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Myocardial Tissue Doppler Velocity in Child Growth

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Background: In adults, tissue Doppler imaging (TDI) is a recommended component of routine echocardiography. However, TDI velocities are less accepted in pediatrics, due to their strong variability and age dependence in children. This study examines the distribution of myocardial tissue Doppler velocities in healthy children to assess the effect of age with cardiac growth on the various echocardiographic measurements.
Methods: Total 144 healthy children were enrolled in this study. They were recruited from the pediatric outpatient clinic for routine well-child visits. The statistical relationships between age and TDI values were analyzed. Also, the statistical relationships between body surface area (BSA) and TDI values, left ventricle end-diastolic dimension (LVEDD) and TDI values were analyzed. Also, we conducted multivariate analysis of cardiac growth parameters such as, age, BSA, LVEDD and TDI velocity data.
Results: All of the age, BSA, and LVEDD had positive correlations with deceleration time (DT), pressure half-time (PHT), peak early diastolic myocardial velocity, peak systolic myocardial velocity, and had negative correlations with peak late diastolic velocity (A) and the ratio of trans-mitral inflow velocity to early diastolic velocity of mitral annulus (E/E'). In the multivariate analysis, all of the age, BSA, and LVEDD had positive correlations with DT, PHT, and negative correlations with A and E/E'.
Conclusion: The cardiac growth parameters related alterations of E/E' may suggest that diastolic myocardial velocities are cardiac growth dependent, and diastolic function has positive correlation with cardiac growth in pediatric group. This cardiac growth related myocardial functional variation would be important for assessment of cardiac involvement either in healthy and sick child.

KEY WORDS: Tissue Doppler imaging · Left ventricular diastolic function · Children · Age.

Introduction

Tissue Doppler imaging (TDI) is now and integrated part of the assessment of myocardial function in cardiology.[1] Especially in adults, TDI velocity is a recommended component of routine echocardiography and widely used for the evaluation of myocardial systolic and diastolic function. Moreover, measuring the early diastolic velocity on TDI is the single most helpful parameter to determine diastolic function of the left and right ventricle.[2]

There are fundamental differences of TDI velocity pattern between adult and childhood. Infants physiologically have much lower velocities than adults. As the velocities increase slowly during childhood, there is a disproportionately greater increase of longitudinal systolic velocities than of radial velocities. In these points, TDI can be estimated that the myocardial velocities would be altered according to the age and growth.[3] The important differences between children and adult TDI velocity imaging that preclude a direct extrapolation of the adult experience to pediatric population. It is because of the age dependence of the entire velocities and disproportionate increase of long axis myocardial motion as the child grows.

However, the study of TDI values according to the age has been insufficient in children. Kim et al.[4] and Kapusta et al.[5] reported that there were no significant correlations between age and TDI values. In contrast, Hiarada et al.,[6] Mori et al.,[7] and Eidem et al.[8] observed that there were positive correlations between age and systolic and early diastolic myocardial velocities. Also, Swaminathan et al.[9] published that there were positive correlations between late diastolic velocity and age. As described, there is no well-established unified consensus about the rela-

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tionships between age and TDI values. Also, there are a limited number studies about cardiac growth and TDI values.

Meanwhile, Eidem et al.[8] studied the relationships between cardiac growth parameters and TDI values in children. In this study, left ventricle (LV) end-diastolic dimension (LVEDD), LV mass, body surface area (BSA) are suggested as index parameters for cardiac growth. Above those parameters, LVEDD and age had been revealed statistically significant positive correlations with systolic and early diastolic myocardial velocities, and LVEDD had been showed the most significant correlations with TDI parameters.

This study examines the distribution of myocardial velocities in healthy children as measured by TDI and then assesses the effect of cardiac growth parameters, such as age, LVEDD, and BSA on the various echocardiographic measurements.

Methods

Study subjects

The study consisted of 144 healthy children (age range: 0 to 19 years; mean age: 5.9 ± 5.1 years) identified by retrospective review of Gangnam Severance Hospital, Seoul, Korea, echocardiographic database from July 2013 to January 2014. Reason for echocardiographic referral included the precordial cardiac murmur, an enlarged cardiothymic silhouette in a chest radiogram, or an incomplete right bundle branch block pattern on an electrocardiogram. Those children with any acute illness by history and physical examination, congenital or acquired heart disease, syndromes or chromosomal abnormalities were excluded. BSA ranged from 0.19 to 2.0 m^2. This study was approved by Institutional Review Board of Yonsei University College of Medicine.

Echocardiography

All of the subjects underwent a complete 2-dimensional spectral Doppler, and color flow Doppler examination. Patients were examined either a resting or sedated state [infants and children < 15 kg were sedated with chloral hydrate (50–100 mg/kg, maximum dose 1 g)]. Echocardiographic studies were obtained by using a Siemens model ACUSON SC2000 (Siemens Medical Solutions USA, Inc., Mountain View, CA, USA) commercial ultrasound system. Echocardiographic examinations were performed by the same experienced echocardiographer. To reduce the influence of respiration on myocardial velocities (and for the fact that breath holding is not feasible in young children), three cardiac cycles were recorded. In each subject, conventional mitral inflow Doppler velocities of routine echocardiographic evaluation were attained, and all the TDI with systolic and diastolic myocardial velocities were acquired at the mitral annuli on apical 4-chamber view. In the mitral inflow Doppler velocities examination, peak early diastolic velocity (E) and peak late diastolic velocity (A) were measured. In the mitral annular TDI velocities examination, peak systolic myocardial velocities (S'), peak early diastolic myocardial velocity (E') and peak late diastolic myocardial velocity (A') were recorded. The ratio of early-diastolic velocity of conventional mitral inflow to early-diastolic velocity of the mitral annulus (E/E') was calculated. The other parameters of myocardial performance index (Tei) or isovolumic acceleration velocity were not included in this study.

Doppler signal quality was enhanced by lowering the Nyquist limit to 10 to 30 cm/s, using the lowest wall filter settings with minimal optimal gain, decreasing Doppler sample volume size to 5 mm, and optimizing the sweep speed to at least 100 mm/s.

Statistical analysis

Statistical analyses were performed using PASW Statistics for Windows (version 18.0, SPSS Inc., Chicago, IL, USA). The correlation between tissue Doppler velocities and age were determined by Pearson's product-moment correlations and linear regression analysis. The correlation between tissue Doppler velocities and BSA were determined by Pearson's product-moment correlations and linear analysis. Also the correlation between tissue Doppler velocities and LVEDD were determined by Pearson's product-moment correlations and linear analysis. And, we conducted multivariate analysis of cardiac growth parameters (i.e., age, BSA, and LVEDD) and tissue Doppler velocity values. In the multivariate analysis, E' was excluded because it had collinearity with E/E'. Also E and A' were excluded because they had no statistical significance in univariate analysis.

A p value < 0.05 was considered statistically significant for all comparisons.

Results

Of the 144 children enrolled in this study, 81 (56%) were male, and 63 (44%) were female. The mean age was 5.9 ± 5.1 years, and the ranges were 0 to 18.9 years.

The mean left ventricular ejection fraction and fractional shortening by age groups and the mean left ventricular TDI parameters by age groups are in Table 1. To better characterize the differences of the measurements with age, this healthy pediatric population was divided into 7 representative subgroups.

We analyzed the linear relationships between cardiac growth parameters (i.e., age, BSA, and LVEDD) and TDI values. All of the age, BSA, and LVEDD had been showed statistically significant positive correlation with deceleration time (DT), pressure half-time (PHT), E', and S'. Whereas all of the age, BSA, and LVEDD had been showed statistically significant negative correlations with A and E/E' (Fig. 1, 2, and 3).

In the multivariate analysis, all of the age, BSA, and LVEDD had statistically significant positive correlations with DT, PHT, and S'. In contrast, all of the age, BSA, and LVEDD had statistically significant negative correlations with A and E/E' (Table 2).

In the analysis between age and TDI parameters, the mitral A had a tendency to decrease the value by 1.257 with increasing age 1 year old, and E/E' ratio had a tendency to decrease the

Table 1. LVEF, FS, and the mean left ventricular TDI parameters by age groups, in children 0 to 19 years of age

	≤ 1 yr	≤ 2 yr	≤ 4 yr	≤ 6 yr	≤ 10 yr	≤ 14 yr	≤ 19 yr	Overall
n	27	18	21	20	23	21	14	144
LVEF (%)	69.13 ± 5.38	67.43 ± 5.70	66.44 ± 4.73	67.21 ± 3.55	66.55 ± 4.55	69.53 ± 5.62	68.10 ± 6.46	67.80 ± 5.18
FS (%)	36.82 ± 4.01	36.09 ± 4.55	35.63 ± 3.59	36.38 ± 2.84	36.11 ± 3.50	39.11 ± 4.67	38.02 ± 5.32	36.84 ± 4.15
LVEDD (mm)	22.49 ± 3.44	27.11 ± 2.54	31.08 ± 2.80	33.72 ± 3.52	35.96 ± 3.62	43.48 ± 4.60	43.79 ± 5.27	33.37 ± 8.23
E (cm/sec)	95.35 ± 21.29	105.06 ± 3.38	106.8 ± 14.19	107.90 ± 14.78	108.43 ± 17.78	105.38 ± 15.81	95.15 ± 16.79	103.77 ± 17.25
A (cm/sec)	63.09 ± 10.99	61.88 ± 10.53	60.50 ± 13.54	52.65 ± 12.84	51.74 ± 10.77	49.57 ± 10.87	42.00 ± 8.93	55.06 ± 13.01
DT (msec)	116.05 ± 22.89	119.83 ± 23.36	127.38 ± 22.26	131.43 ± 21.74	147.22 ± 25.29	158.78 ± 30.25	154.77 ± 18.68	137.0 ± 28.51
PHT (msec)	33.79 ± 6.36	34.83 ± 6.46	37.77 ± 7.21	37.93 ± 6.32	42.72 ± 7.35	45.94 ± 8.79	44.77 ± 5.33	39.81 ± 8.21
E' (cm/sec)	9.11 ± 2.47	11.26 ± 1.46	13.21 ± 1.51	13.45 ± 1.20	14.40 ± 1.68	15.29 ± 2.09	14.41 ± 2.27	12.98 ± 2.74
A' (cm/sec)	6.06 ± 1.17	6.18 ± 1.30	6.40 ± 1.33	5.58 ± 1.73	5.33 ± 1.22	6.27 ± 1.51	5.68 ± 1.24	8.94 ± 1.40
S' (cm/sec)	6.12 ± 0.88	7.01 ± 0.79	7.38 ± 0.98	7.38 ± 1.13	7.82 ± 0.97	8.43 ± 1.06	8.08 ± 0.99	7.43 ± 1.20
E/E'	9.93 ± 1.55	9.39 ± 1.50	7.94 ± 2.66	8.06 ± 1.44	7.61 ± 1.44	6.94 ± 0.92	6.94 ± 1.75	8.13 ± 1.95

LVEDD: left ventricle end-diastolic dimensions, LVEF: left ventricular ejection fraction, FS: fractional shortening, E: peak early diastolic velocity, A: peak late diastolic velocity, DT: deceleration time, PHT: pressure half-time, E': peak early diastolic myocardial velocity, A': peak late diastolic myocardial velocity, S': peak systolic myocardial velocity, TDI: tissue Doppler imaging

value by 0.190 with increasing age 1 year old. DT had a tendency to increase the value by 2.92 with increasing age 1 year old. PHT had a tendency to increase the value by 0.822 with increasing age 1 year old, and S' had a tendency to increase the value by 0.125 increase with increasing age.

In the analysis between BSA and TDI parameters, the mitral A had a tendency to decrease the value by 11.93 with increasing BSA 1 m^2, and E/E' ratio had a tendency to decrease the value by 1.653 with increasing BSA 1 m^2. DT had a tendency to increase the value by 35.085 with increasing BSA 1 m^2. PHT had a tendency to increase the value by 9.797 with increasing BSA 1 m^2, and S' had a tendency to increase the value by 1.309 with increasing BSA 1 m^2.

In the analysis between LVEDD and TDI parameters, the mitral A had a tendency to decrease the value by 0.698 with increasing LVEDD 1 mm, and E/E' ratio had a tendency to decrease the value by 0.106 with increasing LVEDD 1 mm. DT had a tendency to increase the value by 1.902 with increasing LVEDD 1 mm. PHT had a tendency to increase the value by 0.536 with increasing LVEDD 1 mm, and S' had a tendency to increase the value by 0.079 with increasing LVEDD 1 mm.

Discussion

In the recent, TDI, speckle-tracking echocardiography, and three-dimensional echocardiography (3D echocardiography) have emerged as cardiac function assessment tools. As compared with cardiac MRI, the echocardiographic parameters have advantages of promptness and reproducibility. Medvedofsky et al.[10] said that 3D echocardiography is fast, reproducible, and accurate compared with cardiac MRI over a wide range of RV size and function.

TDI is an accurate echocardiographic method to provide quantitative information about myocardial wall velocities and their directions. In adults, tissue Doppler index is known as a useful indicator of systolic and diastolic myocardial function, particularly LV filling pressure for LV diastolic function. Also, mitral inflow velocity is known to be a useful indicator for evaluating diastolic function. Kim et al.[11] reported that TDI velocity may be a sensitive method to evaluation LV function, as compared to mitral inflow Doppler studies, which would not exactly be sufficient as diagnosis tool in heart failure with preserved EF patients. Diastolic dysfunction is associated with both impairment of LV relaxation and an increase in left atrial pressure. These concurrent events tend to have opposing effect on the mitral inflow velocity, rendering it poorly predictive of either process. Combining trans-mitral inflow velocity with tissue Doppler annular velocity (E/E') has been proposed as a tool for assessing LV filling pressure.[2] Ommen et al.[12] published that E/E' < 8 accurately predicted mean normal LV diastolic pressure, and E/E' > 15 identified of increased LV diastolic pressure. Bahler et al.[13] suggested that, TDI with myocardial performance index can be important tool to evaluate LV function in Duchenne's muscular dystrophy patient group.

In pediatric populations, TDI is being investigated as a diagnostic tool for evaluating cardiac dysfunction recently. In patient groups required early cardiac function assessment, TDI is recognized as a reasonable diagnostic tool for evaluating cardiac dysfunction.[14]

Furthermore, there are a few studies about usefulness of TDI for clinical application in congenital heart disease. In children with aortic valve stenosis, there were significantly reduced systolic and early diastolic myocardial velocities.[15] In the tetralogy of Fallot patients after surgical repair, right ventricular myocardial velocities were found to be decreased, and LV myocardial velocities were found to be within normal.[16] Also cardiac mechanical dyssynchrony evaluated by TDI was analyzed in

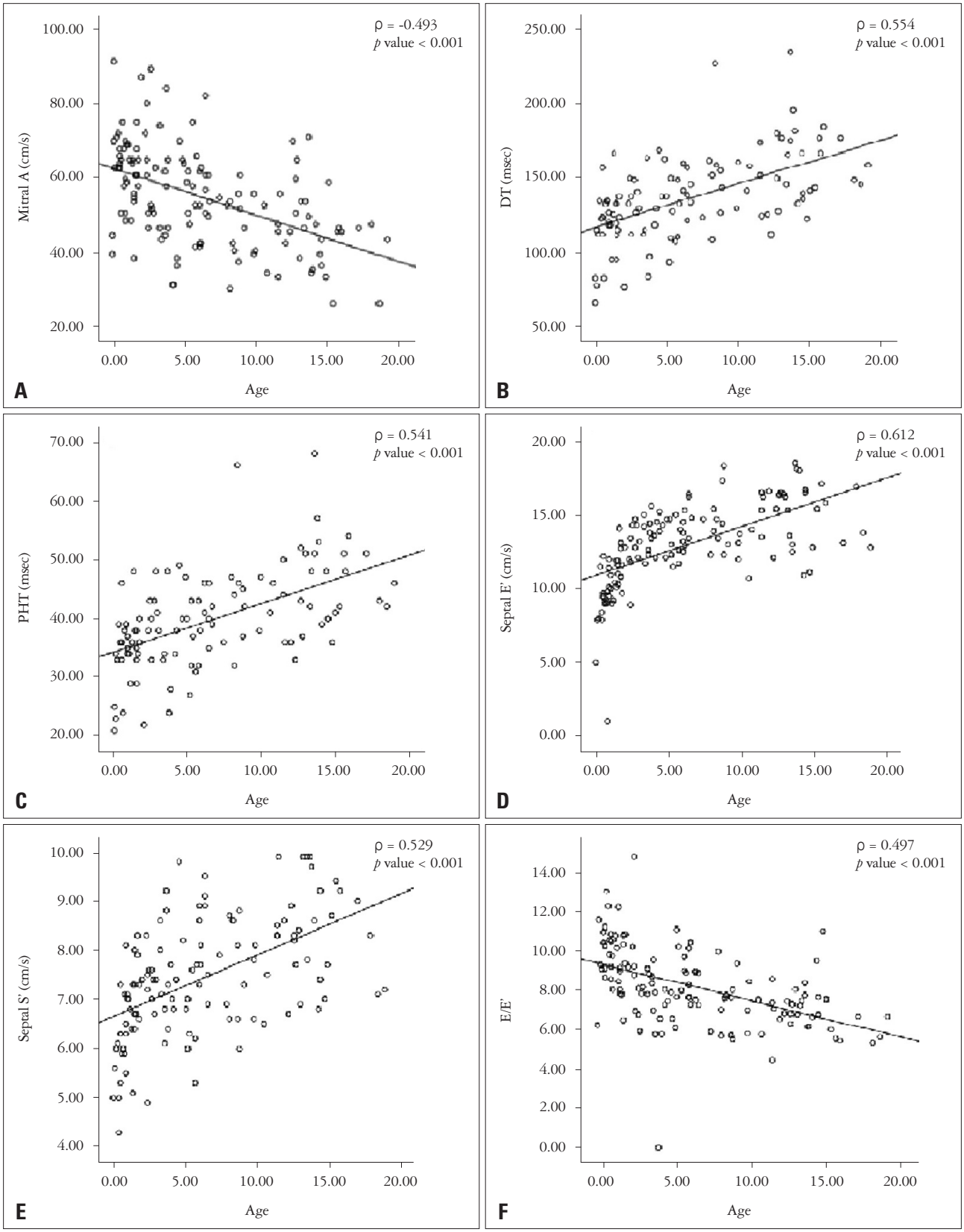

Fig. 1. Scatter plots demonstrating relationships between tissue Doppler indexes and age. Late diastolic velocity (A), DT (B), PHT (C), E' (D), S' (E), E/E' (F). A: late diastolic velocity, DT: deceleration time, PHT: pressure half-time, E': early diastolic myocardial velocity, S': peak systolic velocity, E: early diastolic velocity, E/E': the ratio of early-diastolic velocity of mitral inflow to early-diastolic velocity of the mitral annulus, ρ: Pearson correlation coefficient.

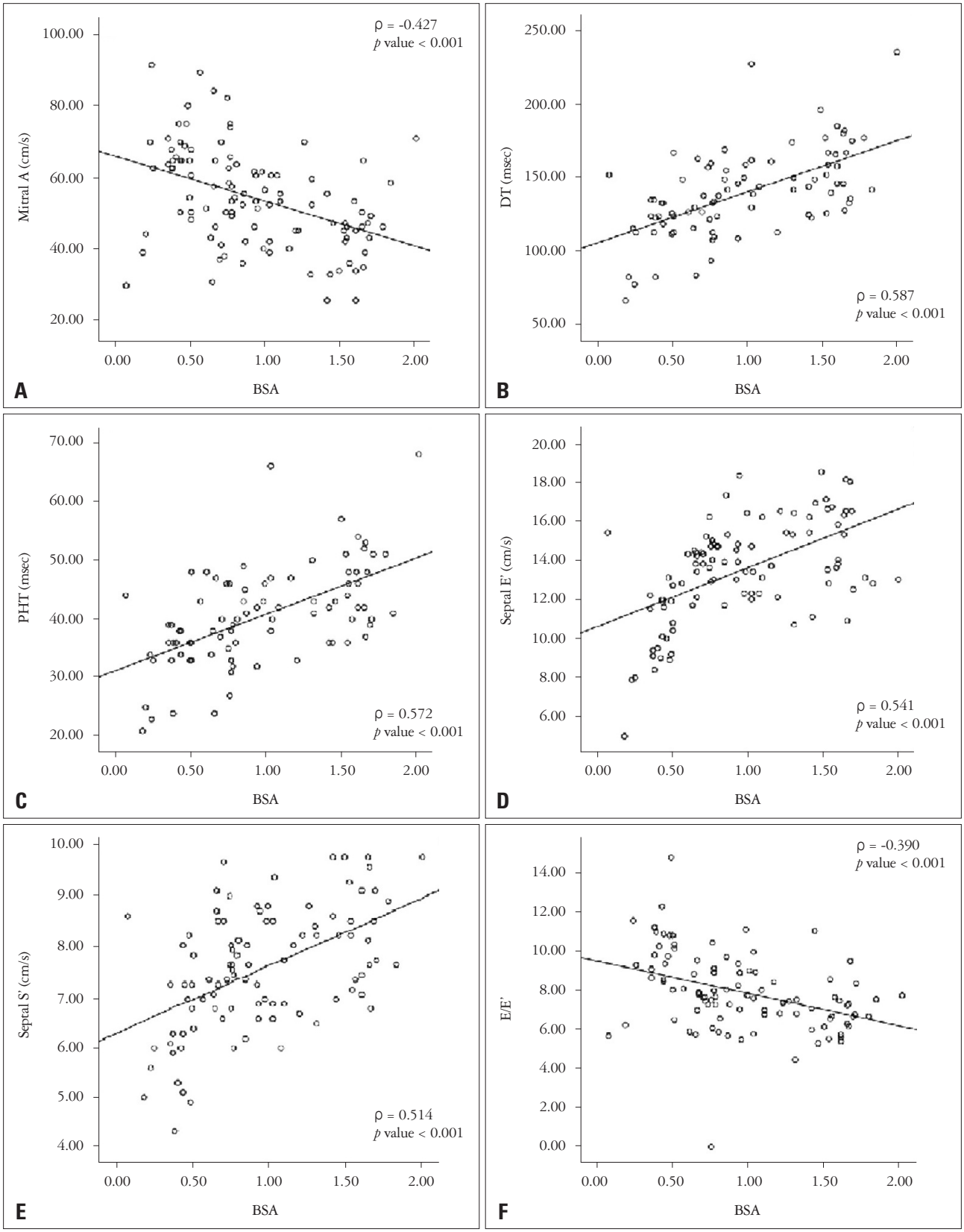

Fig. 2. Scatter plots demonstrating relationships between tissue Doppler indexes and BSA. Late diastolic velocity (A), DT (B), PHT (C), E' (D), S' (E), E/E' (F). A: late diastolic velocity, BSA: body surface area, DT: deceleration time, PHT: pressure half-time, E': early diastolic myocardial velocity, S': peak systolic velocity, E: early diastolic velocity, E/E': the ratio of early-diastolic velocity of mitral inflow to early-diastolic velocity of the mitral annulus, ρ: Pearson correlation coefficient.

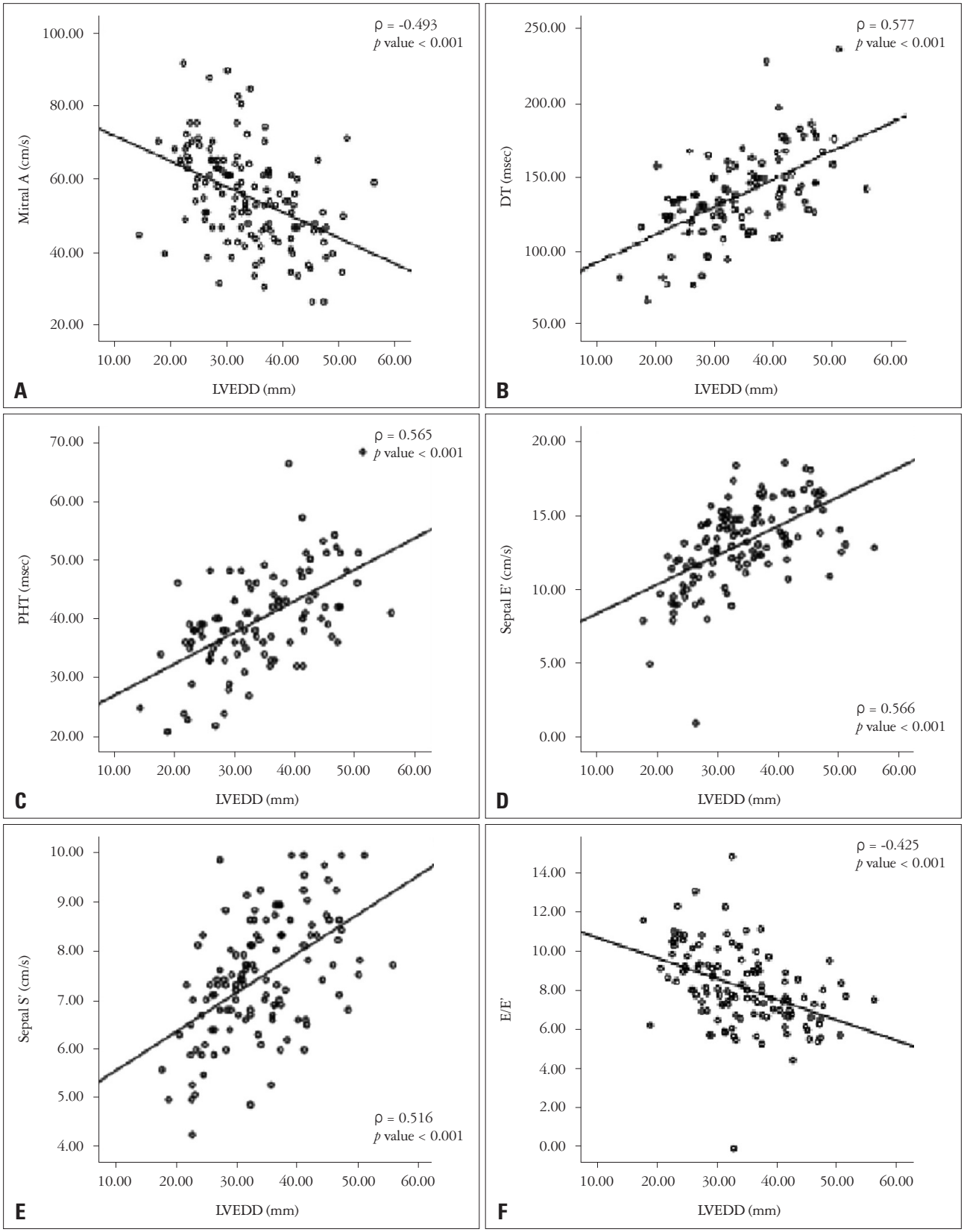

Fig. 3. Scatter plots demonstrating relationships between tissue Doppler indexes and LVEDD. Late diastolic velocity (A), DT (B), PHT (C), E' (D), S' (E), E/E' (F). LVEDD: left ventricle end-diastolic dimension, A: late diastolic velocity, DT: deceleration time, PHT: pressure half-time, E': early diastolic myocardial velocity, S': peak systolic velocity, E: early diastolic velocity, E/E': the ratio of early-diastolic velocity of mitral inflow to early-diastolic velocity of the mitral annulus, ρ: Pearson correlation coefficient.

Table 2. Multivariate analysis between echocardiographic parameters and cardiac growth parameters (i.e., age, LVEDD, and BSA)

	Age		BSA		LVEDD	
	Beta (SE)	*p*-value	Beta (SE)	*p*-value	Beta (SE)	*p*-value
A (cm/sec)	-1.257 (0.191)	< 0.001	-11.93 (2.52)	< 0.001	-0.698 (0.128)	< 0.001
DT (msec)	2.926 (0.429)	< 0.001	35.085 (5.13)	< 0.001	1.902 (0.269)	< 0.001
PHT (msec)	0.822 (0.125)	< 0.001	9.797 (1.494)	< 0.001	0.536 (0.078)	< 0.001
S' (cm/sec)	0.125 (0.018)	< 0.001	1.309 (0.236)	< 0.001	0.079 (0.012)	< 0.001
E/E'	-0.190 (0.030)	< 0.001	-1.653 (0.392)	< 0.001	-0.106 (0.020)	< 0.001

LVEDD: left ventricle end-diastolic dimensions, BSA: body surface area, SE: standard error, E: peak early diastolic velocity, A: peak late diastolic velocity, DT: deceleration time, PHT: pressure half-time, E': peak early diastolic myocardial velocity, S': peak systolic myocardial velocity

only 64% of patients in a European multicenter study evaluating the current practice and results of cardiac resynchronization therapy in pediatric congenital heart disease.[17] Meanwhile, in the hypertensive adolescent group, Ahn et al.[18] reported that E/E' was significantly decreased at the mitral valve annulus, and TDI velocity may be useful in the early detection of ventricular dysfunction.

Nevertheless, in healthy children, there are just a limited number of studies about usefulness of tissue Doppler index as cardiac function evaluation indicators. There are several reasons why the adult tissue Doppler findings cannot be inferred to children. Physiologically, infants and children have much smaller velocities than adults, and as the velocities increase with child growth, there is an inexplicably larger increase of longitudinal systolic velocities than radial velocities.[3] Hiarada et al.[6] suggested that there was positive correlation between age and E/A ratio. Mori et al.[7] insisted that A/E ratio had negative correlation with age. Swaminathan et al.[9] reported that there were positive correlation between E/A ratio and age, and negative correlation between E/E' ratio and age. Eidem et al.[8] published that there were positive correlation between E/A ratio and age, and negative correlation between E/E' ratio and cardiac growth (i.e., age, LVEDD), and they observed LVEDD had been showed the most significant correlations with TDI parameters.

In this study, we suggested the reference ranges of TDI parameters in pediatric population by showing an average value of TDI parameters in 144 subjects of healthy children. Also, we analyzed distribution of TDI values according to cardiac growth and focused on usefulness of tissue Doppler index as cardiac function evaluation indicators. In our result, peak late diastolic myocardial velocities at the mitral (A) and E/E' had negative relations with age, BSA, and LVEDD. Meanwhile, DT, PHT, and S' had positive relations with age, BSA, and LVEDD. In this study, all of the cardiac growth parameters (i.e., age, BSA, and LVEDD) had been showed same result in correlations with TDI parameters, although there were little differences of degree of correlation.

The cardiac growth parameters related alterations of E/E' may suggest cardiac growth related alterations in LV early diastolic function. It certainly suggests that diastolic myocardial velocities are cardiac growth dependent, and diastolic function has positive correlation with cardiac growth in pediatric group. As the heart grows, myocardial velocities gradually increase till they reach adult values in adolescent period. In each child, a given measurement might not be useful if the baseline is unidentified.

This cardiac growth related myocardial functional variation would be important for assessment of cardiac involvement either in healthy and sick children. This age related measurement change would reveal the cardiac growth related cardiac function.

Furthermore, these measurement data with age will be the reference values for children and adolescents.

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