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Tricuspid Annular Plane Systolic Excursion Does Not Correlate With Right Ventricular Ejection Fraction in Patients With Hypoplastic Left Heart Syndrome After Fontan Palliation

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Abstract

Tricuspid annular plane systolic excursion (TAPSE) reflects longitudinal myocardial shortening, the main component of right ventricular (RV) contraction in normal hearts. To date, TAPSE has not been extensively studied in patients with hypoplastic left heart syndrome (HLHS) and systemic RVs after Fontan palliation. This retrospective study investigated HLHS patients after Fontan with cardiac magnetic resonance (CMR) performed between 1 January 2010 and 1 August 2012 and transthoracic echocardiogram (TTE) performed within 6 months of CMR. The maximal apical displacement of the lateral tricuspid valve annulus was measured on CMR (using four-chamber cine images) and on TTE (using two-dimensional apical views). To create TTE–TAPSE z-scores, published reference data were used. Intra- and interobserver variability was tested with analysis of variance. Inter-technique agreement of TTE and CMR was tested with Bland–Altman

analysis. In this study, 30 CMRs and TTEs from 29 patients were analyzed. The age at CMR was 14.1 ± 7.1 years, performed 11.9 ± 7.8 years after Fontan. For CMR–TAPSE, the intraclass correlation coefficients for inter- and intraobserver variability were 0.89 and 0.91, respectively. The TAPSE measurements were 0.57 ± 0.2 cm on CMR and 0.70 ± 0.2 cm on TTE (TTE–TAPSE z score, -8.7 ± 1.0). The mean difference in TAPSE between CMR and TTE was -0.13 cm [95 % confidence interval (CI) -0.21 to -0.05], with 95 % limits of agreement (-0.55 to 0.29 cm). The study showed no association between CMR–TAPSE and RVEF ($R = 0.08$; $p = 0.67$). In patients with HLHS after Fontan, TAPSE is reproducible on CMR and TTE, with good agreement between the two imaging methods. Diminished TAPSE suggests impaired longitudinal shortening in the systemic RV. However, TAPSE is not a surrogate for RVEF in this study population.

Keywords

TAPSE; Right ventricle; Hypoplastic left heart syndrome; Fontan; Cardiac magnetic resonance; Echocardiography

Introduction

Patients with hypoplastic left heart syndrome (HLHS) require serial evaluation of right ventricular (RV) performance after the Fontan operation. Echocardiographic evaluation of RV systolic function is challenging due to the complex RV geometry, which does not allow for simple assessment of systolic function, as does that of the left ventricle [27].

The tricuspid annular plane systolic excursion (TAPSE) is an easily obtained, validated measure of RV longitudinal shortening [6], the main component of RV contraction in the normal heart [2]. Physiologically, TAPSE is defined by the excursion of the tricuspid valve annulus toward the RV apex in systole. Decreased TAPSE, indicating diminished RV function, has been associated with poor prognosis in adults with pulmonary hypertension [5, 26] and congestive heart failure [5].

Pediatric reference values for TAPSE have been established [13], and decreased TAPSE has been demonstrated in a few congenital heart disease states with two normally developed ventricles [14]. In addition, decreased TAPSE in patients with systemic RVs after atrial redirection procedures for transposition of the great arteries has been described [7, 8]. However there are limited reports of TAPSE in patients with single, systemic RVs [9, 21], for whom a refined, noninvasive assessment of RV function on transthoracic echocardiogram (TTE) is of fundamental importance.

Cardiac magnetic resonance (CMR), the gold standard imaging test for quantitative assessment of RV systolic performance, has been increasingly used to assess RV ejection fraction (RVEF) in HLHS patients after Fontan. However, TTE is largely used in the routine assessment of RV function after staged palliation. Both TTE–TAPSE [10, 15, 16] and CMR–TAPSE [3, 19, 20, 28] are associated with RVEF in some populations with acquired and congenital heart disease.

To our knowledge, no studies have explored the relationship between TAPSE and RVEF in patients with HLHS after Fontan palliation. Therefore, this study aimed to determine the reliability of TAPSE measurements on TTE and CMR, to compare the TAPSE values obtained by those two methods, and to determine the association of TAPSE with other CMR-derived measures of RV function in patients with HLHS after Fontan palliation.

Materials and Methods

Patient Population

Patients with HLHS after Fontan palliation who underwent CMR at The Children's Hospital of Philadelphia (CHOP) between 1 January 2010 and 1 August 2012 were retrospectively reviewed. Patients were excluded from the study if their CMR lacked a four-chamber cine (to measure CMR–TAPSE) or a complete stack of short-axis cines (to measure RVEF). Patients also were excluded if they underwent tricuspid valvuloplasty or tricuspid valve replacement at any stage of palliation.

To minimize the possibility of time-related hemodynamic changes, cases were cross-referenced with the TTE database to identify those with available TTEs within 6 months of CMR. The electronic medical record was reviewed for demographic information and clinical variables of interest. This study was approved by the CHOP Institutional Review Board for human research.

TTE Protocol

The echocardiograms were performed on a Phillips IE33 machine (Phillips, Andover, MA, USA). The images were acquired using CHOP's standard imaging protocol. We used 5- or 8-MHz transducers according to the patient's size and acoustic windows.

Although TAPSE was originally described as two-dimensional displacement of the tricuspid annulus, it currently is more commonly measured using M-mode echocardiography, with the cursor placed through the tricuspid annulus to measure the amount of longitudinal motion of the annulus at peak systole [12, 13, 17]. Because M-mode was not available in this study population, we performed offline TAPSE measurements using two-dimensional apical views. We identified the lateral annulus of the tricuspid valve and measured the distance to the apex of the screen sector at end-diastole and end-systole. We then calculated TAPSE as the difference in distance from end-diastole to end-systole.

Electrocardiography was used to determine the phase of the cardiac cycle accurately. This technique was shown to be similar to measurement of the distance by M-mode [18]. Three TTE–TAPSE measurements were averaged for each patient. The TTE–TAPSE values were converted to z-scores using published reference data [13].

CMR Protocol

In this study, CMR studies were performed on a 1.5T Avanto Magnetic Resonance Imaging scanner (Siemens Medical Solutions, Erlangen, Germany) with a six-channel phased-array body coil using a standard imaging protocol. Sedation was used when appropriate according to patient age and ability to lie still for the scan.

The CMR protocol included a contiguous, axial stack of steady-state free-precession images followed by cine steady-state free-precession images in the four-chamber view and a complete stack of short-axis cines. The CMR–TAPSE was measured from the four-chamber cine sequence as the maximum apical displacement of the lateral tricuspid valve annulus from end-diastole to endsystole.

The RV end-diastolic and end-systolic volumes were measured from the short-axis stack of cine images and indexed to body surface area. The RV stroke volume was calculated by subtracting the end-systolic volume from the end-diastolic volume. The RV stroke volume then was divided by the RV end-diastolic volume to derive RVEF, defined as abnormal if it was lower than 50 % [24, 25].

Inter- and Intraobserver Variability

In this study, 10 randomly selected nonstudy patients were chosen for TAPSE “training.” Interobserver variability was assessed for both TTE and CMR–TAPSE in these nonstudy patients by two well-trained observers using repeated measurements. The two observers had different levels of training in TTE and CMR. For TTE–TAPSE, observer 1 was a pediatric cardiology fellow (C.A.), and observer 2 was a pediatric echocardiography attending (L.M.-R.). For CMR–TAPSE, observer 1 was the same pediatric cardiology fellow, and observer 2 was a pediatric CMR attending (K.K.W.). The observers were blinded to the measurements of each other and to clinical information.

Intraobserver variability for TTE–TAPSE was assessed by repeating measurements in the same 10 nonstudy patients 3 weeks after the first measurement. Intraobserver variability for CMR–TAPSE was assessed by repeating the 30 CMR measurements 3 months after the first measurement.

Statistical Analysis

Continuous variables were reported as mean $\pm$ standard deviation or as median (interquartile range) as appropriate for the distribution. Categorical variables were expressed as frequencies. Differences in continuous variables were detected by two-tailed, unpaired Student’s *t* tests. The associations between TAPSE and CMR-derived measures of RV function or other pertinent covariates were determined with Pearson’s correlation coefficients. Multivariable linear regression was used to assess the association of TAPSE (independent variable) with CMR, TTE, and clinical parameters of interest (dependent variables).

The reliability of TTE- and CMR–TAPSE was assessed using intraclass correlation coefficient estimates. Intertechnique agreement of TTE and CMR was assessed with Bland–Altman analysis. All data analyses were performed using Stata version 11.2 (StataCorp LP, College Station, TX, USA). Statistical significance was defined as a *p* value lower than 0.05.

Results

During this study, 29 patients (67 % male, 87 % Caucasian) met the inclusion criteria and underwent 30 CMRs. The age at CMR was 14.1 ± 7.1 years, performed 11.9 ± 7.8 years

after Fontan. Other patient characteristics are described in Table 1. The CMRs and TTEs were performed 2.3 ± 1.7 months apart.

Separate from the 29 included patients, 10 additional HLHS patients with Fontan circulation underwent CMR and TTE during the study period. These 10 patients were excluded from the study due to insufficient CMR images ($n = 8$) or a history of tricuspid valve intervention ($n = 2$). The included and excluded patients did not differ in terms of, race, anatomic subtype, distribution of sex, Fontan type, fenestration status, or age at Fontan. The excluded patients were younger (6.9 ± 3.2 years) than the included patients ($p = 0.004$), with fewer years since Fontan (4.3 ± 4.1 years; $p = 0.005$). However, 6 of the 10 excluded patients underwent CMR as part of a research protocol that did not include the full short-axis volume set necessary for calculation of RVEF. The study recruited younger patients, earlier in the course of staged palliation.

The intraclass correlation coefficients (ICC) for interand intraobserver variability were respectively 0.89 (95 % CI 0.74–1.00) and 0.91 (95 % CI 0.84–0.97) for CMR–TAPSE and 0.94 (95 % CI 0.88–1.00) and 0.99 (95 % CI 0.98–1.00) for TTE–TAPSE (Table 2). The CMR–TAPSE measurement was slightly lower than the TTE–TAPSE measurement (0.57 ± 0.2 vs. 0.70 ± 0.2 cm, respectively) (Table 3). The two measurements were moderately correlated ($R = 0.46$; $p = 0.01$). The mean difference in TAPSE between CMR and TTE was -0.13 cm (95 % CI -0.21 to -0.05), with 95 % limits of agreement of -0.5 to 0.28 (Fig. 1).

On TTE, the TAPSE z -scores were decreased in all the study subjects (z score -8.7 ± 1.0 ; range -10 to -5.7). On CMR, RV function was preserved overall with an RVEF of $55 \% \pm 13 \%$. However 27 % of the patients ($n = 8$) had an RVEF lower than 50 %.

Tricuspid regurgitation was assessed in 15 subjects (50 %), 4 of whom had more than mild regurgitation (regurgitant fraction $>20 \%$) (Table 2). One patient had a tricuspid regurgitant fraction of 97 % and severely diminished RV function (RVEF 27 %) in the setting of tricuspid valve dysplasia. Tricuspid regurgitation was not associated with RVEF in the group overall ($p = 0.16$).

No association between TTE–TAPSE and RVEF ($p = 0.83$) or between TTE–TAPSE z -score and RVEF ($p = 0.83$) was observed. In addition, no differences in TTE–TAPSE z -score, TTE–TAPSE, or CMR–TAPSE were found between the patients with normal and those with abnormal RV function measured by CMR ($p = 0.46$, 0.56 , and 0.66 , respectively). The findings showed no association of CMR–TAPSE with the cardiac index ($R = 0.01$; $p = 0.95$) or the RVEF ($R = 0.08$; $p = 0.67$).

Discussion

This study demonstrated the reliability of TAPSE on TTE and CMR and compared the values obtained by the two methods in patients with HLHS after Fontan palliation. We have shown that TAPSE measurements are reproducible on TTE and CMR. Inter- and intraobserver variability is low, and measurement consistency is comparable with or exceeds that reported in other studies [3, 20, 28]. Some of the interobserver variability may be explained by observer experience, similar to the findings of Caudron et al. [3]. However, the

intraobserver agreement is excellent and therefore not affected by observer experience. We found good agreement between the two imaging methods, similar to the published comparisons of TTE- and CMR-TAPSE [19, 28].

We demonstrated severely diminished TAPSE values in patients with HLHS after Fontan compared with established reference values [13]. A mean TTE-TAPSE z -score of -8.7 reflected marked differences in tricuspid valve systolic excursion between the Fontan patients and the healthy children and adolescents. The average TAPSE values of 0.5 – 0.7 cm in this population were less than the neonatal reference mean of 0.91 cm (z -score ± 3 ; range 0.56 – 1.26 cm) [13].

Our findings are comparable with those reported in limited studies investigating TAPSE in single-ventricle patients. Kasnar-Samprec et al. [9] demonstrated abnormally low TAPSE in patients with HLHS preceding the bidirectional superior cavopulmonary connection (stage 2 palliation). These authors reported median pre-stage 2 TAPSE values of about 60 % expected for patient age. Petko et al. [21] reported a mean TTE-TAPSE of 0.8 ± 0.2 cm for 20 patients (age 7.4 ± 2.6 years) with HLHS after Fontan. This is markedly less than the mean reference value of 1.94 cm (z -score ± 3 ; range 1.49 – 2.39 cm) for a healthy 7-year-old [13] and comparable with our findings in Fontan patients.

In our study population, no association between TAPSE and RVEF was found. This is in contrast to healthy adults and adults with acquired heart disease, whose TAPSE is an indicator of RV function and strongly correlated with RVEF [3, 20, 28]. In this small population of patients with systemic RVs after Fontan, TAPSE is markedly decreased, whereas RVEF is preserved overall (55 ± 13 %). Additionally, the TAPSE z -score distribution shows little variability, with abnormal values seen uniformly across the entire cohort. No difference in TAPSE exists between the patients with normal and those with abnormal RVEF. In this study, TAPSE was not a good discriminator for abnormal global RV function.

Preserved RVEF despite diminished longitudinal shortening suggests that global function of the systemic RV may be more dependent on radial or circumferential contraction. Studies of HLHS patients at other stages of palliation support the notion that the systemic RV adopts a circumferential contraction pattern, similar to the systemic left ventricle [11, 22]. Similarly, patients with d-transposition of the great arteries and systemic RVs after atrial redirection procedures (Mustard/Senning operations) also demonstrate a predominance of circumferential strain over longitudinal strain on speckle-tracking echocardiography of the RV [1, 7, 8, 23]. Values of TAPSE are diminished in this population as well and correlate poorly with RVEF [4, 8].

The aforementioned studies complement our findings that TAPSE may not be a useful assessment of global ventricular function in populations with systemic RVs because systemic RV shortening may be quite different from that of the subpulmonary RV. Future studies may investigate the correlation between TAPSE and RV strain in patients with systemic RVs after Fontan or atrial redirection procedures.

Study Limitations

This study was limited by its retrospective, cross-sectional design. Some potential subjects were excluded from the study due to lack of existing images from which to measure TAPSE or RVEF. We measured TTE–TAPSE “offline” from the apical four-chamber two-dimensional view because M-mode TAPSE was not yet part of our laboratory’s standard echocardiography protocol when the images were obtained. However, as we have previously shown, the TAPSE values obtained by the two TTE methods show minimal difference [18]. Given the cross-sectional design of the study, it is unknown whether TAPSE changes with the stages of single-ventricle palliation and whether decreased TAPSE has prognostic implications. Finally, our small sample size prevented analysis of the data according to anatomic subtype or surgical history. Differences in TAPSE among subtypes of HLHS due to right ventricle–left ventricle interaction may exist in patients with a more substantial left-ventricle cavity.

In summary, in patients with HLHS after Fontan, TAPSE is reproducible on TTE and CMR, with good agreement between the two methods. Diminished TAPSE values in this study population suggest impaired longitudinal shortening with a change in the contraction pattern of the systemic RV. Although TAPSE does not reflect global RV function after Fontan, it may have utility at other stages of single-ventricle palliation or in longitudinal Fontan patient follow-up assessment. Further studies are needed to investigate the use of TAPSE in patients with HLHS.

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References

1. Becker M, Humpel C, Ocklenburg C, Muehler E, Schroeder J, Eickholt C, Hoffmann R, Marx N, Franke A. The right ventricular response to high afterload: comparison between healthy persons and patients with transposition of the great arteries: a 2D strain study. *Echocardiography*. 2010; 27:1256–1262. [PubMed: 20618391]
2. Brown SB, Raina A, Katz D, Szerlip M, Wiegers SE, Forfia PR. Longitudinal shortening accounts for the majority of right ventricular contraction and improves after pulmonary vasodilator therapy in normal subjects and patients with pulmonary arterial hypertension. *Chest*. 2011; 140:27–33. [PubMed: 21106653]
3. Caudron J, Fares J, Vivier PH, Lefebvre V, Petitjean C, Dacher JN. Diagnostic accuracy and variability of three semi-quantitative methods for assessing right ventricular systolic function from cardiac MRI in patients with acquired heart disease. *Eur Radiol*. 2011; 21:2111–2120. [PubMed: 21614615]
4. De Caro E, Bondanza S, Calevo MG, Trocchio G, Lupi G, Domenicucci S, Marasini M. Tricuspid annular plane systolic excursion for the assessment of ventricular function in adults operated on with mustard procedure for complete transposition of the great arteries. *Congenit Heart Dis*. 2013 doi:10.1111/chd.12135.
5. Forfia PR, Fisher MR, Mathai SC, Houston-Harris T, Hemnes AR, Borlaug BA, Chamara E, Corretti MC, Champion HC, Abraham TP, Girgis RE, Hassoun PM. Tricuspid annular displacement predicts survival in pulmonary hypertension. *Am J Respir Crit Care Med*. 2006; 174:1034–1041. [PubMed: 16888289]
6. Hammarstrom E, Wranne B, Pinto FJ, Puryear J, Popp RL. Tricuspid annular motion. *J Am Soc Echocardiogr*. 1991; 4:131–139. [PubMed: 2036225]

7. Iriart X, Horovitz A, van Geldorp IE, Barnetche T, Lederlin M, De Guillebon M, Reant P, Lafitte S, Thambo JB. The role of echocardiography in the assessment of right ventricular systolic function in patients with transposition of the great arteries and atrial redirection. *Arch Cardiovasc Dis.* 2012; 105:432–441. [PubMed: 22958886]
8. Kalogeropoulos AP, Deka A, Border W, Pernetz MA, Georgiopoulou VV, Kiani J, McConnell M, Lerakis S, Butler J, Martin RP, Book WM. Right ventricular function with standard and speckle-tracking echocardiography and clinical events in adults with D-transposition of the great arteries post atrial switch. *J Am Soc Echocardiogr.* 2012; 25:304–312. [PubMed: 22196884]
9. Kasnar-Samprec J, Kuhn A, Horer J, Vogt M, Cleuziou J, Lange R, Schreiber C. Unloading of right ventricle by bidirectional superior cavopulmonary anastomosis in hypoplastic left heart syndrome patients promotes remodeling of systemic right ventricle but does not improve tricuspid regurgitation. *J Thorac Cardiovasc Surg.* 2012; 144:1102–1108. [PubMed: 22964357]
10. Kaul S, Tei C, Hopkins JM, Shah PM. Assessment of right ventricular function using two-dimensional echocardiography. *Am Heart J.* 1984; 107:526–531. [PubMed: 6695697]
11. Khoo NS, Smallhorn JF, Kaneko S, Myers K, Kutty S, Tham EB. Novel insights into RV adaptation and function in hypoplastic left heart syndrome between the first 2 stages of surgical palliation. *JACC Cardiovasc Imaging.* 2011; 4:128–137. [PubMed: 21329896]
12. Koestenberger M. Transthoracic echocardiography in children and young adults with congenital heart disease. *ISRN Pediatr.* 2012 doi:[10.5402/2012/753481](https://doi.org/10.5402/2012/753481).
13. Koestenberger M, Ravekes W, Everett AD, Stueger HP, Heinzl B, Gamillscheg A, Cvirm G, Boysen A, Fandl A, Nagel B. Right ventricular function in infants, children, and adolescents: reference values of the tricuspid annular plane systolic excursion (TAPSE) in 640 healthy patients and calculation of z-score values. *J Am Soc Echocardiogr.* 2009; 22:715–719. [PubMed: 19423286]
14. Koestenberger M, Nagel B, Ravekes W, Everett AD, Stueger HP, Heinzl B, Sorantin E, Cvirm G, Gamillscheg A. Tricuspid annular plane systolic excursion and right ventricular ejection fraction in pediatric and adolescent patients with tetralogy of Fallot, patients with atrial septal defect, and age-matched normal subjects. *Clin Res Cardiol.* 2011; 100:67–75. [PubMed: 20835905]
15. Koestenberger M, Nagel B, Ravekes W, Everett AD, Stueger HP, Heinzl B, Sorantin E, Cvirm G, Fritsch P, Gamillscheg A. Systolic right ventricular function in pediatric and adolescent patients with tetralogy of Fallot: echocardiography versus magnetic resonance imaging. *J Am Soc Echocardiogr.* 2011; 24:45–52. [PubMed: 21074365]
16. Koestenberger M, Nagel B, Avian A, Ravekes W, Sorantin E, Cvirm G, Beran E, Halb V, Gamillscheg A. Systolic right ventricular function in children and young adults with pulmonary artery hypertension secondary to congenital heart disease and tetralogy of Fallot: tricuspid annular plane systolic excursion (TAPSE) and magnetic resonance imaging data. *Congenit Heart Dis.* 2012; 7:250–258. [PubMed: 22494699]
17. Lopez L, Colan SD, Frommelt PC, Ensing GJ, Kendall K, Younoszai AK, Lai WW, Geva T. Recommendations for quantification methods during the performance of a pediatric echocardiogram: a report from the Pediatric Measurements Writing Group of the American Society of Echocardiography Pediatric and Congenital Heart Disease Council. *J Am Soc Echocardiogr.* 2010; 23:465–495. [PubMed: 20451803]
18. Mercer-Rosa L, Parnell A, Forfia PR, Yang W, Goldmuntz E, Kawut SM. Tricuspid annular plane systolic excursion in the assessment of right ventricular function in children and adolescents after repair of tetralogy of Fallot. *J Am Soc Echocardiogr.* 2013; 26:1322–1329. [PubMed: 23928091]
19. Morcos P, Vick GW III, Sahn DJ, Jerosch-Herold M, Shurman A, Sheehan FH. Correlation of right ventricular ejection fraction and tricuspid annular plane systolic excursion in tetralogy of Fallot by magnetic resonance imaging. *Int J Cardiovasc Imaging.* 2009; 25:263–270. [PubMed: 19048388]
20. Nijveldt R, Germans T, McCann GP, Beek AM, van Rossum AC. Semi-quantitative assessment of right ventricular function in comparison to a 3D volumetric approach: a cardiovascular magnetic resonance study. *Eur Radiol.* 2008; 18:2399–2405. [PubMed: 18523785]
21. Petko C, Moller P, Hoffmann U, Kramer HH, Uebing A. Comprehensive evaluation of right ventricular function in children with different anatomical subtypes of hypoplastic left heart syndrome after Fontan surgery. *Int J Cardiol.* 2011; 150:45–49. [PubMed: 20219256]

22. Petko C, Uebing A, Furck A, Rickers C, Scheewe J, Kramer HH. Changes of right ventricular function and longitudinal deformation in children with hypoplastic left heart syndrome before and after the Norwood operation. *J Am Soc Echocardiogr.* 2011; 24:1226–1232. [PubMed: 21962447]
23. Pettersen E, Helle-Valle T, Edvardsen T, Lindberg H, Smith HJ, Smevik B, Smiseth OA, Andersen K. Contraction pattern of the systemic right ventricle shift from longitudinal to circumferential shortening and absent global ventricular torsion. *J Am Coll Cardiol.* 2007; 49:2450–2456. [PubMed: 17599609]
24. Robbers-Visser D, Boersma E, Helbing WA. Normal biventricular function, volumes, and mass in children aged 8 to 17 years. *J Magn Reson Imaging.* 2009; 29:552–559. [PubMed: 19243036]
25. Sarikouch S, Peters B, Gutberlet M, Leismann B, Kelter-Kloepping A, Koerperich H, Kuehne T, Beerbaum P. Sex-specific pediatric percentiles for ventricular size and mass as reference values for cardiac MRI: assessment by steady-state free-precession and phase-contrast MRI flow. *Circ Cardiovasc Imaging.* 2010; 3:65–76. [PubMed: 19820203]
26. Saxena N, Rajagopalan N, Edelman K, Lopez-Candales A. Tricuspid annular systolic velocity: a useful measurement in determining right ventricular systolic function regardless of pulmonary artery pressures. *Echocardiography.* 2006; 23:750–755. [PubMed: 16999693]
27. Sheehan F, Redington A. The right ventricle: anatomy, physiology, and clinical imaging. *Heart.* 2008; 94:1510–1515. [PubMed: 18931164]
28. Speiser U, Hirschberger M, Pilz G, Heer T, Sievers B, Strasser RH, Schoen S. Tricuspid annular plane systolic excursion assessed using MRI for semi-quantification of right ventricular ejection fraction. *Br J Radiol.* 2012; 85:e716–e721. [PubMed: 22919018]

Fig. 1.

The mean difference in tricuspid annular plane systolic excursion (TAPSE) between cardiac magnetic resonance (CMR) and transthoracic echocardiogram (TTE) was -0.13 cm, with 95 % limits of agreement of -0.55 to $+0.29$ ($SD \pm 0.04$ cm; 95 % CI -0.05 to -0.21)

Table 1

Demographic characteristics of the study population

Characteristic	Result <i>n</i> (%)
Male	20 (67)
Caucasian	26 (87)
Age at CMR (years)	14.1 ± 7.1
Anatomy	
MA/AA	15 (50)
MS/AS	11 (37)
MS/AA	3 (10)
MA/AS	1 (3)
Age at Fontan (years)	2.2 ± 1.2
Type of Fontan	
Lateral tunnel	21 (72)
Extracardiac conduit	8 (28)
Fenestration	22 (76)
Time from Fontan (years)	11.9 ± 7.8
Interval between TTE and CMR (months)	2.3 ± 1.7

CMR cardiac magnetic resonance, MA mitral atresia, AA aortic atresia, MS mitral stenosis, AS aortic stenosis, TTE transthoracic echocardiogram

Table 2

Inter- and intraobserver variability for CMR- and TTE–TAPSE

	ICC (95 % CI)	
	Interobserver variability	Intraobserver variability
CMR–TAPSE	0.89 (0.74–1.00)	0.91 (0.84–0.97)
TTE–TAPSE	0.94 (0.88–1.00)	0.99 (0.98–1.00)

CMR cardiac magnetic resonance, TTE transthoracic echocardiogram, TAPSE tricuspid annular plane systolic excursion, ICC intraclass correlation coefficient, CI confidence interval

Table 3

CMR and TTE variables

CMR variable	Result	Indexed for BSA
CMR-TAPSE (cm)	0.57 ± 0.2	0.49 ± 0.2
RVEF (%)	55 ± 13	NA
RVEDV (ml)	116 ± 56	91 ± 29
RVESV (ml)	56 ± 41	44 ± 24
SV (ml)	60 ± 25	48 ± 14
CO (l/min)	4.8 ± 1.7	3.9 ± 1.2
RV mass (g) ($n = 27$)	118 ± 73	89 ± 32
Tricuspid RF: % (range) ($n = 15$)	12 (8;25; 4–97)	NA
Neo-aortic RF (%) ($n = 22$)	9.4 ± 10	NA
TTE variable		
TTE-TAPSE (cm)	0.70 ± 0.2	0.61 ± 0.3
TTE-TAPSE z-score	-8.7 ± 1.0 (range -10 to -5.7)	NA

CMR cardiac magnetic resonance, TTE trans-thoracic echocardiogram, BSA body surface area, TAPSE tricuspid annular plane systolic excursion, RVEF right ventricular ejection fraction, RVEDV RV end-diastolic volume, RVESV RV end-systolic volume, SV stroke volume, CO cardiac output, RF regurgitant fraction, NA not applicable