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The angle of insonation for Doppler measurements of left and right ventricular output in newborns and infants

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Abstract

Background: The angle of insonation can be an important determinant of Doppler-derived cardiac output measurements. It is known anatomically that there is a larger insonation angle for the left vs. right ventricular outflow area, but variability and calculated angles have not been described. The aim of this study was to describe the anatomical position of the left and right outflow areas and determine the geometric angle of insonation in newborn and infants.

Methods: Magnetic resonance images of infants ≤ 2 years of age were explored. For each outflow, the position was determined relative to an anatomical reference point. To obtain the angle of insonation, the angle between the outflow and the hypothetical position of the ultrasound probe beam was calculated.

Results: Forty-five patients were included with a median age of 71 days old. Anatomically, the left outflow is directed almost vertically upwards in sagittal images with a 40º angle to the right in coronal images. The right outflow is directed 53º upwards in sagittal images with a slight angle to the left on axial images.

The median (range) angle of insonation for the left ventricular outflow area using the apical or subcostal view was 40° (22-51) and 28° (7-47) respectively, and 23° (2-40) for the right ventricular outflow area using the parasternal view.

Conclusions: The median geometric angle of insonation of the left outflow was larger than the right. The variation within the group was large, but in each individual case the angle for left was larger than for right.

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Introduction

Pediatric and neonatal intensive care specialists are often faced with clinical hemodynamic dilemmas that are challenging to interpret and manage due to a lack of basic hemodynamic, physiological information. In most units, cardiovascular function is monitored only by continuous heart rate, invasive blood pressure monitoring, and poorly validated clinical signs, such as capillary refill time. Although these parameters provide important information, they provide only indirect and frequently limited insight into the complexities of cardiac function. Doppler ultrasound measurements have been shown to offer a clearer understanding of the pathophysiology underlying the clinical presentations and can help guide treatment choices [1,2].

Hemodynamic monitoring with echocardiography by cardiologists or clinicians is increasingly used in adult, pediatric and neonatal intensive care settings, and training services and accreditation programs are becoming more widely available [3-6].

The echocardiographic parameters that assist in the comprehension of neonatal and pediatric hemodynamics are, amongst others, left ventricular output, right ventricular output, and more recently, flow in the superior vena cava [7,8]. These central blood flow parameters combined with assessment of ductal shunting and shunting through the foramen ovale provide information on global cardiac function and distribution of blood flow between the pulmonary and systemic circulation [9].

Understanding the limitations of Doppler-derived cardiac output measurements is essential. Valve outflow area (diameter) measurements and angle of insonation to determine the integral velocity time are the main contributors to the variability found in cardiac output measurements [10,11]. However, variability in anatomy has not been described, and the angle of insonation has also not been described in any paper to our knowledge. The aim of this study was to describe the anatomical position of the left and right ventricular outflow areas and establish the theoretical angle of insonation for determining left and right ventricular output in newborns and young infants.

Methods

This is a retrospective quantitative analysis of magnetic resonance images (MRI) of infants from birth until 2 years of age. The study was approved by the ethical committee of the University of Newcastle (08/HNE/178).

Magnetic resonance images of the chest, heart, abdomen and/or spine of infants up to 2 years of age were searched for within the radiology database of the John Hunter Hospital from 1997 to 2010. Infants with congenital heart disease or abnormalities of the great vessels were excluded. Infants for whom an abnormal position of the heart in the chest could be expected (e.g. congenital diaphragmatic hernia, scoliosis) were also excluded. Magnetic resonance imaging was performed on a 1.5 Tesla Siemens Vision, a 1.5 Tesla Siemens Avanto or a 3.0 Tesla Siemens Verio scanner (Siemens, Germany) during the study period, and most images were performed without contrast. In most cases, volume T1 images were used to identify the areas of interest. Magnetic resonance images of included infants were explored to obtain clear images of the left ventricular outflow area including the aortic valve annulus, aortic root and ascending aorta, and the right ventricular outflow area including the pulmonary valve annulus and pulmonary trunk. A line representing the flow direction was drawn perpendicular to the valve annulus in the center of the outflow area [12].

We analyzed two aspects of the outflow areas: ii) the position of the outflow areas compared to an anatomical reference point; and ii) The position of the outflow areas compared to an approximate position of the ultrasound probe for Doppler-derived measurements of the left and right ventricular outputs, i.e. the angle of insonation.

For the anatomical analysis, the reference points were: a line perpendicular to the thoracic spine in the sagittal images (Fig. 1), and the midline of the body in the coronal images (Fig. 2) for the left ventricular outflow area; and a line along the thoracic spine in the sagittal images (Fig. 3), and along the back of the ribs in the axial images (Fig. 4) for the right ventricular outflow area.

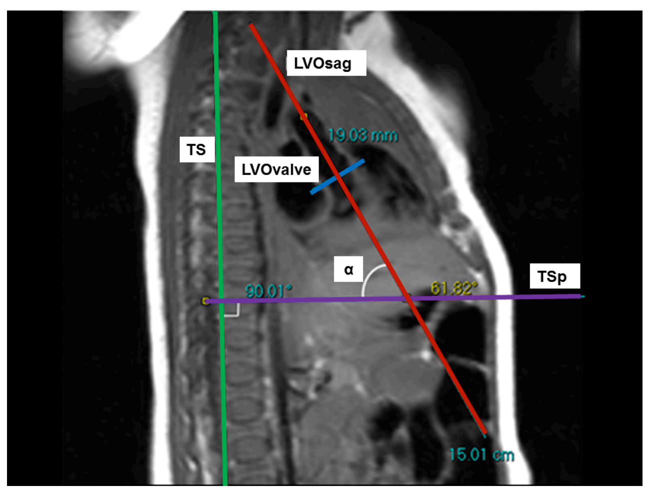

Figure 1. Example of a sagittal image for analysis of the anatomical position of the left ventricular outflow area

A line was placed through the aortic valve annulus (LVOvalve, blue line) with a line perpendicular to represent the left ventricular outflow area on the sagittal images (LVOsag, red line). A line along the thoracic spine was drawn (TS, green line) with a line perpendicular to be used as anatomical reference (TSp, purple line). The angle α between the red and the purple line was calculated by the software.

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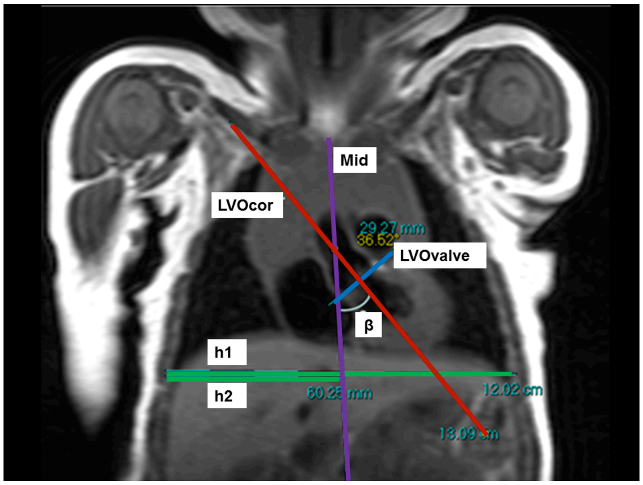

Figure 2. Example of a coronal image for analysis of the anatomical position of the left ventricular outflow area

A line was placed through the aortic valve annulus (LVOvalve, blue line) with a line perpendicular to represent the left ventricular outflow area on the coronal images (LVOcor, red line). A midline of the body (Mid, purple line) was placed using help lines (h1, h2, green). The angle β between the red and the purple line was calculated by the software.

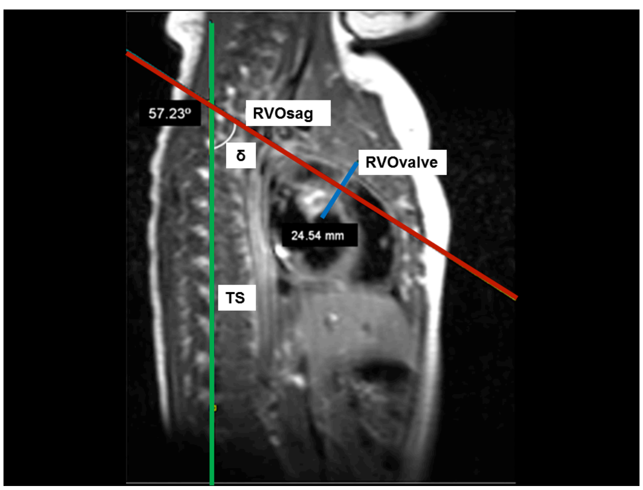

Figure 3. Example of a sagittal image for analysis of the anatomical position of the right ventricular outflow area

A line was placed through the pulmonary valve annulus (RVOvalve, blue line) with a line perpendicular to represent the right ventricular outflow area on the sagittal images (RVOsag, red line). A line along the thoracic spine was drawn (TS, green line). The angle δ between the red and the green line was calculated by the software.

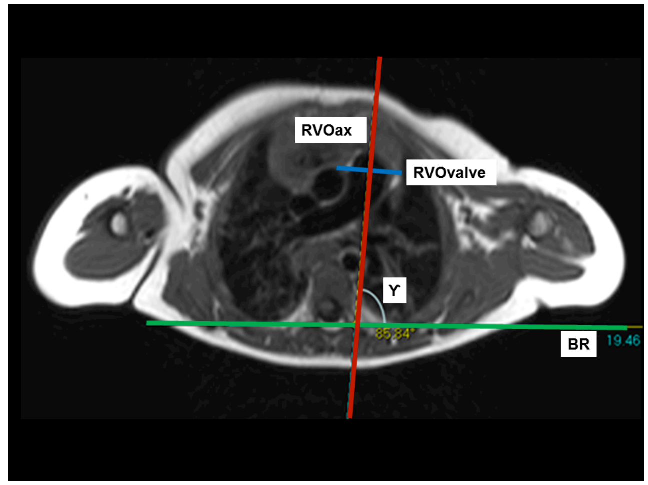

Figure 4. Example of an axial image for analysis of the anatomical position of the right ventricular outflow area

A line was placed through the pulmonary valve annulus (RVOvalve, blue line) with a line perpendicular to represent the right ventricular outflow area on the axial images (RVOax, red line). A line along the back of the ribs was drawn (BR, green line). The angle ϒ between the red and the green lines was calculated by the software.

For the analysis of the angle of insonation, we marked the approximate position of the ultrasound probe on the images and calculated the angle between the outflow areas and this superimposed probe position (Fig. 5). In newborns, left ventricular flow velocity is often measured from the apical or subcostal view, depending on the best views for image acquisition and optimal Doppler flow velocity measurements. For sagittal images, this would represent a position to the left side of the chest or lower along this line. For coronal images, the position of the Doppler probe would be just below the left nipple or left subcostal while avoiding stomach air. Right ventricular flow velocity is commonly measured from the parasternal view, with the ultrasound probe always close to the sternum. All angle calculations were obtained using the incorporated software (Kodak Carestream Pacs version 10.2, Kodak, USA).

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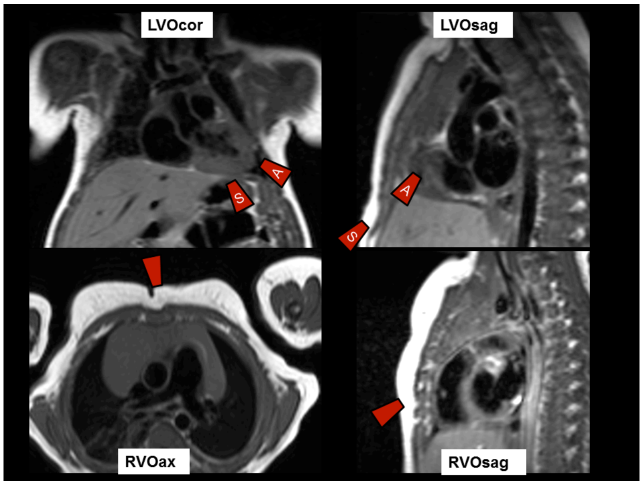

Figure 5. Examples of the approximate superimposed position of the ultrasound probe (red trapezoid) for each outflow tract

For left ventricular output measurements, the apical (A) and subcostal (S) positions are marked. LVOcor, coronal image of left ventricular outflow (LVO); LVOsag, sagittal image of LVO; RVOax, axial image of right ventricular outflow (RVO); RVOsag, sagittal image of RVO

To calculate the three-dimensional median angle of insonation, we used vector analysis. If two identified angles are converted into vectors in a square, the direction of the third vector can be determined. Vector analysis was calculated along the aligned axis. The left ventricular outflow area is aligned along the inferior-superior axis of the body, and the angle of insonation was calculated from the angles in the sagittal and coronal planes. The right ventricular outflow area is aligned along the anterior-posterior axis of the body and the angle of insonation was calculated from the angles in the axial and coronal planes.

Vector analysis of left and right ventricular outflow areas were compared using a Student's t-test, with $p < 0.05$ considered significant.

Results

The John Hunter radiology database revealed 142 chest, spine or abdominal MRIs of infants younger than 2 years of age. In 86 patients, the left or right ventricular outflow areas were not clearly visible on the MRI images and therefore not eligible for inclusion. Eleven patients were excluded because of abnormalities that could have influenced the normal anatomy of the chest or heart (5 scoliosis, 1 diaphragmatic hernia, 2 tumors, 3 cardiac abnormalities or abnormalities of the great vessels). Of the 45 included patients, 29 were male and 16 were female. The median age at examination was 71 days with a range from 2 days to 22 months.

The median angles and ranges of the left and right ventricular outflow areas in relation to anatomical reference points are presented in Table 1. Anatomically, the left ventricular outflow area is directed almost vertically upwards to the head in sagittal images with a 40º angle to the right in coronal images. The right ventricular outflow area is directed upwards with a 53º angle in sagittal images with a slight angle to the left on axial images.

Table 1. Left (LVO) and right ventricular outflow area (RVO) compared to an anatomical reference point

Outflow area	Anatomical reference line	n	Angle in degrees (median, range)
LVO			
Sagittal plane	Perpendicular to the thoracic spine	26	83° (59-93)
Coronal plane	Midline	35	40° (31-51)
RVO			
Sagittal plane	Along the thoracic spine	31	53° (35-73)
Axial plane	Back of the ribs	17	87° (72-96)

The median angles and range of the left and right ventricular outflow areas in relation to the approximate position of the ultrasound probe are presented in Table 2 and the vector analysis is schematically presented in Fig. 6. The left ventricular outflow area angle was significantly higher compared to the right ventricular outflow area angle (apical view left versus parasternal right, $p < 0.001$, subcostal view left versus parasternal right, $p < 0.047$).

Table 2. Angle of insonation of left (LVO) and right ventricular output (RVO)

Outflow area	Doppler probe placement	n	Angle in degrees (median, range)
LVO			
Sagittal plane	Apical or subcostal view	26	30° (4-49)
Coronal plane	Apical view	35	25° (11-33)
	Subcostal view	35	7° (1-22)
RVO			
Sagittal plane	Parasternal view	31	3° (1-14)
Axial plane	Parasternal view	17	23° (1-40)

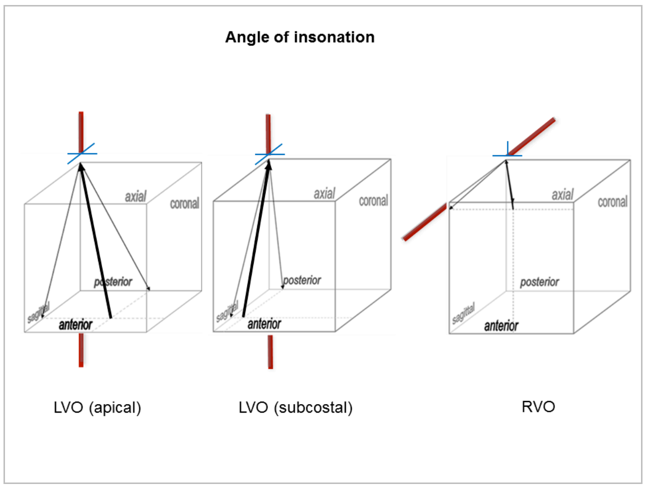

Figure 6. Schematic representation of the vector analysis of the angle of insonation for the left and right ventricular outflow areas

The blue lines represent the valvular annulus and the red lines represent the outflow area direction. The thick vector is the sum of the two thin vectors found on the MRI analysis.

Discussion

This study shows that the median angle of insonation for measuring left ventricular output area was larger than for right ventricular output in children less than 2 years of age. The variation within the group was large with a wide range of findings, but in each individual case, the angle for the left was larger than for the right. The geometric angles are large enough to have a significant effect on cardiac output measurements. In clinical practice, an expert ultrasonographer will tailor the placement of the probe to match the anatomical variation found by probe angulation and careful placement of the Doppler sample. However, zero angle measurements will be difficult to achieve, and according to the data found, the angle will always be greater for left than it will be for the right. This finding corresponds with previous research on the accuracy and reproducibility of various cardiac output measurements, with right showing better diagnostic accuracy compared to left ventricular output measurements [10,11]. This limitation of Doppler-derived cardiac output measurements should be emphasized in training courses.

Very few studies have tried to explore the angle of insonation of Doppler-derived cardiac output measurements. No references or comments related to the expected angle of insonation were found in echocardiography reference manuals, and when exploring the literature we found no studies exploring transthoracic Doppler angles. Two studies explored the Doppler angle of insonation of transesophageal echocardiography by correlating the images with anatomic sections. They found a favorable outcome for right ventricular outflow area measurements, compared to measurements in the ascending aorta [13,14]. Sloth et al. used magnetic resonance phase velocity mapping to obtain information about the direction of flow in the main pulmonary artery [12]. They determined the right ventricular outflow area flow direction from MRI images by drawing a line through the pulmonary valve annulus and comparing right ventricular flow to an anatomical reference point and Doppler images, similar to our methodological approach. Transesophageal multiplane images were performed in all ten healthy adults and a mean Doppler angle of 35º (range 26º - 46º) was found between the right ventricular outflow area and the 45º transesophageal angulated images. This could lead to a 20% underestimation of true cardiac output. They concluded in their studies that further studies should be conducted to reinforce the basis for Doppler velocity recording in the pulmonary artery as well as to investigate other important determinants of Doppler-derived cardiac output, namely assessment of the cross sectional area.

This study has several limitations. As mentioned earlier, the possibility of alternate placement of the probe and angulation of the transthoracic probe towards the direction of flow was not explored in this study. The study also does not take into account patient positioning, skin edema, lung interference or any additional potential variations that can affect probe position. In an ideal study design, ultrasound and MRI are to be performed simultaneously in all subjects with Doppler probe placement marked on the chest so it can be found with MRI image acquisition, providing more accurate angle of insonation calculations.

Our study is limited by its small sample size and relative wide range of age and body surface area, and it is likely that our findings cannot be translated to all age groups. Age-associated changes in left ventricular outflow tract geometry have been found in healthy adults, although the findings were more important for M mode measurement of ejection fraction than actual flow measurements using two-dimensional determination of cross-sectional area and flow velocity [15].

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