolic function include global techniques such as the right ventricular index of myocardial performance (RIMP), fractional area change (FAC) and regional approaches such as tricuspid annular plane systolic excursion (TAPSE) and S′ wave velocity at the tricuspid annulus (S′) (6). Speckle-tracked RV longitudinal strain is a novel technique that has been advocated to overcome some of the difficulties associated with conventional methods. None of these methods have been validated in this population. The challenges of echocardiographic assessment of RV function; the RV's retrosternal position, load dependence and irregular shape may be compounded following thoracic surgery where the presence of fluid, drains and post-operative pain limit imaging quality.

The aim of this study is to assess the utility of TTE methods of assessing RV systolic function in a cohort undergoing lung resection.

Methods

Subjects

This was an *a priori* secondary endpoint of a study using CMR to assess RV function following lung resection. Ethics approval was provided by the West of Scotland Research Ethics Committee (134/WS/0055) and all participants provided written informed consent. Patients attending for elective lung resection by thoracotomy and lobectomy were screened. Subjects who were pregnant, participating in any investigational research which could undermine the scientific basis of the study, had contraindications to CMR imaging or were undergoing; wedge/segmental/sub-lobar lung resection, pneumonectomy, isolated middle lobectomy or thoracoscopic/minimal access lung resection, were excluded. Surgical technique was standardised to a single surgeon performing a postero-lateral muscle-sparing thoracotomy with anatomically appropriate lymph node clearance. Anaesthetic technique was standardised and included volatile agents for anaesthetic maintenance, intra-operative lung protective ventilatory strategies and thoracic epidural blockade.

Measurements

Contemporaneous TTE and CMR imaging were performed pre-operatively, on post-operative day (POD) 2 and at 2-month follow-up. Effort was taken to ensure the imaging studies were performed as close in time as possible. This was often on the same transfer from the ward for example, patients went from the ward to CMR imaging, and then to TTE imaging (or vice versa) and then back to the ward. All imaging studies were randomised and anonymised prior to analysis. The CMR and conventional TTE imaging studies (RIMP, FAC, TAPSE and S′) were dual reported by observers blinded to patient identity and results of the other imaging modality. Twenty-five percent of the speckle tracked strain scans were randomly selected for dual analysis by an expert observer blinded to the CMR results.

Transthoracic echocardiography

TTE image acquisition was performed on a Vivid E9 cardiovascular ultrasound platform (GE Healthcare) by band 7 cardiac physiologists accredited by the British Society of Echocardiography. Image acquisition was performed according to a standardised protocol incorporating all aspects required for a comprehensive standard echocardiogram (7). Where possible, allowing for recent surgery and chest drain placement, imaging took place in the lateral decubitus position. Two-dimensional (2D) recordings were collected with frame rates of 60–80 frames per second and four consecutive cardiac cycles were recorded for further analysis. Three lead ECG analysis took place simultaneously. For determination of FAC, two-dimensional images were obtained from the standard apical 4-chamber (A4C) view. For determination of RIMP and S′, pulsed tissue Doppler imaging was performed of the tricuspid valve annulus and RV free wall. For determination of TAPSE, M-mode analysis was performed offline from 2D images. Analysis of quantitative parameters was consistent with consensus guidelines (6).

Speckle-tracking echocardiography

A4C view images were obtained as part of the comprehensive assessment described above. Analysis was performed offline using semi-automated, proprietary analysis software (EchoPac, GE Healthcare). To measure

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RV global strain, an endocardial border was manually traced in the four-chamber view, thus delineating a region of interest (ROI), composed of six segments. After manual adjustment of the ROI width to fit wall thickness, appropriate tracking was signified by the software and segments with insufficient tracking were excluded. Longitudinal strain curves were generated by the software for each segment and RV global peak longitudinal strain (RV-GPLS) was calculated by averaging values for each of the tracked segments. RV free wall peak longitudinal strain (RV-FWPLS) was determined by averaging the three segments composing the RV free wall.

Cardiovascular magnetic resonance imaging

CMR imaging (1.5 Tesla, Siemens Avanto, Siemens) was performed with ECG-gated fast imaging steady state free precession cines (TrueFISP, Siemens) utilised throughout. Methodological details of importance include standardised imaging parameters of repetition time, echo time, flip angle, voxel size, field of view = 4.3 ms, 1.2 ms, 60°, 1.4 × 1.4 × 6 mm, 340 mm respectively; 6 mm imaging slices were used with a 4 mm interslice gap. Short-axis imaging was performed during breath holds and initiated at the atrioventricular valve plane and propagated sequentially to the cardiac apex providing complete coverage of both ventricles. Image analysis was performed using proprietary software (Argus, Siemens). RV volumes were determined by manual planimetry of short-axis images according to standard methods and the RV ejection fraction ($RVEF_{CMR}$) calculated (8).

Statistics

Data are presented as mean ± s.d. or median (IQR) as appropriate. Inter-observer variability was assessed using the intraclass correlation coefficient for absolute agreement. Association between continuous variables was assessed using Pearson's or Spearman's correlation coefficients. Given the repeated-measures nature of the study, analysis of covariance (ANCOVA) was performed to take account of within-subject correlation (9). To assess the ability of each of the TTE measures (RIMP, FAC, TAPSE, S′, RV-GPLS and RV-FWPLS) to determine a *change* in $RVEF_{CMR}$, the association between the change in echo parameter (Δecho-parameter) and the change in $RVEF_{CMR}$ ($\Delta RVEF_{CMR}$) was assessed. The ability of each of the TTE parameters to predict RV dysfunction (defined as $RVEF_{CMR}$ <45%) (10) was assessed using the area under the receiver-operating characteristic curve (AUROCC). The maximal cut-off of sensitivity and specificity was determined by Youden's index. On an exploratory basis, the ability of a combination of conventional echo parameters to determine RV dysfunction was assessed by examining the number of *abnormal* echo results (RIMP >0.55, FAC <35%, S′ <10 cm/s and TAPSE <16 mm) in those with $RVEF_{CMR}$ <45% and those with $RVEF_{CMR}$ ≥45%.

Statistical analyses were performed using SPSS for Windows, version 22 (IBM Corp). A *P* value <0.05 was considered significant.

Results

From September 2013 to August 2014, 28 patients were recruited. One patient was excluded from further study participation as a result of the unexpected discovery of an embedded piece of ferromagnetic material in their chest wall during pre-operative CMR imaging. There were no clinical sequela, but as the patient was unable to take any part in the main study, the patient was removed from all further analyses. Patient demographics are displayed in Table 1. Twenty-six patients underwent lobectomy or bilobectomy (incorporating the right middle lobe), one patient required unplanned intra-operative conversion to a pneumonectomy, but is included in all analyses. Sensitivity analysis revealed this patient was not an outlier in any analysis (not shown).

Echocardiography was well tolerated with all 27 patients (100%) completing the pre-operative protocol. Twenty-six patients (96.3%) completed the protocol on day 2 and 24 (88.9%) at 2 months. The one patient not scanned on POD 2 declined imaging. Of the

Table 1 Patient characteristics.

Patient characteristics	*n* = 27
Age (years)	67.0 (59.0, 74.0)
Sex, *n* Female	17 (63.0%)
Operative variables	
Pneumonectomy, *n* (%)	1 (3.7%)
Lobectomy, *n* (%)	22 (81.5%)
Bilobectomy, *n* (%)	4 (14.8%)
Right sided procedure, *n* (%)	17 (63.0%)
Duration of surgery (min)	146.0 (116.0, 169.0)
Duration of OLV (min)	56.0 (48.0, 84.0)
Length of hospital stay (days)	8 (7.0, 11.0)
Length of critical care unit stay (h)	47 (29.2, 53.5)
Pathology	
Primary lung cancer	24 (88.9%)
Metastatic malignancy	1 (3.7%)
Benign	2 (7.4%)

Data are presented as median (IQR) or *n* (%).
OLV, one lung ventilation.

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patients not completing TTE imaging at 2 months, two declined and one was unwell at another hospital with a broncho-pleural fistula. CMR was well tolerated, with all patients completing the protocol pre-operatively. Due to an administration error, one patient did not have short-axis images obtained, so it was not possible to calculate $RVEF_{CMR}$ in this patient. Twenty-two patients (81.5%) completed the scan protocol on POD2, with 24 (88.9%) completing the protocol at 2 months. Mean (s.d.) time to 2-month follow-up was 55.9 (13.1) days. Of the five patients unable to be imaged on POD 2, three declined, one was unwell with MRI transfer deemed unsafe and a final patient had an epidural catheter *in situ* that was not MRI compatible (11). Of the three patients unable to complete the protocol at 2 months; one declined, one was an inpatient at another hospital and the third had a contraindication to MRI as a result of recent cataract surgery.

This resulted in 69 paired CMR and TTE studies for analysis. Mean $RVEF_{CMR}$ (for all patients across all time points) was 47.12% (7.0). Of these 69 scans, paired echo results (both observers agreeing a result was obtainable) were available for RIMP in 66 (95.7%) patients, FAC in 45 (65.2%), TAPSE in 66 (95.7%) and S′ in 68 (98.6%). RV-GPLS and RV-FWPLS were available in 66 (95.7%) patients. There was poor inter-observer variability for FAC with an intraclass correlation coefficient (ICC) for absolute agreement of 0.12. RIMP showed good inter-observer variability with an ICC of 0.71. TAPSE, S′ and strain (RV-GPLS and RV-FWPLS) demonstrated excellent inter-observer variability with ICCs for absolute agreement of 0.94, 0.91 and 0.91 respectively.

Association between each of the TTE variables and $RVEF_{CMR}$ was assessed (Fig. 1A, B, C, D, E, F and Table 2). Although there was weak-to-moderate association (r=0.29 to −0.48) on pooled analysis for TAPSE, S′, RV-GPLS and RV-FWPLS, once within-subject association was accounted for by ANCOVA, only RV-FWPLS *approached* significance (P=0.05) with weak association (r=0.31). Other than RV-FWPLS, which demonstrated a weak relationship (r=−0.32), there was no association between Δecho-parameter and $\Delta RVEF_{CMR}$ (Fig. 2A, B, C, D, E, F and Table 3). AUROCC analysis demonstrated that TAPSE, RV-GPLS and RV-FWPLS had predictive power for RV dysfunction (Fig. 3 and Table 4). TAPSE had an AUROCC of 0.65 (P=0.04) with 21.3 mm having a 65.7% sensitivity and 71.4% specificity for detecting RV dysfunction. RV-GPLS and RV-FWPLS had an AUROCC of 0.74 and 0.76 (P<0.01 for both) respectively. A RV-GPLS value of −17.7% had 76.0% sensitivity and 66.7% specificity for

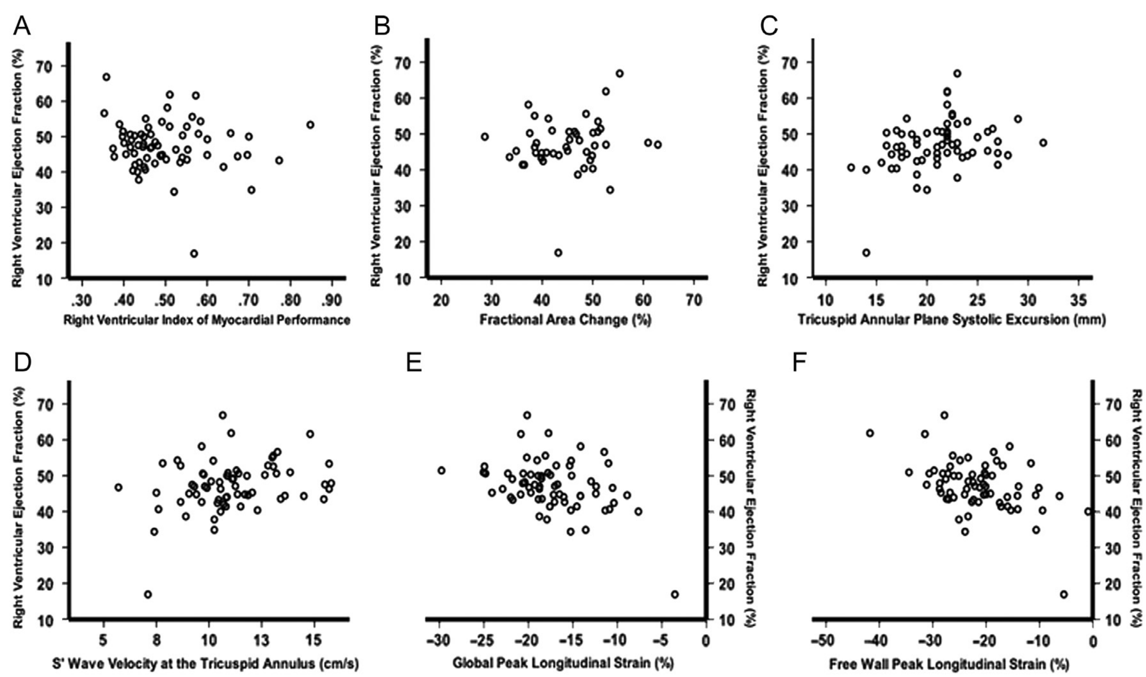

Figure 1
(A, B, C, D, E and F) Association between echo variables and cardiovascular magnetic resonance determined right ventricular ejection fraction. Association between right ventricular ejection fraction and (A) right ventricular index of myocardial performance, (B) FAC, (C) tricuspid annular plane systolic excursion, (D) S′ wave velocity at the tricuspid annulus, (E) right ventricular global peak longitudinal strain and (F) right ventricular free wall peak longitudinal strain. Tests of association and significance are demonstrated in the manuscript text and Table 2.

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Table 2 Association between echo variables and $RVEF_{CMR}$.

	RIMP	FAC	TAPSE	S′	RV-GPLS	RV-FWPLS
	n = 66	*n* = 45	*n* = 66	*n* = 68	*n* = 66	*n* = 66
Pooled analysis (Pearson's correlation coefficient)	−0.12	0.14	**0.34**	**0.29**	**−0.41**	**−0.48**
P	0.36	0.37	**<0.01**	**0.02**	**<0.01**	**<0.01**
Within-subject analysis (ANCOVA)	0.09	0.27	0.05	0.12	0.12	0.31
P	0.62	0.29	0.78	0.49	0.45	0.05

Right ventricular free wall peak longitudinal strain. Significant results are highlighted in bold. ANCOVA, analysis of covariance; FAC, fractional area change; RIMP, right ventricular index of myocardial performance; $RVEF_{CMR}$, cardiovascular magnetic resonance determined right ventricular ejection fraction; RV-GPLS, right ventricular global peak longitudinal strain; S′, S′ wave velocity at the tricuspid annulus; TAPSE, tricuspid annular plane systolic excursion.

identifying RV dysfunction, with a RV-FWPLS value of −20.0% having 62.5% sensitivity and 79.5% specificity.

Given the difficulties with analysis of FAC, it was not included in the assessment of combined parameters. When two or three of RIMP, TAPSE or S′ were abnormal, $RVEF_{CMR}$ was always below 45%. There were 23 participants with $RVEF_{CMR}$ <45% who had one or no parameters in the abnormal range (Table 5).

Discussion

This is the first study to compare TTE parameters of RV function to CMR-derived RV ejection fraction in a lung resection cohort. Our main finding is that the conventional parameters for assessing RV function such as RIMP, FAC, TAPSE and S′ may not be considered suitable for *routine* use in this population. Speckle-tracked strain assessment of the RV free wall performs better and may have utility in this challenging group.

Previous work by our group using CMR has demonstrated that $RVEF_{CMR}$ deteriorates following lung resection, falling from 50.5% (6.9) pre-op to 45.6% (4.5) on POD2 and remaining reduced at 44.9% (7.7) at 2 months (1). CMR is a reference method for assessing RV function and $RVEF_{CMR}$ has been used for validation of TTE measures of RV function in other populations (10, 12, 13, 14, 15, 16). TTE assessment of the RV is technically challenging,

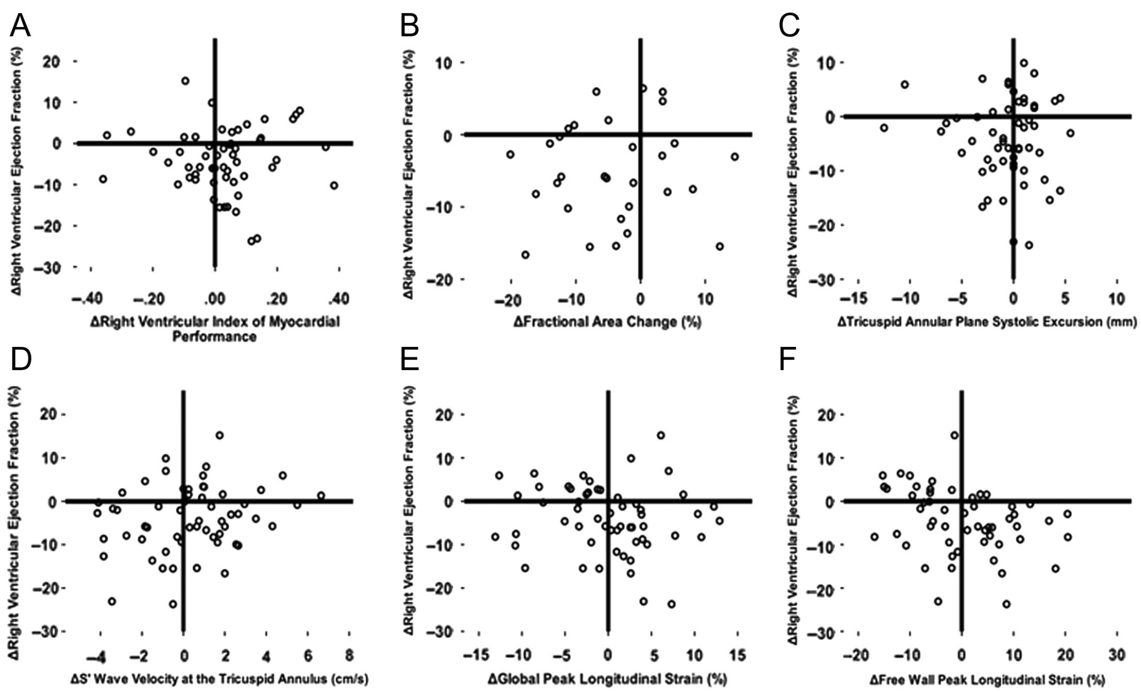

Figure 2
(A, B, C, D, E and F) Association between change in (Δ) echo variables and change in (Δ) cardiovascular magnetic resonance determined right ventricular ejection fraction. Association between ΔRight ventricular ejection fraction and (A) ΔRight ventricular index of myocardial performance, (B) ΔFractional area change, (C) ΔTricuspid annular plane systolic excursion, (D) ΔS′ wave velocity at the tricuspid annulus, (E) ΔRight ventricular global peak longitudinal strain, (F) ΔRight ventricular free wall peak longitudinal strain. Tests of association and significance are demonstrated in the manuscript text and Table 3.

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Table 3 Association between change in (Δ) echo variables and change in (Δ) $RVEF_{CMR}$.

	ΔRIMP	ΔFAC	ΔTAPSE	ΔS′	ΔRV-GPLS	ΔRV-FWPLS
	n = 55	*n* = 30	*n* = 55	*n* = 58	*n* = 56	*n* = 54
Association (Pearson's correlation coefficient)	0.01	0.06	−0.08	0.22	−0.12	**−0.32**
P	0.95	0.76	0.54	0.11	0.38	**0.02**

Right ventricular free wall peak longitudinal strain. Significant results are highlighted in bold. FAC, fractional area change; RIMP, right ventricular index of myocardial performance; $RVEF_{CMR}$, cardiovascular magnetic resonance determined right ventricular ejection fraction; RV-GPLS, right ventricular global peak longitudinal strain; S′, S′ wave velocity at the tricuspid annulus; TAPSE, tricuspid annular plane systolic excursion.

and its retrosternal position means visualisation of the anterior RV free wall is difficult. The complex geometry means summation disc volume calculations (in contrast to Simpsons bi-plane measurement of the LV) are not easy to perform and ultimately inaccurate (17). Despite the difficulties associated with TTE, it is by far the most commonly used modality in clinical practice; it is portable, widely available, inexpensive and non-invasive and involves no exposure to ionising radiation.

TTE was well tolerated in this study, with all patients completing the protocol pre-op and the majority completing it post-op. Despite the majority of patients undergoing TTE imaging, not all parameters were available in all patients. The main discrepancy between observers was for determination of FAC. One observer had adequate images to obtain a result in 67 (95.7%) scans and the other in 48 (68.6%) scans. The main time for disagreement between observers was on POD2 when one observer obtained a result in 96.2% of images and the other in 46.2% of images. On subjective review of the images, it appeared that those with poor visualisation of the apex were the main source of disagreement. Sensitivity analysis (not shown) using only values derived by *either* observer demonstrated no change to the results reported in this study. Even in those patients where both observers were able to obtain a result, there was significant disagreement in FAC with an ICC of 0.12. In previous work by Kjaergaard *et al*. (in a non-thoracic surgery cohort), images were of sufficient quality to determine FAC in 82% of patients (13). This is substantially better than the current investigation and highlights the challenge of image acquisition in this population.

Association between FAC and $RVEF_{CMR}$ has been previously demonstrated in other populations, (Pearson's correlation coefficient of 0.47–0.77) with good ability to identify poor RV function (AUROCC 0.78–0.89) (10, 15, 16). There was no association between FAC and $RVEF_{CMR}$ in the current study and FAC showed no ability to identify a change in RV function or determine poor RV function.

RIMP, TAPSE and S′ have been shown to be predictive of clinical outcomes in pulmonary hypertension and cardiac failure and have shown good association with $RVEF_{CMR}$ in other patient groups, with good ability to predict poor RV function (10, 13, 15, 16). However, there is a lack of consistency, with parameters being predictive in some clinical settings but not in others (18). Likewise, parameters show variable association with $RVEF_{CMR}$ depending on the magnitude of RV dysfunction.

In this study, there was no association between RIMP, TAPSE, S′ and $RVEF_{CMR}$. Additionally, there was no association between a change in any of the echo parameters and a change in $RVEF_{CMR}$. RIMP and S′

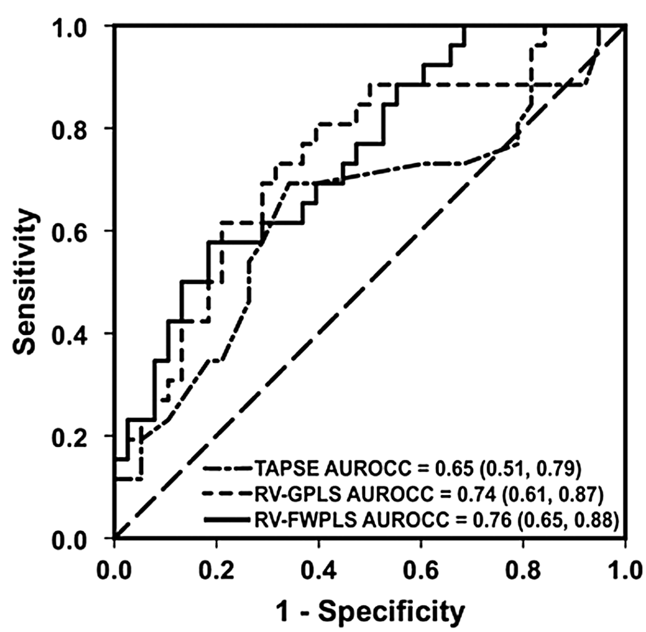

Figure 3
Receiver-operator curves to identify RV dysfunction ($RVEF_{CMR}$ ≤45%). Dashed-dotted line represents TAPSE. Dashed line represents RV-GPLS and continuous line represents RV-FWPLS. Diagonal dashed line is the line of no effect. AUROCC, area under the receiver-operator characteristic curve; RV-GPLS, right ventricular global peak longitudinal strain; RV-FWPLS, right ventricular free wall peak longitudinal strain; TAPSE, tricuspid annular plane systolic excursion. Values are area (95% CI).

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Table 4 Predictive performance of echo parameters to detect RV dysfunction ($RVEF_{CMR}$ ≤45%).

	RIMP	FAC	TAPSE	S′	RV-GPLS	RV-FWPLS
	n = 66	*n* = 45	*n* = 66	*n* = 68	*n* = 66	*n* = 66
AUROCC (95% CI)	0.60 (0.46, 0.73)	0.61(0.45, 0.78)	**0.65 (0.51, 0.79)**	0.57 (0.43, 0.71)	**0.74 (0.61, 0.87)**	**0.76 (0.65, 0.88)**
P	0.19	0.21	**0.04**	0.33	**<0.01**	**<0.01**

Right ventricular free wall peak longitudinal strain. Significant results are highlighted in bold. FAC, fractional area change; RIMP, right ventricular index of myocardial performance; RV-GPLS, right ventricular global peak longitudinal strain; S′, S′ wave velocity at the tricuspid annulus; TAPSE, tricuspid annular plane systolic excursion.

showed no discriminative ability for RV dysfunction and although TAPSE demonstrated an ability to predict poor RV function, with an AUROCC of 0.65, this is not at a level that would be clinically useful (19).

A number of reasons may contribute to why these parameters are predictive in other populations but not in the current lung resection cohort. The majority of previous studies had patient populations with heterogeneous examples of cardiovascular disease (ischaemic heart disease, cardiomyopathy, valvular heart disease, congenital heart disease, structural heart disease and pulmonary hypertension) with likely cardiac dysfunction. Of the cohort in the current investigation, only six patients (22.2%) had IHD and none had active cardiac failure. Given the load dependence of the TTE measures of RV function, the mechanism of RV dysfunction may be important. The primary hypothesised mechanism of RV dysfunction following lung resection is elevated afterload, but other mechanisms were present in previous studies.

The narrow range of $RVEF_{CMR}$ values seen in the current study may also be important. In validation studies, wide ranges of patients (e.g. those with good RV function and those with very poor RV function) are often used to assess the ability of parameters to predict different levels of function. This wide range can contribute to improved correlation statistics and improved prediction. For example, in the study by Pavlicek *et al.*, 27 patients (12.1%) had $RVEF_{CMR}$ ≤30%, in contrast to one (1.5%) in the current investigation. In the same study, the performance of parameters was shown to depend on level of RV dysfunction, in those patients with $RVEF_{CMR}$ ≤30%, AUROCC for RIMP was 0.95 but with $RVEF_{CMR}$ ≤50% it was 0.68.

It appears that the population undergoing lung resection has a lower RVEF than the normal population and that when RV dysfunction develops that it is less severe than those with primary cardiac pathology. This tighter range means that association is harder to demonstrate in this patient group, meaning measures need to be more sensitive to determine subtle changes in RV function. No patients developed overtly clinical RV failure in this cohort, so it is not possible to say how these parameters would perform, if a patient developed RV failure.

Speckle-tracked RV longitudinal strain may overcome some of the difficulties associated with the conventional parameters of RV systolic function, such as angle dependence, reliance of a single region to represent the whole ventricle (in contrast to TAPSE and S′) and global cardiac displacement. In addition, the semi-automated software used to determine speckle-tracked RV strain may account for the reduced variability between observers in this study, when compared to other parameters such as FAC. When $RVEF_{CMR}$ has been used as a reference method, speckle-tracked RV strain, particularly of the RV free wall, has been shown to perform markedly better than the conventional parameters for predicting poor RV function (10, 15, 20). Focardi *et al*. demonstrated RV-FWPLS had an AUROCC of 0.92 for prediction of poor RV function, in contrast to AUROCC's of 0.66, 0.77 and 0.78 for TAPSE, FAC and RV-GPLS respectively.

This was the case in the current study with RV-FWPLS being the only variable to approach significance with within-subject analysis (P=0.05). There was also association between change in RV-FWPLS and change in $RVEF_{CMR}$ but not with other variables. Both RV-GPLS and RV-FWPLS showed ability to predict RV dysfunction as reflected by AUROCC's of 0.74 and 0.76 respectively.

Table 5 Ability of a combination of abnormal values of RIMP, S′ and TAPSE to determine RV dysfunction.

	RVEF <45%	RVEF ≥45%
	n = 26	*n* = 37
0 Abnormal	12 (46.2%)	19 (51.4%)
1 Abnormal	11 (42.3%)	18 (48.6%)
2 Abnormal	2 (7.7%)	0
3 Abnormal	1 (3.8%)	0

Data are presented as *n* (%). Abnormal parameters defined as right ventricular index of myocardial performance >0.55, S′ wave velocity at the tricuspid annulus <10 cm/s and tricuspid annular plane systolic excursion <16 mm.

As no patients developed severe RV dysfunction, it is not possible to say from this study how these parameters would perform if a patient were to develop post-operative RV failure. Consensus guidelines by the American Society of Echocardiography (Endorsed by the European Association of Echocardiography) recommend RV assessment should be based on a combination of qualitative and quantitative parameters and in the situation of RV failure, this may be useful (6).

The same guidance advocates that combining more than one measure of RV function may more reliably distinguish normal from abnormal RV function. For the purposes of this study, the combination of *abnormal* parameters was used to determine the ability to predict RV dysfunction. Analysis of the current cohort demonstrated that in the only participant where RIMP, S′ and TAPSE were *all* abnormal (RIMP >0.55, S′ <10 cm/s and TAPSE <16 mm), RV function was significantly impaired (RVEF = 16.94%). In those patients where two *or* three of RIMP, S′ and TAPSE were abnormal, all had RV dysfunction (RVEF <45%) with a positive predictive value of 100% but a negative predictive value of 61.7%. This suggests the combination of parameters in this population is specific, but not sensitive.

Strengths and weaknesses

A strength of this study is that it attempts to examine parameters in the population where they are used and not extrapolate them from other clinical situations.

As this was a secondary endpoint of another study, there was no power analysis. Lack of agreement between the observers for analysis of FAC is a weakness of this study, with paired analyses only available for two-thirds of the patients. This illustrates the challenge of echocardiography in this population. As is common, the software utilised for strain analysis in this investigation had no specific RV tool, requiring an LV protocol was applied to the RV. Although this has been widely reported in the literature, packages have been developed with specific RV analysis tools, meaning results may be influenced by the software used (21, 22).

Conclusion

Conventional echo parameters for assessment of RV function have limited utility in a lung resection cohort. FAC was not reproducible and showed no agreement with RV function. Although RIMP, TAPSE and S′ could all be reliably measured, there was no association between them and CMR-derived RVEF. None of them showed any independent ability to determine a *change* in RV function or *poor* RV function. The combination of parameters performed better however, and may help identify RV dysfunction in this challenging patient group. Speckle-tracked strain performs better than the conventional parameters and may have utility in this population. Further validation is needed before this novel technique can be routinely advocated in patients undergoing lung resection.

Declaration of interest
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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Author contribution statement
All authors contributed significantly to the submitted work. P M led patient recruitment and acquisition of data, contributed to analysis and interpretation of data, and drafted the final manuscript. A S and P S contributed to analysis of data. J K contributed to study design. B S conceived of the study, obtained funding and supervised all aspects of the study. All authors critically revised and approved the final manuscript.

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