Original Research Article

Non-Invasive Qp/Qs ratio measurement with phase contrast MRI and echocardiography in patients with atrial septal defect: comparison with heart catheterization

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Received: 10-04-2021 / Revised: 20-05-2021 / Accepted: 11-06-2021

Abstract

Background: The objective of this study was to determine whether the assessment of pulmonary and systemic flow in patients with isolated atrial septal defects obtained by velocity encoded phase contrast magnetic resonance imaging was comparable to those acquired by heart catheterization and echocardiography.**Results:**Study population comprised 32 patients with Atrial Septal Defect.. All the three tests i.e. PC-MRI, Echocardiography, oximetry were done in all the patients after an informed consent with an average time gap of less than 24 hours between each. The mean values of Qp Qs as measured by the three methods depicted good correlation among them with p value 0.0001. The Bland–Altman plots for the measurement of Qp and Qs shows good agreement between the three methods, with correlation coefficient for Qp 0.85 measured by oximetry vs Echo and 0.93 fpr oximetry vs MRI and those for Qs 0.82 and 0.71 respectively. Qp/Qs ratios measured by MRI vs echo and oximetry showed excellent agreement, Mean differences of Qp/Qs ratios between echo and oximetry, and oximetry and MRI was 0.18% and 0.24% respectively. Both Qp/Qs ratios strongly correlated with correlation coeffient of 0.77 for oximetry vs echo and 0.72 for oximetery vs MRI. The Bland–Altman plots also showed good agreement between the three methods.**Conclusion:**Qp, Qs and Qp/Qs obtained by noninvasive methods ie Echocardiography and PC-MRI correlates well with that obtained by invasive oximetry. PC-MRI is non invasive, safe, feasible, reliable and accurate in assessment of flow dynamics in patients with ASD and has good agreement with invasive oximetry.

Keywords: Atrial Septal defect; pulmonary flow; systemic flow; phase contrast MRI.

Introduction

Atrial septal defect (ASD) is a common congenital heart defect that enables blood to flow between left and right atria through a defect in the interatrial septum. 10-15% of all congenital heart disease burden is attributed to ASD. Mixing of arterial (high oxygen content) and venous (low oxygen content) blood due to the left to right shunt causes eventual right ventricular overload and increases the pulmonary vascular resistance. The haemodynamic assessment of ASD or any shunt lesion is done by measuring Qp/Qs (pulmonary to systemic flow) ratio, which helps determine the treatment pathway as for a Qp/Qs ratio of >1.5, interventional or surgical closure is indicated. [1-5,8,19,21-24]This assessment can be performed by

1. Invasive methods like heart catheterization and indicator dilution method[1-4]
2. Noninvasive methods like phase contrast MRI, Doppler echocardiography and Radionuclide scintigraphy[5-16,21].

Cardiac catheterization/oximetry remains the traditional gold standard for quantification of shunt which is based on Fick's principle and is associated with radiation exposure. PC-MRI is a noninvasive technique to measure blood flow. The method is based on the principle that hydrogen nuclei is made to move in a magnetic field gradient that generates phase shift proportional to its velocity. Using this information a two dimensional map of velocities can be constructed. The product of average spatial velocity and cross sectional area of the vascular structure gives the volume of flow. Two dimensional echocardiography and doppler can be used to detect and quantify inta-cardaic shunts. In case of ASD RVOT diameter is taken in parasternal short axis view. Next step is to obtain VTI of RVOT using pulsed wave Doppler in parasternal short axis view. Then LVOT diameter is measured in parasternal long axis view. After that LVOT VTI is measured in apical five chamber view. Following formula is used to quantify QP and QS.

Methods

Qp = RVOT VTI ×π [RVOT/2]2
Qs = LVOT VTI ×π [LVOT/2]2
Qp/Qs Ratio = Qp/Qs [1, 2,8, 17,19]

This was a prospective study conducted in the Department of cardiology.The study population comprised 32 patients of diagnosed Atrial Septal Defect on echocardiography, without any other concomitant shunts,implanted pacemaker, severe arrythmia or claustrophobia. All the three tests i.e. MRI,Echocardiography, oximetry were performed after written informed consent, keeping the time gap between assessments as minimum as possible. During each evaluation patient's heart rate,blood pressure, respiratory rate and saturations were monitored.Magnetic resonance imaging studies were performed on a 1.5 Tesla scanner (Siemens).Cine images were acquired in multiple short axis and long axis views by fast imaging with steady-state free precession (SSFP) to assess cardiac function

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and localisation of the ASD (SSFP, slice thickness 8 mm, echo time 1.53 ms, pixel bandwidth 1085 Hz,repetition time 3.14 ms, matrix 256*202). Scout images of the ascending aorta and pulmonary trunk were obtained in three planes with SSFP sequences. Volumes of blood flowing in the ascending aorta and pulmonary trunk were determined in the isocentre of the magnet using plane phase-contrast MRI (PC-MRI) using retrospective gating under normal state of respiration ((flash 2D; slice thickness 5 mm, echo time 3.2 ms, pixel bandwidth 391 Hz, repetition time 41 ms, matrix 256*192). Using the SSFP scout images, PC-MRI was done orthogonally to the ascending aorta and the main pulmonary artery. Slice position in the ascending aorta was taken at approximately 2.0–3.0 cm above the aortic valve distal to the coronary arteries at the level of the right pulmonary artery whilst in pulmonary trunk slice position was approximately 1.5– 2.0 cm above the pulmonary valve but proximal to the bifurcation.In order to optimise the accuracy of PC-MRI, the velocity encoding was set as low as possible while avoiding aliasing artefacts. Usually, the velocity encoding was 100-150 cm/s for the measurement of the aortic and pulmonary flow. PC-MRI was performed during normal respiration to achieve flow results as physiological as possible. Data analyses were performed using ARGUS Flow software (Siemens). For the calculation of pulmonary (Qp) and systemic (Qs) flow volumes, the cross-sectional areas of the pulmonary trunk and ascending aorta were drawn manually for each time frame on the magnitude images and transferred to the corresponding phase image and Qp and Qs was obtained[19-23]Cardiac catheterization was performed and calculation of Qp and Qs was done as described by Grossman. Using right femoral vein access MP catheter was passed in the IVC-RA-RV-PA. Blood samples were taken from the superior and inferior vena cavae, right atrium and ventricle, pulmonary arteries. Using Rt femoral artery access, catheter was passed in aorta and systemic pressure was checked and sample was taken from aorta to determine the oxygen saturation. The invasive method of calculation of the blood flow for the systemic and pulmonary circulation was determined by Fick's principle.[1-3]Indexed Pulmonary Flow (QP) = O_2 consumption (mL/min/m2)

Pulmonary venous O_2 content – Pulmonary arterial O_2 content

Index systemic Flow (QS) = O_2 consumption (mL/min/m2)

Systemic arterial O 2 content - Mixed venous O 2 content

Mixed Venous O 2 content = 3(SVC O 2 Content) +1(IVC O 2 content)[5-8]

The transthoracic echocardiographic study was performed within 24 h before or after the diagnostic cardiac catheterization by an experienced investigator, who was unaware of findings obtained by other methods. It was ensured that the clinical condition (including heart rate) and medication of the patients did not change between cardiac catheterization and echocardiography. Patients were examined in the left lateral recumbent position while breathing in a relaxed manner. Left and right ventricular outflow tracts were recorded using Doppler and echocardiographic approaches without breathing in mid-expiration to minimize breath-dependent flow changes. No significant changes in heart rate were recorded in this short period. In a short-axis view, images of the right ventricular outflow tract, pulmonary ring and main pulmonary artery were obtained in a two dimensional Echo. Doppler ultrasound was used to determine the flow velocity in the centre just proximal to the pulmonary valve leaflets after excluding pulmonary regurgitation. The five chamber view was obtained by positioning transducer at apex. After excluding Aortic regurgitation by Doppler echocardiography, the flow velocity was measured directly proximal to the aortic leaflets in the center of the aortic annulus. The angle between the assumed blood flow and the cursor line of the sample volume was kept <20°, in each sampling.

Qp = RVOT VTI ×π [RVOT/2]2

Qs = LVOT VTI ×π [RVOT/2]2

Qp/Qs Ratio = Qp/Qs

LVOT Left ventricular outflow tract diameter (mm)

LVOT VTI LVOT subvalvular velocity time integral (cm)

RVOT Right ventricular outflow tract diameter (mm)

RVOT VTI RVOT subvalvular velocity time integral (cm)

Qp/Qs Pulmonary-Systemic Shunt Ratio

Data was analysed using paired t-test. P-value<0.05 was considered to be statistically significant. Statistical software SPSS-version 22 was used for data analysis. To verify the agreement between the methods, intraclass correlation coefficient was used.

Results

A total of 32 patients were included in our study, age ranging from 8years to 58 years with a mean age of 29.25 years. Sex ratio was 1:3 (M/F). All of the patients tolerated all three procedure well with no complications. All patients had normal sinus rhythm. No statistically significant differences were found in the age, gender, body mass index, heart rate, blood pressure and other clinical parameters of the patients. The time gap between MRI and cardiac catheterization was less than 24 hours for all patients. All echocardiograms were done within 24 hours of the diagnostic cardiac catheterization. The mean values of Qp Qs as measured by the three methods are described in Table 1 and the scatterplots in Figure 1 depicting good correlation among them with p value 0.0001(Figure 1 and table 1) . The Bland–Altman plots for the measurement of Qp and Qs shows good agreement between the three methods (Figure 2). Mean difference (solid line) and +- 2SD from this difference (broken lines) across all patients, with correlation coefficient for Qp 0.85 measured by oximetry vs Echo and 0.93 fpr oximetry vs MRI and those for Qs 0.82 and 0.71 respectively. Qp/Qs ratios measured by MRI vs echo and oximetry are depicted with a scatterplot (Figure 3) with excellent agreement, Mean differences of Qp/Qs ratios between echo and oximetry, and oximetry and MRI was 0.18% and 0.24%, respectively. Both Qp/Qs ratios strongly correlated with correlation coeffient of 0.77 for oximetry vs echo and 0.72 for oximetery vs MRI. The Bland–Altman plots also showed good agreement between the three methods(Figure 4).

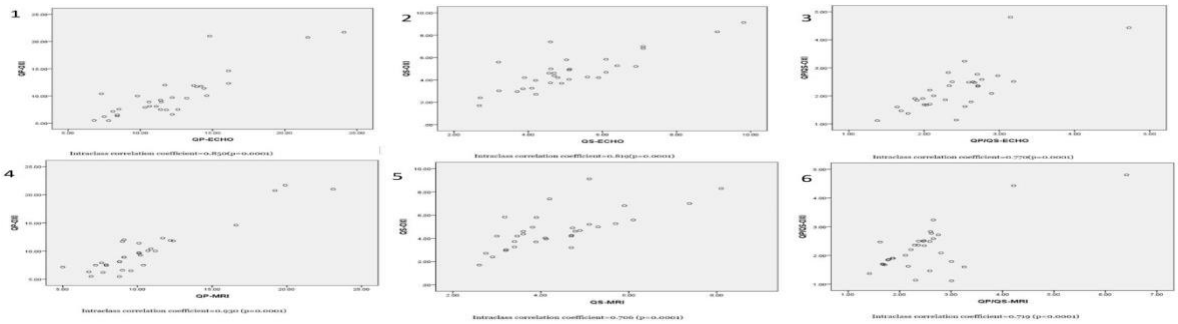

Figure 1 (1-6) Scatter diagrams showing correlation between
1 Qp obtained by Oximetry and that obtained by Echocardiography
2 Qs obtained by Oximetry and that obtained by Echocardiography
3 Qp/Qs obtained by Oximetry and that obtained by Echocardiography
4 Qp obtained by Oximetry and that obtained by MRI
5 Qs obtained by Oximetry and that obtained by MRI
6 Qp/Qs obtained by Oximetry and that obtained by MRI

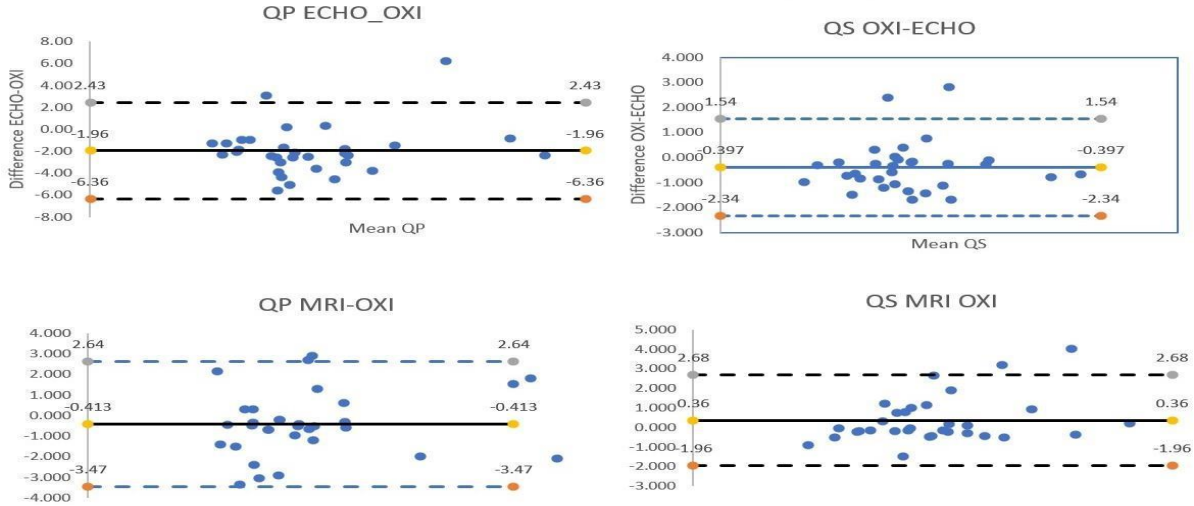

Fig 2: (1-6) The Bland–Altman plots for the measurement of Qp and Qs shows good agreement between Echocardiography , Oximetry and PC- MRI

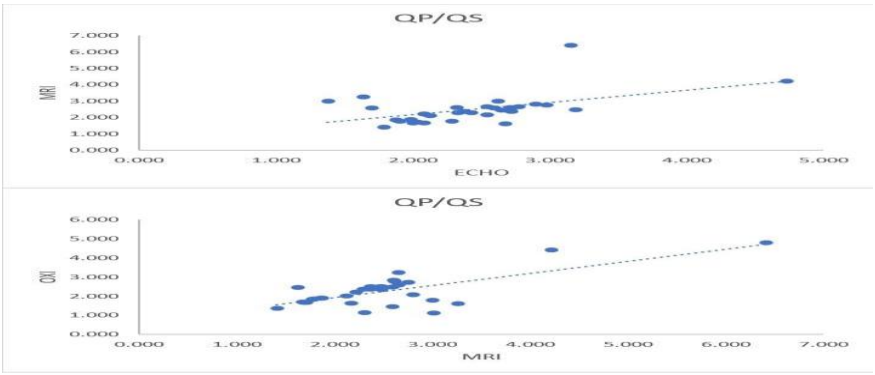

Fig 3: Scatter Plots. Qp/Qs ratios measured by MRI vs echo and oximetry, Mean difference (solid line) and +- 2SD from this difference (broken lines) across all patients.

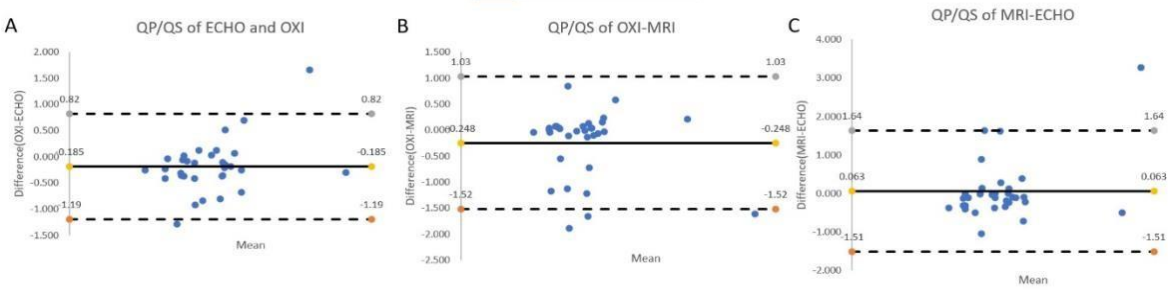

Fig 4: Bland Altman analysis For Qp/Qsas measured by the three methods: Echocardiography,Oximetry and PC-MRI

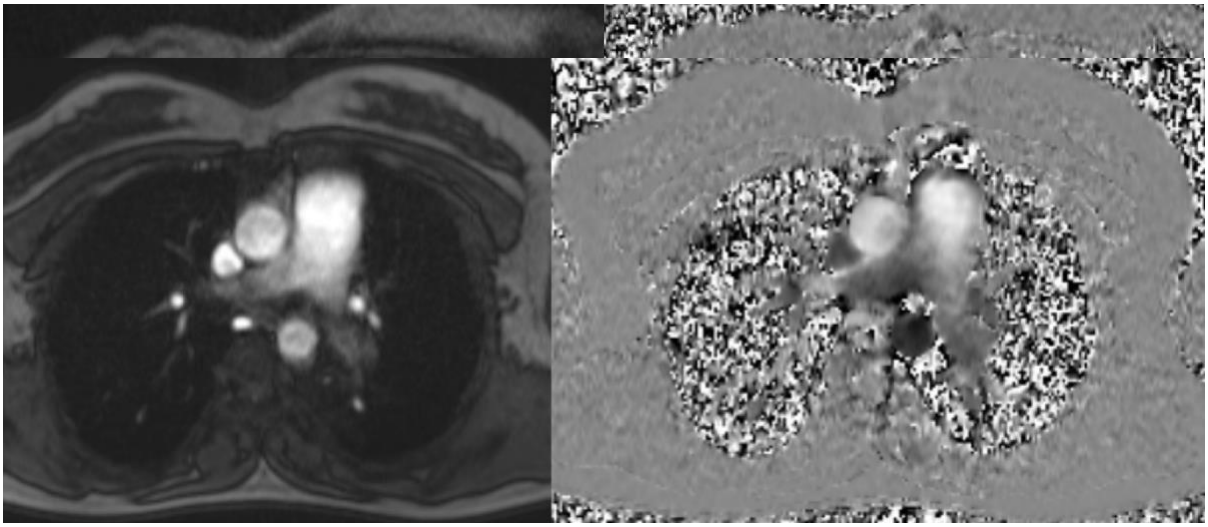

Fig 5 :Magnitude and Phase images for measurement of pulmonary flow by placing region of interest over the pulmonarytrunk

Table 1: The mean values of Qp Qs as measured by the three methods : Echocardiography ,Oximetry and PC- MRI

Parameter (n-32)	Mean value (l/m) (±2SD)	Intra class Correlation coefficient (r)	P
QP-OXI & QP-ECHO	10.1188±4.23453 12.0856±3.84929	0.850	<.0001
QP-OXI & QP-MRI	10.1188±4.23453 10.5322±3.96228	0.930	<.0001
QP-OXI & QS-ECHO	4.7188±1.66655 5.1156±1.62415	0.819	<.0001
QP-OXI & QS-MRI	4.7188±1.66655 4.3584±1.29050	0.706	<.0001
QP/QS-OXI & QP/QS-ECHO	2.2454±0.84880 2.4307±0.61253	0.770	<.0001
QP/QS-OXI & QP/QS-MRI	2.2454±0.84880 2.3802±0.91288	0.719	<.0001

Discussion

A plethora of methods are available to help estimate the pulmonary and systemic flow in patients with ASD, each with their own advantages and shortcomings. (1-5,8,21-24) In our study of 32 patients with an atrial septal defect, the mean value of Qp obtained by Oximetry is 10.1188±4.23453 (2SD) (l/m) and by Echocardiography is 12.0856±3.84929 (2SD) (l/m) with good correlation(r =0.850, p=0.0001). However, echocardiography slightly overestimates Qp compared to Oximetry on account of difficulty in measurement of RVOT diameter. This was also reported in a study in which 32 patients were divided into 3groups: match-group (Within 20% of the difference of Qp/Qs between Echocardiography and Fick method, n = 18), underestimate-group (more than 20% lower Qp/Qs by Echo method, n = 6) and overestimate- group (more than 20% higher Qp/Qs by Echo method, n = 7).

Conclusion

To summarise , we intended to determine, if any, correlation between non invasive methods (MRI and Echocardiography) of determining QP, QS and QP/QS with those of invasive methods (Heart Catheterization). We found that all the three parameters QP, QS and QP/QS used in shunt quantification in ASD are well correlated between Echocardiography and oximetry(r = 0.850, p=0.0001; r=0.819, p=0.0001; r=0.770, p=0.0001, respectively) as well as (r = 0.930, p=0.0001; r=0.706, p=0.0001; r=0.719, p=0.0001, respectively). QP, QS and QP/QS ratio determined by Echocardiography are slightly overestimated compared with that of oximetry. Thus, our study concludes that the quantification of left-to-right shunting in ASD by PC-MRI is non invasive, safe, feasible, reliable and accurate. There is good correlation to the data derived by invasive oximetry, with a slight overestimation of Qp/Qs ratios by PC-MRI. MRI additionally provides comprehensive anatomical information about the defect shape, rims and any additional anomalies of the pulmonic and systemic circulation.

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Conflict of Interest: Nil
Source of support:Nil