Reference Values and the Z-Score Values of Tricuspid Annular Plane Systolic Excursion in Chinese Children

Danlei Chen

Children's Hospital Attached to the Capital Institute of Pediatrics

Jinghui Guo

Children's Hospital Attached to the Capital Institute of Pediatrics

Bo Liu

Children's Hospital Attached to the Capital Institute of Pediatrics

Chunhua Zheng

Children's Hospital Attached to the Capital Institute of Pediatrics

Guimin Huang

Capital Institute of Pediatrics

Liyi Huang

Children's Hospital Attached to the Capital Institute of Pediatrics

Hui Zhang

Children's Hospital Attached to the Capital Institute of Pediatrics

Yi Luo

Children's Hospital Attached to the Capital Institute of Pediatrics

Dan Wei (✉ eyesweidan@163.com)

Children's Hospital attached to the Capital Institute of Pediatrics <https://orcid.org/0000-0002-9718-9027>

Research Article

Keywords: TAPSE, reference values, right ventricular systolic function, children

Posted Date: January 13th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1233810/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Objective To establish age-specific and body surface area (BSA)-specific reference values of Tricuspid Annular Plane Systolic Excursion (TAPSE) for children under 15 years old in China.

Study design A retrospective study was conducted in Children's Hospital Attached to the Capital Institute of Pediatrics. A total of 702 cases were included in this research to establish reference values of TAPSE. SPSS 25.0 (IBM) was used for data analysis. Lambda-mu-sigma method was used to calculate and construct the age-specific and BSA-specific percentiles and Z-score curves of TAPSE.

Results The mean value of TAPSE increased with age and BSA from 0 to 15 years in a nonlinear way and reached the adult level (17mm) until 1 year old. No difference could be observed in genders.

Conclusions TAPSE values increased with age and BSA in Chinese children aged between 0-15 years and there was no difference between boys and girls. A multi-center study from different parts of China is supposed to be conducted in the future to reflect the whole spectrum of TAPSE in Chinese children.

Introduction

The assessment of right ventricle (RV) systolic function is important in patients with congenital heart disease, especially during the perioperative period. However, in comparison to left ventricle, the structure of RV is more complex^[1], which hampering the development of non-invasive techniques evaluating RV function. More recently, researches on RV have been significantly improved both in quantity and quality with new techniques approach^[2-4]. Cardiac magnetic resonance (CMR) is known to be a gold standard for measurement of the ejection fraction (EF) as well as volume and the cardiac mass, especially for RV. Whereas, CMR is inferior to echocardiography no matter in facility, portability, costs or time consumption^[5, 6]. Among different parameters evaluating RV systolic function, TAPSE, which mainly represents the longitudinal RV contraction has been recommended for routinely clinical use in adults by the American Society of Echocardiography (ASE) since 2010^[7]. The guideline pointed out that TAPSE less than 16mm indicates decreased RV function. However, for children, it is improper to use one single cutoff value to evaluate RV function for children at different ages because of their developmental characteristics. Therefore, growth-related reference values of TAPSE are required for clinical use in children. Over the past 10 years, several centers from different countries have reported their reference values of TAPSE in children^[8-13]. To date, there are still no available reference values of TAPSE for Chinese children, so we conducted this study to determinate reference values of TAPSE in Chinese children aged 0-15 years.

Methods

Population

Of 877 medical records screened, a total of 702 children were finally selected for this study, including 393 males (56.0%) and 309 females (44.0%) respectively. All subjects were selected from those who had accepted echocardiography examinations in outpatient department from September 2020 to July 2021. Subjects were included if they were aged between 0 and 15 years and their echocardiography index except for TAPSE were normal. Patients who had hypertension, pulmonary hypertension, arrhythmia, Kawasaki disease and those who were diagnosed with chromosomal disease or receiving cardiac medication were excluded. Of the 877 medical records we screened, a total of 702 subjects met our study criteria at last.

Echocardiographic techniques

Patients were examined in a resting state with Philips IE 33 Doppler ultrasonocardiograph with a transducer of S5-1 and frequency of 1~5MHz. Uncooperative subjects aged between 3 months and 3 years old were allowed to use Chloral hydrate under the consent of the guardian. TAPSE was measured according to the 2010 ASE Guideline: Placing sampling point at the junction of the anterior tricuspid annulus and the RV free wall in the standard apical four-chamber view, the amount of longitudinal motion of the annulus at peak systole is the value of TAPSE^[7] (Fig 1).

Statistical analysis

SPSS 25.0 (IBM) was used for statistical analysis. Quantitative data were shown as median and IQR(25th and 75th percentile) or mean±SD (Standard Deviation) as appropriate, categorical data were shown as counts and percentages. BSA was calculated using the Stevenson formula^[14] ($BSA[m^2] = 0.0128 \times \text{weight}[kg] + 0.0016 \times \text{height}[cm] - 0.1529$). For continuous variables, the Unpaired t-test or Wilcoxon rank-sum test was used to test significance of differences. $P < 0.05$ was considered to be significant. Lambda-mu-sigma (LMS) method (LMS Chart Maker Pro Version 2.3, Medical Research Council, London, UK) was used to establish growth-related curves of TAPSE, mainly by converting the skewed distribution to normal using the maximum penalized likelihood method and adjusting curves of three parameters: median curve (M), coefficient of variation curve (S) and box Cox transformation power (L)^[15]. We optimized the M, S, L curves in order by increasing and/or decreasing the equivalent degrees of freedom (edf)

by 1 unit until the change in deviance is small— a change of less than 4 per unit change in edf is modest. Once a growth-related model has been fitted, the original data were presented as numerous spots in a Z Scores Graph, which could be used for excluding outliers. TAPSE that greater than +3SD or less than -3SD will be eliminated and rest of the data were used to conduct a new fitted model. Z values of TAPSE (y) are calculated from the L, M and S curves, using values appropriate for age or BSA, as the following two formulae layout:

$$Z = \frac{(y/M)^L - 1}{L \times S}, \text{ if } L \neq 0$$

$$Z = \frac{\log(y/M)}{S}, \text{ if } L = 0$$

Origin Pro 2019b was used to plot reference values curves of TAPSE across the age and BSA ranges.

Results

Subjects were separated into sixteen groups according to BSA and nineteen groups according to age. The age of the children was 62(23,96) months, with average height of 112(86,133) cm, weight of 19(12,30) kg, TAPSE of 19.3±3.9 mm, LVEDD of 33.6±7.2 mm, LVESD of 20.5±4.4 mm, LVEF of 69.4%±4.4%, LVFS of 38.1%±3.7%. There were no statistically significant differences between genders in these characteristics ($P>0.05$), seen in Table 1. We also found no significant differences on TAPSE values between boys and girls in different subgroups, seen in Table 2.

Data from 702 children were analyzed to draw age-related reference percentile as well as Z-score values and BSA-related reference percentile as well as Z-score values. Through 4 rounds of screening and LMS model fitting, we finally chose 0, 4, 4 and 1, 4, 4 as the best set of the edf of L, M and S for BSA and age in model fitting. The deviance in BSA was smaller than that in age(3282.8 vs.3305.6), which means the fit goodness in BSA is better than that in age. Table 3-4 respectively presented the Z-score and percentile reference values of TAPSE according to age and BSA. Overall, the mean value of TAPSE showed an increasing trend with both age and BSA. As was shown in Table 3, TAPSE increased from a mean value of 10.1mm in neonates to 22.7 mm in 15 years old children. Similarly, the mean value of TAPSE increased from 9.1mm ($BSA \leq 0.2m^2$) to 23.3mm ($BSA > 1.6m^2$), as was shown in Table 4. Fig. 2 respectively presents the smoothed LMS curves for mean, mean±1SD, mean±2SD, mean±3SD and the 3th percentile, 10th percentile, 25th percentile, 50th percentile, 75th percentile, 90th percentile, 97th percentile for TAPSE in different age and BSA groups. As was shown in Fig. 2, TAPSE increased rapidly with age in a nonlinear way and reached the adult level (17mm) until 1 year old, then increased slightly until 15 years old, both in Z-score curves as well as percentile curves. BSA-based growth curves of TAPSE showed similar trend both in Z-score curves and percentile curves.

Table 1
Anthropometric Characteristics of Population

	Total	Male	Female	P
	702	393 (56.0%)	309(44.0%)	
Age,month,median(IQR)	62(23,96)	58(21,96)	67(31,97)	0.263
Height,cm,median(IQR)	112(86,133)	110(86,134)	113 (85,133)	0.799
Weight,Kg,median(IQR)	19(12,30)	19(12,31)	19(12,29)	0.612
BSA,m ² ,median(IQR)	0.77(0.54,1.04)	0.76(0.52,1.06)	0.80(0.60,1.02)	0.719
TAPSE,mm,mean±SD	19.3±3.9	19.4±4.0	19.2±3.9	0.478
LVEDD,mm,mean±SD	33.6±7.2	33.8±7.6	33.2±6.8	0.271
LVESD,mm,mean±SD	20.5±4.4	20.7±4.6	20.3±4.1	0.224
LVEF,%,mean±SD	69.4±4.4	69.3±4.2	69.4±4.5	0.750
LVFS,%,mean±SD	38.1±3.7	38.0±3.5	38.1±3.9	0.727
BSA, body surface area; TAPSE, tricuspid annular plane systolic excursion; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction; LVFS, left ventricular fractional shortening.				

Table 2
Classification table for TAPSE values between genders

	Male			Female			<i>P</i>
	N	Mean	SD	N	Mean	SD	
BSA(m ²)							
≤0.20	10	9.4	1.8	8	8.9	1.6	0.529
0.20-0.30	17	11.4	1.9	14	11.3	1.7	0.914
0.30-0.40	21	15.6	1.7	20	15.7	1.9	0.926
0.40-0.50	46	17.0	1.8	23	16.7	1.7	0.504
0.50-0.60	36	17.6	2.3	14	17.8	2.3	0.812
0.60-0.70	40	19.8	2.2	39	18.8	2.1	0.047
0.70-0.80	48	20.3	1.9	39	19.9	1.9	0.339
0.80-0.90	31	21.1	2.5	34	20.6	2.4	0.346
0.90-1.00	27	20.8	2.3	31	21.2	2.7	0.563
1.00-1.10	31	21.6	2.2	34	21.5	2.9	0.826
1.10-1.20	22	21.7	2.1	17	22.1	2.7	0.612
1.20-1.30	10	21.7	2.8	10	20.8	2.2	0.430
1.30-1.40	9	23.6	3.2	11	22.0	2.8	0.261
1.40-1.50	19	23.1	3.9	5	22.5	2.4	0.760
1.50-1.60	9	21.9	2.6	6	22.7	5.1	0.700
>1.60	17	24.2	2.9	4	23.5	3.9	0.666
Age							
0-1m	21	10.1	1.7	15	9.7	1.9	0.484
1-3m	7	12.5	2.2	8	12.3	1.3	0.769
3-6m	9	15.7	0.7	13	15.3	1.8	0.578
6-9m	16	15.8	1.7	7	16.9	1.6	0.177
9-12m	19	17.0	1.7	8	16.5	1.9	0.502
1-2y	39	17.4	2.2	17	16.9	2.0	0.403
2-3y	38	18.8	2.5	16	18.0	1.6	0.264
3-4y	27	19.4	2.0	39	19.1	2.1	0.495
4-5y	27	20.9	2.0	17	19.9	2.7	0.174
5-6y	36	20.4	2.5	25	20.3	2.0	0.908
6-7y	29	21.6	2.3	33	21.2	2.4	0.535
7-8y	34	21.6	2.2	33	21.8	2.9	0.860
8-9y	13	21.5	2.4	26	20.6	2.4	0.309
9-10y	8	22.1	2.5	17	22.0	3.4	0.927
10-11y	19	22.2	3.2	9	20.1	2.3	0.086
11-12y	12	22.4	3.3	10	21.6	2.5	0.527
12-13y	15	24.3	2.0	5	25.1	2.5	0.469
13-14y	13	22.8	3.7	8	21.3	3.8	0.355

TAPSE, tricuspid annular plane systolic excursion; BSA, body surface area; SD, standard deviation.

	Male			Female			<i>P</i>
	N	Mean	SD	N	Mean	SD	
14-15y	11	21.6	3.5	3	21.3	2.1	0.894
TAPSE, tricuspid annular plane systolic excursion; BSA, body surface area; SD, standard deviation.							

Table 3
Reference values of TAPSE based on age

Age	N	L	S	-3SD	-2SD	-1SD	Mean	+1SD	+2SD	+3SD	Percentile						
											P3	P10	P25	P50	P75	P90	P97
0-1m	36	0.498	0.168	5.7	7.0	8.5	10.1	11.9	13.8	15.8	7.2	8.1	9.0	10.1	11.3	12.4	13.5
1-3m	15	0.498	0.144	7.6	9.1	10.7	12.4	14.3	16.2	18.3	9.3	10.2	11.2	12.4	13.6	14.8	16.0
3-6m	22	0.498	0.126	9.5	11.0	12.6	14.4	16.2	18.2	20.3	11.2	12.2	13.2	14.4	15.6	16.8	18.0
6-9m	23	0.498	0.116	10.8	12.3	14.0	15.8	17.7	19.6	21.7	12.5	13.5	14.6	15.8	17.0	18.2	19.4
9-12m	27	0.498	0.114	11.6	13.2	14.9	16.8	18.7	20.8	23.0	13.4	14.4	15.5	16.8	18.1	19.3	20.6
1-2y	56	0.498	0.114	12.2	13.9	15.7	17.7	19.7	21.9	24.2	14.1	15.2	16.3	17.7	19.0	20.3	21.6
2-3y	54	0.498	0.113	12.8	14.6	16.5	18.5	20.6	22.9	25.3	14.8	15.9	17.1	18.5	19.9	21.3	22.6
3-4y	66	0.498	0.112	13.3	15.2	17.2	19.3	21.5	23.9	26.3	15.4	16.6	17.8	19.3	20.8	22.2	23.6
4-5y	44	0.498	0.113	13.8	15.7	17.8	20.0	22.3	24.7	27.3	15.9	17.2	18.5	20.0	21.5	23.0	24.4
5-6y	61	0.498	0.115	14.1	16.1	18.2	20.5	22.9	25.5	28.2	16.3	17.6	19.0	20.5	22.1	23.7	25.2
6-7y	62	0.498	0.118	14.2	16.3	18.6	21.0	23.5	26.2	29.0	16.6	17.9	19.3	21.0	22.7	24.3	25.9
7-8y	67	0.498	0.121	14.3	16.5	18.8	21.3	24.0	26.8	29.8	16.7	18.1	19.6	21.3	23.1	24.7	26.4
8-9y	39	0.498	0.124	14.3	16.6	19.0	21.6	24.3	27.3	30.4	16.9	18.3	19.8	21.6	23.4	25.2	26.9
9-10y	25	0.498	0.127	14.3	16.6	19.1	21.8	24.7	27.7	30.9	16.9	18.4	20.0	21.8	23.7	25.5	27.3
10-11y	28	0.498	0.129	14.3	16.7	19.3	22.0	25.0	28.1	31.4	17.0	18.5	20.1	22.0	24.0	25.8	27.7
11-12y	22	0.498	0.131	14.3	16.8	19.4	22.2	25.2	28.4	31.8	17.1	18.6	20.3	22.2	24.2	26.1	28.0
12-13y	20	0.498	0.134	14.3	16.8	19.5	22.4	25.5	28.8	32.2	17.1	18.7	20.4	22.4	24.4	26.4	28.4
13-14y	21	0.498	0.136	14.3	16.8	19.6	22.5	25.7	29.0	32.6	17.1	18.8	20.5	22.5	24.6	26.6	28.6
14-15y	14	0.498	0.137	14.3	16.9	19.7	22.7	25.9	29.3	33.0	17.2	18.8	20.6	22.7	24.8	26.8	28.9
N, number; L, lambda; S, coefficient of variation; SD, standard deviation; TAPSE, tricuspid annular plane systolic excursion																	

Table 4
Reference values of TAPSE based on BSA

BSA(m ²)	N	L	S	-3SD	-2SD	-1SD	Mean	+1SD	+2SD	+3SD	Percentile						
											P3	P10	P25	P50	P75	P90	P97
≤0.20	18	1	0.178	4.2	5.9	7.5	9.1	10.7	12.4	14.0	6.1	7.0	8.0	9.1	10.2	11.2	12.2
0.20-0.30	31	1	0.153	6.5	8.4	10.2	12.1	13.9	15.8	17.6	8.6	9.7	10.8	12.1	13.3	14.4	15.6
0.30-0.40	41	1	0.130	9.0	11.0	12.9	14.8	16.8	18.7	20.6	11.2	12.3	13.5	14.8	16.1	17.3	18.5
0.40-0.50	69	1	0.117	10.9	12.9	14.8	16.8	18.7	20.7	22.6	13.1	14.3	15.5	16.8	18.1	19.3	20.4
0.50-0.60	50	1	0.112	12.1	14.1	16.1	18.2	20.2	22.2	24.2	14.3	15.6	16.8	18.2	19.5	20.8	22.0
0.60-0.70	79	1	0.109	13.0	15.1	17.2	19.3	21.4	23.5	25.6	15.3	16.6	17.8	19.3	20.7	21.9	23.2
0.70-0.80	87	1	0.109	13.5	15.7	17.9	20.1	22.3	24.5	26.7	16.0	17.3	18.6	20.1	21.6	22.9	24.2
0.80-0.90	65	1	0.112	13.8	16.1	18.4	20.7	23.0	25.3	27.7	16.4	17.8	19.2	20.7	22.3	23.7	25.1
0.90-1.00	58	1	0.115	13.9	16.3	18.7	21.2	23.6	26.0	28.5	16.6	18.1	19.5	21.2	22.8	24.3	25.8
1.00-1.10	65	1	0.118	13.9	16.5	19.0	21.5	24.1	26.6	29.2	16.8	18.3	19.8	21.5	23.3	24.8	26.3
1.10-1.20	39	1	0.121	13.9	16.6	19.2	21.8	24.5	27.1	29.8	16.9	18.5	20.1	21.8	23.6	25.2	26.8
1.20-1.30	20	1	0.124	13.9	16.7	19.4	22.1	24.9	27.6	30.4	17.0	18.6	20.3	22.1	24.0	25.6	27.3
1.30-1.40	20	1	0.127	13.9	16.7	19.6	22.4	25.3	28.1	31.0	17.1	18.8	20.5	22.4	24.4	26.1	27.8
1.40-1.50	24	1	0.130	13.8	16.8	19.8	22.7	25.7	28.7	31.6	17.2	18.9	20.7	22.7	24.7	26.5	28.3
1.50-1.60	15	1	0.134	13.8	16.9	20.0	23.0	26.1	29.2	32.3	17.2	19.1	21.0	23.0	25.1	27.0	28.8
>1.60	21	1	0.137	13.7	16.9	20.1	23.3	26.5	29.7	32.9	17.3	19.2	21.2	23.3	25.5	27.4	29.4
N, number; L, lambda; S, coefficient of variation; SD, standard deviation; TAPSE, tricuspid annular plane systolic excursion																	

Discussion

A deep understanding of RV function is helpful for improving the prognosis of patients with cardiovascular disease^[16–19]. Unfortunately, non-invasive techniques evaluating RV function remain hampered because of RV's complex structure. Unlike LV, RV consists of two layers of fibres that contribute to contraction. The superficial myocardial fibres which arranged in a circumferential direction and paralleled to the atrioventricular groove were thinner and mainly participate in the transverse contraction of RV. While the deep myocardial fibres which was longitudinally aligned from the apex to base was relatively thick and mainly engaged in the longitudinal contraction of RV^[20]. In general, RV longitudinal contraction accounts for 80% of RV systolic function^[21, 22].

Assessment of RV systolic function is of great importance in clinical. The current methods for the assessment of RV contraction include CMR, 2-dimensional and 3-dimensional echocardiography. Typically, CMR is regarded as a gold standard to evaluate RV geometry and function, whereas the use of CMR is limited due to its high cost as well as time consumption and for patients who had implantable devices cannot be used, too^[5, 6]. New technique such as 3-dimension echocardiography allows comprehensive and quantitative assessment of RV geometry and function, but this method requires special echocardiography training and is also time-consuming^[23].

TAPSE, which is a simple and reusable indicator to assess RV systolic function by longitudinal displacement of the anterior tricuspid annulus, was first validated by Kaul in 1984^[24] and has been considered to represent RV contraction for years^[25]. It was recommended to be used routinely to estimate RV systolic function in adults with a lower limit (16mm) of reference values for impaired RV systolic function by ASE 2010 Guideline^[7]. In

2015, ASE changed the cutoff value from 16mm to 17mm, which means the TAPSE values less than 17mm represents impaired RV systolic function^[26]. Both these two guidelines are recommendations for adults, whereas there is no guideline or expert consensus that recommends TAPSE reference values for children. So far, there are only several studies from abroad determined reference values of TAPSE for children. Koestenberger from Austria first reported the reference values and Z-scores of TAPSE in children in 2009^[11], then several studies from other countries such as Spain, Turkey, Japan and sub-Saharan Africa determined reference values of TAPSE in children except China^[8, 11–13, 27]. As has been reported by Fahrettin Uysal^[8], the mean TAPSE value of Turkish children in 6-12 months age group is only 13.46 mm while it is 15.17 mm in Spanish children at the same age group^[13]; in Japan, the mean TAPSE value of the 6-12 months children is 16.9 mm^[12], which is much higher than both of the former two countries. As stated above, TAPSE values in children was different among various countries. Up to now, reference values of TAPSE in Chinese children has not been reported yet. Therefore, our study was undertaken to attain growth-related reference values of TAPSE in Chinese Children. We found that TAPSE increased with age and BSA in Chinese children under 15 years old, which is consistent with previous studies from different countries. However, when we compared our specific growth-related reference values of TAPSE with other studies, we found significant differences among these different countries. In our study, we found that the mean TAPSE values in Chinese children reached the adult level (17.0mm) in 1 year old, which grew faster than that of Turkish as well as Spanish children; while in Japan, TAPSE showed the most proximal reference values with Chinese children, as has been mentioned before. All of these differences might be explained by genetic diversity, economic status and diet habits^[8, 12].

This finding is meaningful for Chinese children, especially for those with cardiopulmonary diseases, as RV function could be affected by different disease states such as acute respiratory distress syndrome (ARDS) as well as post-operation period in congenital heart diseases and different treatment. For instance, RV systolic function influences strategies to adjust positive end-expiratory pressure (PEEP) in patients with ARDS^[28]; procedures involving tricuspid valvuloplasty^[29] and cardiopulmonary bypass (CPB) with pericardial incision^[20] were shown to have adverse effects on RV systolic function. Therefore, applying improper reference values of TAPSE can lead to the misjudgment of RV systolic function, which may interfere the decision-making in treatment. Accordingly, TAPSE values between different countries must be well-realized and each country must have its own reference values of TAPSE to evaluate RV systolic function.

In conclusion, we established the growth-related normal ranges of TAPSE for children aged between 0-15 years in China. We found that TAPSE showed different reference values among different countries and increased with age and BSA without gender difference. Besides, the mean value of TAPSE remains a lower level than adult (17mm) until 1 year old in China. We hope these reference values could be used for assessing RV systolic function for Chinese children. However, there are two limitations in our present study. First, children aged between 16-18 are scarce in children's hospital, therefore, in this study, we included children aged 0-15 year old instead of 0-18 year old. Second, this was a single-center study and we think multi-center study from different area of China is supposed to be performed in the future to reflect the whole spectrum of TAPSE in Chinese children.

Declarations

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interests The authors have no relevant financial interests to disclose.

Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Danlei Chen, Jinghui Guo, Bo Liu, Chunhua Zheng, Guimin Huang, Liyi Huang, Hui Zhang, Yi Luo, Dan Wei. The first draft of the manuscript was written by Danlei Chen and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval This retrospective study was approved by the Institutional Review Board of the Capital Institute of Pediatrics. (SHERLLM2021035)

References

1. Torrent-Guasp F, Buckberg GD, Clemente C, Cox JL, Coghlan HC, Gharib M (2001) The structure and function of the helical heart and its buttress wrapping. VII. Critical importance of septum for right ventricular function. *Semin Thorac Cardiovasc Surg* 13:301–319. <https://doi.org/10.1053/stcs.2001.29961>
2. Mehra MR, Park MH, Landzberg MJ, Lala A, Waxman AB (2014) Right heart failure: Toward a common language. *J Heart Lung Transplant* 33:123–126. <https://doi.org/10.1016/j.healun.2013.10.015>
3. Ivy D (2020) The failing right ventricle: Where do we go from here. *Acta Physiol* 229:e13523. <https://doi.org/10.1111/apha.13523>
4. Galli E, Le Rolle V, Smiseth OA, Aalen J, Sade EL, Hernandez A et al Importance of systematic right ventricular assessment in patients undergoing cardiac resynchronization therapy: A machine-learning approach (2021) *J Am Soc Echocardiogr*.13:59–60. <https://doi.org/10.1016/j.echo.2020.12.025>
5. Arnold JR, McCann GP (2020) Cardiovascular magnetic resonance: Applications and practical considerations for the general cardiologist. *Heart* 106:174–181. <https://doi.org/10.1136/heartjnl-2019-314856>

6. Mauger C, Gilbert K, Lee AM, Sanghvi MM, Aung N, Fung K et al (2019) Right ventricular shape and function: Cardiovascular magnetic resonance reference morphology and biventricular risk factor morphometrics in UK Biobank. *J Cardiovasc Magn Reson* 21:41. <https://doi.org/10.1186/s12968-019-0551-6>
7. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K et al (2010) Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *J Am Soc Echocardiogr* 23:685–713. <https://doi.org/10.1016/j.echo.2010.05.010>
8. Uysal F, Bostan ÖM, Çil E (2016) Determination of reference values for tricuspid annular plane systolic excursion in healthy Turkish children *Anatol J Cardiol.* 16:354–359. <https://doi.org/10.5152/akd.2015.6227>
9. Keskin M, Kaya Ö, Yoldaş T, Karademir S, Örün UA, Özgür S et al (2020) Tricuspid annular plane systolic excursion and mitral annular plane systolic excursion cardiac reference values in 1300 healthy children: Single-center results. *Echocardiography* 37:1251–1257. <https://doi.org/10.1111/echo.14793>
10. Kurath-Koller S, Avian A, Cantinotti M, Burmas A, Grangl G, Schweintzger S et al Normal Pediatric Values of the Subcostal Tricuspid Annular Plane Systolic Excursion (S-TAPSE) and Its Value in Pediatric Pulmonary Hypertension (2019)*Can J Cardiol.*35:899–906. <https://doi.org/10.1016/j.cjca.2019.01.019>
11. Koestenberger M, Ravekes W, Everett AD, Stueger HP, Heinzl B, Gamillscheg A et al 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 (2009)*J Am Soc Echocardiogr.*22:715–719. <https://doi.org/10.1016/j.echo.2009.03.026>
12. Hashimoto I, Watanabe K, Kaneda H (2015) Z-values of tricuspid annular plane systolic excursion in Japanese children. *Pediatr Int* 57:199–204. <https://doi.org/10.1111/ped.12491>
13. úñez-Gil IJ, Rubio MD, Cartón AJ, López-Romero P, Deiros L, García-Guereta L et al (2011) Determination of Normalized Values of the Tricuspid Annular Plane Systolic Excursion (TAPSE) in 405 Spanish Children and Adolescents. *Rev Esp Cardiol* 64:674–680. <https://doi.org/10.1016/j.recesp.2011.04.006>
14. Stevenson PH Height-weight-surface formula for the estimation of surface area in Chinese subjects (1937)*Chin J Physiol.* 3:327–330
15. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH (2000) Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ* 320:1240–1243. <https://doi.org/10.1136/bmj.320.7244.1240>
16. Wu VC, Takeuchi M (2018) *Cardiovasc Diagn Ther* 8:70–79. <https://doi.org/10.21037/cdt.2017.06.05>. Echocardiographic assessment of right ventricular systolic function
17. Nguyen T, Cao L, Movahed A (2014) Altered Right Ventricular Contractile Pattern after Cardiac Surgery: Monitoring of Septal Function Is Essential. *Echocardiography* 31:1159–1165. <https://doi.org/10.1111/echo.12657>
18. Chen J, Xie L, Dai L, Yu L, Liu L, Zhou Y et al Right Heart Function of Fetuses and Infants with Large Ventricular Septal Defect: A Longitudinal Case–Control Study (2016)*Pediatr Cardiol.* 37:1488–1497. <https://doi.org/10.1007/s00246-016-1462-z>
19. Singh A, Huang X, Dai L, Wyler D, Alfirevic A, Blackstone EH et al (2020) Right ventricular function is reduced during cardiac surgery independent of procedural characteristics, preoperative status, or pericardiectomy. *J Thorac Cardiovasc Surg* 159:1430–1438e4. <https://doi.org/10.1016/j.jtcvs.2019.04.035>
20. Ho SY, Nihoyannopoulos P (2006) Anatomy, echocardiography, and normal right ventricular dimensions. *Heart* 92:2–13. <https://doi.org/10.1136/hrt.2005.077875>
21. Hashimoto I, Watanabe K (2016) *Echocardiography* 33:299–306. <https://doi.org/10.1111/echo.13039>. Geometry-Related Right Ventricular Systolic Function Assessed by Longitudinal and Radial Right Ventricular Contractions
22. Buckberg G, Hoffman JIE (2014) Right ventricular architecture responsible for mechanical performance: Unifying role of ventricular septum. *J Thorac Cardiovasc Surg* 148:3166–3171. <https://doi.org/10.1016/j.jtcvs.2014.05.044>
23. Dutta T, Aronow WS Echocardiographic evaluation of the right ventricle: Clinical implications (2017)*Clin Cardiol.* 40:542–548. <https://doi.org/10.1002/clc.22694>
24. Kaul S, Tei C, Hopkins JM, Shah PM (1984) Assessment of right ventricular function using two-dimensional echocardiography. *Am Heart J* 107:526–531. [https://doi.org/10.1016/0002-8703\(84\)90095-4](https://doi.org/10.1016/0002-8703(84)90095-4)
25. Gupta S, Khan F, Shapiro M, Weeks SG, Litwin SE, Michaels AD The associations between tricuspid annular plane systolic excursion (TAPSE), ventricular dyssynchrony, and ventricular interaction in heart failure patients (2008)*Eur J Echocardiogr.*9:766–771. <https://doi.org/10.1093/ejechocard/jen147>
26. Lang RM, Badano LP, Victor MA, Afilalo J, Armstrong A, Ernande L et al (2015) Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr* 28:1–39.. e14. <https://doi.org/10.1016/j.echo.2014.10.003>
27. Majonga ED, Rehman AM, McHugh G, Mujuru HA, Nathoo K, Patel MS et al (2017) Echocardiographic reference ranges in older children and adolescents in sub-Saharan Africa. *Int J Cardiol* 248:409–413. <https://doi.org/10.1016/j.ijcard.2017.06.109>

28. Wadia SK, Shah TG, Hedstrom G, Kovach JA, Tandon R Early detection of right ventricular dysfunction using transthoracic echocardiography in ARDS: a more objective approach (2016) *Echocardiography*. 33:1874–1879. <https://doi.org/10.1111/echo.13350>
29. Hashimoto I, Watanabe K Alternation of right ventricular contraction pattern in healthy children - Shift from radial to longitudinal direction at approximately 15 mm of tricuspid annular plane systolic excursion (2014) *Circ J*.78:1967–1973. <https://doi.org/10.1253/circj.cj-14-0083>

Figures

Figure 1

Measurement of TAPSE in M-mode echocardiography. A. TAPSE in apical four-chamber view, the M-mode sampling line was placed at the junction of anterior tricuspid annulus and RV free wall at the end of RV diastole. B. M-mode tracing curve, the white arrow represents the upper and lower measure points. TAPSE, tricuspid annular plane systolic excursion; RV, right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium.

Figure 2

Reference values curves of TAPSE based on age and BSA cohort. **a.** Z-scores of TAPSE based on age. Red area, mean to mean-1SD or mean to mean+1SD; Yellow area, mean-1SD to mean-2SD or mean+1SD to mean+2SD; Green area, mean-2SD to mean-3SD or mean+2SD to mean+3SD; **b.** Z-scores of TAPSE based on BSA. Red area, mean to mean-1SD or mean to mean+1SD; Yellow area, mean-SD to mean-2SD or mean+SD to mean+2SD; Green area, mean-2SD to mean-3SD or mean+2SD to mean+3SD; **c.** Percentiles of TAPSE based on age. Red area, 25th to 50th or 50th to 75th; Yellow area, 10th to 25th or 75th to 90th; Green area, 3th to 10th or 90th to 97th; **d.** Percentiles of TAPSE based on BSA. Red area, 25th to 50th or 50th to 75th; Yellow area, 10th to 25th or 75th to 90th; Green area, 3th to 10th or 90th to 97th. TAPSE, tricuspid annular plane systolic excursion; BSA, body surface area; SD, standard deviation.