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Original Article

The repeatability of echocardiographic determination of right ventricular output in the newborn

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Abstract *Background:* Non-invasive measurement of left ventricular output has been shown to be a repeatable technique. Little is known about the repeatability using echocardiography in determining pulmonary arterial diameters or right ventricular output. *Aims:* To find the most repeatable point at which to measure pulmonary arterial diameter, and to compare the repeatability of determining right ventricular output with left ventricular output. *Methods:* We assessed the Intra-observer and inter-observer repeatability for measuring the diameter of the pulmonary trunk in 24 term and 26 preterm infants, respectively. Inter-observer repeatability was assessed for the diameters of the pulmonary trunk and aorta, for stroke distance, and for left and right ventricular output. *Results:* The coefficients of variation for intra-observer repeatability were 4%, 7.5% and 9% respectively for measurements of the pulmonary valve, the pulmonary trunk, and the right ventricular outflow tract. There were significant differences between observers for measurement of the pulmonary trunk ($p< 0.001$) and right ventricular outflow tract ($p= 0.011$) but not for the pulmonary valve measured in either its long ($p= 0.22$) or short axis ($p= 0.22$). Significant differences between observers were also found for the pulmonary stroke distance measured in the long axis ($p= 0.004$) and aortic diameter at end-diastole ($p< 0.001$). The other parameters did not differ significantly and were used to calculate right and left ventricular output, respectively. Mean left ventricular output was 241mls/kg/min, with mean differences between observers of 0.6mls/kg/min (95% confidence interval (CI): –39.2 to 40.3mls/kg/min). Mean right ventricular output was 255mls/kg/min, with mean differences of 0.3mls/kg/min (95% CI: –24.1 to 23.4mls/kg/min). *Conclusion:* Measuring the diameter of the pulmonary trunk at the base of the valvar hinge points was most repeatable. Repeatability of right ventricular output was similar to that of left, with absolute values similar to those published by other workers.

Keywords: repeatability, pulmonary arteries diametre, 2D-echocardiography, newborn infant, right ventricular output

NON-INVASIVE ASSESSMENT OF LEFT VENTRICULAR output has become increasingly popular as a clinical and research tool in neonatology, and studies have shown that it is a valid and repeatable technique.[1–6] Recent investigators have also used echocardiography to assess right ventricular output in newborns[7]. Its measurement is of particular interest due to the rapid changes in atrial and ductal shunting. Critical to this is the measurement of the diameter of the pulmonary trunk. In determining right ventricular output, the cross-sectional area of the pulmonary trunk is derived using πr^2, where r is the radius of the vessel. This is multiplied by the Doppler flow-integral (or "stroke distance") to derive stroke volume. Right ventricular output is then calculated by multiplying stroke volume by heart rate.

Studies at all ages, including the newborn, have shown good repeatability when assessing the diamter of the aortic root [8–11] to determine left ventricular output, but no such study so far has

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evaluated the measurment of the diameter of the pulmonary trunk in the newborn. This study was performed to rectify the deficiency. Specifically, we sought to

- find the most repeatable point at which to measure the diameter of the pulmonary trunk
- define the repeatability of echocardiographic determination of right ventricular output
- compare the repeatability of determination of right ventricular output with that obtained for left ventricular output

Methods

Following informed parental consent, all infants underwent clinical cardiovascular examination. Cross-sectional echocardiography to exclude congenital cardiac malformations was performed using a Hewlett-Packard Sonos 2500 ultrasound machine. All infants were resting quietly without sedation.

Approval was given by the Local Research Ethics Committee.

Repeatability of measurement of the diameter of the pulmonary trunk

The ventriculo-pulmonary junction was visualized from the standard parasternal short axis and the diameter was measured at three points (Fig. 1):

- at the basal attachment of the hinge points of the valve
- within the pulmonary trunk, approximately half way between pulmonary valve and the bifurcation
- at the base of the muscular subpulmonary infundibulum.

Measurements were taken from the inner surface of the outflow tract for the second and third positions.

Between and within observer repeatability was assessed for these three views. A fourth view, using the tilted parasternal long axis view of the trunk measuring at the basal attachments of the hinge points of the valve, was also assessed for between observer repeatability (Fig. 2).

Within (intra) observer repeatability

Population studied: One examiner (BTG) studied 24 healthy infants born at term. Their age ranged from 10 hours to 4 days, and their weights at birth from 2960g to 4200g.

Methods: The ultrasound probe was placed parasternally on the chest so as to visualise the pulmonary trunk in its short axis. The screen was then frozen to permit measurement of the three diameters described above. Prints were taken of the frozen screen with the measured values. The area of the screen showing the measured value was obscured throughout the measurement period to avoid potential subjective bias from knowing the earlier measurements. The procedure was repeated up to 6 times or until the infant became restless. It proved possible to make 6 measures in 2 infants; 5 measures in 21 infants; and 4 measures in one infant.

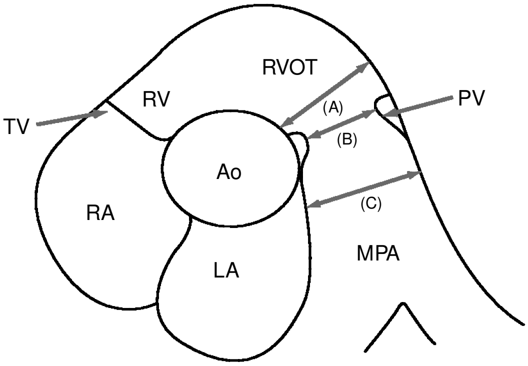

Figure 1.
Schematic drawing of the right ventricular outflow tract (RVOT) as seen in parasternal short axis, showing the diamters measured (a) hinge points of the leaflets of the pulmonary valve (PV) (b), the pulmonary trunk (MPA) (c) (LA = left atrium, RA = right atrium, TV = tricuspid valve, RV = right ventricle, AO = Aorta)

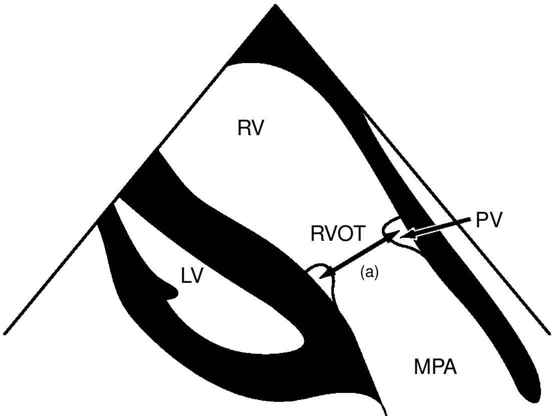

Figure 2.
Schematic drawing of the right ventricular outflow tract as seen in long axis: This view is obtained by tilting transducer anteriorly. The diameter of the pulmonary trunk is taken at the basal attachments of the leaflets of the pulmonary valve (a) (LV = left ventricle, RV = right ventricle, RVOT = right ventricular outflow tract)

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Statistical analysis: A one-way analysis of variance was used for each of the three positions and components of variation were calculated for between- and within-child. The within-child standard deviation is a measure of repeatability of readings performed on the same child by the same observer. In order to compare the three positions, the pooled standard deviation was further divided by the mean across all children in order to obtain a within-child "coefficient of variation" (standard deviation x100/mean).

Between (inter) observer repeatability

Population studied: Two examiners (BTG and JRS) studied 26 healthy infants, 16 born at term and 10 prior to term, consecutively without sedation. Those born at term were aged between 14 hours and 3 days, with weights at birth between 2480g and 4050g. For those born prior to term, gestational age ranged from 27 weeks to 32 weeks, chronological age from 3 days to 3 months, and weights at the time of the echo from 925g to 1670g.

Methods: The two observers investigated the same babies consecutively, placing the probes independently on the chest. Each observer recorded representative cycles of the pulmonary trunk viewed in short and long axis onto videotape. The diameter for each of the four positions was measured retrospectively over 5 cardiac cycles to allow for respiratory variation. Each observer was unaware of the results of the other observer.

Statistical Analysis: The units of observation for this analysis were the means and the standard deviations across a set of 5 measurements. For the differences in the means, or the observer bias, we investigated first using Bland-Altman plots[12] and then with paired Student's t-tests. Regarding observers as a 'random effect ', components of variation between observers and between infants were calculated from the two-way analysis of variance.

Differences between observers in the standard deviations across 5 measurements, albeit the repeated 5 cycles are not 'true' replications here, were investigated using the Wilcoxon matched-pairs signed ranks tests. Only pooled within-child standard deviations, however, were used for data summary.

Repeatability of measurements of left and right ventricular output

Population studies: Right and left ventricular outputs were measured independently by 2 observers (BTG and JRS) in a further 9 healthy infants born at term when aged from 7.5 hours to 3 days, and with weights at birth ranging from 2.69kg – 3.89kg).

Methods: So as to calculate right ventricular output, we measured the diamteter of the outflow tract at the level of the pulmonary valve in the short and long axis as previously described. Pulmonary stroke distance was measured using pulsed-wave Doppler, with the sampling volume placed at the tips of the leaflets of the pulmonary valve in short and then long axis.

Measuring left ventricular output: The internal diameter of the aortic root was measured from the parasternal long axis view using M-mode echocardiography. It was measured both at end-systole and at end-diastole, using the trailing-to-leading edge technique to give the internal diameter (Fig. 3).[9] The aortic stroke distance was measured from the suprasternal notch using a blind non-imaging continuous-wave Doppler probe.[9,13]

The two observers investigated the same babies consecutively, placing the probes independently on the chest. Each observer recorded representative cycles of the pulmonary trunk viewed in short and long axis, and the pulmonary arterial stroke distance, onto videotape. For the diameter of the aortic root, the aorta was visualized in the parasternal long axis view and m-mode pictures of the root taken in systole and diastole were recorded onto videotape. Measurements for each of the seven parameters for left and right ventricular output were taken off-line and averaged over 5 cardiac cycles to allow for respiratory variation. The presence of atrial and ductal shunting, and the directions of the shunts, were noted using colour Doppler ultrasound. Each observer was unaware of the results of the other observer.

Heart rate was obtained from the beat-to-beat interval from the Doppler recording.

Right and left ventricular output were calculated for each baby according to the formula:

Cardiac output = $\pi r^2 \times$ stroke distance $\times$ heart rate – where radius r is half the diameter of either the pulmonary trunk or the aorta, respectively.

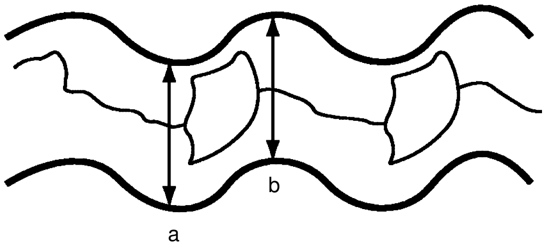

Figure 3.
Methods of measuring aortic diameter in parasternal long axis m-mode (a) = trailing edge to leading edge (end-diastole) (b) = trailing edge to leading edge (end-systole)

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Statistical analysis

Statistical analyses for the seven parameters were the same as for the comparisons made between observers for the first study. Right and left ventricular outputs were calculated using the non-biased parameters.

Results

Repeatability of measurements of the pulmonary trunk

Within (intra) observer study: The results for within-observer repeatability are shown in Table 1. Our data suggests that the standard deviation for measurements made in the same child, which gives an indication of repeatability for one observer, was smallest when measured at the pulmonary valve and largest when measured at the level of the infundibulum. This is also shown by the coefficient of variation, which is a ratio of standard deviation and mean for measurements taken in the same child. Variation amongst each of the 5 measurements, which is attributed to each infant, or the standard deviation between different children is very similar for each site of measurement. The repeatability of measurement for one observer, therefore, was best when taken at the basal attachments of the leaflets of the valve.

Between (inter) observer study: Summary of the results for the repeatability between observers is shown in Table 2. Summary statistics are given separately for babies born at term and prior to term. There were no significant differences between the two groups and statistical analyses are therefore based on both groups combined.

There was a significant overall disagreement between the two observers for the pulmonary trunk and infundibulum when measured in the short axis. For the pulmonary trunk, the means for the second observer were, on average, 0.8mm (95% CI: 0.5mm to 1.2 mm) smaller than those for the first observer. For the infundibulum, the means were higher by 0.5mm (95% CI: 0.1 mm to 0.8 mm). There is no significant difference between the observers when the diameter was measured at the level of the valve, irrespective of whether it was measured in short axis (mean difference: 0.2 mm, 95% CI: -0.1 mm to 0.4 mm) or long axis (mean difference: 0.2mm, 95%CI: –0.1mm to 0.6 mm). This is also reflected by the components of variation, which is the sum of variation between observers, between babies, and residual (error) variance. The variation between observers is negligible when the pulmonary trunk is measured at the level of the valve. Standard deviations for cycles measured within the same child are given for completeness.

Measurement of right and left ventricular output: Table 3 gives the results of differences between observers for the seven parameters. There was a significant bias between observers when the aortic diameter was measured at end-diastole (mean difference: –8.33mm, 95% CI: –13.01 mm to –3.66 mm), and for the pulmonary stroke distance measured in long axis (mean difference: 9 mm, 95% CI: 1.5 mm to 3.4mm). There was no observer bias seen with the other measurements.

Right and left ventricular outputs were calculated using the non-biased parameters. Left ventricular output was calculated, therefore, using the aortic diameter at end-systole. For the first observer, the average values for aortic diameter and aortic stroke distance were 8.1mm and 135mm, while for the second observer they were 8.1mm and 128mm, respectively.

Right ventricular output was based on the diameter of the pulmonary trunk measured in its short axis. For the first observer, the average values for diameter and pulmonary stroke distance were 9.5mm and 102mm, with values of 9.4mm and 101mm, respectively, obtained by the second observer.

The mean left ventricular output was 241 mls/kg/min, with a mean difference between observers of 0.6 mls/kg/min (95% CI: –39.2 to 40.3mls/kg/min). Mean right ventricular output

Table 1: Results of variability within observers measuring the diameter of the right ventricular outflow tract at three positions in 24 healthy infants born at term

Position of measurement in tern infants (n= 24)	**Mean of individual infants' means (mm)**	**Within-child standard deviation (mm)**	**Between-child standard deviation (mm)**	**Coefficient of Variation**
Pulmonary valve	10	0.4	1.2	3.9%
Pulmonary Trunk	9.3	0.7	1.1	7.2%
Right ventricular outflow tract	9.5	0.9	1.1	9.3%

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Table 2. Results of variability between observers measuring diamteres within the right ventricular outflow tract at four positions in 16 healthy infants born at term, and 10 healthy preterm infants

		(a) Mean {SD} (mm)			**(b) within child (between cycle) SD (mm)**	
		Obs1	**Obs2**	**Difference**	**Obs1**	**Obs2**
Pulmonary valve (long) axis	Term*	10[0.9]	10[0.8]		0.250	0.322
	Preterm*	7.8[1.0]	7.5[1.4]		0.385	0.295
	All	**9.3[1.6]**	**9.1[1.7]**	**0.2 [0.9] p= 0.22**	**0.31**	**0.31**
Pulmonary valve (short axis)	Term	9.6[0.7]	9.5[0.6]		0.332	0.286
	Preterm	7.6[1.3]	7.4[1.3]		0.213	0.278
	All	**8.9[1.4]**	**8.7[1.4]**	**0.2 [0.7] p= 0.22**	**0.332**	**0.286**
Pulmonary trunk	Term	8.9[1.0]	10[0.8]		0.489	0.434
	Preterm	7.3[1.0]	7.6[1.4]		0.426	0.311
	All	**8.3[1.4]**	**9.1[1.6]**	**–0.8[0.8] p< 0.001**	**0.466**	**0.391**
Right ventricular outflow tract	Term	11[0.9]	10[0.9]		0.619	0.63
	Preterm	8.5[1.6]	7.9[1.6]		0.482	0.58
	All	**9.7[1.5]**	**9.2[1.6]**	**0.5[0.9] p= 0.011**	**0.57**	**0.64**

*Term n= 16; Preterm n= 10

Table 3. Results of variability between observers measuring the seven components needed for calculation of right and left ventricular outputs

	(a) Mean [SD] (mm)			**Within-child SD (mm)**	
	obs1	**obs2**		**obs1**	**obs2**
Pulmonarystroke distance (long axis)	10.9 [1.33]	9.7 [1.41]	p= 0004	0.51	0.60
Pulmonary stroke distance (short axis)	10.2 [1.34]	10.1 [1.43]	p= 0.72	0.58	0.47
Pulmonary truncal diameter (long axis)	9.5 [0.78]	9.7 [1.12]	p= 0.55	0.28	0.38
Pulmonary truncal diameter (short axis)	9.5 [0.88]	9.5 [1.08]	p= 0.72	0.34	0.31
Aortic diameter (end systole)	8.1 [0.62]	8.1 [0.64]	p= 0.43	0.22	0.27
Aortic diameter (end-diastole)	7.1 [0.7]	8.1 [0.8]	p< 0.001	0.25	0.33
Aortic stroke distance	13.5 [1.34]	12.7 [1.04]	p= 0.015	0.74	0.36

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was 255 mls/kg/min, with a mean difference between observers of 0.3 mls/kg/min (95% CI: –24.1 to 23.4 mls/kg/min).

Discussion

Assessment of left ventricular output with echocardiography is now an established research tool in the neonatal setting, having undergone studies of validation and repeatability.[1–6] At all ages, the largest source of errors in repeatability is the measurement of diameters of vessels.[8–11] Since cardiac output is derived by multiplying stroke distance and heart rate by cross-sectional area (πr^2), any error in diameter, and hence radius, is squared.

Hudson and colleagues[9] found that aortic diameter was measured most repeatably with m-mode echocardiography at end-diastole, and aortic flow velocity with continuous wave Doppler. We, therefore, elected to use m-mode echocardiography to measure this parameter. Measurements at end-diastole and end-systole were equally repeatable, but one observer consistently measured a larger diameter than the other in end-diastole, so we based our calculations of left ventricular output calculations on measurements taken at end-systole. Velocities of aortic flow were measured with continuous-wave Doppler from the suprasternal notch, which we have also previously shown to be a repeatable technique.[13]

Recent haemodynamic studies in the newborn have included assessment of right ventricular output using very similar echocardiographic techniques.[7,14,15]To the best of our knowledge, however, there has not been a study evaluating repeatability of this method in the newborn.

The right ventricular outflow tract is a more elastic structure than the aortic root, and tends to expand more during systole. Furthermore, due to relatively poor lateral resolution, structures that lie perpendicular to the interrogating ultrasound beam are better defined than structures which are parallel to the beam. When insonating the pulmonary trunk from the precordium, the walls are parallel to the ultrasound beam, resulting in poorer definition. M-mode echocardiography requires structures to be perpendicular to the ultrasound beam and cannot, therefore, be used to measure diameters within the right ventricular outflow tract.

Taking these points into consideration, it is perhaps surprising that it is possible to obtain an error for repeatability between observers as low as 3.9% for the measurement of the diameter of the pulmonary trunk. We found that the best position for making this measurement was at the attachment of the pulmonary valvar leaflets as seen in the parasternal short axis view.

When two observers are involved in assessing right ventricular output in the same infant, and thus in measuring diameters, we found that repeatability was best when measured at the pulmonary valve irrespective of whether in parasternal short or long axis. Measuring the stroke distance, however, was most repeatable in short axis.

We are not aware of any previous studies comparing repeatability of measurement of right ventricular output to those of the left ventricle in the newborn, although serial measurements of both have been used in longitudinal assessment of haemodynamics in preterm infants with respiratory failure.[15,16] Unlike later in life, it is important to be able to measure both independently in the newborn period because of the large influence of interatrial and ductal shunting.[16] A high left ventricular output can, for example, be associated with a low right ventricular output in the presence of a large left-to-right ductal shunt.

It is important to stress that none of the infants in this study had a large left-to-right ductal shunt. Turbulence from ductal flow within the pulmonary trunk can disturb the Doppler signal, and could lead to inaccuracy in deriving the flow integral in determining right ventricular output. The technique is, therefore, validated for use in infants with a closed arterial duct, or those with low velocity ductal shunting, such as infants with persistent pulmonary hypertension. These infants often have low cardiac output, which may warrant intervention.[7,13]

Our study shows that right ventricular output can be measured with a similar repeatability to that of left ventricular output. The absolute value for left ventricular output (241 mls/kg/min) was comparable to those published by Hudson[9] et al. 231 mls/kg/min) and Alverson[2] et al (226 mls/kg/min). In our hands, measurement of aortic diameter using m-mode was more repeatable when taken at end-systole rather than end-diastole, as was also found by Hudson and colleagues. Cross-sectional measurements of the right ventricular outflow tract pose greater problems. In two separate studies, nonetheless, we have found that measurement can be performed repeatably at the basal attachment of the leaflets of the pulmonary valve in systole, using parasternal short or long axis views. Nevertheless, during serial assessment, it is probably wise to measure the diameter on one occasion, and assume it remains unchanged over a short period of time. Changes in right ventricular output can then be calculated solely on changes in the Doppler flow integral, also known as the stroke distance. We

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found this to be measured most reliably in the parasternal short axis view.

Intermittent assessment of cardiac output will remain valuable, but continuous measurement would be ideal. The development of a system to record right ventricular output continuously, avoiding errors of repeated measurementts of diameters, is now our ongoing project.[17]

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