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Two-Dimensional Echocardiographic Valve Measurements in Healthy Children: Gender-Specific Differences

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Abstract. The goal of this study was to create nomograms of echocardiographic two-dimensional valve dimensions based on a large group of children without heart disease. Children aged 0–18 years underwent standard echocardiographic evaluation. Referring diagnoses were chest pain, heart murmur, or syncope. Only patients with a structurally normal heart and normal systolic and diastolic function were included. All four valves were measured at their maximal dimensions. A total of 748 children (314 girls and 434 boys) met the inclusion criteria. Mean values and standard deviations were calculated, and *z* value nomograms based on body surface area were developed. Surprisingly, the boys had larger valve dimensions at all ages. These valve dimension differences were statistically significant for three of four valves even after adjustment for the differences in body sizes. The difference may be due to higher circulating blood volume in boys compared to that in girls. Because the differences are subtle, they reach statistical significance only when evaluated in a large group of subjects. Presented normal value data will be helpful in following cardiology patients and evaluating intervention strategy in patients with valve hypoplasia.

Key words: Pediatric echocardiography — Normal valve measurements

Knowledge of cardiac valve dimensions is important in managing patients with congenital and acquired heart diseases. Currently, published pediatric two-dimensional (2-D) normative data are based on a relatively small (48 –196) number of subjects [3, 10, 16]. The aim of this study was to create *z* value nomograms of echocardiographic valve dimensions based on a larger group of children without heart disease.

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Materials and Methods

The subjects were children aged 0–18 years referred to the Cincinnati Children's Hospital echocardiography laboratory. Referring diagnoses were chest pain, heart murmur, or syncope evaluation. Only patients with structurally normal heart and normal systolic and diastolic function were included. Exclusion criteria were arterial hypertension, chronic renal failure, the presence of oncologic disease, or any other conditions that could affect cardiac function or geometry. The weight, height, and race of each patient were recorded at the time of the echocardiography evaluation.

The studies were performed using a Philips Sonos 5500 (Andover, MA, USA) or GE Vivid 5 (Milwaukee, WI, USA) echocardiography system. Measurements were performed off-line using Cardiology Analysis System software (Digisonics, Houston, TX, USA). The valves were measured at their maximal dimensions using the distance between "hinge points" at the level of the annulus. Aortic valves were measured in the parasternal long-axis view in systole, pulmonary valves in the parasternal short-axis view in systole, and mitral and tricuspid valves in the apical four-chamber view in diastole.

Results

A total of 748 children met inclusion criteria. There were 314 girls and 434 boys. Their ages ranged from 0 to 18 years. Racial distribution was as follows: Caucasian, 629; African American, 80; Asian, 9; Hispanic, 2; biracial, 11; unknown, 17.

Data were plotted vs body surface area (BSA) and height. Mean values and standard deviations were calculated. Analysis of covariance (ANCOVA) modeling was performed, initially to determine whether to use height, BSA (calculated by Dubois formula), or a combination as the indexing variable, and then to compare the regression lines (slopes and intercepts) for the boys and girls for each valve.

Visual inspection of smoothed regression curves indicated that the relationships between each valve and either BSA or height were very similar for boys

Table 1. Gender-specific z value formulae for two-dimensional valve measurements

Valve	*Z*value		
	Girls	Boys	*p* value[a]
Mitral	(lnMV-(0.733 + 0.408 * LnBSA))/0.18	(lnMV-(0.765 + 0.425 * LnBSA))/0.169	0.022
Tricuspid	(lnTV-(0.755 + 0.364 * LnBSA))/0.186	(lnTV-(0.817 + 0.391 * LnBSA))/0.171	0.0001
Aortic	(lnAV-(0.437 + 0.461 * LnBSA))/0.127	(lnAV-(0.472 + 0.492 * LnBSA))/0.141	0.002
Pulmonary	(lnPV-(0.597 + 0.476 * LnBSA))/0.144	(lnPV-(0.618 + 0.498 * LnBSA))/0.152	0.126

AV, aortic valve dimension (cm); BSA, body surface area (m^2); In, natural logarithm; MV, mitral valve dimension (cm); PV, pulmonary valve dimension (cm); TV, tricuspid valve dimension (cm).
[a] *p*value for male and female differences in mean values.

and girls, with the curves being slightly higher for boys in each case. It was determined that a log transformation was appropriate to make each of the valve distributions suitably near normal. Furthermore, log transformation of BSA and height yielded the strongest correlations with all of the valves. Correlations were stronger with BSA than with height for all four valves. Correlations with BSA were 0.81, 0.91, 0.89, and 0.84 for tricuspid, aortic, pulmonary, and mitral valves, respectively, for boys and 0.76, 0.91, 0.89, and 0.80, respectively, for girls. Corresponding correlations with height were 0.72, 0.83, 0.81, and 0.75 for boys and 0.70, 0.86, 0.87, and 0.73 for girls. The relationships between the valve measurements and BSA were significantly different between boys and girls for three of the four valves ($p < 0.05$) (Table 1). We found that although the slopes were the same for girls and boys, the intercepts were different. Thus, the boys had higher means after adjusting for differences in BSA. This gender difference was also observed when valve measurements were adjusted for both BSA and height simultaneously in the ANCOVA models. Furthermore, there was no independent effect due to height for any valve when it was included in the model with BSA. Therefore, the nomograms presented in Figs. 1, 2, 3, 4 were developed separately for boys and girls using results of regression analyses taking the form $y = \alpha + \beta(ln(\text{BSA}))$, where y is the natural logarithm of the mean normal value for the valve (cm), *ln* is natural logarithm, BSA is body surface area (m^2), α is the intercept, and β is the regression coefficient. These nomograms are based on the following relationship: $z = [\,ln(\text{valve}) - ln(\text{mean normal value})]/$ root mean square error.

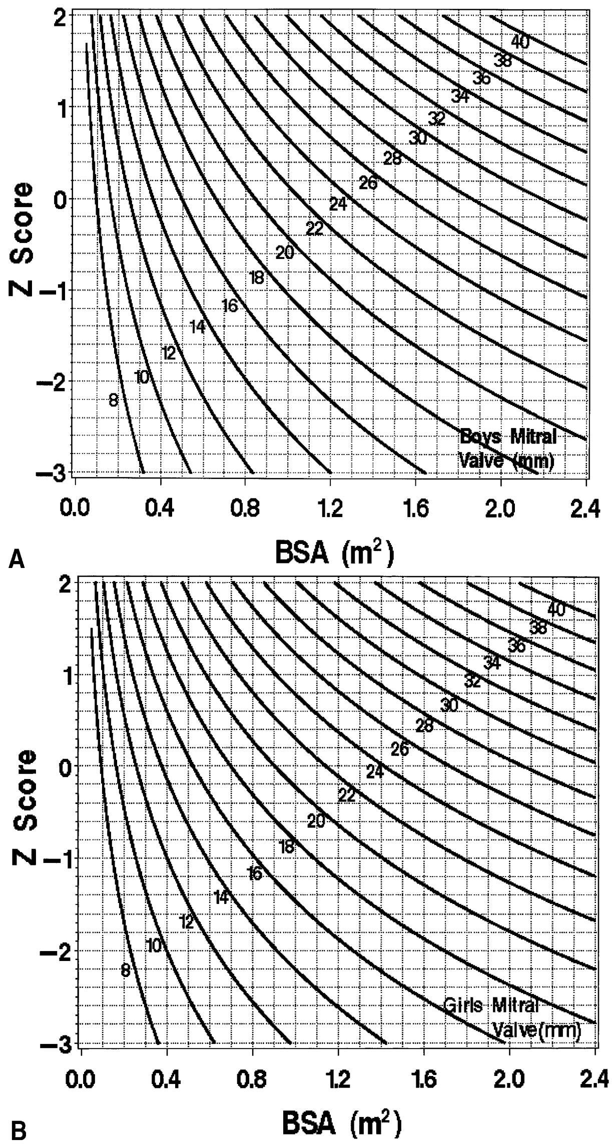

Fig. 1. Mitral valve *z* value nomogram for (left) boys and (right) girls, *BSA*, body surface area.

Discussion

This is the largest study of pediatric normal valves that provides standardized 2-D measurements in pediatric patients. It reflects valve sizes in children from the greater Cincinnati metropolitan area.

As valve dimensions undergo changes through infancy and childhood, their measurements need to be correlated to a given size of the body. Previously published studies used BSA [1, 3, 8, 9, 13, 14], height

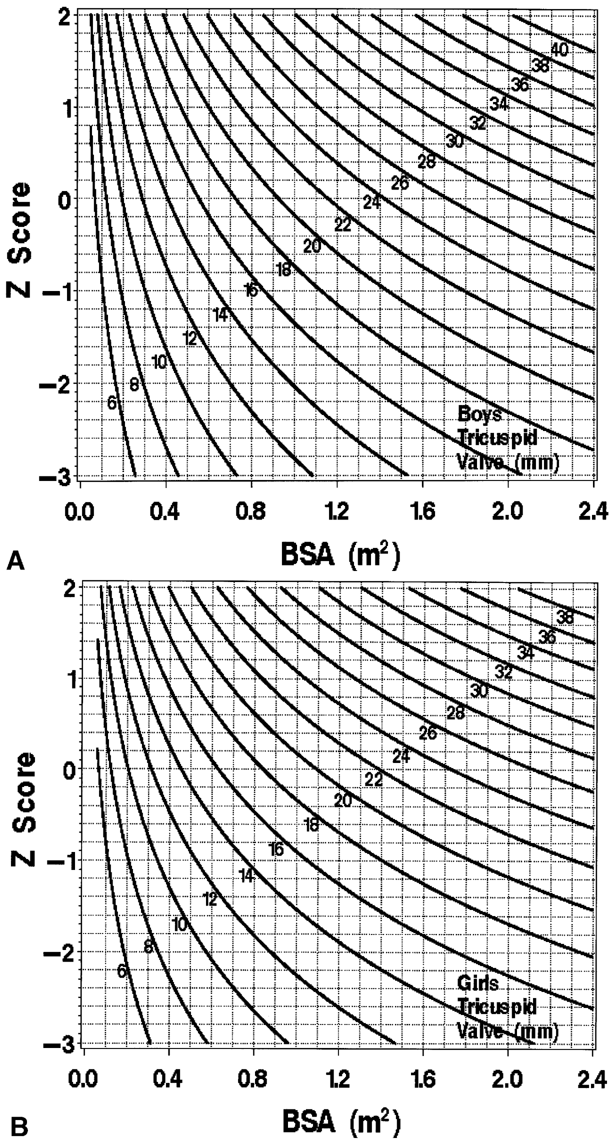

Fig. 2. Tricuspid valve *z* value nomogram for boys (left) and (right) girls. *BSA*, body surface area.

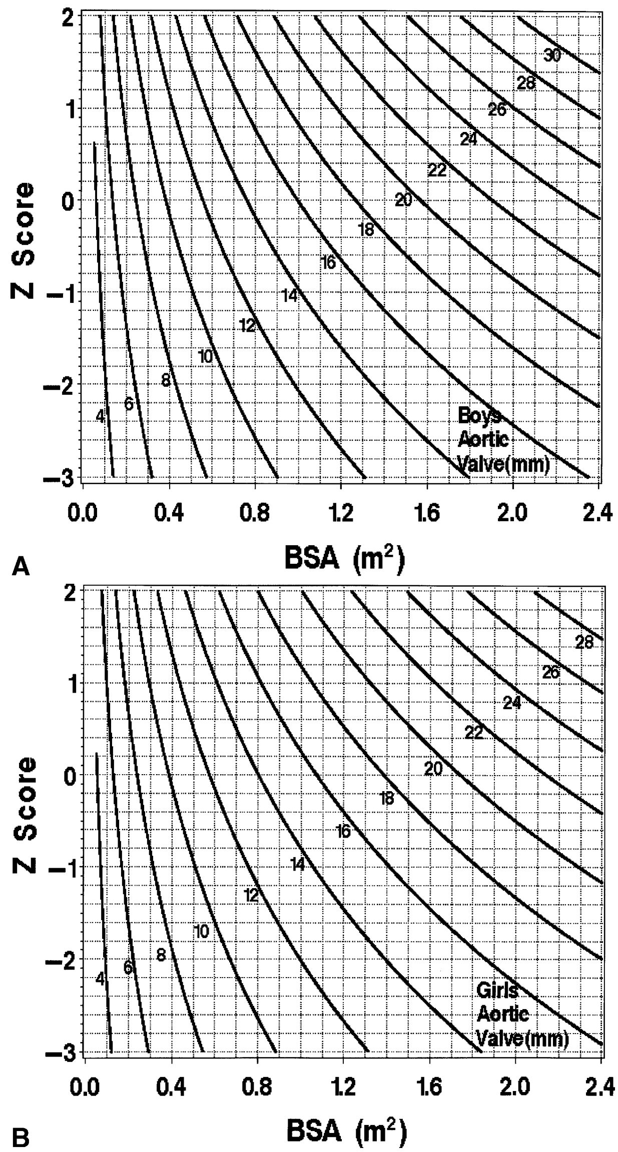

Fig. 3. Aortic valve *z* value nomogram for (left) boys and (right) girls. *BSA*, body surface area.

[5, 7, 10, 12, 16, 18, 19], or, for neonate assessment, weight [7, 12, 18, 19]. Sheil et al. [16] showed that in correlating with aortic root diameter, BSA was not superior to height. In order to find a normalizing factor that would address this issue more closely, we evaluated valve dimensions indexing to BSA and height, separately and combined. In our group of patients, BSA was clearly a better independent predictor, and height gave no added explanatory value in the models.

There is no universally accepted method of measuring cardiac valve dimensions. Roman et al. [14] applied the recommendations of the American Society of Echocardiography regarding M-mode measurements [15] to 2-D measurements. Sheil et al. [16] showed that systolic aortic valve dimensions were consistently greater than the diastolic ones, and they used systolic dimensions for analysis. As have many other investigators [3, 6, 9], we measured valves at their maximal dimensions (i.e., aortic and pulmonary valves in the early systole and mitral and tricuspid valves in late diastole).

An interesting finding of this study is the small but statistically significant gender differences in valve dimensions after adjustment for differences in body sizes. Valve dimension gender difference has been shown in adult studies. Assessing 135 adults, Roman

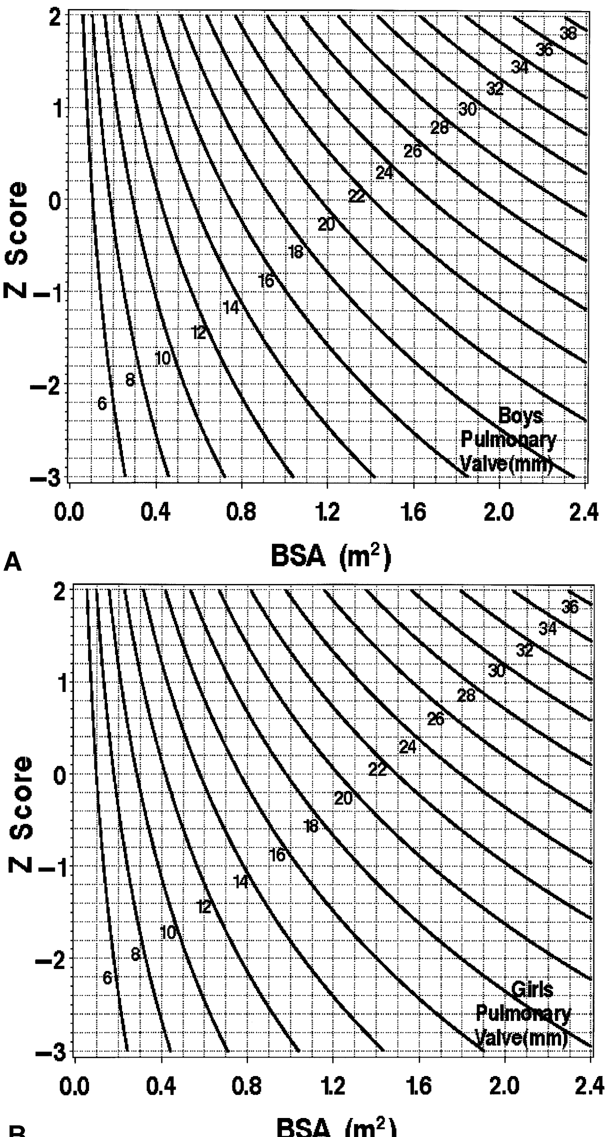

Fig. 4. Pulmonary valve *z* value nomogram for (left) boys and (right) girls. *BSA*, body surface area.

et al. [14] showed gender differences in the absolute values of aortic root dimensions, including the aortic annulus, although the values were similar when indexed to BSA. The authors concluded that sex-specific differences in aortic root dimensions were due to the differences in body sizes. Previously performed pediatric studies based on much smaller groups of subjects show no gender difference [3, 6, 9, 14, 16, 17]. However, prepubertal gender difference in left ventricular mass has been shown by de Simone et al. [4]. These authors studied 424 children from Cincinnati Children's Hospital. Although the gender difference in left ventricular mass, before puberty was not statistically significant, in each age group boys had 5%–8% higher left ventricular mass than girls. The authors observed that the gender difference in left ventricular mass was parallel to differences in body height. A small sex difference in left ventricular mass was found in children 7–11 years old in the Bogalusa Heart Study [2]. The authors concluded that sex differences play a considerable role in the determination of heart size. Additional evidence of prepubertal gender differences in heart measurements was presented by O'Leary et al. [11]. When evaluating diastolic function in 223 children, the authors found that boys had a slightly larger mitral E wave and pulmonary vein diastolic time velocity integrals as well as lower ratio of pulmonary vein systolic-to-diastolic time velocity integrals than were observed in girls. The differences reached statistical significance. The data showing that prepubertal boys have higher left ventricular mass [2, 4] and higher transmitral flow [11] are in agreement with our findings of larger valve dimensions in boys. We speculate that these collective data may reflect higher circulating blood volume in prepubertal boys compared to that in prepubertal girls. Because the differences are subtle, they reach statistical significance only when evaluated in a large group of subjects.

Study Limitations

Our study has some limitations. First, there may be a possible decrease in the precision of the measurements of mitral, tricuspid, and pulmonary valve diameters, because the measurements were performed in the direction of lateral, rather than axial, resolution of the equipment. We chose these views because they are used routinely by the majority of echocardiography laboratories. Second, for the smallest values for each valve, a small difference in BSA has a great effect on the value of *z* scores, making these nomograms of possible lesser use in the smallest patients.

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