Relationship Between Tei Index and PEP-Derived Myocardial Performance Index in Sinus Rhythm

Feyzullah Besli, MD, Cengiz Basar, MD, Ismail Ekinozu, MD, and Yasin Turker, MD

Abstract: The goal of this study was to evaluate the preejection time (PEP)-derived myocardial performance index (MPI) in hypertensive (HT) patients with sinus rhythm and its relationship to the classic Tei index.

One hundred five patients were enrolled in the study (65 HT and 40 control subjects). The mean age of all patients was 50.5 ± 15 years and 60% were female. Echocardiography was performed on all patients. MPI was measured with the classic Tei method (MPI-Tei index) and the PEP-derived MPI method by using tissue Doppler echocardiography. Although the MPI-Tei index is defined as the ratio of isovolumetric contraction time (IVCT) along with isovolumetric relaxation time (IVRT) to ejection time (ET), PEP-derived MPI is defined as the ratio of PEP and IVRT to ET. We compared echocardiographic data between the HT group and the control group.

MPI-Tei index and the PEP-derived MPI values were higher in the HT group compared with controls (0.52 ± 0.10 vs 0.39 ± 0.07, P < 0.001, and 0.51 ± 0.09 vs 0.39 ± 0.07). PEP-derived MPI was strongly correlated with the MPI-Tei index (r = 0.945, P < 0.001).

Our study determined that the PEP-derived MPI might be used in the evaluation of left ventricular function in patients with HT, similar to the classic MPI-Tei index.

Abbreviations: AF = atrial fibrillation, Am = late-diastolic mitral annular velocity, EF = ejection fraction, Em = early-diastolic mitral annular velocity, ET = ejection time, HT = hypertensive, IVCT = isovolumetric contraction time, IVRT = isovolumetric relaxation time, LV = left ventricular, ECG = electrocardiogram, LVEDD = left ventricular end-diastolic diameter, LVESD = left ventricular end-systolic diameter, LV IVS = left ventricular interventricular septum diameter, LV PW = left ventricular posterior wall, MPI = myocardial performance index, PEP = preejection time, S = peak systolic mitral annular velocity, SD = standard deviation.

INTRODUCTION

The use of classical echocardiographic indexes has many limitations in the assessment of systolic and diastolic left ventricular (LV) function. Age, heart rate, cardiac conduction disturbances, and changes in loading affect the Doppler signal of transmural flow, which is the most commonly used method for studying systolic and diastolic function. Chuwa Tei devised an index of myocardial performance (MPI or the Tei index) that evaluates the LV systolic and diastolic function in combination. The Tei index is calculated as the ratio of the sum of the isovolumetric contraction time (IVCT) and isovolumetric relaxation time (IVRT) over the ejection time (ET). The Tei index has proved to be a reliable method for the evaluation of LV systolic and diastolic performance, with clear advantages over older, established indexes. The MPI values obtained from healthy subjects were 0.39 ± 0.05 for LV. The MPI has been demonstrated to be a powerful and independent prognostic indicator in patients with various cardiac disorders and has been studied in congestive heart failure syndrome, congenital heart diseases, cardiac rejection following transplantation, and valvular heart diseases.

However, because of the loss of mechanical atrial function, the end of LV diastolic activity cannot be clearly determined in patients with atrial fibrillation (AF). Therefore, IVCT cannot be measured in patients with AF. Pre-ejection period (PEP) can easily be obtained in AF patients, and PEP may be used instead of IVCT in AF patients. PEP interval was measured from the onset of QRS to the onset of the systolic mitral annular velocity pattern. Su et al. defined the “PEP-derived MPI” in patients with AF; it is calculated as the ratio of PEP along with IVRT to ET. In a recent study, it was reported that the PEP-derived MPI was a useful predictor of adverse cardiovascular events, and could offer an additional prognostic benefit over conventional clinical and echocardiographic parameters in patients with AF.

To our knowledge, the importance of PEP-derived MPI used in AF has not been determined in patients with sinus rhythm. Our goal was to evaluate the role of PEP-derived MPI in hypertensive (HT) patients with sinus rhythm and compare it to the Tei index.

METHODS

Study Design and Population

One hundred five patients who were admitted to the Duzce State Hospital and the Duzce University Department of Cardiology between March 2013 and September 2014 with HT (n = 65) and healthy subjects (n = 40) were included in the study. The mean age of all patients was 50.5 ± 15 years, and 60% were women. Informed consent was obtained from each subject for participation in the study. The study conforms to the principles outlined in the Declaration of Helsinki and was approved by the local Ethics Committee for clinical research. The clinical diagnosis of HT was made on the basis of clinical history and physical examination, and was defined as abnormally high arterial blood pressure that is usually indicated by an adult average systolic BP of ≥140 mm Hg or a diastolic BP of ≥90 mm Hg at rest.
velocities on the tissue Doppler images were calculated by averaging the velocities from the 2 sites at 5 cardiac cycles from the recorded data.

PEP-Derived MPI and Tei Index

IVCT is defined as the interval measured from the end of the late-diastolic mitral annular velocity pattern to the onset of the systolic mitral annular velocity pattern; PEP is defined as the interval measured from the onset of QRS to the onset of the systolic mitral annular velocity pattern; ET is the interval measured from the onset of QRS to the onset of the late-diastolic mitral annular velocity pattern; and IVRT is the interval measured from the end of the systolic mitral annular velocity pattern to the onset of the diastolic mitral annular velocity pattern on the same cardiac cycle (Figure 1A and B).

The MPI, the Tei index, also called the MPI-Tei index, was defined as the ratio of IVCT along with IVRT to ET, whereas the PEP-derived MPI was defined as the ratio of PEP along with IVRT to ET.8

Reproducibility

The interobserver and intraobserver variability were calculated for 2 cardiologists who previously analyzed the recorded images offline. Fifteen patients were randomly selected to evaluate the interobserver variability of the PEP-derived MPI and the MPI-Tei index measurements by 2 independent observers. To determine the intraobserver variability, the same measurements were repeated 2 weeks apart. Mean percent error was calculated as the absolute difference divided by the average of the 2 observations.

Statistical Analysis

The SPSS 15.0 (SPSS, Inc., Chicago, IL) was used for statistical analysis. The baseline, echocardiographic, and laboratory characteristics of study subjects are presented as percentages for dichotomous variables and mean ± standard deviation and as appropriate according to the distribution of the data. Categorical variables were given by number and percentage. The differences between groups were checked by χ² test for categorical variables or by independent t test for...
TABLE 1. Baseline Clinical Characteristics and Laboratory Features of All Subjects, Hypertensive Group, and Control Group

|                        | All Patients | Hypertensive group | Control group | P Value |
|------------------------|--------------|--------------------|---------------|---------|
| n = 105                | n = 65       | n = 40             |               |<0.001* |
| Age, y                 | 50.5 ± 15    | 58.7 ± 11.3        | 37.3 ± 12.1   |<0.001* |

Continuous variables. The relationship between 2 continuous variables was assessed by a bivariate correlation method (Pearson correlation). All tests were 2 sided, and the level of significance was established as P < 0.05.

RESULTS

The HT group was older than the controls (58.7 ± 11.3 vs 37.3 ± 12.1 years, P < 0.001). No significant differences in sex frequency, glucose, creatinine, white blood cells, hemoglobin, and platelet count were detected between the HT group and the controls (Table 1).

When echocardiographic findings were evaluated, LV EF was 64.2 ± 4.3, MPI-Tei index was 0.47 ± 0.11, and PEP-derived MPI was 0.46 ± 0.10 in all patients. LV EF, LVDD, and LVSD exhibited no significant differences between the HT group and the control group. Compared with the control group, LV IVS (12.2 ± 1.5 vs 10.2 ± 0.9, P < 0.001), LV PW (11.3 ± 1.2 vs 10.0 ± 0.8, P < 0.001), A wave (93.5 ± 16.9 vs 77.1 ± 13.5, P < 0.001), Am (10.3 ± 2.1 vs 8.5 ± 2.3, P < 0.001), E/Em (9.5 ± 3.1 vs 7.1 ± 1.8, P < 0.001), IVCT (74.7 ± 22.3 vs 59.7 ± 21.2, P < 0.001), and PEP (70.5 ± 22.3 vs 60.2 ± 18.7, P = 0.009) were higher, whereas E wave (8.5 ± 2.5 vs 13.7 ± 3.4, P < 0.001), S (8.7 ± 1.8 vs 10.5 ± 1.8, P < 0.001), and Em (8.5 ± 2.5 vs 13.7 ± 3.4, P < 0.001) were lower in the HT group (Table 2).

Both the MPI-Tei index and the PEP-derived MPI values were higher in the HT group than controls (0.52 ± 0.10 vs 0.39 ± 0.07, P < 0.001, and 0.51 ± 0.09 vs 0.39 ± 0.07, P < 0.001) (Table 2).

PEP-derived MPI was strongly correlated with the MPI-Tei index (r = 0.945, P < 0.001) (Figure 2). In addition, PEP-derived MPI was significantly correlated with age, LVEF, E/Em, LV IVS, and LV PW (r = 0.429, P < 0.001; r = 0.362, P < 0.001; r = 0.450, P < 0.001; and r = 0.385, P < 0.001, respectively) (Table 3). Similarly, the MPI-Tei index was correlated with age, LVEF, E/Em, LV IVS, and LV PW (r = 0.443, P < 0.001; r = 0.327, P < 0.001; r = 0.458, P < 0.001; and r = 0.364, P < 0.001, respectively). The strong correlation between PEP-derived MPI and MPI-Tei index were also observed in HT group and control group, separately (r = 0.941, P < 0.001, and r = 0.870, P < 0.001, respectively).

Reproducibility

The intraobserver mean percent errors for the PEP-derived MPI and the MPI-Tei index measurements in study patients were 4.2 ± 2.1% and 4 ± 2.1%, respectively. The interobserver mean percent errors for the PEP-derived MPI and MPI-Tei index measurements in study patients were 6.3 ± 3.2% and 5.9% ± 3.1%, respectively.

DISCUSSION

This study revealed that the PEP-derived MPI and the MPI-Tei index were significantly higher in the HT group and there was a strong relationship between the PEP-derived MPI and the MPI-Tei index. The MPI-Tei index is well correlated with the widely accepted systolic and diastolic hemodynamic parameters. The MPI-Tei index was determined to be a useful method in studies of congestive heart failure, congenital heart diseases, in the evaluation of interventional therapies with regard to global LV performance, in cardiac rejection following transplantation,
myocardial infarction, and valvular disease. Hypertension causes deterioration in the systolic and diastolic function of LV. The relationship between HT and MPI-Tei index was investigated in a large number of studies, and these determined that the value of the MPI-Tei index was higher, whereas E wave, S, and Em were lower in the HT group. PEP-derived MPI can also detect an impairment of LV systolic and diastolic function, similar to the MPI-Tei index measurement.

In this study, the MPI-Tei index was powerfully correlated with the PEP-derived MPI. In addition, both the MPI-Tei index and the PEP-derived MPI correlated with age, LVEF, E/Em, IVCT, and PEP were higher, whereas E wave, S, and Em were lower in the HT group. MPI-Tei index was 0.52 and the PEP-derived MPI was 0.51 ± 0.09 in the HT group, and both were significantly higher than the control group. Consistent with previously published studies, we concluded that LV systolic and diastolic function was impaired in patients with HT. PEP-derived MPI can also detect an impairment of LV systolic and diastolic function, similar to the MPI-Tei index measurement.

In our study, we determined that mitral A wave, E/Em, IVCT, and PEP were higher, whereas E wave, S, and Em were lower in the HT group. MPI-Tei index was 0.52 ± 0.10 and the PEP-derived MPI was 0.51 ± 0.09 in the HT group, and both were significantly higher than the control group. Consistent with previously published studies, we concluded that LV systolic and diastolic function was impaired in patients with HT. PEP-derived MPI can also detect an impairment of LV systolic and diastolic function, similar to the MPI-Tei index measurement.

A = transmitral diastolic A-wave velocity, Am = late-diastolic mitral annular velocity, E = transmitral diastolic E-wave velocity, Em = early-diastolic mitral annular velocity, ET = ejection time, IVCT = isovolumetric contraction time, IVRT = isovolumetric relaxation time, LEDD = left ventricular end-diastolic diameter, LVIDD = left ventricular end-diastolic diameter, LVEF = left ventricular ejection fraction, LVIDS = left ventricular interventricular septum, LV PW = left ventricular posterior wall, MPI-Tei index = myocardial performance index with Tei method, PEP = pre-ejection period, PEP-derived MPI = myocardial performance index using PEP, S = peak systolic mitral annular velocity.

### TABLE 2. Echocardiographic Features of All Subjects, Hypertensive Group, and Control Group

|                   | All Patients | Hypertensive Group | Control Group | P Value |
|-------------------|--------------|--------------------|---------------|---------|
| n = 105           | n = 65       | n = 40             |               |         |
| LVEF, %           | 64.2 ± 4.3   | 63.0 ± 4.0         | 66.1 ± 4.0    | 0.138   |
| LVDD, mm          | 43.9 ± 3.4   | 43.8 ± 3.2         | 44.1 ± 3.6    | 0.635   |
| LVSD, mm          | 27.7 ± 3.3   | 28.0 ± 3.1         | 27.3 ± 3.6    | 0.337   |
| LV IVS, mm        | 11.4 ± 1.6   | 12.2 ± 1.5         | 10.2 ± 0.9    | <0.001* |
| LV PW, mm         | 10.8 ± 1.2   | 11.3 ± 1.2         | 10.0 ± 0.8    | <0.001* |
| E, cm/s           | 83.0 ± 17.9  | 76.2 ± 13.9        | 93.9 ± 18.5   | <0.001* |
| A, cm/s           | 87.2 ± 17.6  | 93.5 ± 16.9        | 77.1 ± 13.5   | <0.001* |
| S, cm/s           | 9.4 ± 2.0    | 8.7 ± 1.8          | 10.5 ± 1.8    | <0.001* |
| Am, cm/s          | 10.5 ± 3.8   | 8.5 ± 2.5          | 13.7 ± 3.4    | <0.001* |
| PEP, ms           | 9.6 ± 2.4    | 10.3 ± 2.1         | 8.5 ± 2.3     | <0.001* |
| ICST, ms          | 35.6 ± 17.9  | 35.4 ± 17.9        | 35.7 ± 17.9   | 0.091   |
| IVCT, ms          | 284.7 ± 35.4 | 284.7 ± 35.4       | 291.9 ± 35.8  | 0.319   |
| ET, ms            | 0.47 ± 0.11  | 0.52 ± 0.10        | 0.39 ± 0.07   | <0.001* |
| PEP-derived MPI   | 0.46 ± 0.10  | 0.51 ± 0.09        | 0.39 ± 0.07   | <0.001* |

A = transmitral diastolic A-wave velocity, Am = late-diastolic mitral annular velocity, E = transmitral diastolic E-wave velocity, Em = early-diastolic mitral annular velocity, ET = ejection time, IVCT = isovolumetric contraction time, IVRT = isovolumetric relaxation time, LEDD = left ventricular end-diastolic diameter, LVIDD = left ventricular end-diastolic diameter, LVEF = left ventricular ejection fraction, LVIDS = left ventricular interventricular septum, LV PW = left ventricular posterior wall, MPI-Tei index = myocardial performance index with Tei method, PEP = pre-ejection period, PEP-derived MPI = myocardial performance index using PEP, S = peak systolic mitral annular velocity.

* P < 0.05.
used in patients with sinus rhythm, but because of the loss of mechanical atrial function, cannot be utilized in patients with AF. However, PEP-derived MPI can be used in patients with both a sinus rhythm and AF. Therefore, PEP-derived MPI may be a more useful method than the Tei index. Additionally, LV function in HT patient can be evaluated using modern techniques like strain. The analysis of left atrial function in HT patients by novel echocardiographic techniques provides further insights into cardiac function in HT disease.

This study has several limitations, which includes cross-sectional design, being performed at 2 different centers over a restricted time period, including a limited number of patients and absence of follow-up in terms of clinical events. We excluded patients with coronary artery disease according to medical history and ECG, but some may have been missed. We assessed LV function, but did not measure right ventricular function and invasive hemodynamic measurements in our study population. Therefore, in order to reveal the importance of PEP-derived MPI and assess its prognostic impact/role in hypertension, randomized, controlled follow-up trials involving larger groups of patients are needed.

CONCLUSION

According to our findings, there is a strong association between the PEP-derived MPI and the MPI-Tei index. PEP-derived MPI may be used in conjunction with the MPI-Tei index, or without it, in cases of sinus rhythm to assess the LV global functions in patients with HT.

REFERENCES

1. Tei C, Ling LH, Hodge DO, et al. New index of combined systolic and diastolic myocardial performance: a simple and reproducible measure of cardiac function—a study in normals and dilated cardiomyopathy. J Cardiol. 1995;26:357–366.
2. Tei C, Nishimura RA, Seward JB, et al. Noninvasive Doppler-derived myocardial performance index: correlation with simultaneous measurements of cardiac catheterization measurements. J Am Soc Echocardiogr. 1997;10:169–178.
3. Bruch C, Schmermund A, Dagres N, et al. Tei index in coronary artery disease validation in patients with overall cardiac and isolated diastolic dysfunction. Z Kardiol. 2002;91:472–480.
4. Lakoumentas JA, Panou FK, Kotseroglou VK, et al. The Tei index of myocardial performance: applications in cardiology. Hellenic J Cardiol. 2005;46:52–58.
5. Salehian O, Schwerzmann M, Merchant N, et al. Assessment of systemic right ventricular function in patients with transposition of the great arteries using the myocardial performance index: comparison with cardiac magnetic resonance imaging. Circulation. 2004;110:3229–3233.
6. Vivekananthan K, Kalapura T, Mehrm A, et al. Usefulness of the combined index of systolic and diastolic myocardial performance to identify cardiac allograft rejection. Am J Cardiol. 2002;90:517–520.
7. Haque A, Otsuji Y, Yoshifuku S, et al. Effects of valve dysfunction on Doppler Tei index. J Am Soc Echocardiogr. 2002;15:877–883.
8. Su HM, Lin TH, Hsu PC, et al. Myocardial performance index derived from pre-ejection period: novel and feasible parameter in evaluation of cardiac performance in patients with permanent atrial fibrillation. Echocardiography. 2011;28:1081–1087.
9. Chu CY, Lee WH, Hsu PC, et al. Myocardial performance index derived from pre-ejection period as a novel and useful predictor of cardiovascular events in atrial fibrillation. J Cardiol. 2015;65:466–473.
10. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr. 2015;28:1–39.
11. Lacorte J, Cabreraiza S, Rabkin D, et al. Correlation of the Tei index with invasive measurements of ventricular function in a porcine model. J Am Soc Echocardiogr. 2003;16:442–447.
12. Dujardin K, Tei C, Yeo T, et al. Prognostic value of a Doppler index combining systolic and diastolic performance in idiopathic dilated cardiomyopathy. Am J Cardiol. 1998;82:1071–1076.
13. Ikeda R, Yuda S, Kobayashi H, et al. Usefulness of right ventricular Doppler index for predicting outcome in patients with dilated cardiomyopathy. J Cardiol. 2001;37:157–164.
14. Izumi C, Kibira S, Watanabe H, et al. Validity of the right ventricular Doppler index for assessment of severity of congestive heart failure in patients with dilated cardiomyopathy. Heart Vessels. 1999;14:232–239.
15. Bruch C, Schmermund A, Dagres N, et al. Tei index in coronary artery disease validation in patients with overall cardiac and isolated diastolic dysfunction. Z Kardiol. 2002;91:472–480.
16. Eidem B, O’Leary P, Tei C, et al. Usefulness of the myocardial performance index for assessing right ventricular function in congenital heart disease. Am J Cardiol. 2000;86:654–658.
17. Eidem B, Tei C, O’Leary P, et al. Nongeometric quantitative assessment of right and left ventricular function: myocardial performance index in normal children and patients with Ebstein anomaly. J Am Soc Echocardiogr. 1998;11:849–856.
18. Nearchou N, Tsakiris A, Lolaka M, et al. Influence of perindopril on left ventricular global performance during the early phase of inferior acute myocardial infarction: assessment by Tei index. Echocardiography. 2003;20:319–327.
19. Nearchou N, Tsakiris A, Lolaka M, et al. Influence of angiotensin II receptors blocking on overall left ventricle’s performance of patients with acute myocardial infarction of limited extent. Echocardiographic assessment. Int J Cardiovasc Imaging. 2006;22:191–198.
20. Poulsen S, Jensen S, Nielsen J, et al. Serial changes and prognostic implications of a Doppler derived index of combined left ventricular systolic and diastolic myocardial performance in acute myocardial infarction. Am J Cardiol. 2000;85:19–25.
21. Nearchou N, Tsakiris A, Stathakopoulos D, et al. A new Doppler index combining systolic and diastolic myocardial performance.
Behavior and significance during hospitalization of patients with acute myocardial infarction. *Hellenic J Cardiol.* 1999;40:486–496.

22. Aurigemma GP, Gottdiener JS, Shemanski L, et al. Predictive value of systolic and diastolic function for incident congestive heart failure in the elderly: the cardiovascular health study. *J Am Coll Cardiol.* 2001;37:1042–1048.

23. Wachtell K, Palmieri V, Olsen MH, et al. Change in systolic left ventricular performance after 3 years of antihypertensive treatment: the Losartan Intervention for Endpoint (LIFE) Study. *Circulation.* 2002;106:227–232.

24. Yilmaz R, Seydaliyeva T, Ünlü D, et al. The effect of left ventricular geometry on myocardial performance index in hypertensive patients. *Anadolu Kardiyol Derg.* 2004;4:217–222.

25. Sahin DY, Gür M, Elbasan Z, et al. Myocardial performance index and aortic distensibility in patients with different left ventricle geometry in newly diagnosed essential hypertension. *Blood Press.* 2013;22:329–335.

26. Sarkar H, Siddique MA, Haque KM, et al. Evaluation of left ventricular global function, using Doppler myocardial performance index in patients with systemic hypertension. *Med J.* 2008;17 (2 suppl):S65–S71.

27. Başar C, Beşli F, Türker Y, et al. Myocardial performance index in patients with dipper and non-dipper hypertension. *Blood Press Monit.* 2014;19:216–219.

28. Akintunde AA, Akinwusi PO, Opadijo GO. Relationship between Tei index of myocardial performance and left ventricular geometry in Nigerians with systemic hypertension. *Cardiovasc J Afr.* 2011;22:124–127.

29. Besli F, Basar C, Kecebas M, et al. Improvement of the myocardial performance index in atrial fibrillation patients treated with amiodarone after cardioversion. *J Inter V Card Electrophysiol.* 2015;42:107–115.

30. Camm AJ, Lip GY, De Caterina R, et al. Focused updates of the ESC Guidelines for the management of atrial fibrillation: an update of the 2010 ESC Guidelines for the management of atrial fibrillation. Developed with the special contribution of the European Heart Rhythm Association. *Europace.* 2012;14:1385–1413.

31. Hensel KO, Jenke A, Leischik R. Speckle-tracking and tissue-doppler stress echocardiography in arterial hypertension: a sensitive tool for detection of subclinical LV impairment. *BioMed Res Int.* 2014;2014:9.

32. Mor-Avi V, Lang RM, Badano LP, et al. Current and evolving echocardiographic techniques for the quantitative evaluation of cardiac mechanics: ASE/EAE consensus statement on methodology and indications endorsed by the Japanese Society of Echocardiography. *Eur J Echocardiogr.* 2011;12:167–205.

33. Celic V, Tadic M, Suzic-Lazic J, et al. Two- and three-dimensional speckle tracking analysis of the relation between myocardial deformation and functional capacity in patients with systemic hypertension. *Am J Cardiol.* 2014;113:832–839.

34. Leischik R, Littwitz H, Dworrak B, et al. Echocardiographic evaluation of left atrial mechanics: function, history, novel techniques, advantages, and pitfalls. *BioMed Res Int.* 2015.

35. Sahebjam M, Mazareei A, Lotfi-Tokaldany M, et al. Comparison of left atrial function between hypertensive patients with normal atrial size and normotensive subjects using strain rate imaging technique. *Arch Cardiovasc Imaging.* 2014;2:e19613.