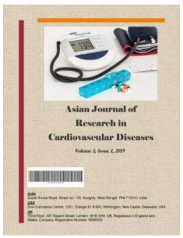

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Reference Ranges for the Diameter of the Right Ventricular Outflow Tract by Cardiovascular Magnetic Resonance and Comparison with Echocardiographic Measurements

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Authors' contributions

This work was carried out in collaboration between both authors. Author AK investigation, formal analysis, writing - original draft, visualization. Author MP conceptualization, methodology, validation, writing - review and editing, supervision. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: To provide reference ranges for the right ventricular outflow tract (RVOT) diameter by cardiovascular magnetic resonance (CMR) in children, and compare the measurements with two-dimensional (2D) transthoracic echocardiography (TTE).
Place and duration of study: Lausanne University Hospital, between January 2014 and December 2018.
Methods: We measured the RVOT diameter in 49 children (35 male, 14 female; age range 2-18 years) with normal RVOT anatomy on balanced steady-state free precession (bSSFP) CMR images in the strict transverse and sagittal views, and on 2D TTE images in parasternal short axis (PSAX) and parasternal long-axis (PLAX) views.
Results: Based on 63 measurements, we obtained the following mean RVOT diameters and their reference ranges, indexed to body surface area: 15.2 mm/m^2 (7.0 - 23.3 mm/m^2) in the strict transverse view, and 14.0 mm/m^2 (7.8 - 20.2 mm/m^2) in the strict sagittal view. Pearson correlation

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showed a very strong correlation between the CMR strict transverse view and the 2D TTE PSAX view (r = 0.84; P < .001), and a strong correlation between the CMR strict sagittal view and the 2D TTE PLAX view (r = 0.78; P < .001). The Bland-Altman analysis showed poor agreement between the CMR strict transverse view and the 2D TTE PSAX view (bias -3.34 mm/m^2 or -16.6%), and between the CMR strict sagittal view and the 2D TTE PLAX view (bias -3.90 mm/m^2 or -19.7%).

Conclusions: There is strong correlation but poor agreement between the measurements of the RVOT diameter in the strict transverse and sagittal views by CMR and the similar PSAX and PLAX views by 2D TTE. The static bSSFP CMR images in the strict transverse and sagittal views should not be used to define RVOT dilatation in children.

Keywords: Cardiac magnetic resonance imaging; two-dimensional echocardiography; right ventricular outflow tract; arrhythmogenic right ventricular cardiomyopathy/dysplasia.

ABBREVIATIONS

RVOT : Right ventricular outflow tract
ARVC/D : Arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D)
TTE : Transthoracic echocardiography
PSAX : Parasternal short-axis
PLAX : Parasternal long-axis
CMR : Cardiovascular magnetic resonance imaging
BSSFP : Balanced steady state free precession

1. INTRODUCTION

Dilatation of the right ventricular outflow tract (RVOT), in association with regional right ventricular (RV) akinesia, dyskinesia, or aneurysm, is one of the major criteria in the diagnosis of arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D) [1]. It is defined by measuring the diameter of the RVOT by two-dimensional (2D) transthoracic echocardiography (TTE) at end diastole in the parasternal short-axis (PSAX) and the parasternal long-axis (PLAX) views.

Cardiovascular magnetic resonance imaging (CMR) could also be used to measure the end-diastolic diameter of the RVOT, in views that are similar to the 2D TTE views, which could be helpful in diagnosing RVOT dilatation in patients with poor echocardiographic windows. However, the reference ranges for the RVOT diameter by CMR have not been reported, and the correlation and agreement between CMR and TTE measurements has not been studied in children.

We therefore aimed to provide reference ranges for the RVOT diameter in the strict transverse and sagittal views by CMR in children and adolescents with normal RVOT anatomy, and to compare the measurements with those obtained by 2D TTE according to the recommendations in the 2010 revised Task Force Criteria of ARVC/D [1].

2. METHODS

2.1 Patient Population

We searched our CMR database to identify all patients 18 years of age or younger who underwent a CMR exam before 2018. Patients were included only if they had a normal RVOT anatomy, if they had static balanced steady state free precession (bSSFP) images performed in the strict transverse and sagittal views, and if they had 2D TTE images of the RVOT in the PSAX and PLAX views within 6 months of their CMR exam.

2.2 CMR Measurements

CMR was performed on a 1.5 Tesla scanner (Magnetom Aera, Siemens Medical Systems, Erlangen, Germany). Static bSSFP images were acquired during free breathing and triggered to end-diastole. The typical imaging parameters were as follows: in-plane spatial resolution 2.0 x 1.5 mm^2, slice thickness 5 mm, interslice gap 0 mm, 1 average. The RVOT diameter was measured on the strict transverse and sagittal views, perpendicular to the anterior wall of the RVOT, at the level of the aortic valve, from inner edge to inner edge, as illustrated in Fig. 1.

2.3 TTE Measurements

2D TTE was performed with commercially available echocardiography machines (Sonos iE33, Philips, Andover, MA, USA; Vivid E9, GE Healthcare, Milwaukee, WI, USA) using transducers of 5 and 8 MHz according to patient size. The RVOT diameter was measured at end-diastole in the PSAX and PLAX views, from inner edge to inner edge, according to the published guidelines, as illustrated in Fig. 2. [2]

2.4 Statistical Analysis

The measurements were indexed to the body surface area (BSA) using the Mosteller formula. The indexed diameters of the RVOT were confirmed to be normally distributed using the Kolmogorov-Smirnov test. The mean, standard deviation (SD) and reference range, using two SDs on either side of the mean, were calculated for all measurements. The RVOT diameter in the strict transverse view by CMR was compared with the RVOT diameter in the similar PSAX view by 2D TTE, and the RVOT diameter in the strict sagittal view by CMR was compared with the RVOT diameter in the similar PLAX view by 2D TTE. The correlation between the measurements was evaluated using the Pearson correlation coefficient, and the strength of the relationship was interpreted according to the published recommendations [3]. Agreement between the measurements was evaluated using the Bland-Altman plot. Significant relationships between the measurements were sought using the paired Student's *t*-test. *P* values <0.05 were considered statistically significant.

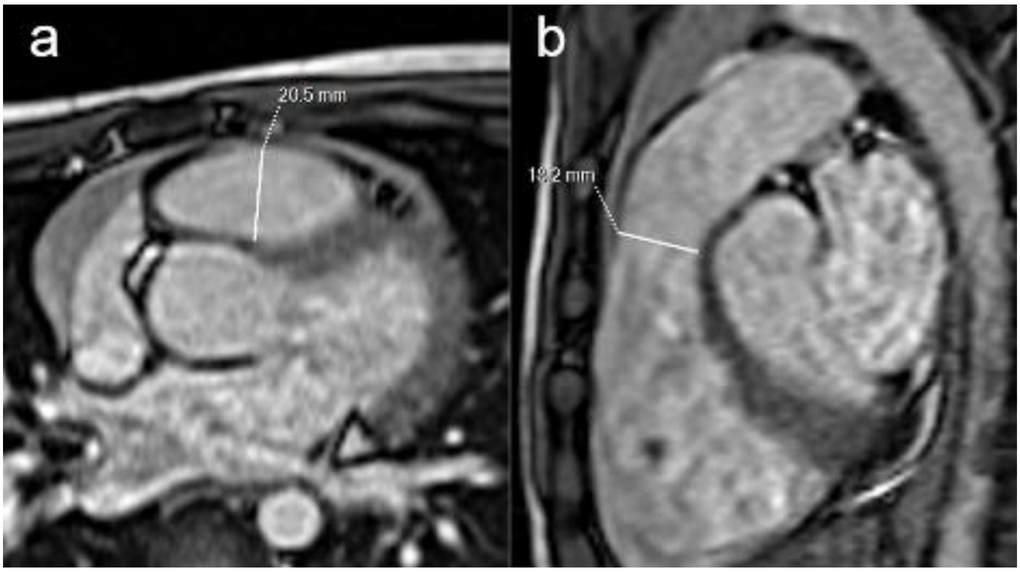

Fig. 1. Illustration of the method of measurement of the RVOT diameter by CMR in the strict transverse (a) and the strict sagittal (b) views. AO = aorta, LA = left atrium, LV = left ventricle, MPA = main pulmonary artery, RV = right ventricle, RVOT = right ventricular outflow tract

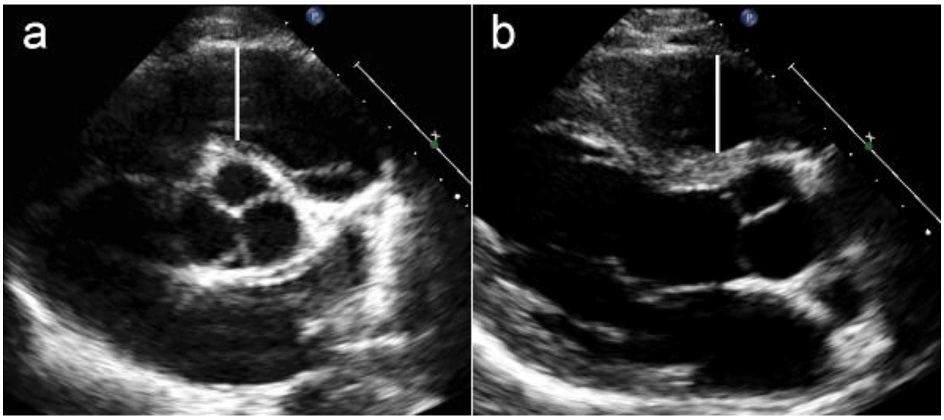

Fig. 2. Illustration of the method of measurement of the RVOT diameter by 2D TTE in the PSAX (a) and the PLAX (b) views. AO = aorta, LA = left atrium, LV = left ventricle, RVOT = right ventricular outflow tract

3. RESULTS

We retrospectively identified 49 patients (mean age 13 years, range 2-18) who met the inclusion criteria. Their characteristics are presented in Table 1. They had 63 CMR and 2D TTE exams allowing measurements adequate for analysis and comparison. The means, SDs, and reference ranges of the RVOT diameters by CMR and 2D TTE, indexed to BSA, are presented in Table 2.

Fig. 3 and Fig. 4 show the correlation between the CMR and 2D TTE measurements. The RVOT diameter measured in the strict transverse view by CMR exhibited very strong correlation with the similar PSAX view by 2D TTE (r = 0.84; P <.001), and the RVOT diameter measured in the strict sagittal view by CMR exhibited strong correlation with the similar PLAX view by 2D TTE (r = 0.78; P <.001).

Fig. 5 and Fig. 6 show the agreement between the CMR and 2D TTE measurements. The RVOT diameter measurements in the strict transverse view by CMR and the similar PSAX view by 2D TTE exhibited poor agreement with significant bias (bias = -3.34 mm/m^2 or -16.6%; SD of bias = 2.81 mm/m^2 or 14.6%). The RVOT diameter measurements in the strict sagittal view by CMR and the similar PLAX view by 2D TTE also exhibited poor agreement with significant bias (bias = -3.90 mm/m^2 or -19.7%; SD of bias = 3.18 mm/m^2 or 13.4%).

4. DISCUSSION

In patients with ARVC/D, it has been demonstrated that the RVOT is the most commonly dilated anatomical structure [4]. It has therefore been proposed, when associated with regional RV akinesia, dyskinesia, or aneurysm, as a major diagnostic criterion in the 2010 revised TFC of ARVC/D [1]. Since 2D TTE is the most readily available imaging modality to evaluate cardiac anatomy, RVOT dilatation is defined in the revised TFC as an echocardiographic diameter ≥ 21 mm/m^2 in the PSAX view or ≥ 19 mm/m^2 in the PLAX view. However, accurate measurements of the RVOT diameter by 2D TTE may be difficult to obtain in patients with poor echocardiographic windows and there may be significant variation between operators [5]. CMR may overcome these echocardiographic limitations and provide very accurate and reliable measurements [6]. Since static bSSFP images in the three orthogonal planes are routinely obtained with all CMR protocols in our institution, we sought to provide reference ranges for the RVOT diameter in children and adolescents in the strict transverse and sagittal views and compare the measurements with the echocardiographic PSAX and PLAX views, respectively.

Table 1. Patient characteristics

		All patients (n = 49)
Age (years)		13 ± 4
Male (%)		35 (71)
BSA (m^2)		1.51 ± 0.33
Diagnosis	Normal	21
	Coarctation of aorta	11
	Marfan syndrome	11
	LV hypertrabeculation	6

Data are presented as mean ± SD. BSA = body surface area; LV = left ventricular

Table 2. Means, SDs, and reference ranges (mean ± 2SD) of indexed RVOT diameters by CMR and TTE

	CMR Transverse view	**CMR Sagittal view**	**2D TTE PSAX view**	**2D TTE PLAX view**
Mean RVOT diameter, mm/m^2	15.2	14.0	18.5	18.0
SD	4.1	3.1	5.1	5.0
Mean ± 2SD	7.0, 23.3	7.8, 20.2	8.3, 28.7	8.0, 28.0

CMR = cardiovascular magnetic resonance imaging; TTE = transthoracic echocardiography; PSAX = parasternal short-axis; PLAX = parasternal long-axis; RVOT = right ventricular outflow tract

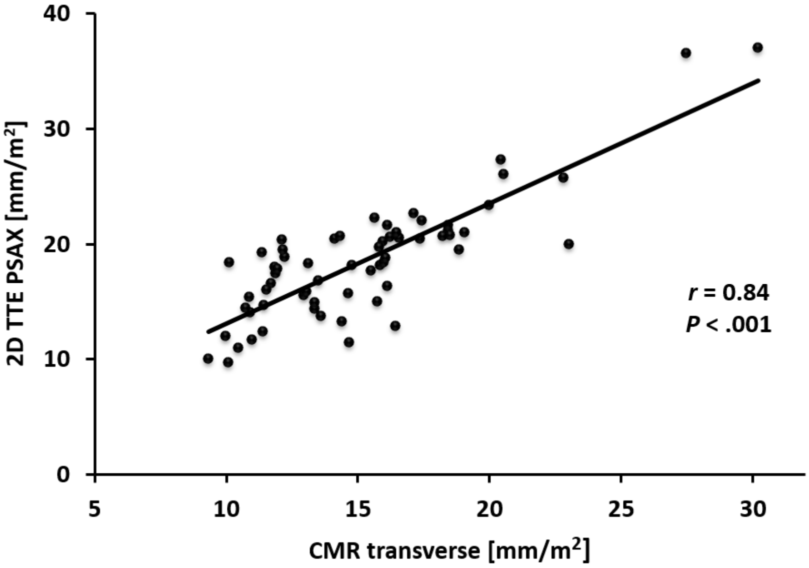

Fig. 3. Correlation between the measurements of the RVOT diameter in the strict transverse view by CMR and the PSAX view by 2D TTE

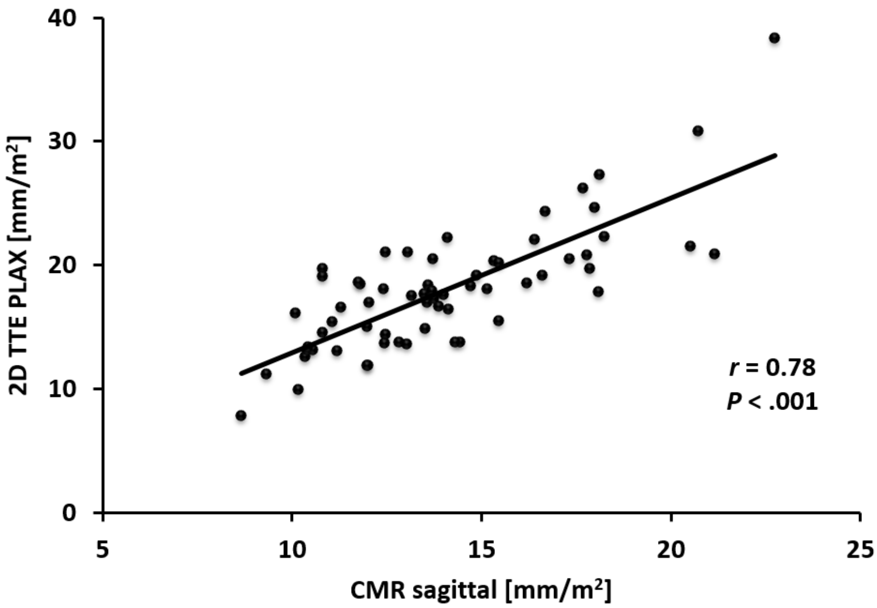

Fig. 4. Correlation between the measurements of the RVOT diameter in the strict sagittal view by CMR and the PLAX view by 2D TTE

We obtained high SDs and consequently very wide reference ranges for the RVOT diameter by CMR. This could be explained by possible imprecision of the measurements due to lower spatial and temporal resolution of CMR compared to 2D TTE. However, we observed even higher SDs for the RVOT diameter by 2D TTE, with a large proportion of the measurements being greater than the cut-off values for RVOT dilatation according to the 2010 revised TFC. In fact, 22% of the measurements in the PSAX view were ≥ 21 mm/m^2 and 30% of the measurements in the PLAX view were ≥ 19 mm/m^2. These wide variations may be attributed to the fact that 2D TTE was performed by many different operators, including less experienced ones, and the RVOT may have been imaged in many cases in an oblique view. Alternatively, pediatric data on normal values of echocardiographic RVOT diameter measurements is rare, and the RVOT diameter may normally exhibit wider variations in children compared to adults [7,8]. Although to a lesser degree than in our study, Koestenberger et al. also obtained a wide range for their normal reference values of RVOT proximal diameter in the pediatric age group, with a similarly large proportion of patients having measurements in the PSAX view ≥ 21 mm/m² [9]. Finally, the echocardiographic measurements of the RVOT diameter as recommended in the 2010 revised TFC may not be optimal for ARVC/D diagnosis, as they have been shown to have low sensitivity [10].

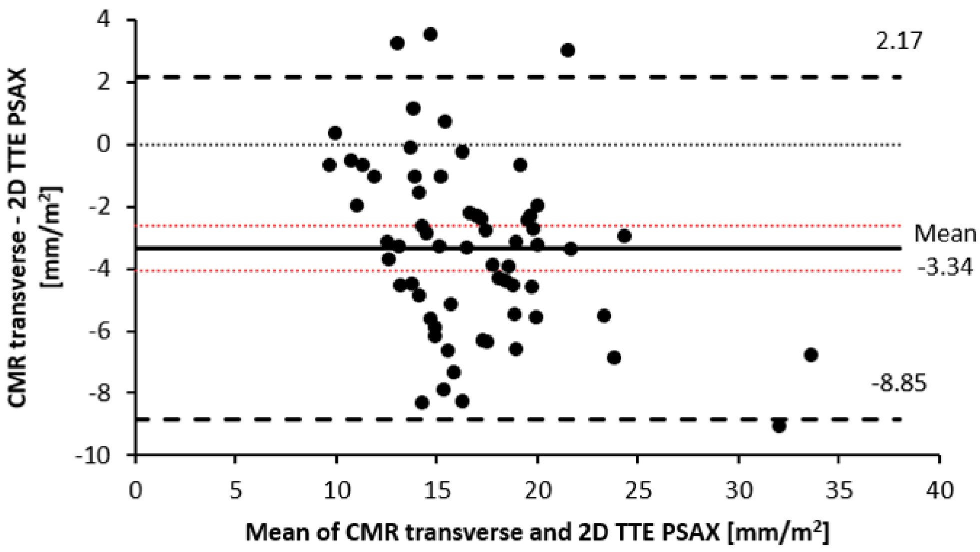

Fig. 5. Bland-Altman plot for the measurements of the RVOT diameter in the strict transverse view by CMR and the PSAX view by 2D TTE, with the representation of the limits of agreement (dashed black lines) and the confidence interval limits for the mean (dotted red line)

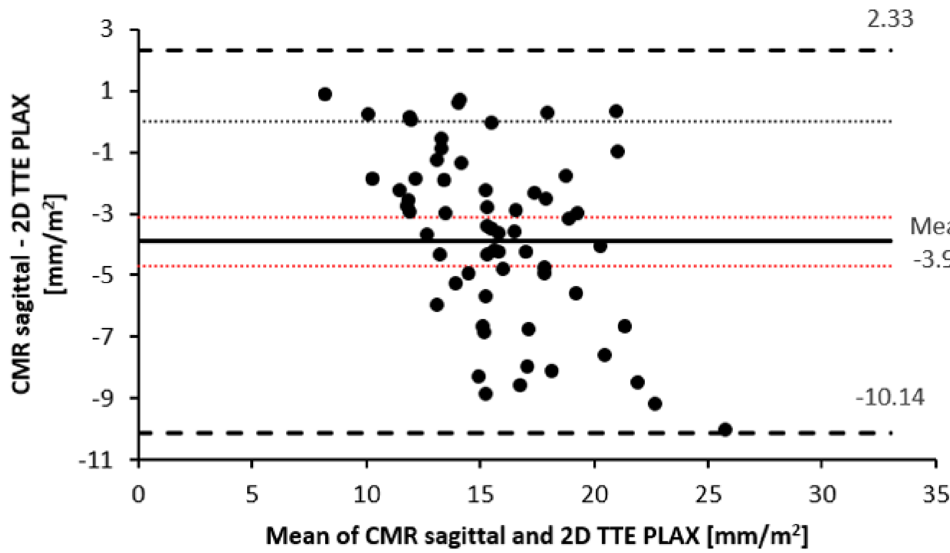

Fig. 6. Bland-Altman plot for the measurements of the RVOT diameter in the strict sagittal view by CMR and the PLAX view by 2D TTE, with the representation of the limits of agreement (dashed black lines) and the confidence interval limits for the mean (dotted red line)

Despite their wide reference ranges, the RVOT diameter measurements by CMR showed a strong correlation with the echocardiographic measurements, suggesting that the static bSSFP images triggered to end-diastole in the strict transverse and sagittal views may provide accurate measurements of the RVOT diameter. However, there was poor agreement between the CMR and 2D TTE measurements, with CMR on average significantly underestimating the RVOT diameter compared to 2D TTE. This may not be surprising as the strict transverse and sagittal views by CMR are oriented more perpendicular to the RVOT than the PSAX and PLAX views by 2D TTE, which image the RVOT obliquely. Gotschy et al. demonstrated better agreement between RVOT diameter measurements by CMR and 2D TTE when equivalent views were compared, although they also obtained wide limits of agreement, especially for the PSAX view by 2D TTE vs. the anatomical correlate by CMR. [10] Their method of comparison was not possible in our study as the CMR views equivalent to the 2D TTE PSAX and PLAX views are not routinely obtained with all CMR protocols in our institution, and therefore too few measurements would have been compared.

5. CONCLUSIONS

There is scant reference data on echocardiographic or CMR measurements of the normal RVOT diameter in the pediatric age group. Our study provides preliminary reference ranges for the end-diastolic RVOT diameter in the strict transverse and sagittal views by CMR in children and adolescents. However, despite their strong correlation with the similar 2D TTE PSAX and PLAX views, there is poor agreement between these CMR and echocardiographic measurements. As a result, the static bSSFP CMR images in the strict transverse and sagittal views should not be used to define RVOT dilatation in pediatric patients. Defining RVOT dilatation in children therefore remains problematic. A further study comparing anatomically equivalent CMR and 2D TTE views in a large pediatric cohort is warranted.

6. LIMITATIONS

Limitations of our study include a sample size that is too small to provide normal values for the RVOT diameter by CMR, and the fact that we did not assess intraobserver and interobserver reliability of the measurements.

CONSENT AND ETHICAL APPROVAL

The local ethics committee (EC VAUD) approved the study (ID 2018-02204) and written informed consent was waived. The study was performed in accordance with the ethical standards as laid down in the Helsinki Declaration as revised in 2013.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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