ORIGINAL ARTICLE

https://doi.org/10.1590/1806-9282.20221215

Right ventricular myocardial performance index (Tei) in premature infants

Eliane Lucas[1,2], Carmem Lucia Ribeiro[2], Nathalie Jeanne Bravo-Valenzuela[3], Edward Araujo Júnior[4,5]*, Rosane Reis de Mello[1,2]

SUMMARY

OBJECTIVE: The objective of this study was to evaluate the right ventricular myocardial performance index) based on echocardiography in very low birth weight premature neonates, close to hospital discharge.

METHODS: This was a prospective cross-sectional study that included premature neonates with birth weight <1,500 g and gestational age <37 weeks at the Intermediate Neonatal Unit of Bonsucesso Federal Hospital from July 2005 to July 2006. The infants underwent two-dimensional color Doppler echocardiography, being the right ventricular myocardial performance index evaluated close to hospital discharge. We compared the neonatal and echocardiographic variables in neonates with and without bronchopulmonary dysplasia.

RESULTS: A total of 81 exams were analyzed. The mean birth (standard deviation) weight and gestational age were 1,140 (235) g and 30 (2.2) weeks, respectively. The incidence of bronchopulmonary dysplasia was 32%. The mean right ventricle myocardial performance index (standard deviation) of the sample was 0.13 (0.06). We found a significant difference in aortic diameter [non-bronchopulmonary dysplasia 0.79 (0.07) vs. bronchopulmonary dysplasia 0.87 (0.11) cm, p=0.003], left ventricle in diastole [non-bronchopulmonary dysplasia 1.4 (0.19) vs. bronchopulmonary dysplasia 1.59 (0.21) cm, p=0.0006], ventricular septal thickness [non-bronchopulmonary dysplasia 0.23 (0.03) vs. bronchopulmonary dysplasia 0.26 (0.05) cm, p=0.032], and "a" measurement [(= sum of the isovolumetric contraction time, ejection time, and isovolumetric relaxation time) when calculating the myocardial performance index (p=0.01)].

CONCLUSION: Higher "a" interval in neonates with bronchopulmonary dysplasia suggests right ventricle diastolic dysfunction. We conclude that the right ventricle myocardial performance index is an important indicator both of ventricular function and for serial follow-up testing of very low birth weight premature neonates, especially those with bronchopulmonary dysplasia.

KEYWORDS: Bronchopulmonary dysplasia. Infant, low birth weight. Ventricular dysfunction, right. Echocardiography, doppler, color.

INTRODUCTION

Despite tremendous technological progress and new practices in handling very low birth weight (VLBW) neonates, bronchopulmonary dysplasia (BPD) is still a major complication, due to its high morbidity and mortality, principally in the first 2 years of life[1]. In 1995, Fanaroff et al.[2] reported BPD in 51% of neonates weighing from 501 to 750 g and 35% of those from 751 to 1,000 g. BPD, especially in the severe form, can evolve with cardiovascular complications such as right ventricular dysfunction associated with pulmonary hypertension (PH). Right ventricle (RV) dysfunction can increase the mortality rate to 39% in these patients[3]. It is thus recommended to perform cardiologic evaluation and routine echocardiography to estimate the presence of PH, thereby aiding the proper management of these infants[4].

In the past 20 years, echocardiography has proven to be an important tool for anatomical diagnosis of congenital and acquired cardiopathies, in addition to allowing systolic and diastolic functional evaluation of both ventricles. In special situations such as the absence of tricuspid valve regurgitation on color Doppler mapping, as well as alterations in heart rate and RV geometry, it is sometimes difficult to achieve morphofunctional assessment of the RV in PH when using traditional parameters to perform echocardiographic measurements[5].

In 1995, a new echocardiographic measurement, known as the myocardial performance index (MPI or Tei index), was

[1]National Institute of Women, Children and Adolescents Health Fernandes Figueira, Oswald Cruz Foundation, Department of Pediatrics – Rio de Janeiro (RJ), Brazil.
[2]Bonsucesso Federal Hospital, Service of Cardiology – Rio de Janeiro (RJ), Brazil.
[3]Federal University of Rio de Janeiro, Department of Internal Medicine, Discipline of Pediatrics – Rio de Janeiro (RJ), Brazil.
[4]Federal University of São Paulo, Paulista School of Medicine, Department of Obstetrics – São Paulo (SP), Brazil.
[5]Municipal University of São Caetano do Sul, Medical Course – São Paulo (SP), Brazil.
*Corresponding author: araujojred@terra.com.br

Conflicts of interest: the authors declare there is no conflicts of interest. Funding: none.
Received on December 23, 2022. Accepted on January 10, 2023.

developed, which measures time intervals using Doppler and allows for estimating global ventricular performance[6]. Several studieson children have shown its value as a sensitive indicator of the presence of left and right ventricular dysfunction[7-9]. This measurement has been considered operator-friendly and reproducible and has advantages over traditional measurements since it is not altered by variations in heart rate or ventricular geometry.

Therefore, the objective of this study was to assess the RV function in VLBW newborns with and without BPD using the RV MPI, close to hospital discharge.

METHODS

This study protocol was approved by the Research Ethics Committee of Bonsucesso Federal Hospital (nº 23/05) and the National Institute of Women, Children and Adolescents Health Fernandes Figueira/Oswaldo Cruz Foundation (IFF/FIOCRUZ) (nº 045/065). This was a prospective cross-sectional study carried out at an Intermediate Neonatal Unit (INU) of Bonsucesso Federal Hospital from July 2005 to July 2006. The inclusion criteria were prematurity (gestational age (GA) <37 weeks), birth weight <1,500 g, and patients whose at least one of the parents or legal guardians has provided written informed consent. Neonates admitted to the INU from other units and more than 3 days old were excluded, as were those with thoracic or diaphragmatic malformations or congenital cardiopathies. The study sample was divided into two groups, namely, newborns with and without BPD.

Gestational age was calculated based on the last menstrual period (LMP), and when this date was unknown, it was calculated based on the early obstetric ultrasound, which was performed up to 18 weeks of gestation. When neither of the above was available, GA was estimated by the new Ballard method[10]. Adequacy of birth weight for GA was classified as adequate for GA (AGA), small for GA (SGA), and large for GA (LGA) based on the Lubchenco classification[11]. BPD was defined as the use of oxygen therapy for 28 days or longer[12].

The echocardiogram was performed using two-dimensional color Doppler (Philips EnVisor C HD model, sector transducer 21350A, 5 MHz, 400 filter, with speeds of 50 and 100 ms). Images were stored in digital format in HD and CD for subsequent analysis. Echocardiography was performed once by the same examiner (EL) when the patient was clinically and hemodynamically stable, without the need for oxygen, close to hospital discharge. The mean of three measurements was taken for each echocardiographic parameter. A single pediatric cardiologist (EL), blinded to the newborns' clinical data, used a high-resolution echocardiography machine. Patients underwent echocardiography without sedation and with continuous electrocardiographic monitoring.

The echocardiographic parameters by the M mode included the left ventricular systolic and diastolic diameters (LVs and LVd), RV, left atrium (LA), aorta (AO), ventricular septal thickness (VST), and posterior wall of the left ventricle (PW). The Doppler method was used to acquire the following measurements: calculation of systolic pressure (SAP) estimated by tricuspid regurgitation, analysis of the pulmonary systolic flow curve, and RV MPI. We estimated pressure gradient values using the Bernoulli equation ($\Delta P=4\ V^2$, where P=pressure gradient and V=maximum velocity of the flow curve).

To calculate the RV MPI, we obtained the RV inlet tract (tricuspid valve) and outlet tract curves. Measurement "a" corresponds to the time interval between the end and beginning of RV flow, which equals the sum of the isovolumetric contraction time (ICT), ejection time (ET), and isovolumetric relaxation time (IRT). Measurement "b" corresponds to the ejection time (ET) of the RV outlet tract. As the Tei index is calculated according to the formula ICT + IRT/ET, one must subtract "b" from "a" and divide by "b" (= a-b/b). The size of the Doppler sample volume was standardized at 2 mm to obtain the time intervals, and the means were calculated for at least five consecutive cardiac cycles.

To calculate the sample size, considering an altered RV MPI rate of 3% for the age bracket, 95% confidence interval, and 3% precision, the necessary sample size was 56 infants.

The maternal and neonatal variables were described through frequency measurements and means, medians, and respective standard deviations (SDs). We used statistical tests for differences between means and proportions, Student's t-test/F-statistic, and Fisher's exact test, respectively. The statistical significance level for comparisons was set at 5%.

RESULTS

A total of 84 preterm newborns with GA <37 weeks and birth weight <1,500 g were admitted to the INU. We excluded two neonates with congenital pulmonary malformations and one newborn aged more than 3 days and was transferred from another hospital unit. Therefore, the final sample size was 81 newborns.

Regarding gender, 34 newborns (42%) were male and 47 (58%) were female. Of the entire sample, 49 (60.5%) were AGA and 32 (39.5%) were SGA, with no LGA preterm newborn. Birth weight was distributed as follows: <750 g: 2 (2.5%), 750–999 g: 22 (27.5%), 1,000–1,249 g: 24 (29.6%), and 1,250–1,499 g: 33 (40.7%). Birth weight ranged from 575 to 1,495 g, with a mean of 1,140±235 g (median: 1,142 g). The mean GA was 30±2.2 weeks (median: 30 weeks). For 31 cases (40%), it was not possible to estimate GA according to the LMP.

Regarding postnatal complications, 47 newborns (58%) had hyaline membrane disease, and surfactant was used in 46, corresponding to 56.8% of the total sample. Mechanical ventilation was required in 53 newborns (65.4%), and the mean time (SD) and the median were 14.9 (18.9) days and 5.5 days, respectively. Nasal continuous airway positive pressure (CPAP) was required in 69 (85.1%), for a mean time (SD) of 5.9 (6.8) days and a median of 3.0 days. Oxyhood was used for a mean (SD) of 3.1 (3.9) days and a median of 2.0 days, and oxygen catheter was used for a mean (SD) of 7.1 (11.7) days and a median of 1.5 days. The total oxygen time ranged from 4 to 120 days, with a mean (SD) of 24.7 (28.6) days and a median of 9.0 days.

Of note, 26 infants (32%) met the diagnostic criteria for BPD, 19 of which were classified as moderate. No neonate was classified as severe. The infants were distributed with and without BPD, based on birth weight brackets, and 18 (69%) of the neonates with BPD were born weighing <1,000 g. Time on mechanical ventilation and total O_2 demand in the BPD group were higher compared to the group without BPD (SD) [23.6 (20.9) vs. 4.1 (4.7) days and 59.0 (23.4) vs. 7.2 (1.1) days, respectively].

Newborns with BPD showed statistically significant differences in weight and GA on the exam date compared to those without BPD (SD) [1,643 (113) vs. 1,991 (352) g (p= 0.001) and 34.5 (2.2) vs. 38.2 (3.3) weeks (p=0.001), respectively].

Table 1. Echocardiographic measurements of neonates (n=81) admitted to the Intermediate Neonatal Unit.

Echocardiographic parameter	Mean	SD
LA (cm)	0.82	0.09
AO (cm)	0.86	0.15
LVd (cm)	1.46	0.21
LVs (cm)	0.86	0.15
RV (cm)	0.66	0.14
VST (cm)	0.24	0.04
PWT (cm)	0.23	0.03
“a” measurement (ms)	215	15
“b” measurement (ms)	189	14
RV MPI	0.13	0.06

LA: left atrium; AO: aorta; SD: standard deviation; LVd left ventricle in diastole; LVs: left ventricle in systole; RV: right ventricle; VST: ventricular septal thickness; PWT: posterior wall thickness.

Patent ductus arteriosus was found in 18 newborns (22.2%), and surgical closure was indicated in 9. Septicemia confirmed by positive blood culture occurred in 15 cases (18.5%).

Table 1 shows the analysis of the echocardiographic values of the 81 children in the sample. Table 2 shows that the diameters of the aorta, left ventricle in diastole, ventricular septum, and posterior wall in diastole were also significantly higher in the BPD group. There was no significant difference between the two groups in terms of RV and LA diameters.

Evaluating the ventricular septal excentricity index, no alteration was observed in the study sample. Doppler mapping analysis of the right atrioventricular valve identified only 9 (11%) newborns with mild tricuspid regurgitation. The mean RV MPI (SD) was 0.13 (0.06), and no statistically significant difference was observed in this value when comparing neonates with and without BPD (Table 2).

Considering the measures comprising the MPI separately, at the time of the echocardiograph exam (Table 3), we observed that there were no differences in the “b” measurement but a statistically significant difference in the “a” measurement between the two groups (BPD vs. non-BPD).

DISCUSSION

BPD is a complex disease and extensively studied in the literature[13,14]. However, with technological advances and improved perinatal care, the incidence of severe BPD has decreased, and “new BPD” is now the most common presentation[15]. Some authors have shown that 20–25% of newborns with BPD can

Table 2. Echocardiographic measurements of neonates without and with bronchopulmonary dysplasia admitted to the Intermediate Neonatal Unit.

Echocardiographic parameter	Non-BPD (n=55) Mean (SD)	BPD (n=26) Mean (SD)	p-value
LA (cm)	0.85 (0.14)	0.90 (0.17)	0.23
AO (cm)	0.79 (0.07)	0.87 (0.11)	0.003
LVd (cm)	1.40 (0.19)	1.59 (0.21)	0.0006
LVs (cm)	0.84 (0.15)	0.91 (0.13)	0.053
RV (cm)	0.65 (0.13)	0.68 (0.16)	0.392
VST (cm)	0.23 (0.03)	0.26 (0.05)	0.032
PWT (cm)	0.22 (0.03)	0.25 (0.04)	0.01
“a” measurement (ms)	213 (14)	221 (17)	0.03
“b” measurement (ms)	189 (13)	191 (15)	0.41
RVMPI	0.12 (0.05)	0.14 (0.06)	0.23

LA: left atrium; AO: aorta; BPD: bronchopulmonary dysplasia; SD: standard deviation; LVd: left ventricle in diastole; LVs: left ventricle in systole; RV: right ventricle; VST: ventricular septal thickness; PWT: posterior wall thickness.

present cardiac involvement, and a significant portion can evolve to PH[16,17]. During the clinical follow-up of these infants, cardiac assessment is of the most importance, orienting adequate treatment with diuretics and vasodilators, the prolonged use of which can have adverse effects on these VLBW infants[5]. In our study, we observed that 11% of newborns with BPD evolved to PH with a higher prevalence of cardiac involvement related to RV diastolic dysfunction.

The prevalence of BPD in our study was 32%. Of these, 76% were O_2-dependent with 36 weeks of GA corrected at the moment of evaluation and classified as moderately severe. The morphometric data of the newborns in this study were within the normal range for GA[18]. Comparing the groups with and without BPD, there was a statistically significant difference in the aorta, left ventricle in diastole, ventricular septal thickness, and posterior wall. This finding can be attributed to the fact that newborns with BPD require more time on oxygen therapy, presenting higher corrected GA and weight compared to those without BPD, reflected in the measurements of the cardiac cavities. There was no statistically significant difference between the two groups in the RV and LA measurements.

Color Doppler mapping of the study sample identified only three cases of mild tricuspid regurgitation, absence of RV hypertrophy, and no case of alteration in the ventricular septal excentricity index, showing that in these 81 neonates, there were no signs of PH as evaluated by the traditional echocardiographic methods.

MPI has been used for predicting perinatal morbidity and mortality in fetuses of pregnant women with diabetes mellitus, fetal growth restriction, and twin-to-twin transfusion syndrome[19]. This study satisfactorily measured the RV MPI in newborns, confirming the reports in the literature that this is a simple and user-friendly method[20,21]. In this study, the mean value of this index (SD) was 0.13 (0.06), which is within the range reported in the literature for infants born at term[22]. Ishii et al.[23] reported mean RV MPI (SD) values of 0.24 (0.04), but their findings are difficult to compare with our results because the authors studied normal children with ages ranging from 30 days to 18 years, which were different from those of our sample. Malakan-Rad and Momtazmanesh[24] studied neonates at term between 48 and 72 h after birth and found a mean RV MPI (SD) of 0.23 (0.14), but again a comparison is difficult because the authors studied neonates at term in an initial phase of life in which the RV MPI presents higher values (as days pass, the pulmonary vascular resistance decreases and these values tend to drop). Our study evaluated MPI in premature infants close to hospital discharge that were clinically stable at the time of examination, with a mean GA of 36 weeks corrected for prematurity.

Schmitz et al.[25] studied LV diastolic function in healthy neonates and infants through mitral valve flow parameters. They demonstrated that the isovolumetric relaxation time in neonates is significantly prolonged compared to infants older than 2 months. This may indicate that immature LV diastolic function plays an important role in the severity of cardiopulmonary complications in this age group. In our study, although the values found in the "a" measurement (which includes the isovolumetric relaxation and contraction times) showed a statistically significant difference between neonates with and without BPD, we cannot compare our results with the abovementioned study because we evaluated not only the diastolic ventricular function but also the global RV function.

The limitations of this study were the lack of long-term postnatal follow-up about the applicability of MPI and the absence of interobserver variability analysis.

In summary, from our data, we conclude that RV MPI is an important indicator of combined ventricular function and important for serial follow-up testing of VLBW neonates, especially those with BPD.

Table 3. Characteristics of the study sample based on the right ventricle myocardial performance index (RV MPI) values.

Variable	MPI≤0.24 n=76 Mean (SD)	MPI>0.24 n=5 Mean (SD)	p-value
Birth weight (g)	1,149 (237)	1,103 (278)	>0.05
Gestational age (days)	209 (17.1)	208 (15.8)	>0.05
Weight at exam (g)	1,739 (245)	1,941 (498)	>0.05
Corrected GA (weeks)	35.5 (2.6)	38.1 (6.0)	>0.05
Total O_2 time (days)	23.2 (26.4)	45.2 (49.2)	>0.05
Ventilation time (days)	14.6 (18.4)	19.7 (28.0)	>0.05
"a" measurement (ms)	215 (15)	229 (12)	0.04
"b" measurement (ms)	191 (14)	179 (8)	>0.05

SD: standard deviation; GA: gestational age.

AUTHORS' CONTRIBUTIONS

EL: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. **CLR:** Conceptualization, Formal Analysis, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **EAJ:** Formal Analysis, Methodology, Software, Validation, Visualization, Writing – review & editing. **RRM:** Formal Analysis, Methodology, Software, Validation, Visualization, Writing – review & editing. **NJBV:** Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

REFERENCES

1. Chowdhury N, Giles BL, Dell SD. Full-term neonatal respiratory distress and chronic lung disease. Pediatr Ann. 2019;48(4):e175-81. https://doi.org/10.3928/19382359-20190328-01
2. Fanaroff AA, Wright LL, Stevenson DK, Shankaran S, Donovan EF, Ehrenkranz RA, et al. Very-low-birth-weight outcomes of the National Institute of Child Health and Human Development Neonatal Research Network, May 1991 through December 1992. Am J Obstet Gynecol. 1995;173(5):1423-31. https://doi.org/10.1016/0002-9378(95)90628-2
3. Altit G, Bhombal S, Feinstein J, Hopper RK, Tacy TA. Diminished right ventricular function at diagnosis of pulmonary hypertension is associated with mortality in bronchopulmonary dysplasia. Pulm Circ. 2019;9(3):2045894019878598. https://doi.org/10.1177/2045894019878598
4. Abman SH. Monitoring cardiovascular function in infants with chronic lung disease of prematurity. Arch Dis Child Fetal Neonatal Ed. 2002;87(1):F15-8. https://doi.org/10.1136/fn.87.1.f15
5. Howard LS, Grapsa J, Dawson D, Bellamy M, Chambers JB, Masani ND, et al. Echocardiographic assessment of pulmonary hypertension: standard operating procedure. Eur Respir Rev. 2012;21(125):239-48. https://doi.org/10.1183/09059180.00003912
6. Tei C. New non-invasive index for combined systolic and diastolic ventricular function. J Cardiol. 1995;26(2):135-6. PMID: 7674144
7. Azevedo VM, Albanesi Filho FM, Santos MA, Castier MB, Tura BR, Amino JG, et al. Is myocardial performance index an independent echocardiographic marker of death in children with idiopathic dilated cardiomyopathy? Clin Cardiol. 2008;31(9):424-30. https://doi.org/10.1002/clc.20264
8. Murase M, Ishida A, Morisawa T. Left and right ventricular myocardial performance index (Tei index) in very-low-birth-weight infants. Pediatr Cardiol. 2009;30(7):928-35. https://doi.org/10.1007/s00246-009-9464-8
9. Uçar T, Ileri T, Atalay S, Uysal Z, Tutar E, Ertem M. Early detection of myocardial dysfunction in children with beta-thalassaemia major. Int J Cardiovasc Imaging. 2009;25(4):379-86. https://doi.org/10.1007/s10554-008-9404-3
10. Ballard JL, Khoury JC, Wedig K, Wang L, Eilers-Walsman BL, Lipp R. New Ballard Score, expanded to include extremely premature infants. J Pediatr. 1991;119(3):417-23. https://doi.org/10.1016/s0022-3476(05)82056-6
11. Lubchenco LO, Hasman C, Dressler M, Boyd E. Intrauterine growth as estimated from liveborn birth-weight data at 24 to 42 weeks gestation. Pediatrics. 1963;32:793-800. PMID: 14075621
12. Jobe AH, Bancalari E. Bronchopulmonary dysplasia. Am J Respir Crit Care Med. 2001;163(7):1723-9. https://doi.org/10.1164/ajrccm.163.7.2011060
13. Principi N, Di Pietro GM, Esposito S. Bronchopulmonary dysplasia: clinical aspects and preventive and therapeutic strategies. J Transl Med. 2018;16(1):36. https://doi.org/10.1186/s12967-018-1417-7
14. Gilfillan M, Bhandari A, Bhandari V. Diagnosis and management of bronchopulmonary dysplasia. BMJ. 2021;375:n1974. https://doi.org/10.1136/bmj.n1974
15. Coalson JJ. Pathology of new bronchopulmonary dysplasia. Semin Neonatol. 2003;8(1):73-81. https://doi.org/10.1016/s1084-2756(02)00193-8
16. Nicolarsen J, Ivy D. Progress in the diagnosis and management of pulmonary hypertension in children. Curr Opin Pediatr. 2014;26(5):527-35. https://doi.org/10.1097/MOP.0000000000000135
17. Katz SL, Luu TM, Nuyt AM, Lacaze T, Adamo KB, Adatia I, et al. Long-term follow-up of cardiorespiratory outcomes in children born extremely preterm: recommendations from a Canadian consensus workshop. Paediatr Child Health. 2017;22(2):75-9. https://doi.org/10.1093/pch/pxx028
18. Zecca E, Romagnoli C, Vento G, De Carolis MP, De Rosa G, Tortorolo G. Left ventricle dimensions in preterm infants during the first month of life. Eur J Pediatr. 2001;160(4):227-30. https://doi.org/10.1007/s004310000702
19. Peixoto AB, Bravo-Valenzuela NJM, Martins WP, Mattar R, Moron AF, Araujo Júnior E. Reference ranges for the left ventricle modified myocardial performance index, respective time periods, and atrioventricular peak velocities between 20 and 36 + 6 weeks of gestation. J Matern Fetal Neonatal Med. 2021;34(3):456-65. https://doi.org/10.1080/14767058.2019.1609933
20. Jurko A, Jurko A, Minarik M. Doppler-derived myocardial performance index in healthy children. Bratisl Lek Listy. 2011;112(2):77-9. PMID: 21456506
21. Kizilca O, Ozmen D, Bahaettin Öncü S, Zihni C, Kir M, Soylu A, et al. Assessments of left ventricular systolic and diastolic functions with tissue Doppler imaging and myocardial performance index in children with chronic kidney disease. Pediatr Int. 2021;63(12):1483-489. https://doi.org/10.1111/ped.14705
22. Ichihashi K, Yada Y, Takahashi N, Honma Y, Momoi M. Utility of a Doppler-derived index combining systolic and diastolic performance (Tei index) for detecting hypoxic cardiac damage in newborns. J Perinat Med. 2005;33(6):549-52. https://doi.org/10.1515/JPM.2005.098
23. Ishii M, Eto G, Tei C, Tsutsumi T, Hashino K, Sugahara Y, et al. Quantitation of the global right ventricular function in children with normal heart and congenital heart disease: a right ventricular myocardial performance index. Pediatr Cardiol. 2000;21(5):416-21. https://doi.org/10.1007/s002460010100
24. Malakan-Rad E, Momtazmanesh N. Doppler-derived right ventricular myocardial performance in neonates: normal values. Acta Medica Iranica. 2002;40(4):226-9.
25. Schmitz L, Xanthopoulos A, Koch H, Lange PE. Doppler flow parameters of left ventricular filling in infants: how long does it take for the maturation of the diastolic function in a normal left ventricle to occur?. Pediatr Cardiol. 2004;25(5):482-91. https://doi.org/10.1007/s00246-003-0605-1