# Right ventricular function in patients with pulmonary hypertension; the value of myocardial performance index measured by tissue Doppler imaging

Inês Zimbarra Cabrita[1]*, Cristina Ruisanchez[2], David Dawson[3], Julia Grapsa[3], Bernard North[4], Luke S. Howard[5], Fausto J. Pinto[6], Petros Nihoyannopoulos[1], and J. Simon R. Gibbs[1]

[1] Department of Cardiovascular Sciences, Hammersmith Hospital, Imperial College London, NHLI, Du Cane Road, W12 0HS London, UK; [2]Hospital Universitario Marques de Valdecilla, Avda. Valdecilla no 25, Santander, Cantabria 39008, Spain; [3]Echocardiography Department, Hammersmith Hospital, Imperial College Healthcare NHS Trust, Du Cane Road, London W12 0HS, UK; [4]Statistical Advisory Service, Imperial College London, 4th Floor, 8 Princes Gardens, London SW7 1NA, UK; [5]Department of Cardiac Sciences, Hammersmith Hospital, Imperial College Healthcare NHS Trust, Du Cane Road, London W12 0HS, UK; and [6]Centro de Cardiologia da Universidade de Lisboa (CCUL), Instituto Cardiovascular de Lisboa, Rua Tomás da Fonseca, F-P2 1600-209 Lisboa, Portugal

| | |
|---|---|
| **Aims** | Myocardial performance index (MPI) measured by conventional Doppler is routinely used to assess right ventricular (RV) systolic function in patients with pulmonary hypertension (PH). Our aim was to determine whether MPI measured by Doppler tissue imaging (tMPI) is effective in assessing RV function in these patients. |
| **Methods and results** | Retrospectively, we have studied 196 patients with chronic PH [pulmonary arterial systolic pressure (PASP) 81 ± 40 mmHg] and 37 healthy volunteers (PASP of 27 ± 7 mmHg). According to the exclusion criteria, 172 patients were included in the final study cohort. All patients were evaluated for RV systolic function by different parameters. MPI was measured by both conventional and tissue Doppler imaging. Bland−Altman analysis showed moderate agreement between MPI and tMPI (the mean difference was −0.02, absolute difference = −0.32 to 0.29; 95% intervals of agreement, percentage of average = −46.6 to 40.8%). In 50 consecutive PH patients where additional parameters were calculated, we found a significant correlation between tMPI and RV ejection fraction ($r = -0.73$, $P < 0.0001$) and RV fractional area change ($r = -0.58$, $P < 0.0001$). No significant inter- and intra-observer variability was identified. |
| **Conclusion** | This study demonstrated a moderate agreement between two methods of measuring MPI. A good correlation of tMPI with RV ejection fraction and RV fractional area change was found indicating that tMPI might be superior to MPI Doppler. tMPI is a parameter unaffected by RV geometry and importantly has the advantage of simultaneously recording the time intervals from the same cardiac cycle. |
| **Keywords** | Pulmonary hypertension • Myocardial performance index • Doppler tissue imaging • Right ventricle |

## Introduction

Pulmonary hypertension (PH) is defined by a mean pulmonary artery pressure ≥25 mmHg at rest assessed by right heart catheterization.[1] Pulmonary arterial hypertension (PAH) also requires a pulmonary capillary wedge pressure (PCWP) ≤15 mmHg with a normal or reduced cardiac output.[1]

The new clinical classification of PH[2] identifies six different clinical groups. Most aetiologies of PH are associated with a poor prognosis.

* Corresponding author. Tel: +44 208 383 4068; Fax: +44 208 383 2269, Email: ines.cabrita05@imperial.ac.uk

The best haemodynamic predictors of prognosis are based on measures of cardiac output and right ventricular (RV) failure. The heart responds to a high resistance by increasing pulmonary arterial pressure to maintain the cardiac output. Since RV function is afterload dependant, this may result in RV hypertrophy and dilatation eventually leading to RV failure and death.[3]

Echocardiography is the first available imaging modality for screening for PH but it is challenging due to the complex geometry of the RV.[4,5]

A simply measured non-invasive index of myocardial performance (MPI) has been proposed[6–8] for the evaluation of combined systolic and diastolic ventricular function. This index that can be measured by both pulsed-wave Doppler and tissue Doppler imaging (TDI), has been proved to correlate well with invasive procedures such as catheterization,[9] to reflect disease severity and to have prognostic power for adverse outcomes in patients with idiopathic dilated cardiomyopathy[10] and following mitral valve surgery.[11] It has been shown that MPI has high sensitivity and negative predictive value for detecting abnormal RV systolic function.[12] However, TDI has been more frequently used for RV and left ventricle instead of the conventional approach.[8] When TDI is performed on the lateral aspect of the tricuspid annulus, it allows the evaluation of parameters required to calculate MPI, namely isovolumic contraction and relaxation times, as well as ejection time.[13]

## Aims

Our aim was to establish the degree of agreement between conventional and TDI methods of measuring MPI in patients with PH.

## Methods

### Participants

One hundred and ninety-six consecutive patients with chronic PH were included in this study. A second group of 37 age-matched healthy people with pulmonary artery systolic pressure (PASP) <39 mmHg was included as a control group. All patients underwent an echocardiographic study between May 2005 and April 2007 at the echocardiography laboratory of Hammersmith Hospital, after being referred from the PH Service. Patients were diagnosed by right heart catheterization, with mean RV systolic pressure >25 mmHg, pulmonary vascular resistance >3 Wood units and PCWP <15 mmHg, to exclude co-existing left ventricular failure.

Exclusion criteria were: incomplete data on echocardiogram, other rhythm than in sinus rhythm, the presence of a pacemaker or defibrillator lead in the right ventricle, severe tricuspid regurgitation,[14] complete right or left bundle branch block in order to avoid alterations in timings of the cardiac cycle due to conduction disturbances,[15] and patients with coexistent left heart disease (impairment of systolic or diastolic function and valvular disease) to avoid the possible influence of ventricular interaction.[16,17]

### Echocardiography

Subjects were studied with an ultrasound equipment (Philips Sonos 7500, transducer S3 1.8–3 MHz) equipped with TDI and simultaneous electrocardiogram recording. Qualitative estimation (visual estimation of RV impairment according to trabeculation, dilatation, hypertrophy, and contractility), tricuspid free wall annular plane systolic excursion (TAPSE), RV peak systolic velocity (S-wave), and MPI were used to assess RV function. In addition, in 50 patients from the study population, RV ejection fraction (RVEF) and fractional area change (RVFAC) were also evaluated. RVEF was calculated by Simpson's method, subtracting end-systolic volume (ESV) from end-diastolic volume (EDV) divided by EDV: $RVEF\% = 100 \times (EDV - ESV)/EDV$. To determine RVFAC, the RV free wall and septum were traced from base to apex, and the respective RV areas were determined. RVFAC was calculated by using the following formula: (end-diastolic area − end-systolic area)/end-diastolic area.

## Conventional Doppler

To measure MPI by conventional pulsed Doppler, the sample was placed between the tips of the tricuspid leaflets in the four-chamber view and the '*a*' interval was measured between cessation and onset of the tricuspid inflow. The RV inflow was studied placing the sample just below the pulmonary valve in the short-axis view and the '*b*' interval was measured between onset and cessation of the RV outflow. Doppler tracings were recorded with a sweep-speed of 100 mm/s. No angle correction was made. The sum of isovolumic contraction time and isovolumic relaxation time was obtained by subtracting *b* from *a*. Therefore, MPI was calculated as $(a - b)/b$. To account for variations in heart rate, mean values were obtained by averaging a minimum of three consecutive cardiac cycles (*Figure 1*).
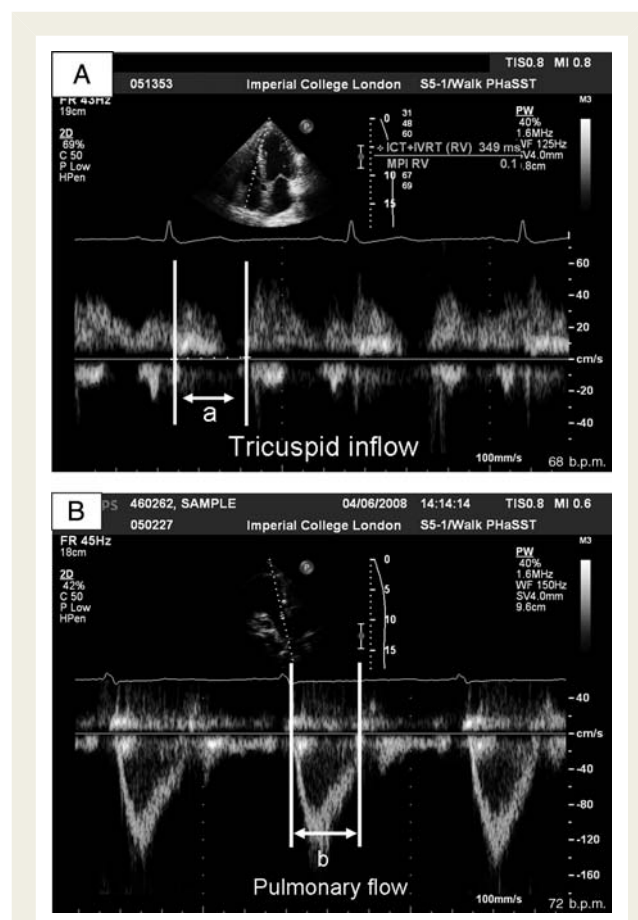


**Figure 1** Time intervals measured from pulsed Doppler transtricuspid inflow (*A*) and right ventricular outflow (*B*): *a* = isovolumic contraction time + isovolumic relaxation time; *b* = right ventricle ejection time; MPI = $(a - b)/b$.
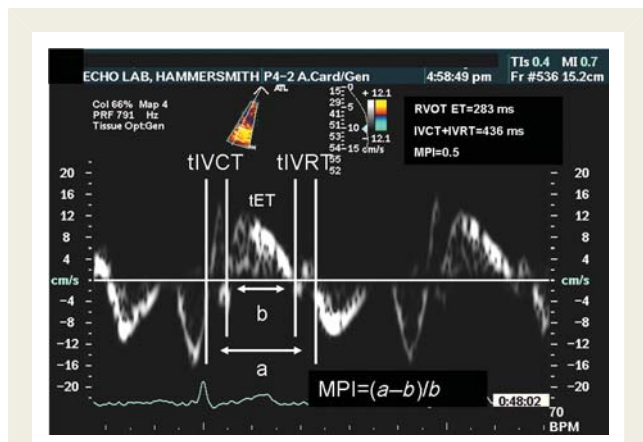
**Figure 2** Intervals measured from pulsed tissue Doppler obtained from the lateral tricuspid annulus. tICT, tissue isovolumic contraction time; tET, tissue ejection time; tIVRT, tissue isovolumic relaxation time; MPI, myocardial performance index.

## Tissue Doppler imaging

Pulsed TDI data were obtained from a 2 mm sample volume placed at the lateral tricuspid annulus in the apical four-chamber view, recorded during held end expiration. The resulting velocities were stored in digital format (ProSolv CardioVascular software, FujiFilm). Filters were set to exclude high-frequency signals. Gains were minimized to allow a clear tissue signal with minimal background noise. Tissue isovolumic contraction time (tICT) was measured between cessation of A′-wave and onset of S-wave; TDI ejection time (tET) was obtained between onset and cessation of S-wave; TDI isovolumic relaxation time (tIVR) was obtained between cessation of S-wave and onset of E′-wave. tMPI was calculated as the sum of tICT and tIVR divided by ejection time (tICT + tIVR)/(tET) (Figure 2).

## Statistical analysis

Statistical analysis was performed using SPSS Version 13.0 (SPSS, Inc., Chicago, IL, USA) and MedCalc for Windows, version 9.5.0.0 (MedCalc Software, Mariakerke, Belgium).

Data are expressed as mean value $\pm$ SD or median $\pm$ SD for non-parametric variables. Data were assessed for normality using the Kolmogorov–Smirnov test. Quantitative variables with a non-parametric distribution were compared between groups using the Mann–Whitney U-test. Agreement between MPI measurements taken by conventional Doppler echocardiography and TDI methods were analysed by Bland–Altman analysis.[18] Pearson's correlation coefficient was used to assess linear correlation between the MPI and other echocardiographic variables. A P-value of <0.05 was considered to be statistically significant. Inter- and intra-observer variability of the TDI measurements were calculated from 50 consecutive patients studied twice as the difference between two measurements divided by their mean and is expressed as percentage.

## Results

### Clinical characteristics of study and control populations

The studied population consisted of 196 PH patients (67% women, mean age 51 years, mean PASP: 81 $\pm$ 24 mmHg) and 37 controls

**Table 1** Patients data

| Characteristics | n | PH group | n | Control group |
|---|---|---|---|---|
| Age (years) | 172 | 51 (16) | 37 | 44.7 (16.4)* |
| Heart rate (b.p.m.) | 172 | 78 (15)[a] | 37 | 71.2 (11.2) |
| Sex (male/female) | 172 | 65/131 | 37 | 16/21 |
| TRV (m/s) | 172 | 4.2 (0.72)[a] | 37 | 2.3 (0.24)* |
| RVSP (mmHg) | 172 | 81.4 (24.7) | 37 | 27.7 (5.5)* |
| MPI Doppler | 157 | 0.70 (0.2)[a] | 20 | 0.24 (0.07)* |
| tMPI | 172 | 0.70 (0.2) | 37 | 0.25 (0.08)*[a] |
| Sm (cm/s) | 172 | 10.38 (2.5)[a] | 35 | 14.3 (2.3)* |
| IVRT | 172 | 110.5 (29.2) | 37 | 41.4 (12.5)* |
| TAPSE (mm) | 39 | 16.3 (3.8) | 20 | 22.8 (0.7)* |

Demographics and echocardiographic characteristics of the study population. Data are mean $\pm$ standard deviation. IVRT, isovolumic relaxation time; MPI, myocardial performance index; RVSP, right ventricular systolic pressure; Sm, peak systolic tissue Doppler velocity of the lateral tricuspid annulus; SD, standard deviation; TAPSE, tricuspid annular plane systolic excursion; tMPI, myocardial performance index by tissue Doppler; TRV, tricuspid regurgitant velocity.
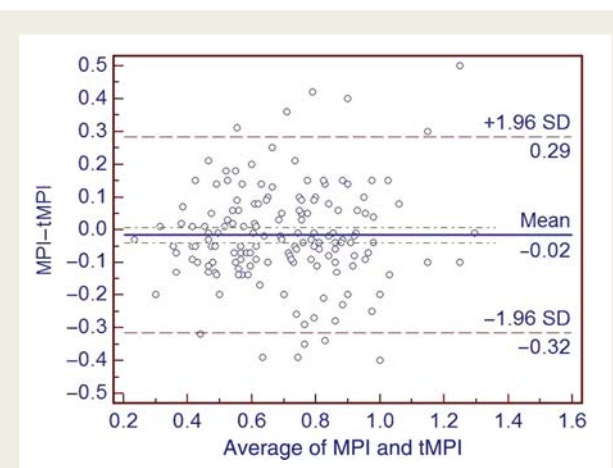[a]Values are median (SD).
*P < 0.0001.



**Figure 3** Bland and Altman plots for the MPI D (by Doppler) and tMPI at basal tricuspid lateral annulus for the PH group. The differences between the methods are displayed against the average of both measures. The lines represent the mean difference and 95% interval of agreement in absolute value of the differences (n = 157).

(58% women, mean age 44, mean PASP 27 $\pm$ 7 mmHg). After applying the exclusion criteria, the final study cohort consisted of 172 patients. The aetiology for PH was PAH (107 patients), veno-occlusive disease (1 patient), lung disease (9 patients), chronic thrombo-embolic PH (45 patients) and PH with unclear/multi-factorial mechanisms (10 patients).

The baseline characteristics of the study population are presented in Table 1. The Bland–Altman analysis as Figure 3 illustrates showed moderate agreement in the PH group between MPI measured by Doppler and tMPI (the mean difference was −0.02 at 95% intervals of agreement, absolute difference = −0.32 to 0.29; 95% intervals

of agreement, percentage of average = −46.6 to 40.8%). A good agreement between both methods was found in the control group (the mean difference was −0.02 at 95% intervals of agreement,
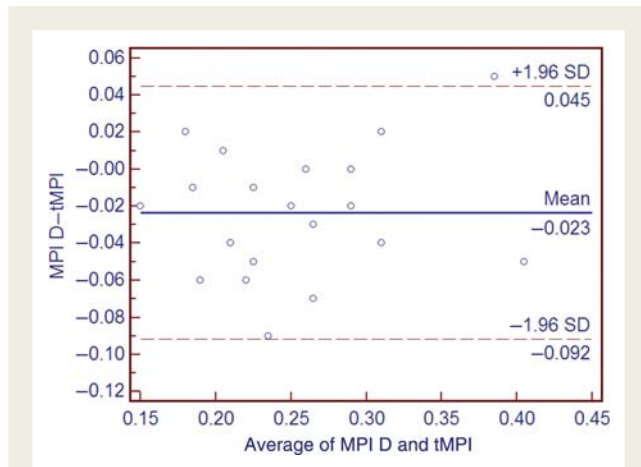


**Figure 4** Bland and Altman plots for the MPI D (by Doppler) and tMPI at basal tricuspid lateral annulus for the control group. The differences between the methods are displayed against the average of both measures. The lines represent the mean difference and 95% interval of agreement in absolute value of the differences (*n* = 20).
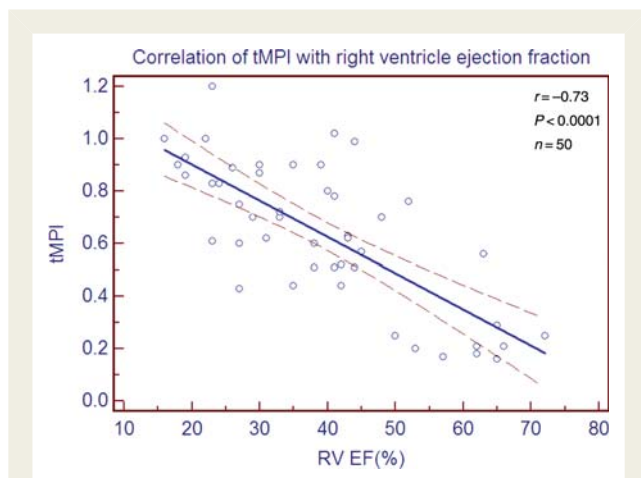


**Figure 5** Correlation of MPI with right ventricular ejection fraction in the PH group (*n* = 50).

absolute difference = −0.04 to 0.09; 95% intervals of agreement, percentage of average = −38.0 to 17.6%) (*Figures 3* and *4*).

We found statistically significant correlation between qualitative estimation of RV function and MPI measured by Doppler (*r* = 0.63; *P* < 0.05) and tMPI (*r* = 0.58; *P* < 0.05). In contrast, the correlation between MPI Doppler and RVFAC was not significant (*r* = −0.30; *P* = 0.05). A weak negative correlation was found between MPI Doppler and RVEF (*r* = −0.43; *P* = 0.004). In relation to tMPI, we found a good significant correlation with RVEF (*r* = −0.73; *P* < 0.0001) and with the RVFAC (*r* = −0.58; *P* < 0.0001) (*Figure 5* and *Table 2*).

## Intra- and inter-observer variability

Intra- and inter-observer variability was performed in 50 consecutive PH patients with the degree of RV systolic impairment and tricuspid regurgitant velocity blinded to the operators.

For the tricuspid lateral annulus tMPI timing measurements (*a* and *b* intervals), inter-observer variability was $10 \pm 2.2\%$ and $4.0 \pm 0.2\%$, respectively. For the MPI Doppler (*a* and *b* intervals), the inter-observer variability was $7.5 \pm 0.2$ and $8.7 \pm 3.2\%$, respectively. Inter-observer variability for MPI Doppler and tMPI was $13 \pm 0.4$ and $11 \pm 0.3\%$, respectively.

The intra-observer variability for MPI Doppler and tMPI was $10 \pm 0.25$ and $8 \pm 0.24\%$, respectively. For the tMPI timing measurements (*a* and *b* intervals), intra-observer variability was $5.8 + 1.2\%$ and $3.8 \pm 0.4\%$, respectively, whereas for the MPI Doppler the variability was $7.9 \pm 3.2$ and $10 \pm 0.5\%$, respectively.

## Discussion

RV dysfunction is a key element in determining prognosis of patients with chronic PH. MPI appears to be a promising parameter for predicting global myocardial function.[19–22] Moreover, the accuracy of echocardiography for the detection of PAH increases when the echocardiographic PASP is combined with an elevated RV MPI.[23]

The existing qualitative parameters for the assessment of RV function have some limitations. However, RVFAC and RVEF might be useful for an estimate of global function. Although, these techniques have some limitations particularly in patients with distorted RV shape. Tricuspid systolic annular motion may provide a simple method for global RV systolic functional assessment with a good correlation with RVEF as assessed by radionuclide angiography.[24] However, it has been described that in the presence of severe tricuspid regurgitation, a significant

**Table 2** Correlations

| MPI method | RVFAC (*n* = 50) | RV ejection fraction (*n* = 50) | Sm (*n* = 157) | TAPSE (*n* = 39) |
| --- | --- | --- | --- | --- |
| MPI Doppler | *r* = −0.30; *P* = 0.05 | *r* = −0.43; *P* < 0.0004 | *r* = −0.18; *P* < 0.05 | *r* = −0.34; *P* < 0.05 |
| tMPI | *r* = −0.58; *P*<0.0001 | *r* = −0.73; *P* < 0.0001 | *r* = −0.23; *P* < 0.05 | *r* = −0.30; *P* = 0.05 |

Correlations of MPI with RVEF and RVFAC, for the different methods of obtaining MPI in patients with pulmonary hypertension. MPI, myocardial performance index; RVFAC, right ventricular fractional area shortening; Sm, peak systolic tissue Doppler velocity of the lateral tricuspid annulus; TAPSE, tricuspid annular plane systolic excursion; tMPI, myocardial performance index by tissue Doppler.

amount of RV mechanical delay may be present resulting in smaller TAPSE values.[25]

Conventional measurement of MPI requires the recording of trans-tricuspid inflow velocities and RV outflow during separate cardiac cycles. Because of the need to average the measurements of the inter-vals of several cardiac cycles, MPI Doppler reproducibility may be reduced. Moreover, although the velocity ratio of E- and A-waves have proved to be useful indicators for the evaluation of diastolic function in the RV, these velocities may not be adequately assessed during tachycardia and may also be affected by loading conditions.[26]

TDI is used in echocardiography to measure the motion (vel-ocity) of the myocardial tissue. Moreover, TDI may be superior to blood flow Doppler, as it reflects the functional status of the myocardium directly, is less subject to background noise and also provides information about systolic and diastolic time intervals in the same cardiac cycle.[13,27] tMPI eliminates the problem of variabil-ity based on changing heart rate, which is inherent in the pulsed Doppler method, because the RV inflow and outflow are not recorded simultaneously by pulsed Doppler.

Although there have been some attempts to validate TDI as a method for measuring RV MPI, the sample size is frequently a limitation.

Our study shows a moderate agreement between tMPI and con-ventional MPI[26] in patients with PH of various aetiologies. Further-more, similar results were found in healthy subjects. Echocardiographic studies should always report which method has been used to calculate MPI and the same method should be applied in future studies in the same patient.

In the subgroup of 50 patients with PH, we found that tMPI had a better correlation with RVEF ($r = -0.73$; $P < 0.0001$) when compared with conventional MPI.

With regards to reproducibility data, we found that the variability of measuring conventional MPI from the same recording appeared not to depend on the observer as shown in previous studies.[28]

According to previous research, RV dysfunction maybe influ-enced by LV performance due to ventricular interdependence.[29] Therefore, it is important to emphasise that we did not include patients with PH due to left heart disease.

It is well known that there may be regional heterogeneity in RV function and that MPI may not account for regional myocardial function. Nevertheless, sampling from apical RV free wall regions may be problematic. An adequate alignment between the ultra-sound beam and the main vector direction of wall motion is necessary in order to obtain an accurate determination of myocar-dial peak velocities and, to a lesser degree, time intervals.[30]

Overall, there should be caution deriving definitive conclusions particularly in patients with PH and all echocardiographic indices should be taken into consideration.[31]

## Study limitations

The first limitation of this study is the presence of a heterogeneous population of patients who were not divided into groups with regards to etiology. Secondly, cardiac magnetic resonance was not used as a comparator for the estimation of RV function. Thirdly, we did not use angle correction to the measurement of either TDI or pulsed Doppler. We do not believe that this is a major source of error since we were measuring time intervals that are minimally affected by angle of incidence.

## Conclusion

MPI measured by tissue Doppler is a simple and quick parameter that can be used in patients with chronic PH to assess global RV function with good accuracy. tMPI is a parameter unaffected by RV geometry and importantly has the advantage of simultaneously recording the systolic and diastolic velocity patterns from the same cardiac cycle. Further studies are needed to assess tMPI in the evaluation and prognosis of patients with PH.

## References

1. Authors/Task Force Members, Galie N, Hoeper MM, Humbert M, Torbicki A, Vachiery J-L et al. Guidelines for the diagnosis and treatment of pulmonary hyper-tension: the Task Force for the Diagnosis and Treatment of Pulmonary Hyperten-sion of the European Society of Cardiology (ESC) and the European Respiratory Society (ERS), endorsed by the International Society of Heart and Lung Trans-plantation (ISHLT). *Eur Heart J* 2009;**30**:2493–2537.
2. Simonneau G, Robbins IM, Beghetti M, Channick RN, Delcroix M, Denton CP et al. Updated clinical classification of pulmonary hypertension. *J Am Coll Cardiol* 2009;**54**:S43–54.
3. Hoeper MM, Rubin LJ. Update in pulmonary hypertension 2005. *Am J Respir Crit Care Med* 2006;**173**:499–505.
4. Bleeker GB, Steendijk P, Holman ER, Yu C-M, Breithardt OA, Kaandorp TAM et al. Assessing right ventricular function: the role of echocardiography and comp-lementary technologies. *Heart* 2006;**92**:i19–26.
5. Ho SY, Nihoyannopoulos P. Anatomy, echocardiography, and normal right ventri-cular dimensions. *Heart* 2006;**92**:i2–13.
6. Tei C, Ling LH, Hodge DO, Bailey KR, Oh JK, Rodeheffer RJ et al. New index of combined systolic and diastolic myocardial performance: a simple and reproduci-ble measure of cardiac function—a study in normals and dilated cardiomyopathy. *J Cardiol* 1995;**26**:357–66.
7. Tei C, Dujardin KS, Hodge DO, Bailey KR, McGoon MD, Tajik AJ et al. Doppler echocardiographic index for assessment of global right ventricular function. *J Am Soc Echocardiogr* 1996;**9**:838–47.
8. Shu-Mei Chang C-CL, Shih-Hung H, Chiu-Yen L, Shu-Hsin Y, Shih-Kai L, Wei-Chen H. Pulmonary hypertension and left heart function: insights from tissue Doppler imaging and myocardial performance index. *Echocardiography* 2007;**24**:366–73.
9. Su H-M, Lin T-H, Voon W-C, Lee K-T, Chu C-S, Yen H-W et al. Correlation of Tei index obtained from tissue Doppler echocardiography with invasive measure-ments of left ventricular performance. *Echocardiography* 2007;**24**:252–7.
10. Dujardin KS, Tei C, Yeo TC, Hodge DO, Rossi A, Seward JB. Prognostic value of a Doppler index combining systolic and diastolic performance in idiopathic-dilated cardiomyopathy. *Am J Cardiol* 1998;**82**:1071–6.
11. Al-Mukhaini M, Argentin S, Morin J-F, Benny C, Cusson D, Huynh T. Myocardial performance index as predictor of adverse outcomes following mitral valve surgery. *Eur J Echocardiogr* 2003;**4**:128–34.
12. Miller D, Farah MG, Liner A, Fox K, Schluchter M, Hoit BD. The relation between quantitative right ventricular ejection fraction and indices of tricuspid annular motion and myocardial performance. *J Am Soc Echocardiogr* 2004;**17**:443–7.
13. Meluzin J, Spinarova L, Bakala J, Toman J, Krejci J, Hude P et al. Pulsed Doppler tissue imaging of the velocity of tricuspid annular systolic motion. A new, rapid,

and non-invasive method of evaluating right ventricular systolic function. *Eur Heart J* 2001;**22**:340–8.

14. Shih-Hung H, Shih-Kai L, Wen-Chin W, Shu-Hsin Y, Pei-Lan G, Chun-Peng L. Severe tricuspid regurgitation shows significant impact in the relationship among peak systolic tricuspid annular velocity, tricuspid annular plane systolic excursion, and right ventricular ejection fraction. *J Am Soc Echocardiogr* 2006;**19**:902–10.

15. Duzenli MA, Ozdemir K, Soylu A, Aygul N, Yazici M, Tokac M. The effect of isolated left bundle branch block on the myocardial velocities and myocardial performance index. *Echocardiography* 2008;**25**:256–63.

16. Severino S, Caso P, Cicala S, Galderisi M, de Simone L, D'Andrea A *et al.* Involvement of right ventricle in left ventricular hypertrophic cardiomyopathy: analysis by pulsed Doppler tissue imaging. *Eur J Echocardiogr* 2000;**1**:281–8.

17. Cicala S, Galderisi M, Caso P, Petrocelli A, D'Errico A, de Divitiis O *et al.* Right ventricular diastolic dysfunction in arterial systemic hypertension: analysis by pulsed tissue Doppler. *Eur J Echocardiogr* 2002;**3**:135–42.

18. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;**1**:307–10.

19. Mörner S, Lindqvist P, Waldenström A, Kazzam E. Right ventricular dysfunction in hypertrophic cardiomyopathy as evidenced by the myocardial performance index. *Int J Cardiol* 2008;**124**:57–63.

20. Grothues F, Moon JC, Bellenger NG, Smith GS, Klein HU, Pennell DJ. Interstudy reproducibility of right ventricular volumes, function, and mass with cardiovascular magnetic resonance. *Am Heart J* 2004;**147**:218–23.

21. Arnlov J, Ingelsson E, Riserirus U, Andren B, Lind L. Myocardial performance index, a Doppler-derived index of global left ventricular function, predicts congestive heart failure in elderly men. *Eur Heart J* 2004;**25**:2220–5.

22. McLean AS, Ting I, Huang SJ, Wesley S. The use of the right ventricular diameter and tricuspid annular tissue Doppler velocity parameter to predict the presence of pulmonary hypertension. *Eur J Echocardiogr 2007* 2007;**8**:128–36.

23. Vonk MC, Sander MH, van den Hoogen FHJ, van Riel PLCM, Verheugt FWA, van Dijk APJ. Right ventricle Tei-index: a tool to increase the accuracy of non-invasive detection of pulmonary arterial hypertension in connective tissue diseases. *Eur J Echocardiogr* 2007;**8**:317–21.

24. Williams L, Frenneaux M. Assessment of right ventricular function. *Heart* 2008;**94**:404–5.

25. López-Candales A, Dohi K, Bazaz R, Edelman K. Relation of right ventricular free wall mechanical delay to right ventricular dysfunction as determined by tissue Doppler imaging. *Am J Cardiol* 2005;**96**:602–6.

26. Harada K, Tamura M, Toyono M, Yasuoka K. Comparison of the right ventricular Tei index by tissue Doppler imaging to that obtained by pulsed Doppler in children without heart disease. *Am J Cardiol* 2002;**90**:566–9.

27. Meluzin J, Spinarova¡ L, Dusek L, Toman J, Hude P, Krejci J. Prognostic importance of the right ventricular function assessed by Doppler tissue imaging. *Eur J Echocardiogr* 2003;**4**:262–71.

28. Rojo EC, Rodrigo JL, Perez de Isla L, Almeria C, Gonzalo N, Aubele A *et al.* Disagreement between tissue Doppler imaging and conventional pulsed wave Doppler in the measurement of myocardial performance index. *Eur J Echocardiogr* 2006;**7**:356–64.

29. Gupta S, Khan F, Shapiro M, Weeks SG, Litwin SE, Michaels AD. The associations between tricuspid annular plane systolic excursion (TAPSE), ventricular dyssynchrony, and ventricular interaction in heart failure patients. *Eur J Echocardiogr* 2008;**9**:766–71.

30. Yu C-M, Chau E, Sanderson JE, Fan K, Tang M-O, Fung W-H *et al.* Tissue Doppler echocardiographic evidence of reverse remodeling and improved synchronicity by simultaneously delaying regional contraction after biventricular pacing therapy in heart failure. *Circulation* 2002;**105**:438–45.

31. Jurcut R, Giusca S, La Gerche A, Vasile S, Ginghina C, Voigt J-U. The echocardiographic assessment of the right ventricle: what to do in 2010? *Eur J Echocardiogr* 2010;**11**:81–96.