Iranian Heart Journal; 2022; 23 (2)

Original Article

Three-Dimensional Echocardiographic Evaluation of the Right Ventricle in Normal Egyptian Children

Sherif Lotfy Wahba[1*], MS; Azza Abdallah EL-Fiky[1], MD; Alaa Roshdy[1], MD; Dina Ezz EL-Din Omar[1], MD

ABSTRACT

Background: The right ventricle (RV) is a major determinant of clinical outcomes in different cardiopulmonary disorders. Quantification of the RV with 2D echocardiography is challenging because of its complex asymmetrical geometry.[1,2] Three-dimensional echocardiography is becoming more prevalent in children because of good acoustic windows and the noninvasive nature of the technique. Three-dimensional echocardiography allows the measurement of RV volumes, thereby overcoming the limitations of 2D echocardiography.[3]

Methods: A prospective observational cross-sectional study was performed on 450 normal Egyptian children randomly chosen including both sexes. The subjects were divided into 2 age groups. ECG-gated 2D and 3D transthoracic echocardiography was done to evaluate RV parameters.

Results: The feasibility of 3D echocardiography was 96%. Mean indexed RVEDV was 40.5±5.4 mL/m^2 in boys and 40.1±5.8 mL/m^2 in girls, mean indexed RVESV was 18.8±3.7 mL/m^2 in boys and 18.7±3.7 mL/m^2 in girls, mean indexed stroke volume was 21.6±3.1 mL/m^2 in boys and 21.3±3.6 mL/m^2 in girls, and mean RVEF was 53.7±5.1% in boys and 53.5±5.4% in girls. A significant negative correlation existed between 3DE RVEF and ESV. A strong positive correlation was observed between mean 3DE RVESV and mean 3DE RVEDV. Further, 2DE and 3DE RVESV and EDV mean indexed and absolute values showed significant differences. Additionally, 2DE and 3DE FAC mean values showed positive significant correlations, and 3DE FAC and RVEF showed modest positive correlations.

Conclusions: Three-dimensional echocardiography provides RV volume quantification and functional assessment without any geometric assumptions. Reference values and percentile curves were established for RV parameters by 3DE for the first time in the Egyptian children population. ***(Iranian Heart Journal 2022; 23(2): 42-52)***

KEYWORDS: Right ventricular volumes and functions, Normal reference values, Three-dimensional echocardiography

[1] Cardiology Department, Faculty of Medicine, Ain Shams University, Cairo, Egypt.

***Corresponding Author:** Sherif Lotfy Wahba, MS; Cardiology Department, Faculty of Medicine, Ain Shams University, Cairo, Egypt.
Email: sherifhindy@gmail.com **Tel:** +20-10-036-80-374

Received: July 25, 2021 **Accepted:** August 29, 2021

Right ventricular (RV) size and function have been found to be important predictors of cardiovascular morbidity and mortality, as well as perioperative and postoperative survival outcomes. Nonetheless, quantification of RV size and function with conventional echocardiography is challenging because of its complex asymmetrical geometry and lack of realistic geometric models for volume calculation.[1,2]
Three-dimensional echocardiography (3DE)-dedicated RV quantification software has been validated and has proven accuracy in measuring RV volumes and function when compared with cardiovascular magnetic resonance imaging (CMR), overcoming the limitations of conventional 2DE RV views.[4]
Further, 3DE has gained significance in the management of patients with congenital heart diseases, particularly with pre-surgical planning, guidance of catheter intervention, and functional assessment of the heart. Indeed, 3DE is increasingly used in children because of its good acoustic windows and noninvasive nature.[3]
The aim of this study was to establish normal reference values for RV assessment by 3DE in Egyptian children aged 6 to 12 years.

METHODS

The study protocol received approval from the Ethics Committee of Ain Shams University, Cairo, Egypt. A prospective observational cross-sectional study was conducted on 450 normal healthy Egyptian children including both males and females with an age range of 6 to 12 years. Subjects were randomly selected and referred to the echocardiography unit in the cardiology department between November 2019 and June 2021.
Subjects were excluded from the study if they were non-Egyptian, younger than 6 years, and older than 12 years. Also excluded were patients with any other comorbidities, patients with congenital heart diseases, patients with any type of arrhythmia, and patients with chest conditions. Subjects were assigned into 2 age groups: 6 to 10 years and 11 to 12 years.

Clinical History and Baseline Investigations

Meticulous history taking, full clinical examinations, and 12- lead echocardiography (ECG) were done. Height in centimeters and weight in kilograms were measured to estimate body surface area in square meters. Body surface area was calculated using the Haycock formula.

Transthoracic Echocardiography (TTE)

Standard 2D ECG-gated TTE was performed by a pediatric echocardiographer using a GE Vivid E95 echocardiography machine with an M4S matrix sector array probe with a frequency of 2.5 MHz (General Electric Vingmed Ultrasound, Horten, Norway).
Sequential analysis was conducted to determine the situs, atrioventricular and ventriculoarterial connections, relationships and abnormalities of the great vessels, ventricular dimensions and functions, states of cardiac valves, venous connections, and pulmonary artery pressure.[5] RV dimensions were measured in the apical 4-chamber view at the end of the diastole. According to the guidelines of the American Society of Echocardiography (ASE), the RV was measured in 3 dimensions: basal, mid-cavity, and longitudinal.[6]
In addition, 2DE RV systolic function was evaluated by more than 1 parameter. Fractional area change (FAC) was measured using the following equation:

$$FAC = \frac{\text{(End Diastolic area)} - \text{(End Systolic area)}}{\text{(End Diastolic area)}}.$$

The RV area measurement was done by tracing the compacted muscle blood–endocardial tissue border from the tricuspid annulus to the apex and back to the tricuspid annulus at end-diastole and end-systole.[6] Tricuspid annular plane systolic excursion (TAPSE) was measured in the apical 4-chamber view with the M-mode cursor placed through the lateral tricuspid annulus. Tricuspid annular total displacement (mm) was measured from the end-systole to the end-diastole.[6] Moreover, 2D RV ejection fraction (EF) was derived from RV end-diastolic volume (EDV) and RV end-systolic volume (ESV), automatically calculated by the software.[6]

Additionally, 2D RV volumes were measured via the area-length (A-L) method by tracing the endocardial tissue border from the tricuspid annulus to the apex and back to the tricuspid annulus in the end-systole and the end-diastole, with myocardial trabeculae and papillary muscles being included in the cavity.[6]

3D TTE: ECG-gated 3D TTE was performed using a dedicated wide-angle, broadband 4V (GE E95) matrix-array transducer to allow the full coverage of the entire RV by the pyramidal volume, with special attention to the outflow tract and the upper anterior wall.

Before the acquisition, images were optimized for the endocardial border visualization, modifying overall gain and adjusting time gain and compression. The images were digitally stored for offline analysis by the available software. The subjects were examined in the left lateral position. Data acquisition was performed during a short period of breath-holding to avoid respiratory artifacts, and real-time 3D echocardiography (RT3DE) full volumes were acquired from the apical RV-focused view.[7,8]

A semi-automated segmentation algorithm was used to measure RV cavity volume during the cardiac cycle. The algorithm was initialized with landmarks defined by the user. The landmarks located and scaled an initial 3D deformable model that represented the RV endocardium and the tricuspid valve plane and included the RV outflow tract. The algorithm computed the deformation of the 3D model by solving a state estimation problem, which combined the RV geometry, a motion model, tissue tracking, and edge-detection algorithms. The fully integrated 4D Auto RVQ workflow tool was used for the analysis and obtaining the results including RVEDV, RVESV, stroke volume (SV), 3D-estimated RV dimensions (basal, mid-cavity, and longitudinal), 3D-estimated TAPSE, 3D-estimated FAC, 3D RVEF, and the 3D model of the RV.[8,9]

The data were statistically analyzed using IBM SPSS Statistics, version 25 (IBM Corporation, Armonk, NY, US). Categorical variables were expressed as numbers and percentages and analyzed using the χ^2 test. Continuous variables were expressed as the mean ± the standard deviation (SD) and analyzed using the independent *t* test for variables that passed normality tests and the Mann–Whitney *U* test for those that did not pass normality. Correlations were analyzed using the Pearson correlation coefficient (*r*). A *P* value of less than 0.05 was considered statistically significant, and a *P* value of less than 0.0001 was considered highly significant.

RESULTS

Baseline Characteristics

The baseline demographic and clinical characteristics of the included subjects are shown in Table 1. The subjects were 229 females (52.6%) and 206 males (47.4%) with an age range of 6 to 12 years (mean age=9.4 y) (Table 2). The subjects were subdivided into 2 subgroups according to age. Group I encompassed subjects with an age range of 11 to 12 years, and Group II consisted of subjects with an age range of 6 to 10 years.

Normal references and percentile curves for 3DE parameters plotted against age for each sex are presented in Table 2 and Figure 1.

RVEDV had a mean value of 47.058±10.2523 mL in boys and 46.620±11.2085 mL in girls. RVESV had a mean value of 21.990±5.9338 mL in boys and 21.891±6.4435 mL in girls. Indexed RVEDV had a mean value of 40.529±5.4627 mL/m^2 in boys and 40.096±5.8437 mL/m^2 in girls, and indexed RVESV had a mean value of 18.859±3.7331 mL/m^2 in boys and 18.707±3.7036 mL/m^2 in girls. SV had a mean value of 25.097±5.3420 mL in boys and 24.795±5.8532 mL in girls, while indexed SV had a mean value of 21.607±3.1662 mL/m^2 in boys and 21.345±3.6066 mL/m^2 in girls. RVEF had a mean value of 53.743±5.1860% in boys and 53.524±5.4059% in girls. RVFAC had a mean value of 47.228±6.7594% in boys and 48.293±6.37% in girls. RV longitudinal dimension had a mean value of 60.102±5.2974 mm in boys and 60.581±5.4273 mm in girls. RV mid-cavity dimension had a mean value of 25.563±4.3922 mm in boys and 25.323±4.1253 mm in girls. RV basal dimension had a mean value of 29.223±3.9778 mm in boys and 29.07±4.0484 mm in girls. TAPSE had a mean value of 20.621±2.7377 mm in boys and 20.253±3.0112 mm in girls.

No statistically significant differences were found between boys and girls in any of the previous mentioned variables.

The RVEDV-indexed fifth percentile ranged from 31.0151 mL/m^2 to 32.5230 mL/m^2 and the 95th percentile ranged from 50.1677 mL/m^2 to 49.3512 mL/m^2 for boys. For girls, the fifth percentile ranged from 29.5020 mL/m^2 to 32.2844 mL/m^2 and the 95th percentile ranged from 45.5506 mL/m^2 to 50.7120 mL/m^2. The RVESV-indexed fifth percentile ranged from 11.3660 mL/m^2 to 13.8532 mL/m^2 and the 95th percentile ranged from 24.9686 mL/m^2 to 25.3104 mL/m^2 for boys. For girls, the fifth percentile ranged from 10.8899 mL/m^2 to 13.7793 mL/m^2 and the 95th percentile ranged from 23.4331 mL/m^2 to 25.7893 mL/m^2. The SV-indexed fifth percentile ranged from 15.9383 mL/m^2 to 16.9697 mL/m^2 and the 95th percentile ranged from 29.1416 mL/m^2 to 26.0509 mL/m^2 for boys. For girls, the fifth percentile ranged from 14.9331 mL/m^2 to 16.7279 mL/m^2 and the 95th percentile ranged from 26.5979 mL/m^2 to 26.8615 mL/m^2. The RVEF fifth percentile ranged from 44.7323% to 45.7537% and the 95th percentile ranged from 67.7785% to 60.3239% for boys. For girls, the fifth percentile ranged from 44.6859% to 44.7461% and the 95th percentile ranged from 66.2407% to 61.3302%.

Table 1: General characteristics of the studied subjects

Variables	Total (N=435)	Group I (n=177)	Group II (n=258)
Clinical characteristics			
Age, y	9.4 ± 2.1	11.6 ± 0.48	8 ±1.5
Male sex, n (%)	206 (47.4%)	84 (47.4%)	122 (47.3%)
Female sex, n (%)	229 (52.6%)	93 (52.6%)	136 (52.7%)
BSA, mL	1.15 ± 0.2	1.34 ± 0.1	1 ± 0.13
Height, cm	136.9 ± 11.4	147.5 ± 6.4	129.7 ± 7.9
Weight, kg	35.4 ± 9.9	44.4 ± 6.7	29.2 ± 6.3

BSA, Body surface area

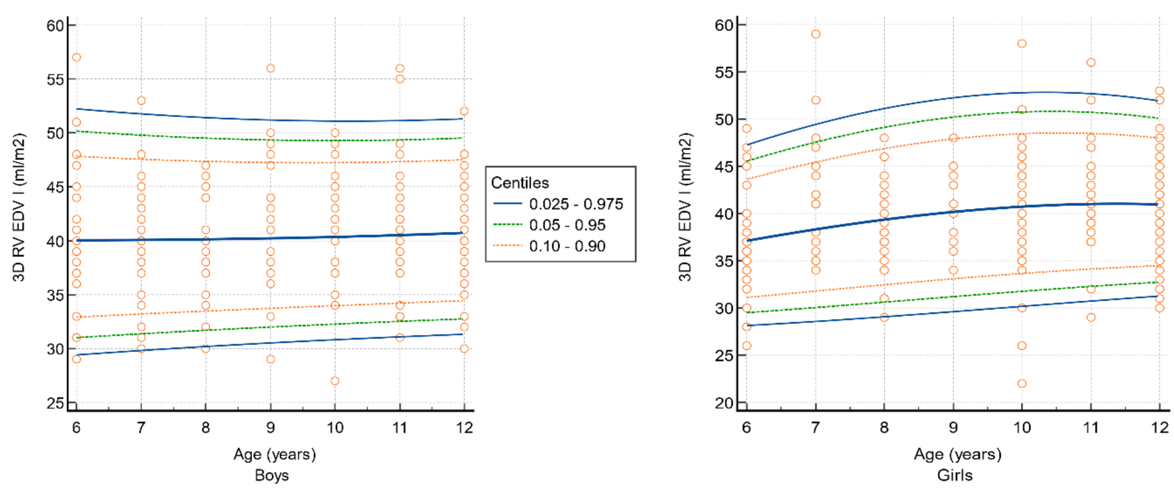
Table 2: Characteristics and 3DE RV parameters in the studied boys and girls

General	Group Type						Paired *t* Test	
	Boys (n=206)			Girls (n=229)			*t*	*P* value
Age, y	9.398	±	2.1338	9.550	±	2.1630	-0.737	0.4614
BSA, m^2	1.154	±	0.2026	1.153	±	0.2033	0.0496	0.9604
Height, cm	136.869	±	11.0792	137.087	±	11.7720	-0.199	0.8426
Weight, kg	35.631	±	10.0898	35.262	±	9.7648	0.387	0.6986
RV base d, mm	29.223	±	3.9778	29.070	±	4.0484	0.398	0.6909
RV mid-cavity d, mm	25.563	±	4.3922	25.323	±	4.1253	0.587	0.5572
RV longitudinal d, mm	60.102	±	5.2974	60.581	±	5.4273	-0.929	0.3533
RVEDV, mL	47.058	±	10.2523	46.620	±	11.2085	0.424	0.6719
RVEDV I, mL/m^2	40.529	±	5.4627	40.096	±	5.8437	0.796	0.4265
RVESV, mL	21.990	±	5.9338	21.891	±	6.4435	0.167	0.8676
RVESV I, mL/m^2	18.859	±	3.7331	18.707	±	3.7036	0.425	0.6709
RVEF, %	53.743	±	5.1860	53.524	±	5.4059	0.429	0.6678
RVSV, mL	25.097	±	5.3420	24.795	±	5.8532	0.561	0.5754
RVSV I, mL/m^2	21.607	±	3.1662	21.345	±	3.6066	0.801	0.4238
FAC %	47.228	±	6.7594	48.293	±	6.3700	-1.690	0.0917
TAPSE, mm	20.621	±	2.7377	20.253	±	3.0112	1.329	0.1847

BSA, Body surface area; RV base d, Right ventricular basal dimension; RV mid cavity d, Right ventricular mid-cavity dimension; RV longitudinal d, Right ventricular longitudinal dimension; RVEDV, Right ventricular end-diastolic volume, RVEDV I, Right ventricular end-diastolic volume indexed; RVESV, Right ventricular end-systolic volume; RVESV I, Right ventricular end-systolic volume indexed, RVEF, Right ventricular ejection fraction; RV SV, Right ventricular stroke volume; RV SV I, Right ventricular stroke volume indexed; RVFAC, Right ventricular fractional area change; TAPSE, Tricuspid annular plane systolic excursion

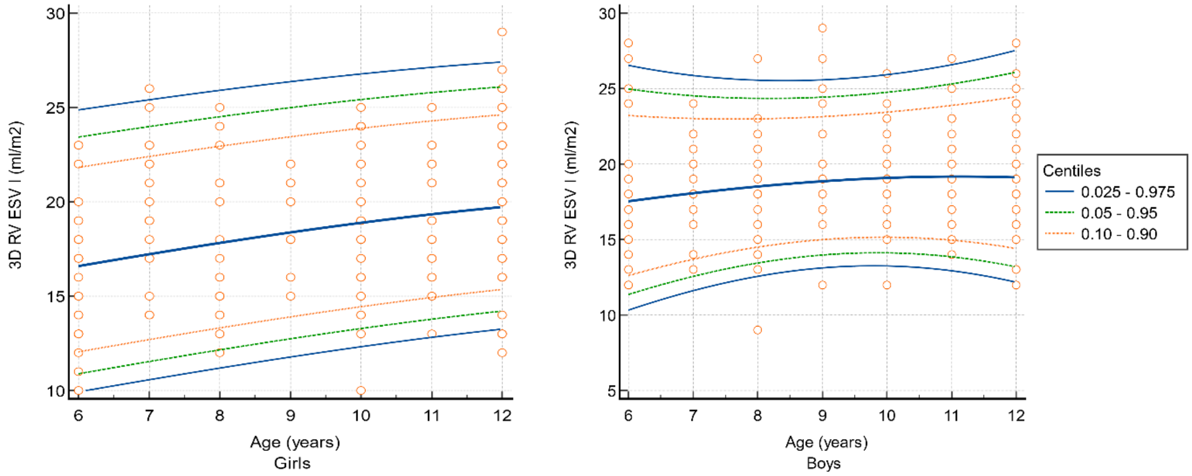
Figure 1: The image demonstrates percentile curves for 3DE-indexed RV volumes plotted to age for the studied boys and girls.

3DE, Three-dimensional echocardiography; RV, Right ventricle



A: The image depicts the 3DE-indexed RVEDV percentile curve plotted to age for the studied boys and girls.

3DE, Three-dimensional echocardiography; RVEDV, Right ventricular end-diastolic volume



B: The image illustrates the 3DE-indexed RVESV percentile curve plotted to age for the studied boys and girls.

3DE, Three-dimensional echocardiography; RVESV, Right ventricular end-systolic volume

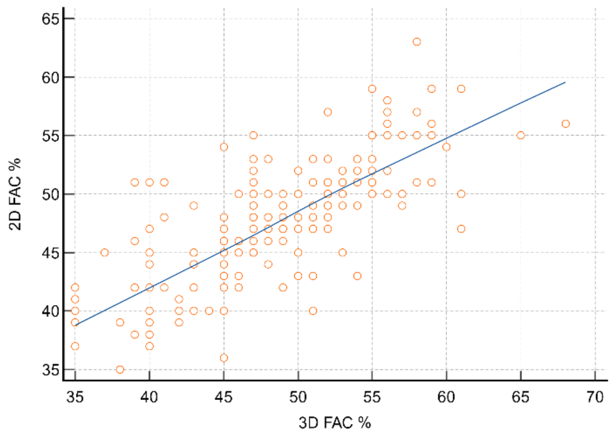


Figure 2: The image shows correlations between 2D RVFAC and 3D RVFAC in Group I.

RV, Right ventricle; FAC, Fractional area change

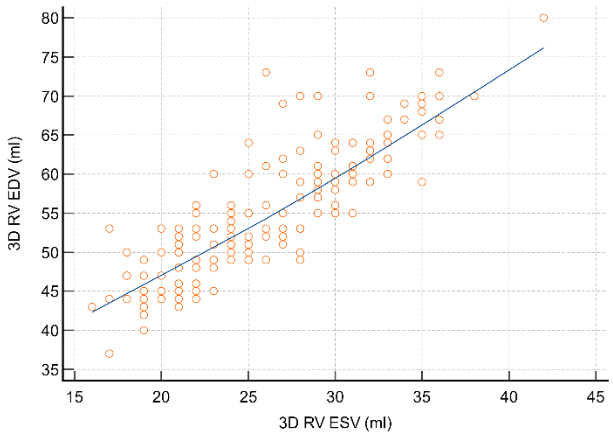


Figure 3: The image demonstrates correlations between 3D RVEDV and 3D RVESV in Group I.

RV, Right ventricle; EDV, End-diastolic volume; ESV, End-systolic volume

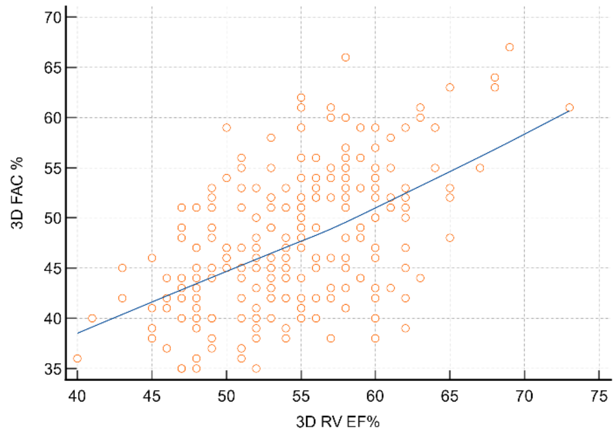


Figure 4: The image illustrates correlations between 3D FAC and 3D RVEF in Group II.

FAC, Fractional area change; RV, Right ventricle; EF, Ejection fraction

2DE and 3DE RV Assessments for Group I: According to our findings, 2DE and 3DE RV basal dimension values showed no significant difference (*P*=0.8858), while RV mid-cavity dimension values and RV longitudinal dimension values showed significant differences (*P*=0.0005 and *P*<0.0001, respectively). Moreover, 2DE and 3DE EDV, ESV, and SV absolute and indexed values showed significant differences (*P*<0.0001). Further, 2DE and 3DE RVEF and TAPSE showed significant differences (*P*<0.0001 and *P*=0.0003, respectively), while FAC showed no significant difference (*P*=0.1656).

In addition, 2DE and 3DE RVFAC showed strong positive correlations (*r*=0.729) (Fig. 2), and TAPSE showed modest positive correlations (*r*=0.540). The results also revealed that 3DE EDV and ESV had strong positive correlations (*r*=0.853) (Fig. 3), and 3DE RVEF and RVESV showed strong negative correlations (*r*= −0.731).

2DE and 3DE RV Assessments for Group II: The results demonstrated that 2DE and 3DE RV basal dimension values and RV longitudinal dimension values had significant differences (*P*<0.0001 for each), while RV mid-cavity dimension values had no significant differences (*P*=0.2083). Moreover, 2DE and 3DE EDV, ESV, and SV absolute and indexed values showed significant differences (*P*<0.0001). Based on the findings, 2DE and 3DE RVEF and TAPSE showed significant differences (*P*<0.0066 and *P*<0.0001, respectively), while FAC values showed no significant differences (*P*=0.0292).

Additionally, 2DE and 3DE RVFAC showed modest positive correlations (*r*=0.543), 3DE EDV and ESV exhibited strong positive correlations (*r*=0.892), 3DE RVEF and FAC showed modest positive correlations (*r*=0.526 (Fig. 4), and 3DE RVEF and RVESV demonstrated modest negative correlations (*r*= −0.635).

DISCUSSION

RV parameters are major determinants of clinical outcomes in a variety of diseases and should be taken into consideration during clinical management and treatment. Every echocardiographic study should include an assessment of the RV.[10]

The normal RV is a crescent-shaped structure that wraps around the left ventricle and is incompletely visible in any single 2DE view. For 2DE RV assessment, multiple echocardiographic views are required.[11] Therefore, quantifying RV size and function with conventional echocardiography is challenging, and direct RV volume calculation remains a challenge, despite the established 2DE quantitative methods. [7]

Notably, 3DE is currently gaining popularity as a more accurate and reproducible technique for RV evaluation. In comparison to CMR, it has shown good accuracy, thereby becoming more useful in treating patients with congenital heart diseases. Currently, 3DE is deemed a feasible, fast, and accurate technique for RV assessment in a variety of clinical situations with the availability of specially created software not requiring any prior modeling or geometric assumptions.[4]

The availability of reference values derived from a large population of healthy people is a major step toward incorporating 3DE into routine clinical practice, and the aim of this study was to establish normal reference values for RV assessment by 3DE in Egyptian children with an age range of 6 to 12 years.

Subjects included in the study were 450 healthy Egyptian children, and 435 subjects (96%) showed good feasibility in that they were adequately analyzed by the GE 4D Auto RVQ software.

According to a study done by De Potter et al[8] in 2021 comparing the feasibility of the GE 4D Auto RVQ software with CMR in RV assessment, the overall reproducibility of RV analysis using this software was comparable to that of other 3DE software and CMR. In addition, reproducibility was good in less experienced observers and was excellent between experienced observers.

The main target of this study was establishing normal reference values for 3DE-derived RVEDV, REESV, SV, RVEF, RVFAC, and RV linear dimensions. Percentile curves for 3DE-derived indexed volumes were plotted against age for each sex.

The feasibility of 3DE in our study was 96%, which is in agreement with a study done by Séguéla et al[12] in 2012 that also showed high feasibility of 3DE in children (94%). A study conducted by Karabiyik et al[14] in 2018 showed 90% feasibility for 3DE. The very good feasibility of RV volume measurements is probably due to the good echogenicity in children. Another study conducted by EL Shahid et al[13] in 2019 targeting Egyptian patients with pulmonary hypertension secondary to congenital heart diseases showed 98% feasibility, with only 1 patient not analyzed out of 50 patients because of the unsatisfactory echocardiographic window. The reason why some subjects were not analyzed was the inability to visualize the RV free wall.[14]

In our study by 3DE, the indexed RVEDV had a mean value of 40.529± 5.4627 mL/m^2 for boys and a mean value of 40.096±5.8437 mL/m^2 for girls. The indexed RVESV had a mean value of 18.859±3.7331 mL/m^2 for boys and a mean value of 18.707±3.7036 mL/m^2 for girls. The indexed SV had a mean value of 21.607±3.1662 mL/m^2 for boys and a mean value of 21.345± 3.6066 mL/m^2 for girls. RVEF had a mean value of 53.743±5.186% for boys and a mean value of 53.524±5.4059% for girls.

Our obtained 3DE values for RV volumes and function were lower than the 3DE values mentioned previously in the literature. Comparison of our results with the studies done by Karabiyik et al[14] in 2018 and Herberg et al[15] in 2021 shows that our indexed values are significantly lower than their indexed values. The age group and the body surface area of the included subjects in their study can explain this difference. The mean age of the included subjects in our study was significantly lower, leading to a significantly lower mean body surface area compared with the subjects included in both studies.

In the previously mentioned studies, the 3D acquisition was made using an ultrasound hardware GE E9 machine or a Philips iE 33 machine, and the 3D data set was analyzed using the evaluation software 4D-RV-Function 2.0 from TOMTEC Imaging

Systems. In our study, the acquisition was done on a GE E95 machine, and the analysis was made by the 4D Auto RVQ software, which is a relatively newer software tool,[14,15] which might explain the significantly lower values. De Potter et al,[8] who validated the 4D Auto RVQ software in the adult population, mentioned that RV-indexed volumes, indexed SV, and RVEF were underestimated when compared with other 3D software-derived values, as well as CMR.

Generally, RVEF was underestimated by 3DE but was still significantly correlated with RVEF by CMR. This finding was reported in earlier studies such as the investigation done by Papavassiliou et al[16] in 1998, which found that the reproducibility of the analysis of RVEF and 3D volumes as assessed by repeated recordings was acceptable.

Accurate assessment of RV linear dimensions is important in treating patients with congenital heart diseases. In some cases, critical therapeutic decisions may depend on the demonstration of or progression of RV dilatation. According to Srinivasan et al[17] in 2011, the 2D RV basal diameter did not correlate with RV volumes measured with CMR in patients with repaired tetralogy of Fallot, proving that the 2DE assessment of RV size was inaccurate when compared with CMR in children and young adults.

In this study, 2DE and 3DE mean RV longitudinal dimension values showed significant differences in both groups ($P<0.0001$), with 3DE showing lower values. The 2DE and 3DE mean RV basal dimension values showed significant differences in Group II, whereas in Group I, the difference was not significant. According to Karabiyik et al,[14] deriving 2D internal dimensions from a 3D data set resulted in significant differences in all RV dimensions. This difference may have been caused by a uniform recording of the RV data sets to calculate the distances because of minimizing foreshortening, as the data set was correctly aligned previously. This strategy prevents greater differences in 2D axes, in which the measurements were obtained. Therefore, RT3DE should be preferred to 2DE when measuring RV linear dimensions.

In our study, the indexed and non-indexed RV volumes obtained by 2DE and 3DE showed a significant difference ($P<0.0001$), with 2DE showing lower values. We measured 2D volumes in the RV-focused view using the A-L method, which explains the significant difference in 2D RV volumes and 3D RV volumes. In a study performed by Kovalova et al[18] in 2006, 2D volumes were measured using the 'ellipsoidal shell model. This method has been validated before for 2D volumes, and it is well correlated with CMR values.

TAPSE mean values measured by 2DE and 3DE showed statistically significant differences, with significantly lower values by 3DE in both groups. TAPSE mean values measured by 2DE and 3DE showed a modest positive correlation in Group I ($r=0.540$). In the study by Karabiyik et al[14] in 2018, this was explained by the discrepancy in the strategy of data measurements that 3D data sets were better aligned because 2D sectional images were always in the same position in each subject. That is why RT3DE should be preferred to 2DE when measuring TAPSE.

Based on our findings, 2DE and 3DE RVFAC mean values showed a modest positive correlation ($r=0.543$) in Group II and a strong positive correlation ($r=0.729$) in Group I. In addition, 3DE RVFAC showed a modest positive correlation with 3DE RVEF ($r=0.526$) in Group II.

Evaldsson et al[19] strongly correlated RVFAC measured by 2DE with CMR-derived RVEF. Moreover, 3DE-derived RVFAC and RVEF were strongly correlated with RVEF obtained by CMR in a study done by Hamilton-Craig et al[20] in 2016. This finding chimes in with the results obtained from our study, which showed significant correlations between FAC measured by 2DE and 3DE and significant correlations between RVFAC measured by 3DE and RVEF measured by 3DE. These findings show the importance and the accuracy of RVFAC measured by 2DE and 3DE as a feasible tool to assess RV systolic function in different settings.

As a clinical application to our study, the present findings might be used for better and more accurate assessments of the RV. As 3DE is becoming more feasible than CMR nowadays with well-correlated and comparable results, these reference values for 3DE-derived RV parameters can be helpful in decision-making in differentiating RV normal physiology from pathology in the Egyptian population.

Study Limitations and Recommendations

The present study is a single-center investigation performed with a relatively novel software tool. A larger-scale study comparing different types of software tools is recommended. The young age group found some difficulty in adequately holding breath during acquisition; thus, more attention should be paid to single-beat acquisition to overcome breath artifacts. No test-retest analysis was performed, and intra and interobserver variabilities were not calculated. Retest analysis is recommended using a new set of study groups in order to validate the results of the current study. The absence of a comparison with a reference standard such as CMR could be regarded as a limitation of this study. This point should be considered when validating these reference values on a larger number of subjects. Further, 2D volumes were measured directly using the A-L method and not using the ellipsoidal shell model. If another modality is required for validating the results, CMR is the modality to be used as it is the gold standard for assessing the RV for the time being.

CONCLUSIONS

To our knowledge, this is the first study done to obtain normal RV reference values by 3DE in the Egyptian population. It should be emphasized that 3DE overcomes the geometric limitations of 2D imaging by providing the quantification of RV volumes and functional assessment without any geometric assumptions. Reference values and percentile curves were established for different RV parameters by 3DE for the first time in the Egyptian children population.

REFERENCES

1. Tamborini G, Marsan NA, Gripari P, Maffessanti F, Brusoni D, Muratori M, et al. Reference values for right ventricular volumes and ejection fraction with real-time three-dimensional echocardiography: evaluation in a large series of normal subjects. Journal of the American Society of Echocardiography. 2010; 23(2):109-15.

2. Ho S, Nihoyannopoulos P. Anatomy, echocardiography, and normal right ventricular dimensions. Heart. 2006; 92(suppl 1):i2-i13.

3. Surkova E, Muraru D, Iliceto S, Badano LP. The use of multimodality cardiovascular imaging to assess right ventricular size and function. International journal of cardiology. 2016; 214:54-69.

4. Grewal J, Majdalany D, Syed I, Pellikka P, Warnes CA. Three-dimensional echocardiographic assessment of right ventricular volume and function in adult patients with congenital heart disease: comparison with magnetic resonance imaging. Journal of the American Society of Echocardiography. 2010; 23(2):127-33.

5. Anderson RH, Becker AE, Freedom RM, Macartney FJ, Quero-Jimenez M, Shinebourne EA, et al. Sequential segmental analysis of congenital heart disease. Pediatric cardiology. 1984; 5(4):281-7.

6. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, et al. 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. Journal of the American society of echocardiography. 2010; 23(7):685-713.

7. Lu X, Nadvoretskiy V, Bu L, Stolpen A, Ayres N, Pignatelli RH, et al. Accuracy and reproducibility of real-time three-dimensional echocardiography for assessment of right ventricular volumes and ejection fraction in children. Journal of the American Society of Echocardiography. 2008; 21(1):84-9.

8. De Potter T, Weytjens C, Motoc A, Luchian ML, Scheirlynck E, Roosens B, et al. Feasibility, Reproducibility and Validation of Right Ventricular Volume and Function Assessment Using Three-Dimensional Echocardiography. Diagnostics. 2021; 11(4):699.

9. Federico Veronesi GRL, Stein Inge Rabben, Jørn Bersvendsen, Healthcare G. 4D Auto RVQ (Right Ventricle Quantification). In: Healthcare G, editor.: GE Healthcare; 2017.

10. Bonnet S, Provencher S, Guignabert C, Perros F, Boucherat O, Schermuly RT, et al. Translating research into improved patient care in pulmonary arterial hypertension. American journal of respiratory and critical care medicine. 2017; 195(5):583-95.

11. Horton KD, Meece RW, Hill JC. Assessment of the right ventricle by echocardiography: a primer for cardiac sonographers. Journal of the American society of echocardiography. 2009; 22(7):776-92.

12. Séguéla PE, Hascoët S, Brierre G, Bongard V, Acar P. Feasibility of three-dimensional transthoracic echocardiography to evaluate right ventricular volumes in children and comparison to left ventricular values. Echocardiography. 2012;29(4):492-501.

13. Esmail YA, EL Shahid GS, Roushdy AM, Hussein MR. EFFECT OF PULMONARY HYPERTENSION SECONDARY TO CONGENITAL HEART DISEASE ON RIGHT VENTRICULAR VOLUMES AND FUNCTION: A COMPARATIVE STUDY BETWEEN TWO DIMENSIONAL, THREE DIMENSIONAL ECHOCARDIOGRAMS AND INVASIVE RV QUANTIFICATION. Ain Shams Medical Journal. 2019; 70(4, 5 & 6):315-24.

14. Laser KT, Karabiyik A, Körperich H, Horst J-P, Barth P, Kececioglu D, et al. Validation and reference values for three-dimensional echocardiographic right ventricular volumetry in children: a multicenter study. Journal of the American Society of Echocardiography. 2018; 31(9):1050-63.

15. Herberg U, Smit F, Winkler C, Dalla-Pozza R, Breuer J, Laser KT. Real-time 3D-echocardiography of the right ventricle—paediatric reference values for right ventricular volumes using knowledge-based reconstruction: a multicentre study. Quantitative Imaging in Medicine and Surgery. 2021; 11(7):2905-17.

16. Papavassiliou DP, Parks WJ, Hopkins KL, Fyfe DA. Three-dimensional echocardiographic measurement of right ventricular volume in children with congenital heart disease validated by magnetic resonance imaging. Journal of the American Society of Echocardiography. 1998; 11(8):770-7.

17. Srinivasan C, Sachdeva R, Morrow WR, Greenberg SB, Vyas HV. Limitations of standard echocardiographic methods for quantification of right ventricular size and function in children and young adults. Journal of Ultrasound in Medicine. 2011; 30(4):487-93.

18. Kovalova S, Necas J, Vespalec J. What is a “normal” right ventricle? European Journal of Echocardiography. 2006;7(4):293-7.

19. Evaldsson AW, Lindholm A, Jumatate R, Ingvarsson A, Smith GJ, Waktare J, et al. Right ventricular function parameters in pulmonary hypertension: echocardiography vs. cardiac magnetic resonance. BMC Cardiovascular Disorders. 2020;20:1-12.

20. Hamilton-Craig CR, Stedman K, Maxwell R, Anderson B, Stanton T, Chan J, et al. Accuracy of quantitative echocardiographic measures of right ventricular function as compared to cardiovascular magnetic resonance. IJC Heart & Vasculature. 2016;12:38-44.