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Echocardiographic determination of right ventricular function

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With advances in surgical technique, more children with complex congenital heart disease are surviving.[1] Increasingly, attention is focusing on late morbidities, such as right ventricular dysfunction.[2] For many common forms of congenital cardiac malformations, the assessment of right ventricular size and function is now essential so as to make optimal decisions concerning management.[3] Commonly encountered examples include the timing for operative replacement of the incompetent pulmonary valve following surgical repair of tetralogy of Fallot, and the assessment of suspected ventricular dysfunction in children with functionally single or systemic right ventricles.[4] Echocardiography remains the most practical method for serially determining right ventricular function, despite its limitations.[5] The easy accessibility of echocardiography has encouraged its continued development as a tool for determining right ventricular function in neonates, infants, and children. A comparison of values established for the right ventricle is shown in Table 1, along with the references from which they were culled. We will describe these values in sequence.

Table 1.

Index	Value	Reference
Right ventricle EDV	53 ± 12 ml/m^2	14
Right ventricle EF	49 ± 5%	14
Right ventricle AFS	54.6 ± 10.5%	17
Right ventricle d*P*/d*t*	1200 mmHg/sec	18
Right ventricle MPI	0.32 ± 0.05	22
Right ventricle MPI	0.3 ± 0.05	17
Right ventricle TDI-derived annular decent (E/a)	170 ± 40/100 ± 20	20

Abbreviations: EDV: end diastolic volume; EF: ejection fraction; AFS: area of fractional shortening; MPI: myocardial performance index; TDI-derived annular decent (E/a): tissue Doppler-derived annular velocities

Right ventricular systolic performance: ejection fraction

The calculation of left ventricular ejection fraction by echocardiography is based on the assessment of left ventricular volumes, using the geometric assumption that the left ventricle conforms to the shape of a "bullet", or an ellipsoid of revolution. The complex shape of the right ventricle confounds determination of the indexes of its ejection phase by similar geometric assumptions. Furthermore, the right ventricle enlarges more in its short than its long axis,[6] and translational motion is significant. Methods based on radionuclide ventriculography, and magnetic resonance imaging, therefore, have been preferred for determining right ventricular volume and function because they are considered non-geometric. In practice, separation of right ventricular borders can be problematic with radionuclide ventriculography, whereas magnetic resonance imaging determines right ventricular volume from the sum of the areas of multiple slices.[7] Using estimates of right ventricular volumes derived using radionuclide ventriculography in 32 children, the normal right ventricular ejection fraction in children has been estimated to be 49 plus or minus 8 percent.[8] Using ultrafast computerized axial tomography, the calculated normal right ventricular ejection fraction in adults is 57 plus or minus 5 percent.[9] In children, the use of magnetic resonance imaging in cohorts of 12[10] and 7[11] patients has produced values of 66 plus or minus 6 percent and 55 plus or minus 3 percent, respectively. The normal diastolic volume of the right ventricle as

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calculated with magnetic resonance imaging has been reported to range between 71 plus or minus 13 milliliters per meter squared in the cohort of 12 children,[10] and 75 plus or minus 13 milliliters per meter squared in a larger series of 75 children.[12]

The method based on area and length is an empirically-derived approximation that estimates right ventricular volume as two-thirds of the product of area as measured in the apical 4 chamber view and the length as seen in subcostal short axis.[13] This value correlates best with magnetic resonance imaging, but assumes a constant relationship between the dimensions of the ventricle in two planes.[7] Using echocardiographically-derived estimates of right ventricular volumes, which in normals equate to 53 plus or minus 12 milliliters per meter squared, the normal right ventricular ejection fraction has been reported as 49 plus or minus 5 percent using an echocardiographic subtraction method.[14] The dependence of ejection fraction on afterload[3,15] downgrades its efficacy in general, but this dependence is a particular problem for right ventricular ejection fraction.[16]

Right ventricular systolic performance: right ventricular area of fractional shortening

The area of fractional shortening of the right ventricle is calculated by subtracting its end-systolic area from the end-diastolic area, and then dividing by the end-diastolic area. When this area, in adults, is correlated with the right ventricular ejection fraction as determined using magnetic resonance, the value obtained with resonance imaging is equal to the right ventricular area of fractional shortening minus 7.16 and divided by 0.831.[6] The area of fractional shortening as determined for a group of children with a mean age 8 plus or minus 4.3 years has been reported to be 54.6 plus or minus 10.5 percent. The area of fractional shortening has been shown to be significantly lower, at 43 plus or minus 10 percent, in a group of 32 asymptomatic children having a systemic right ventricle pumping the Fontan circulation,[17] confirming that the area of fractional shortening, as with right ventricular ejection fraction, is afterload dependent.

Right ventricular systolic performance: the rate of rise of ventricular pressure

In the presence of significant tricuspid insufficiency and pulmonary hypertension, it is possible to determine the rate of rise of right ventricular pressure, the so-called right ventricular dP/dt. Echocardiographic determination of this value requires tricuspid regurgitation at peak velocities with greater than 3 meters per second.[18] Normal values have been reported as greater than 1200 millimeters of mercury per second, and abnormal ones as less than 1000 millimeters of mercury per second. While the rate of rise of right ventricular pressure is non-geometric, it is likely to be dependent on preload, as is the case with the left ventricle.[19]

Right ventricular systolic performance: tricuspid annular velocity

The normal values for systolic velocity and acceleration of the annulus of the tricuspid valve have been established in a group of 141 children, the velocity being dependent on age.[20] Systolic annular velocity is 60 plus or minus 10 millimeters per second, and the acceleration is 206 plus or minus 65 centimeters per second squared, for infants under 1 year of age. Comparable values for children older than 1 year of age are 100 plus or minus 50 millimeters per second and 210 plus or minus 47 centimeters per second squared, respectively. The normal reported value for systolic velocity in adults is 155 plus or minus 26 millimeters per second.[21] The positive predictive value for this parameter as an indicator for right ventricular dysfunction has been established in adults,[21] but not in children.

Composite indexes of right ventricular performance

The myocardial performance index, also known as the Tei index, is a non-geometric method for estimating both systolic and diastolic performance.[22] The systolic parameters, namely isovolumic contraction and ejection times, along with isovolumic relaxation time as a diastolic parameter, are determined using Doppler echocardiography. The index is then calculated by summing the contraction and diastolic times, and dividing by the ejection time.

The normal index has been calculated in a small sample of 7 subjects as 0.32 plus or minus 0.05,[22] and as 0.3 plus or minus 0.05 in a larger sample of 32 subjects.[17] Use of the index is probably invalidated in the setting of heart block and arrhythmias. Furthermore, whilst the index is touted as being load-insensitive, the effects of loading are still controversial.

Right ventricular diastolic performance: annular velocities derived using tissue Doppler

Ventricular filling is an index of the compliance properties of the ventricle, and hence a global measure of diastolic performance. Peak velocity through the ventricular inlet typically shifts from the passive early filling to the later active filling with decreased ventricular compliance. Velocities of inflow through

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the mitral and tricuspid valves, however, are typically highly dependent on load.[23]

Using tissue Doppler imaging, it is possible to determine the velocities of the atrioventricular valvar annuluses. With the transducer positioned to acquire the apical four chamber view, the sample volume is placed on the lateral aspect of the tricuspid annulus. Normally, both early, the so-called pre-p wave, and a later "post-p wave" are seen as peaks in the trace showing velocity, with the early peak predominating. In a group of 141 children, the normal velocity of the early peak has been calculated as 170 plus or minus 40 millimeters per second, with the velocity of the late peak measured at 100 plus or minus 20 millimeters per second.[20]

The velocities of the mitral valvar annulus have been studied more extensively than the tricuspid annulus. In diseased states, velocities of the mitral annulus appear more insensitive to pre-load than to inflow velocities through the mitral valvar orifice. Extrapolating from the behaviour of the velocities of the mitral valvar annulus in diastole, we anticipate that the velocities of the tricuspid valvar annulus will also be more insensitive to load than inflow velocities through the tricuspid valve. With decreasing ventricular compliance, the maximum diastolic annular velocity in patients studied serially would be expected to shift from early to late. Of note, the newborn appears to be less compliant, exhibiting equivalent velocities of early and late filling,[24] as well as equivalent velocities.[20]

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