

Conventional Doppler myocardial performance index, tricuspid and mitral annular plane systolic excursions in the assessment of fetal heart functions

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Abstract

Objective: Tei index and TAPSE & MAPSE are very useful and reliable non-invasive methods to assess the global myocardial systolic and diastolic functions, and right and left ventricular longitudinal myocardial functions, respectively. In this study, we aimed to assess fetal right and left ventricle (RV and LV) functions by myocardial performance index (Tei index) and tricuspid and mitral annular plane systolic excursions (TAPSE and MAPSE).

Methods: The findings of fetal echocardiographies performed in our center for control purposes between December 2015 and April 2017 were assessed. By obtaining appropriate positions in 152 fetuses which are at eligible weeks of gestation, Tei index and TAPSE and MAPSE measurements were recorded. Repeating echocardiographies were excluded from the study.

Results: Of all fetuses included in the study, LV Tei index was 0.47 ± 0.16 , RV Tei index was 0.52 ± 0.17 , TAPSE was 0.47 ± 0.1 cm, and MAPSE 0.36 ± 0.07 cm. Seventy-two fetuses were at 20+3–26 weeks of gestation, and 80 fetuses were at 26+3–37+3 weeks of gestation. Both groups were measured separately and they were compared. While there was no significant increase in LV and RV Tei indices and mitral valve gradient during the advanced weeks of gestation, significant difference was observed in TAPSE and MAPSE values ($p=0.001$ for both).

Conclusion: Tei index, and TAPSE and MAPSE are reliable non-invasive methods for global heart functions and annular plane systolic longitudinal functions of right and left ventricles, respectively, which are easily used on fetuses as well as children who are healthy or with congenital heart disease; and these methods also can be used in the routine practice.

Keywords: Fetal heart functions, Tei index, TAPSE, MAPSE.

Özet: Fetal kalp fonksiyonlarının değerlendirilmesinde konvansiyonel Doppler miyokardiyal performans indeksi, triküspid ve mitral kapak anüler düzlem sistolik hareketleri

Amaç: Tei indeksi, global miyokardiyal sistolik ve diastolik fonksiyonların, TAPSE ve MAPSE, sağ ve sol ventriküler longitudinal miyokardiyal fonksiyonların değerlendirilmesinde oldukça yararlı, güvenilir, non-invaziv yöntemlerdir. Bu çalışmada fetal sağ ve sol ventrikül (RV ve LV) fonksiyonlarının miyokardiyal performans indeksi (Tei indeksi); triküspid ve mitral kapak anüler düzlem sistolik hareketleri (TAPSE ve MAPSE) ile değerlendirilmesi amaçlanmıştır.

Yöntem: Aralık 2015 – Nisan 2017 tarihleri arasında kontrol amaçlı olarak merkezimizde yapılan fetal ekokardiyografik bulgular incelendi. Uygun gestasyonel haftadaki 152 fetüste, uygun pozisyonlar elde edilerek Tei indeksi ölçümleri, TAPSE ve MAPSE ölçümleri kaydedildi. Tekrarlanan ekokardiyografiler çalışma kapsamı dışında bırakıldı.

Bulgular: Çalışmaya alınan tüm fetüslerin; LV Tei indeksi 0.47 ± 0.16 , RV Tei indeksi 0.52 ± 0.17 , TAPSE 0.47 ± 0.1 cm, MAPSE 0.36 ± 0.07 cm idi. Yetmiş iki fetüs 20+3–26. hafta, 80 fetüs 26+3–37+3 hafta arasında bulunuyordu. Ölçümler bu iki grup için ayrı ayrı gerçekleştirildi ve karşılaştırıldı. İlerleyen gestasyon haftasında LV ve RV Tei indeksi ve mitral kapak gradiyentinde anlamlı artış bulunmazken, TAPSE ve MAPSE değerlerinde anlamlı artış olduğu görüldü (her ikisi için $p=0.001$).

Sonuç: Tei indeksi, global kalp fonksiyonlarının, TAPSE ve MAPSE ise sağ ve sol ventriküllerin anüler düzlem sistolik longitudinal fonksiyonlarının non-invaziv olarak değerlendirilmesinde, sağlıklı ve konjenital kalp hastalığı bulunan çocuklarda olduğu gibi, fetüslerde de kolay uygulanabilen, rutinde de kullanılacak, güvenilir yöntemlerdir.

Anahtar sözcükler: Fetal kalp fonksiyonları, Tei indeksi, TAPSE, MAPSE.

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Introduction

Myocardial performance index (Tei index), which was first defined in healthy individuals and adult patients with dilated cardiomyopathy and for which many studies have been performed so far on children who were normal, healthy and had congenital heart disease, is an echocardiographic assessment method which is obtained by Doppler echocardiographic measurements and has a significant role for the assessment of global myocardial systolic and diastolic functions.^[1-5]

For about two decades, echocardiography, radionuclide studies and various methods such as magnetic resonance imaging as well as right ventricular functions which were considered to be “neglected” in the past have been the subjects of many studies. Tricuspid annular plane systolic excursion (TAPSE) is an echocardiographic method which has been studied well in all age groups, a wide range of patient groups and healthy children, of which mean and z-score values have been determined for age groups, which is reliable and easy to perform, can be obtained by M-mode measurements, useful for the assessment of right ventricular longitudinal myocardial function and which is independent from heart rate, ventricle size and geometry.^[6-8]

Mitral annular plane systolic excursion (MAPSE) is a reliable and easy-to-perform non-invasive method to assess left ventricular longitudinal myocardial functions which is performed on adults and children who are healthy or have disease, obtained by M-mode measurements, of which mean and z-score values have been determined, and for which many studies have been performed so far.^[9-11]

There are a limited number of studies where annular plane systolic excursions of atrioventricular valves (TAPSE and MAPSE) and Tei index are assessed in healthy fetuses by M-mode echocardiography during fetal period.^[12-15]

In this study, we aimed to assess fetal right and left ventricle (RV and LV) functions by conventional Doppler myocardial performance index (Tei index) and tricuspid and mitral annular plane systolic excursions (TAPSE and MAPSE) in healthy fetuses, to compare the data we obtained and investigate the relationship between them.

Methods

Patient group

The findings of fetal echocardiographies performed in our center for control purposes between December

2015 and April 2017 were assessed. The pregnant women who were 18–40 (mean: 27.7±5.17) years old, of which 72 (47.4%) were at 20+3 – 26 weeks of gestation and 80 (52.6%) at 26+3 – 37+3 weeks of gestation were assessed by fetal echocardiography. By obtaining appropriate positions in 152 fetuses which were at 20+3 – 37+3 weeks of gestation and did not have congenital heart disease, dysrhythmia, myocarditis, pericardial effusion and valve insufficiency, Tei index measurements, and pulse wave Doppler measurements of atrioventricular and semilunar valves were performed. The pregnant women were asked to be full before the fetal echocardiography

Echocardiography

Echocardiography measurements of all fetuses were performed by the same investigator (Dr. ŞP) via Phase Array pediatric transducer S8-3 mHz of 2005 HD11-XE device (©Philips Medical System Nederland BV, Best, the Netherlands). The measurements were done separately for each valve. Sample volume was obtained by placing on the farthest ends of atrioventricular valve leaflets on apical 4 chamber position. The mean of three consecutive valve flow measurements was calculated. All valve flow rates were obtained while sweep rate was 50 mm/sec. E and A waves of mitral and tricuspid valves, E/A rates, aortic and pulmonary artery flows were obtained. Fetal heart rates were measured four times when calculating the flows of mitral valve, aortic valve, tricuspid valve and pulmonary valve. Ejection fraction (EF) and fractional shortening (FS) values, TAPSE and MAPSE measurements, and minimum and maximum heart rates were recorded.

Statistical analysis

All data were recorded to Excel (2010; Microsoft Office Corp., Redmond, WA, USA), and transferred to SPSS 15.0 SPSS for Windows v.15.0; IBM-SPSS Inc., Chicago, IL, USA) for statistical analysis. The difference between mean values among independent groups was analyzed by independent sample test. The values were given as standard +/- deviation (SD). Pearson correlation and linear regression analyses were used to find the relationship between the variables. As the correlation coefficient, $r < 0.25$ was considered poor, $0.25-0.49$ was considered average, $0.50-0.74$ was considered strong and > 0.75 was considered very strong.

Table 1. General characteristics of all fetuses..

Variable	Second trimester (Group 1)	Third trimester (Group 2)	All fetuses (Group 1+2)
Mean gestational age (week)	23.82±1.41	29.95±2.89	27.05±3.83
LV Tei index	0.46±0.16	0.47±0.15	0.47±0.16
RV Tei index	0.51±0.16	0.53±0.18	0.52±0.17
MV E/A	0.59±0.07	0.65±0.1	0.624±0.09
TV E/A	0.63±0.07	0.67±0.08	0.656±0.08
Minimum heart rate (/min)	139.23±7.24	135.62±8.77	137.2±7.99
Maximum heart rate (/min)	149.37±6.48	148.17±7.5	148.73±7.05
TAPSE (cm)	0.44±0.08	0.52±0.11	0.47±0.1
MAPSE (cm)	0.32±0.07	0.39±0.07	0.36±0.07
EF (%)	74.99±4.48	75.01±4.93	75±4.70
FK (%)	39.56±3.84	40.1±4.52	39.84±4.20

Results

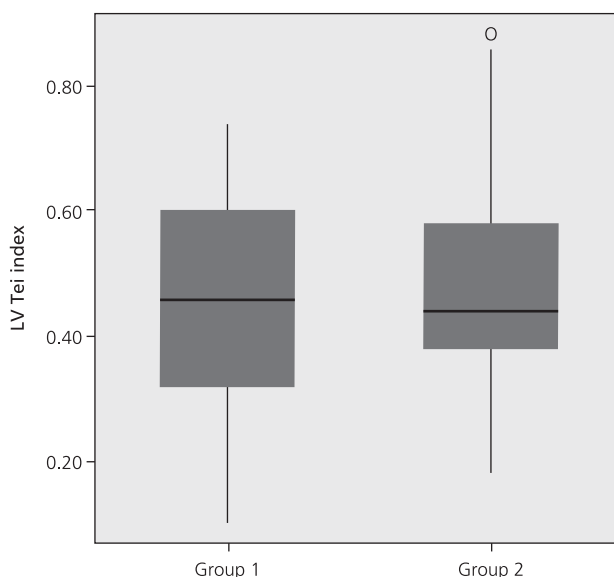
Mean parameter values of all fetuses included in the study were as following: LV Tei index: 0.47 ± 0.16 , RV Tei index: 0.52 ± 0.17 , EF: $75 \pm 4.7\%$, FS: $39.84 \pm 4.2\%$, TAPSE: 0.47 ± 0.1 cm, MAPSE: 0.36 ± 0.07 cm, mitral E/A: 0.624 ± 0.09 , tricuspid E/A: 0.656 ± 0.08 , aortic valve flow: 71.43 ± 12.53 cm/sec, pulmonary valve flow: 66.16 ± 8.61 cm/sec, minimum heart rate: 137.2 ± 7.99 /min, maximum heart rate: 148.73 ± 7.05 /min. The fetal assessments were done during the first pregnancy in 21.7% of the patients, during the second pregnancy in 30.3% of them, during the third pregnancy in 14.5% of them, during the fourth pregnancy in 8.6% of them, during the fifth pregnancy in 0.7% of them, and during the sixth pregnancy in 1.3%. Pregnancy information could not be obtained in 23% of the patients.

The mean values in the second trimester group (Group 1) were as following: LV Tei index: 0.46 ± 0.16 , RV Tei index: 0.51 ± 0.16 , mitral valve E/A: 0.59 ± 0.07 , tricuspid valve E/A: 0.63 ± 0.07 , minimum heart rate: 139.23 ± 7.24 /min, maximum heart rate: 149.37 ± 6.48 /min, aortic valve flow: 68.05 ± 12.5 cm/sec, pulmonary valve flow: 64.37 ± 8.98 cm/sec, TAPSE: 0.44 ± 0.08 cm, and MAPSE: 0.32 ± 0.07 cm.

The mean values in the third trimester group (Group 3) were as following: LV Tei index: 0.47 ± 0.15 , RV Tei index: 0.53 ± 0.18 , mitral valve E/A: 0.65 ± 0.1 , tricuspid valve E/A: 0.67 ± 0.08 , minimum heart rate: 135.62 ± 8.27 /min, maximum heart rate: 148.17 ± 7.5 /min, aortic valve flow: 74.38 ± 11.86 cm/sec, pulmonary valve flow: 67.72 ± 8.0 cm/sec, TAPSE: 0.52 ± 0.11 cm, and MAPSE:

0.39 ± 0.07 cm. The variables of the groups are shown in **Table 1**.

When we investigated to find whether there is any statistically significant difference between two groups in terms of all parameters assessed during advanced weeks of gestation, we found that there was no significant difference among LV Tei index, RV Tei index, and mitral valve mean gradient values while there was a significant increase in TAPSE and MAPSE values ($p=0.001$ and $p=0.001$, respectively) (**Figs. 1–4**). Also, we found a significant increase in aortic and pulmonary valve flows and tricuspid valve mean gradient value ($p=0.002$, $p=0.017$

**Fig. 1.** Difference between the groups in terms of LV Tei index.

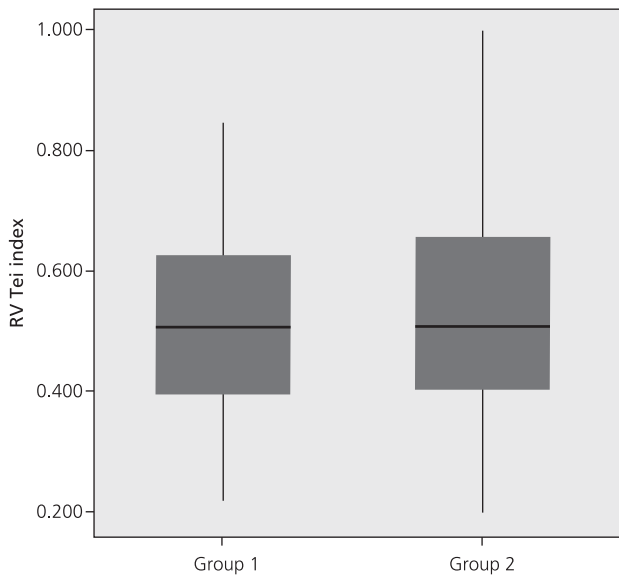


Fig. 2. Difference between the groups in terms of RV Tei index.

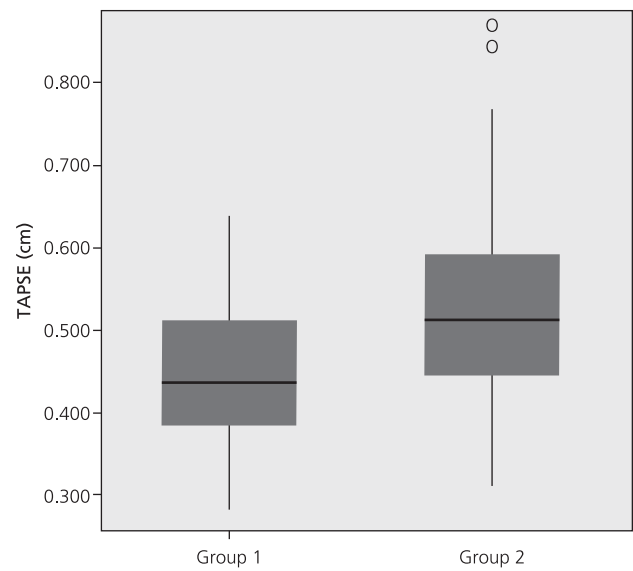


Fig. 3. Difference between the groups in terms of TAPSE value.

and $p=0.001$, respectively). In terms of heart rates, minimum heart rate was significantly different between two groups ($p=0.006$) while maximum heart rate was similar in both groups. The correlations between RV and LV Tei indexes and the week of gestation were $r=0.091$; $p=0.298$ and $r=0.137$; $p=0.097$, respectively. There was a strong and statistically significant correlation between TAPSE and the week of gestation ($r=0.537$; $p=0.001$). There was also a strong and statistically significant correlation between MAPSE and the week of gestation ($r=0.523$; $p=0.001$). There was an average and statistical-

ly significant correlation between TAPSE and RV Tei index ($r=0.322$; $p=0.001$). However, there was a negative, poor and statistically significant correlation between MAPSE and LV Tei index ($r=-0.157$; $p=0.208$).

Mean TAPSE and MAPSE values and LV and RV Tei indices \pm SD of the fetuses between 22 and 32 weeks of gestation are shown in **Table 2**.

Table 2. The mean TAPSE, MAPSE, RV and LV Tei index values of the fetuses between 22 and 32 weeks of gestation.

Week of gestation	TAPSE (cm)	MAPSE (cm)	LV Tei index	RV Tei index
22	0.39 ± 0.07	0.39 ± 0.12	0.49 ± 0.14	0.53 ± 0.17
23	0.43	0.25	0.56	0.53
24	0.44 ± 0.06	0.32 ± 0.05	0.42 ± 0.19	0.48 ± 0.20
25	0.42	0.25	0.48	0.61
26	0.47 ± 0.07	0.37 ± 0.08	0.55 ± 0.10	0.61 ± 0.14
27	0.45	0.37	0.50	0.58
28	0.55 ± 0.05	0.33 ± 0.0	0.45 ± 0.15	0.57 ± 0.24
29	0.51	0.39	0.42	0.53
30	0.47 ± 0.12	0.35 ± 0.04	0.52 ± 0.17	0.49 ± 0.11
31	0.56	0.28	0.46	0.65
32	0.57 ± 0.07	0.37 ± 0.01	0.52 ± 0.17	0.46 ± 0.15

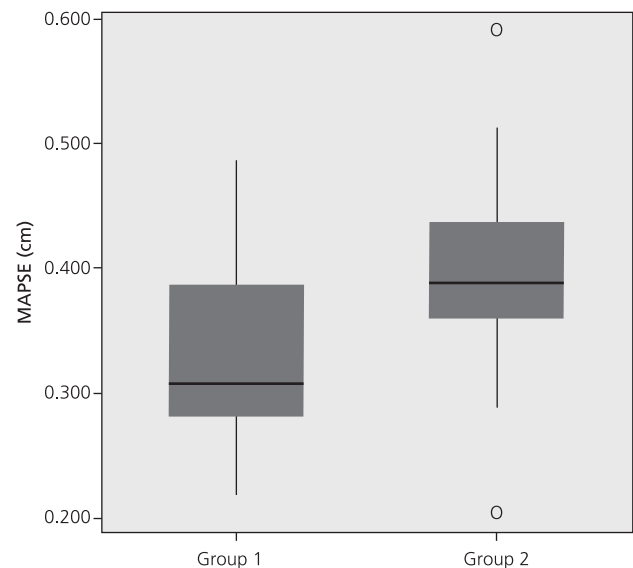


Fig. 4. Difference between the groups in terms of MAPSE value.

Discussion

Assessing fetal myocardial functions properly is critically significant to identify high-risk fetuses.^[12,16] When assessing systolic and diastolic functions, Tei index which is independent from the size and shape of ventricle and heart rate is one of the important parameters determining the fetal heart health. Some studies have reported that it increases in advanced weeks of gestation while some other studies have argued that there is no such correlation and there is even a negative correlation.^[12,16,17] In our study, we did not observe a significant increase in advanced weeks of gestation. When calculating Tei index, some authors measured ventricle entrance (mitral and tricuspid valves) and exit (aortic and pulmonary) pulsed Doppler records separately while some authors only measured time intervals that they obtained from a single Doppler record placed on an appropriate position. In our study, we measured aortic and mitral, tricuspid and pulmonary valve flows consecutively and separately and we took the mean value of three different measurements. Friedman et al. studied Tei index on 74 healthy pregnant women whose mean gestational age was 24 ± 3.4 (range: 18–31) weeks, and they found the mean LV Tei index 0.53 ± 0.13 .^[12] Tsutsumi and Eidem et al. reported LV Tei index 0.62 ± 0.07 (range: 18–26) week and 0.35 ± 0.03 in their studies, respectively.^[16,18] Mori et al. reported RV Tei index 0.35 ± 0.07 and showed that it did not change during gestation.^[19] In our study, mean RV Tei index was 0.52 ± 0.17 and LV Tei index was 0.47 ± 0.08 in the entire group. In the following weeks, RV and LV Tei index did not exhibit any statistically significant increase.

It has been reported that Tei index values increased in fetal ventricular dysfunction cases (such as intrauterine growth retardation, twin-to-twin transfusion syndrome, maternal diabetes mellitus, preeclampsia, and congenital heart diseases).^[20,21] Diastolic dysfunction which provides information about compliance and relaxation capacity of myocytes can be assessed by the flow pattern of tricuspid and mitral valves. In our study, mean mitral and tricuspid E/A values for the entire group were 0.62 ± 0.09 and 0.65 ± 0.08 , respectively. E/A rate is usually <1 , and it exhibits a constant increase during gestation. E wave is early or passive filling wave and it is associated with the relaxation function of myocardium and the negative pressure

applied by the ventricles. A wave is atrial, active or late wave, and it reflects the atrial contraction during ventricular filling. Chronic hypoxia and cardiac overload can be given as the examples changing this rate.^[22] While mitral E/A was 0.624 ± 0.09 and tricuspid E/A was 0.656 ± 0.08 in our study, Parasuraman et al. reported LV E/A and RV E/A values 0.68 ± 0.07 and 0.716 ± 0.109 , respectively.^[13] In the intrauterine growth retardation, the rates are lower in the fetuses with same gestational ages compared to the normal ones. The values found were at 10–25 percentile values for mitral E/A and tricuspid E/A according to the reference values determined by Parasuraman et al.^[13] Also, the aortic valve flow was 71.43 ± 12.53 cm/sec and pulmonary valve flow was 66.16 ± 8.61 cm/sec in the entire group. These values were at 10–25 percentile values for aortic and pulmonary valve flows according to the reference values determined in a previous report. Messing et al. compared conventional fetal TAPSE and spatiotemporal image correlation (STIC)-TAPSE methods, and they reported high correlation for both methods ($r=0.904$).^[23] In their study, conventional fetal TAPSE value was 0.36 ± 0.11 cm at 21 weeks of gestation while it was 0.86 ± 0.15 cm at 39 weeks of gestation. The mean TAPSE and MAPSE values according to the gestational age reported by Koestenberger et al. in different studies and the mean TAPSE and MAPSE values we found in our study according to the week of gestation were consistent.^[11,15] It has been reported that TAPSE value was higher than MAPSE value at any week of gestation due to the fact that dominant ventricle is the right ventricle in fetus and due to the structural characteristics of myocardial fibril distribution.^[24] In our study, we found TAPSE value higher than MAPSE value, and TAPSE/MAPSE ratio was 1.37 at the second trimester while it was 1.33 at the third trimester. It is known that TAPSE value decreases in pathological conditions.^[25,26] It has been reported that MAPSE value decreases in adult patients, and cardiovascular disease and extracardiac pathological conditions.^[9,27]

Conclusion

Tei index, and TAPSE and MAPSE are reliable non-invasive methods for global heart functions and annular plane systolic longitudinal functions of right and left ventricles, respectively, which are easily used on fetuses as well as children who are healthy or with con-

genital heart disease; and these methods also can be used in the routine practice. Knowing normal values in healthy fetuses and children will help to understand cardiac and extracardiac pathological conditions better where these parameters increase and decrease. We believe that TAPSE, MAPSE, LV Tei and RV Tei values that we found according to the gestational age will provide an insight for the studies to be performed by advanced techniques.

Conflicts of Interest: No conflicts declared.

References

1. 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 reproducible measure of cardiac function – a study of normal and dilated cardiomyopathy. *J Cardiol* 1995;26:357–66.
2. Eto G, Ishii M, Tei C, Tsutsumi T, Akagi T, Kato H. Assessment of global left ventricular function in normal children and in children with dilated cardiomyopathy. *J Am Soc Echocardiogr* 1999;12:1058–64.
3. Song B, Qi Q, Liu R, Xing W, Tang H, Li Y. Clinical value of Tei index in pediatric patients with repaired tetralogy of Fallot. *Int J Clin Exp Med* 2015;8:7971–6.
4. Cui W, Roberson DA. Left ventricular Tei index in children: Comparison of tissue Doppler imaging, pulsed wave Doppler, and M-mode echocardiography normal values. *J Am Soc Echocardiogr* 2006;19:1438–45.
5. Kır M, Ünal N, Sağın Saylam G, Karadaş U, Şahin M. Ventriküler septal defektli çocuklarda sol ventrikül fonksiyonlarının miyokardiyal performans indeksi (Tei indeksi) kullanılarak değerlendirilmesi. *Dokuz Eylül Üniversitesi Tıp Fakültesi Dergisi* 2008;22:113–9.
6. Koestenberger M, Nagel B, Ravakes W, Urlesberger B, Raith W, Avian A, et al. Systolic right ventricular function in preterm and term neonates: reference values of the tricuspid annular plane systolic excursion (TAPSE) in 258 patients and calculation of Z-score values. *Neonatology* 2011;100:85–92.
7. Paytoncu Ş. Tricuspid annular plane systolic excursion (TAPSE) and cardiac Z score values in 827 healthy Turkish children: single center results. *Türkiye Klinikleri Journal of Cardiovascular Sciences* 2015;27:95–102.
8. Halimić M, Terzić S, Kadić A, Begić Z, Vukas E, Mišanović V, et al. Right ventricular systolic longitudinal function in infants: correlation of TAPSE with gestational age and body weight. *Journal of Pediatric and Neonatal Individualized Medicine* 2018;7:e070216.
9. Kai H, Dan L, Herrmann S, Niemann M, Gaudron PD, Voelker W, et al. Clinical implication of mitral annular plane systolic excursion for patients with cardiovascular disease. *Eur Heart J Cardiovasc Imaging* 2013;14:205–12.
10. Tomomasa T, Kazuhino M, Miki I, Hayabuchi Y. Mitral annular plane systolic excursion / left ventricular length (MAPSE/L) as a simple index for assessing left ventricular longitudinal function in children. *Echocardiography* 2016;33:1703–9.
11. Koestenberger M, Nagel B, Ravekes WA, Avian A, Heinzl B, Frithsch PW, et al. Left ventricular long-axis function: reference values of mitral annular plane systolic excursion in 558 healthy children of Z-score values. *Am Heart J* 2012;164:125–31.
12. Friedman D, Buyon J, Kim M, Glickstein JS. Fetal cardiac function assessed by Doppler myocardial performance index (Tei index). *Ultrasound Obstet Gynecol* 2003;21:33–6.
13. Parasuraman R, Osmond C, Howe DT. Gestation-specific reference intervals for fetal cardiac Doppler indices from 12 to 40 weeks of gestation. *Open Journal of Obstetrics and Gynecology* 2013;3:97–104.
14. Bravo-Valenzuela NJ, Peixoto AB, Nardoza LM, Souza AS, Araujo Junior E. Applicability and technical aspects of two-dimensional ultrasonography for assessment of fetal heart function. *Med Ultrason* 2017;19:94–100.
15. Koestenberger M, Nagel B, Ravekes W, Gamillscheg A, Binder C, Avian A, et al. Longitudinal systolic left ventricular function in preterm and term neonates: reference values of mitral annular plane systolic excursion (MAPSE) and calculation of Z-scores. *Pediatric Cardiol* 2015;36:20–6.
16. Tsutsumi T, Ishii M, Eto G, Hota M, Kato H. Serial evaluation for myocardial performance in fetuses and neonates using a new Doppler index. *Pediatr Int* 1999;41:722–7.
17. Nair A, Radhakrishnan S. Fetal left ventricular myocardial performance index: defining normal values for Indian population and review of literature. *Ann Pediatr Cardiol* 2016;9:132–6.
18. Eidem BW, Edwards JM, Cetta F. Quantitative assessment of fetal ventricular function: establishing normal values of the myocardial performance index in the fetus. *Echocardiography* 2001;18:9–13.
19. Mori Y, Rice MJ, McDonald RW, Reller MD, Wanitkun S, Harada K, et al. Evaluation of systolic and diastolic ventricular performance of the right ventricle in fetuses with ductal constriction using the Doppler Tei index. *Am J Cardiol* 2001;88:1173–8.
20. Battista MC, Calvo E, Chorvatova A, Comte B, Corbeil J, Brochu M. Intra-uterine growth restriction and the programming of left ventricular remodeling in female rats. *J Physiol* 2005;565:197–205.
21. Mahajan A, Henry A, Meriki N, Hernandez-Andrade E, Crispi F, Wu L, et al. The (Pulsed-wave) Doppler fetal myocardial performance index: technical challenges, clinical applications and future research. *Fetal Diagn Ther* 2015;38:1–13.
22. Hernandez-Andrade E, Benavides-Serralde JA, Cruz-Martinez R, Welsh A, Mancilla-Ramirez J. Evaluation of conventional Doppler fetal cardiac function parameters: E/A ratios, outflow tracts and myocardial performance index. *Fetal Diagn Ther* 2012;32:22–9.
23. Messing B, Gilboa Y, Lipschuetz M, Valsky DV, Cohen SM, Yagel S. Fetal tricuspid annular plane systolic excursion (f-

- TAPSE): evaluation of fetal right heart systolic function with conventional M-mode ultrasound and spatiotemporal image correlation (STIC) M-mode. *Ultrasound Obstetr Gynecol* 2013;42:182–8.
24. Gardiner HM, Pasquini L, Wolfenden J, Barlow A, Kulinskaya E, Henein M. Myocardial tissue Doppler and long axis function in the fetal heart. *Int J Cardiol* 2006;113:39–47.
 25. Koestenberger M, Nagel B, Avian A, Ravekes W, Sorantin E, Cvirn G, et al. Systolic right ventricular function in children and young adults with pulmonary artery hypertension secondary to congenital heart disease and tetralogy of Fallot: tricuspid annular plane systolic excursion (TAPSE) and magnetic resonance imaging data. *Congenit Heart Dis* 2012;7:250–8.
 26. Mercer-Rosa L, Parnell A, Forfia PR, Yang W, Goldmuntz E, Kawut SM. Tricuspid annular plane systolic excursion in the assessment of right ventricular function in children and adolescents after repair of tetralogy of Fallot. *J Am Soc Echocardiogr* 2013;26:1322–9.
 27. Bergenzaun L, Öhlin H, Gudmundson P, Willenheimer R, Chew MS. Mitral annular plane systolic excursion (MAPSE) in shock: a valuable echocardiographic parameter in intensive care patients. *Cardiovasc Ultrasound* 2013;11:16.