Quantitative Measurement of Mitral Regurgitation: Comparison between Echocardiography and Cardiac Magnetic Resonance Imaging

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Background and Objective: *Echocardiography is usually performed to quantify the severity of regurgitation. Magnetic resonance imaging (MRI) can also quantify mitral regurgitation. This study was performed to determine whether MRI can reliably quantify the severity of mitral regurgitation when compared with echocardiography.*

Material and Method: *The authors retrospectively studied patients who underwent cardiac MRI between January 2008 and January 2011. Echocardiography was performed within 3 months of MRI. Mitral regurgitation was quantified by 3 methods of MRI; 1) difference of left ventricular stroke volume and right ventricular stroke volume, 2) difference of left ventricular stroke volume and forward flow volume in ascending aorta and 3) calculation of regurgitation fraction from the ratio of area of regurgitant jet and area of the left atrium. Proximal isovelocity surface area was the echocardiography parameter for mitral regurgitation.*

Results: *Forty-three subjects (24 women and 19 men; 47 to 85 years of age) were enrolled. Mitral regurgitation grading by MRI (2nd method) was mild (n = 28) moderate (n = 11) and severe (n = 4). There was moderate correlation between echocardiography and MRI assessments of regurgitation volume as follows; (1) difference between left ventricular stroke volume and right ventricular stroke volume ($r = 0.48$, $p = 0.016$), (2) subtracting forward flow volume of ascending aorta from left ventricular stroke volume ($r = 0.48$, $p = 0.012$). There was also correlation between regurgitation volume by echocardiography and fraction of maximal area of regurgitant jet divided by the area of the left atrium ($r = 0.72$, $p < 0.001$)*

Conclusion: *Cardiac MRI compares favorably with echocardiography for quantifying mitral regurgitation severity.*

Keywords: *Mitral regurgitation, Magnetic resonance imaging, Mitral valve, Cardiovascular images*

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Mitral regurgitation (MR) is common finding of valvular heart disease. The diagnosis is based on history and physical examination and is confirmed by echocardiography. Doppler echocardiography is a standard method was to assess hemodynamic and quantify the severity of regurgitation(1). However, echocardiography has a limitation in some patients who have poor acoustic window and is an operator-dependent method.

Cardiac magnetic resonance imaging (MRI), an alternative, noninvasive and reproducible method, would be a useful clinical tool to assess the severity of MR(2) by either qualitative or semiquantitative method. Currently, there is limited data regarding to the accuracy of assessing MR by using cardiac MRI(2).

The authors conducted the present study to determine whether MRI can reliably quantify the severity of MR compared to echocardiography.

Material and Method

Study population

The authors retrospectively reviewed 43 patients who documented MR by cardiac MRI and underwent echocardiographic study within 3 months of MRI between January 2008 and January 2011. Patients with atrial fibrillation, premature ventricular

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contraction more than 20 beats per minute (bpm), aortic or tricuspid regurgitation of more than a mild degree were excluded. The present study protocol was approved by the institutional review board of Siriraj Hospital. All patients provided written informed consent prior to participation.

Study protocol

All patients who enrolled in the present study were recorded the following parameters; patient characteristics, MRI and echocardiographic parameters. The authors compared the severity of MR between these two methods.

Magnetic resonance imaging technique

MRI was performed with a 1.5 T (Achieva XR, Phillips, Netherlands). Each patient was positioned supine on the MRI table after placement of ECG monitoring leads. MRI was performed with a method flip angle of 60° echo time of 1.8 msec and pulse repetition time of 3.6 msec phase encoding grouping (PEG) 25, which acquires multiple phase encoding steps for each cardiac frame during each cardiac cycle. The acquisition was keyed to the heart rate with advancement of the phase-encoding gradient with the heart beat[3,4]. The acquisition matrix was 1.5 x 1.5 mm, reconstruction to 1.3 x 1.3 mm. The entire heart of each patient was imaged at a 8-mm interval.

Forward stroke volume was assessed by velocity encoded phase contrast sequences with the acquisition plane perpendicular to the ascending aorta at the level 1 centimeter above aortic valve and coronary ostia. The scanning parameters were Echo time (TE) 3.6 ms, repetitive time (TR) 5.3 msec, refocusing flip angle 12°, slide thickness 8 mm, Field of view in x axis (FOVx) 320 mm, Field of view in y axis (FOVy) 270 mm, typical matrix size 160 *132 mm, typical acquired spatial resolution 2.0*2.04 mm, temporal resolution 30-50 ms, and velocity encoding 170 cm/s.

MR severity was quantified by regurgitation volume (Rvol) measured by 3 methods of MRI: 1) difference of left ventricular stroke volume (LVSV) and right ventricular stroke volume (RVSV) (Fig. 1)[5], 2) difference of LVSV and forward flow volume in ascending aorta (FFV) (Fig. 2)[3,4] and 3) calculation of regurgitation fraction from the ratio of area of regurgitant jet and area of the left atrium (LA) during end-systole by tracing LA area excluding pulmonary vein (Fig. 3)[6].

Echocardiography

Color Doppler examinations were acquired by the same operator using a commercial available echocardiographic machines; iE33 (Philips Medical Systems, Netherlands) and Vivid 7 (GE, USA). Based on fluid dynamic theory, as flow approaches an orifice (a regurgitant lesion), there is an assumption that it converges radially forming concentric hemispheric shells of similar velocities. Flow rate (Q) for these isovelocity shells is derived by this formula: $Q = 2\pi r^2 \times Vr$, where r is the radius from the orifice to the outer surface and Vr is the aliasing velocity. The effective regurgitant orifice area (ROA) is derived by dividing

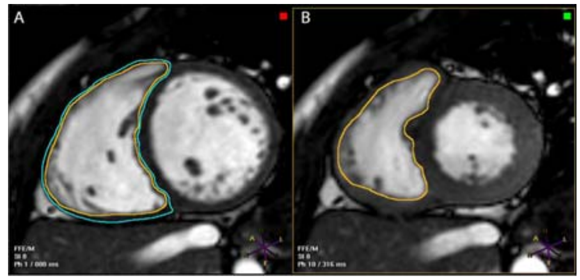

Fig. 1 Cine MRI of short axis view in diastole (A) and systole (B). Right ventricular area was drawn to calculated stroke volume by Simpson's method

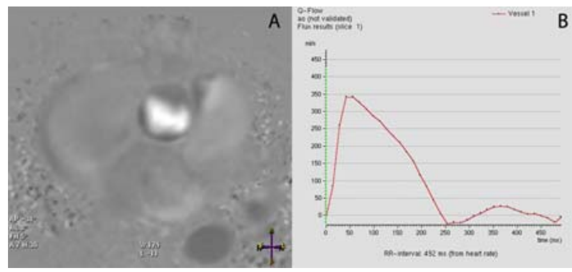

Fig. 2 Quantitative measurement of aortic flow from velocity-encoded MRI (A) with corresponding flow-time curve (B)

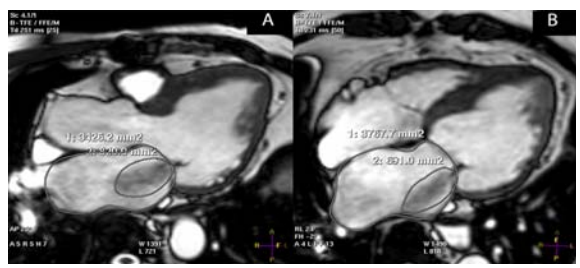

Fig. 3 Cine MRI of MR at level of left atrium shows drawing of MR jet area over left atrial area in horizontal long axis view (A) and 4 chamber view (B)

the flow rate by the peak velocity of the MR jet (PkVreg) measured from continuous wave Doppler: effective ROA = Q/PkVreg. Subsequently, the regurgitant volume (Rvol) was estimated by multiplying effective ROA by the velocity time integral of the MR jet[1].

A grading of MR severity of both MRI and echocardiography was classified as previously described[7].

Statistical analysis

Data was expressed as mean and standard deviation (SD) for continuous variables and as number of cases and percentages for categorical variables. An analysis of the differences of the measurement was performed by using Bland-Altman technique with 95% limit of agreement, intra-class correlation coefficient (ICC). Pearson correlation coefficient was used to analyze correlation of continuous data between echocardiogram and MRI.

Results

From January 2008 through January 2011, 43 patients were enrolled in our study. Twenty-four patients (55.8%) were women and the mean age was 67 years old. Baseline characteristics are shown in Table 1. The authors classified the patients according to severity of MR by MRI (graded by the difference of LVSV and forward flow volume in ascending aorta) into 3 groups; mild (n = 28), moderate (n = 11) and severe (n = 4). Reproducibility of repeated measurement of effective ROA and Rvol by echocardiogram was tested on 12 randomly selected patients by the same reader. The ICC for the agreement was 0.718, p = 0.015 and 0.803, p = 0.005, respectively.

Regurgitation volume derived from LVSV-RVSV

There was moderate correlation between MR severity grading by Rvol derived from PISA method by echocardiography and from LVSV-RVSV derived by cardiac MRI (r = 0.48, p = 0.016) Table 2. Rvol derived from this method by MRI had poor agreement with those from PISA method by echocardiography in patients with significant MR; this is defined as moderate or severe MR (K = -0.33, p = 0.75). Rvol between echocardiography and cardiac MRI showed moderate correlation of intra-class correlation coefficient of mean regurgitation volume between echocardiography and MRI = 0.47 (95% CI: 0.10-0.73). Bland-Altman analysis of mean regurgitation volume between echocardiography and this MRI technique showed a bias of -6.4 and limit of agreement from -49.3 to 36.3 (Fig. 4).

Regurgitation volume derived from LVSV-FFV

There was moderate correlation between MR severity grading by Rvol derived from PISA method by echocardiography and from LVSV-FFV derived by cardiac MRI (r = 0.48, p = 0.012) Table 2. Rvol derived

Table 1. Baseline Characteristics

Variables	Number (percentage) or mean ± SD
Age (years)	67 ± 10
Male	19 (44.2)
Height (cm)	157 ± 10
Weight (kg)	58.5 ± 11.5
SBP (mmHg)	138 ± 25
DBP (mmHg)	77 ± 13
Heart rate (bpm)	87 ± 14
Severity of MR by MRI*	
Mild	28 (65.1)
Moderate	11 (25.6)
Severe	4 (9.3)

SBP = systolic blood pressure, DBP = diastolic blood pressure, MR = mitral regurgitation, MRI = Magnetic resonance imaging.
* Graded by the difference of LVSV and forward flow volume in ascending aorta

Table 2. Validating methods of mitral regurgitant severity by MRI

Caridac MRI method	reference standard: Method	r	p
Gradient echo cine: difference biventriucular stroke volume	TTE; Rvol (PISA)	0.48	0.016
Velocity mapping: left venticular stroke volume-forward stroke volume	TTE: Rvol (PISA)	0.48	0.012
Gradient echo cine: regurgitant jet area/left atrium area	TTE: Rvol (PISA)	0.72	< 0.01

TTE = transthoracic echocardiography, Rvol = regurgitation volume, PISA = proximal isovelocity surface area, r = correlation coefficient from this method by MRI had substantial agreement with those from PISA method by echocardiography in patients with significant MR ($K = 0.62$, $p = 0.06$). Bland-Altman analysis of mean regurgitation volume between echocardiography and this MRI technique showed a bias of 3.71 and limit of agreement from -34.7 to 42.1 (Fig. 5).

Fraction of regurgitation jet area and LA area

There was moderate correlation between MR severity grading by Rvol derived from PISA method by echocardiography and percentage of regurgitant area by cardiac MRI ($r = 0.72$, $p < 0.001$) (Table 2). There was substantial agreement between these two methods in patients with significant MR (Kappa = 0.73, $p = 0.001$). Since this technique requires manual tracing of jet area and LA area, the authors also analyzed reproducibility of repeated measurement by the same reader on 12 randomly selected patients. The ICC for the agreement was 0.738, $p = 0.002$.

Discussion

The authors demonstrated that cardiac MRI can quantify MR and the severity of MR by MRI correlated with those measured by echocardiography, particularly in patients with significant MR. The following three methods of measurement by MRI have been used in the present study: firstly, regurgitation volume derived from difference of stroke volume of left ventricle and right ventricle, secondly, difference of stoke volume of left ventricle and forward flow volume of ascending aorta and finally, percentage of regurgitant jet to LA area.

MRI is suitable for cardiac anatomy and measuring flow. Virtually, flow measurement and ventricular volume may be identified with any plane of image and measuring velocity, making MRI is an attractive method for evaluation of MR(8,9). However, the limitations of MRI in the present study are the disturbance of flow by other valves may take effect on measurement, thus becoming time consuming for processing and analysis. The authors excluded errors in negative value of stroke volume from statistic calculation and measurement of regurgitation volume in echocardiography, labeling them “no” to “trivial”.

Correlation between echocardiography and MRI by calculation of RVSV and LVSV are poor.

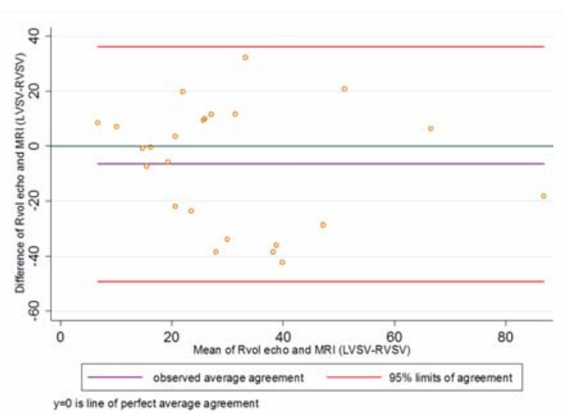

Fig. 4 Bland Altman plot of Rvol between echocardiography and cardiac MRI (LVSV-RVSV). LVSV = left ventricular stroke volume, RVSV = right ventricular stroke volume, Rvol = regurgitation volume

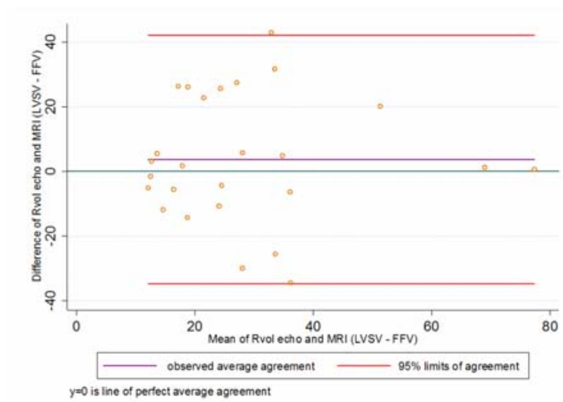

Fig. 5 Bland Altman plot of Rvol between echocardiography and cardiac MRI (LVSV-FSV). LVSV = left ventricular stroke volume, FSV = forward stroke volume, Rvol = regurgitation volume

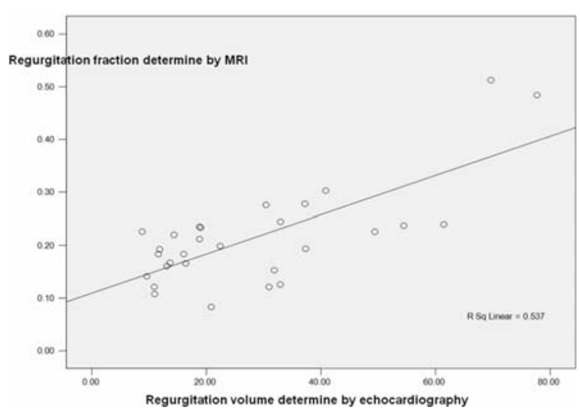

Fig. 6 Scatter plot of echocardiography (Rvol) and RF by fraction of regurgitant jet area and LA area by cardiac MRI. Rvol = regurgitation volume, RF = regurgitation fraction

Theoretically stroke volume of right side and left side must be equal. In patients with MR, LVSV should be greater than RVSV. In present study, in some cases of mild MR the RVSV is greater than LVSV which should be due to error in the measurement.

Mean regurgitation volume between echocardiography and MRI by LVSV-RVSV, LVSV-FSV showed moderate correlation and good correlation grading between regurgitation volume determine by echocardiography and regurgitation fraction determine by MRI, which explain the correlation of MRI and echocardiography in quantification of MR. Bland-Altman plot of regurgitant volume between echocardiography and cardiac MRI indicates that there was a significant discrepancy of the results between the 2 techniques in patients with mild degree of MR. However, the agreement is better in patients with moderate or severe degree of MR.

Previous studies in patients with MR have established MRI could use both qualitative and quantitative indices of regurgitant severity similar to echocardiography[2]. Approach of measuring MR by calculating stroke volume, forward stroke volume in ascending aorta representing as regurgitation volume makes MRI a promising tool for evaluating MR. The present study emphasizes the clinical utility of these quantitative measurements. The present study did not change the method of quantitative measurement of MR from echocardiography to MRI but provides for a complementary assessment for the quantitative measurement of MR when a patient undergoes cardiac MRI study.

There are some limitations of the present study. First, the effect of eccentric jet of MR on the agreement was not performed. Also since the author's patients had very few ectopic beats, the authors cannot analyze the effect of ectopic beats on the results of the present study. Second, angiogram of the left ventricle is also a gold standard for the assessment of severity of MR. However, it is invasive and no patient in the present study had the results of the angiogram of the left ventricle. Third, correlation of severity of MR by some methods of cardiac MRI and echocardiography was not good probable due to majority of patients in our study had mild degree of MR.

Conclusion

Severity of MR assessed by cardiac MRI had a moderate to good correlation with echocardiography for quantifying the severity of MR. The correlation was not good in patients with mild MR.

Potential conflicts of interest

None.

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การศึกษาเปรียบเทียบการวัดลิ้นหัวใจไมตรัลรั่วในเชิงปริมาณระหว่างคลื่นเสียงสะท้อนหัวใจกับคลื่นแม่เหล็กไฟฟ้าหัวใจ

บัญญพนต์ สุขประพฤติ, ศรีสกุล จิรกาญจนากร, เขมจิรา การเกตกลาง, อาทิตย์ ยินดีงาม, รุ่งโรจน์ กฤตยพงษ์

วัตถุประสงค์: *คลื่นเสียงสะท้อนหัวใจใช้ในการวัดเชิงปริมาณการรั่วของลิ้นหัวใจไมตรัล โดยที่คลื่นแม่เหล็กไฟฟ้าหัวใจสามารถวัดเชิงปริมาณการรั่วของลิ้นหัวใจไมตรัลได้เช่นกัน วัตถุประสงค์ของการศึกษาเพื่อเปรียบเทียบการวัดเชิงปริมาณของลิ้นหัวใจไมตรัลรั่วระหว่างคลื่นเสียงสะท้อนหัวใจกับคลื่นแม่เหล็กไฟฟ้าหัวใจ*

วัสดุและวิธีการ: *เป็นการศึกษาย้อนหลังโดยรวบรวมข้อมูลผู้ป่วยจากหน่วยหทัยวิทยา ภาควิชาอายุรศาสตร์ โรงพยาบาลศิริราช ช่วงระยะเวลาตั้งแต่ มกราคม พ.ศ. 2551 ถึง มกราคม พ.ศ. 2554 ที่มีประวัติการตรวจวินิจฉัยโดยคลื่นแม่เหล็กไฟฟ้า และพบว่ามีลิ้นหัวใจไมตรัลรั่ว และมีการตรวจด้วยคลื่นเสียงสะท้อนหัวใจ ภายใน 3 เดือน ลิ้นหัวใจไมตรัลรั่วถูกวัดด้วยคลื่นแม่เหล็กไฟฟ้า 3 วิธี 1) ผลต่างระหว่างปริมาณเลือดที่บีบออกจากหัวใจซีกซ้ายและขวา 2) ผลต่างระหว่างปริมาณเลือดที่บีบออกจากหัวใจซีกซ้ายและปริมาณที่บีบสู่ระบบไหลเวียนโลหิต 3) สัดส่วนระหว่างพื้นที่การไหลของเลือดที่ย้อนกลับสู่หัวใจเอเทรียมด้านซ้ายกับพื้นที่หัวใจเอเทรียมด้านซ้าย โดยเทียบกับคลื่นเสียงสะท้อนหัวใจซึ่งใช้วิธี proximal isovelocity surface area ในการวัดปริมาณลิ้นหัวใจ ไมตรัลรั่ว*

ผลการศึกษา: *ผู้ป่วยที่ได้รับการวินิจฉัยลิ้นหัวใจไมตรัลรั่วจากคลื่นแม่เหล็กไฟฟ้าหัวใจมี 43 คน แบ่งเป็น หญิง 24 คน ชาย 19 คน อายุอยู่ระหว่าง 47 ถึง 85 ปี การแบ่งระดับปริมาณการรั่วของลิ้นหัวใจไมตรัลเป็น 3 ระดับคือ น้อย 28 คน ปานกลาง 11 คน รุนแรง 4 คน ซึ่งมีความสัมพันธ์อยู่ในระดับปานกลางระหว่างคลื่นแม่เหล็กไฟฟ้าและคลื่นเสียงสะท้อนหัวใจ การประเมินผลใช้ปริมาณเลือดที่ไหลย้อน 1) ผลต่างระหว่างปริมาณเลือดที่บีบออกจากหัวใจซีกซ้ายและขวากับคลื่นเสียงสะท้อนหัวใจ มีความสัมพันธ์กันอย่างมีนัยสำคัญ ($r = 0.48$, p-value = 0.016) 2) ผลต่างระหว่างปริมาณเลือดที่บีบออกจากหัวใจซีกซ้ายและปริมาณที่บีบสู่ระบบไหลเวียนโลหิตเทียบกับคลื่นเสียงสะท้อนหัวใจ มีความสัมพันธ์กันอย่างมีนัยสำคัญ ($r = 0.48$, p-value = 0.012) 3) สัดส่วนระหว่างพื้นที่การไหลของเลือดที่ย้อนกลับสู่หัวใจเอเทรียมด้านซ้ายกับพื้นที่หัวใจเอเทรียมด้านซ้ายเทียบกับคลื่นเสียงสะท้อนหัวใจ มีความสัมพันธ์กันอย่างมีนัยสำคัญ ($r = 0.72$, p-value < 0.001)*

สรุป: *ผู้ป่วยที่มีลิ้นหัวใจไมตรัลรั่ว การเปรียบเทียบลิ้นหัวใจไมตรัลรั่วในเชิงปริมาณระหว่างคลื่นเสียงสะท้อนหัวใจกับคลื่นแม่เหล็กไฟฟ้าหัวใจอยู่ในเกณฑ์ดี*