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Original article

Nomograms for echocardiographic right ventricular sub-costal view dimensions in healthy Caucasian children: A new approach to measure the right ventricle

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ABSTRACT

Background: The sub-costal examination of the heart is part of routine examination in pediatric echocardiography, and has the advantage to visualize also the infundibulum part of the right ventricle (RV). Despite this fact, currently nomograms for sub-costal RV dimensions are lacking.
Methods: We prospectively studied healthy Caucasian Italian children by two-dimensional echocardiography. Measurements included: sub-costal end diastolic basal-apical and latero-lateral diameters, end diastolic and end systolic area, 4 chamber end diastolic and end systolic area and length, end diastolic basal (RV1) and mid-cavity (RV2) diameters. Age, weight, height, heart rate (HR), and body surface area (BSA) were used as independent variables in different analyses to predict the mean values of each measurement. Structured Z scores were then computed. Agreement of RV diameters and areas in subcostal view and 4-chamber view were investigated.
Results: 732 subjects (age 0 days-17 years; 48% female; BSA 0.12-2.12 m2) were studied. The Haycock formula was used when presenting data as predicted values (mean ± 2 SDs) for a given BSA and within equations relating echocardiographic measurements to BSA. The predicted values and Z-score boundaries for all measurements are presented. Excellent correlations were found among two-dimensional diameters and area calculated in sub-costal view with those evaluated in 4-chamber view.
Conclusions: We report echocardiographic nomograms for RV diameters and areas measured in the sub-costal view. Our data may implement normative data for 2D echocardiography evaluation of the RV in children.

Introduction

Evaluation of the right ventricle (RV) is often critical to the diagnosis and disease severity estimation in children with congenital heart disease (CHD) [1,2]. Two-dimensional (2D) echocardiography represents the first modality used for the evaluation of the RV. The RV dimensions may be assessed by echocardiography by the use of different projections (i.e. apical 4-chamber with different probe angulation, apical 5-chamber, parasternal long- and short-axis view) [3,4]. According to adult recommendations [3,4] for a complete evaluation of the RV measurements of both linear dimensions (i.e. maximal transversal basal and mid-cavity diameters, proximal and distal right ventricular outflow tract – RVOT – diameters) and areas should be achieved. All the methods used to evaluate RV size by 2D echocardiography however have multiple limitations [5,6], particularly in the valuation of the infundibulum that may be dilated and constitute an important part of ventricular body in many children with CHD after surgical correction/palliations [7,8]. The

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difficulty for a correct estimation of the RV dimension by conventional projections has led a few authors to evaluate new approaches such as the RV 3-chamber view [9,10].

The sub-costal examination is part of routine examination in pediatric echocardiography, and may provide an overview of cardiac anatomy [10]. The sub-costal coronal plane may allow the evaluation of RV body dimensions, area, and function offering the advantage to visualize also the infundibulum [11]. Sub-costal coronal plane measurements are commonly performed in the algorithm for 3D estimation of RV volumes [5,7,8,12] and are similar to the ones employed to measure RV by magnetic resonance imaging (MRI) [13]. However, 2D sub-costal diameters and area have been rarely proposed as an adjunctive tool to estimate RV dimensions [8].

The aim of this paper was to establish pediatric nomograms for RV diameters and area calculated by using different approaches, including 4-chamber view and sub-costal view. The second aim of this paper was to compare RV diameters and area calculated by different approaches such as MRI.

Materials and methods

Inclusion and exclusion criteria

Healthy Caucasian children evaluated from April 2015 to October 2016 in the outpatient pediatric cardiology department at the Fondazione G. Monasterio CNR-Regione Toscana of Massa for CHD screening were prospectively recruited. These data included 280 subjects presented in two recent investigations that evaluated other measurements [14,15]. The inclusion and exclusion criteria have been reported elsewhere [14,15].

Only those with technically adequate echocardiographic examinations were enrolled in the study. The presence of intra-cardiac defects that represent normal circulatory physiology such as a patent ductus arteriosus with small left-to-right shunting in the first 3 days of life, or a patent foramen ovale was considered normal [14,15]. Premature neonates were included only if they had an APGAR score ≥8, did not require ventilatory support, and had good clinical status [14,15].

All subjects with clinical, electrocardiographic, or echocardiographic evidence of congenital or acquired heart disease were excluded. Other exclusion criteria consisted of patients with known or suspected neuro-muscular disease, genetic syndromes, or chromosomal abnormalities; body mass index (BMI) ≥95th percentile for children ≥2 years old [16,17] or weight-for-length Z-score ≥2 based on the World Health Organization (WHO) Child Growth Standards for children <2 years old [16,17]; pulmonary hypertension [18]; systemic hypertension (for children > 4 year of age), connective tissue disease; or family history of genetic cardiac disease (i.e. Marfan syndrome or cardiomyopathy) [14,15]. All non-Caucasian subjects were also excluded to avoid racial variability bias.

All patients underwent a complete 2D echo examination and images were digitally stored for subsequent offline analysis. Approval for this study was obtained from the Local Ethics Committee. Parents or legal guardians of all the children were informed and accepted to participate in the study by signing a written consent form.

Echocardiographic examination

The RV was visualized in a sub-costal coronal axis view including the tricuspid valve and the pulmonary valve in diastole [8,11]. Images were obtained by sub-xiphoid short axis view with leftward probe angulation in order to visualize a cross sectional view of the left ventricle (LV), mitral valve, the RVOT, and the pulmonary valve [11]. Papillary muscles and small trabeculations were not included in the trace border [8]. The following parameters were evaluated: diastolic and systolic areas, maximal systolic and diastolic basal-apical (maximal diameter from base to the pulmonary valve) and latero-lateral diameters (at the level of the tricuspid valve attachment, parallel to the RV diaphragmatic ventricular wall) (Fig. 1 and Video 1 supplementary material). RV systolic and diastolic areas and length were also measured in 4-chamber view. Since we already published nomograms for RV dimensions and areas calculated in 4-chamber view [15], these data were used only for comparative analysis.

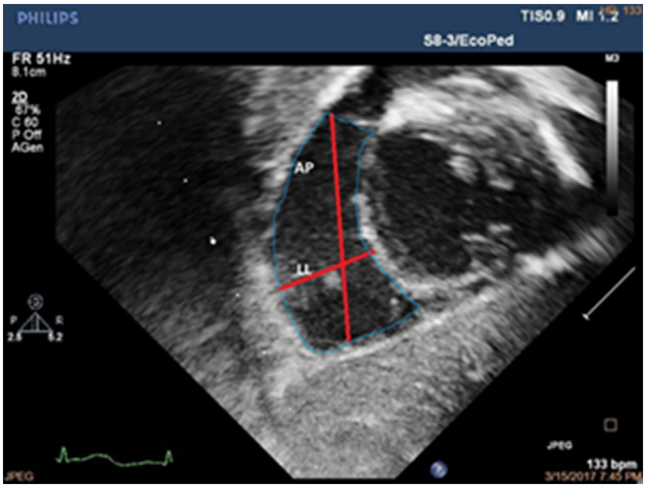

Fig. 1. Sub-costal short axis view with leftward probe angulation in order to visualize a cross sectional view of the left ventricle (LV), mitral valve the right ventricular outflow tract (RVOT) and the pulmonary valve. LL, latero-lateral; AP, anterior–posterior.

All studies were performed with simultaneous electrocardiographic monitoring, and the onset of diastole was taken at the end of the electrocardiographic T-wave. Rates of intra-observer and inter-observer variability of selected echocardiographic indexes were calculated from 10 patients who were randomly selected from both groups.

Echocardiograms were performed using Philips iE33 systems (Philips Medical Systems, Bothell, WA, USA). Offline measurements were performed on a commercially available computer workstation (EnConcert, Philips Medical Systems, Andover, MA, USA) according to recent guidelines [1,15]. Measurements were only made if excellent and unambiguous views were available.

Statistical methods

Statistical methods have been described in previous works [14,15,19–26] and will be briefly summarized. To examine the relationship between parameters of body size, heart rate, age and each of the echocardiographic variables, multiple models using linear, logarithmic, exponential, and square root equations were tested [14,15]. Among the models that satisfied the assumption of homoscedasticity, the model with the highest R^2 value was considered to provide the best fit. The presence or absence of heteroscedasticity, a statistical term used to describe the behavior of variance and normality of the residuals, was tested by the White test and the Breusch–Pagan test as described previously [19,20]. To test the normality of residuals, the Shapiro–Wilk and Lilliefors (Kolmogorov–Smirnov) tests were used [25,26]. Age, weight, height, heart rate (HR), and body surface area (BSA) [14,15,21] were used as independent variables in different regression analyses to predict the mean values of each echocardiographic measurement. The Haycock formula was used to calculate BSA

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