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Original Article

Tissue Doppler, strain, and strain rate measurements assessed by two-dimensional speckle-tracking echocardiography in healthy newborns and infants

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Abstract *Objectives:* To evaluate cardiac maturational and haemodynamic alteration in healthy newborns and infants and determine reference values in this period using tissue Doppler, strain, and strain rate echocardiography. *Material and Methods:* The study included 149 healthy subjects. Babies from 1 day to 3 months were selected from the well-baby nursery department, and infants were selected from paediatric clinics during routine visits for health maintenance. Subjects were allocated to four groups: preterm (36–37 weeks, $n = 32$), term (≥ 38 weeks, $n = 32$), 1 month of age ($n = 47$), and 3 months of age ($n = 38$). Standard echocardiographic evaluations, pulsed wave Doppler, tissue Doppler echocardiography, strain, and strain rate studies were applied by the same person using a MyLab50 echo machine. Longitudinal and circumferential systolic strain and strain rate measurements were assessed by two-dimensional speckle-tracking echocardiography in all subjects. *Results:* The longitudinal systolic velocity, strain, and strain rate values derived from left ventricle apical four-, three-, and two-chamber images, and circumferential systolic velocity, strain, and strain rate values derived from left ventricle short-axis images decreased from the base to the apex in all subjects ($p < 0.001$). *Conclusion:* Significant cardiac haemodynamic alterations occurred during the newborn and early infancy periods and were detected by tissue Doppler, strain, and strain rate echocardiography. Although two-dimensional speckle-tracking echocardiography is useful and can produce improved, reliable results in clinical practice, it has some limitations. Therefore, more studies on this issue are required.

Keywords: Newborn; infant; tissue Doppler; strain; strain rate

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Ventricular myocardium differentiates both qualitatively and quantitatively throughout the growth process.[1,2] When the physiology of foetal circulation changes with birth such that gas exchange is transferred from the placenta to the lungs, fetal shunts are gradually closed down and significant haemodynamic changes occur.[3–5]

The compliance of the neonatal heart rapidly increases in the first few days following birth because of changes in connective tissue, collagen, and the extracellular matrix.[1,2] Myocardial performance in neonates is limited to changes in the ventricular preload, contractility, and afterload. The dominance of parasympathetic activity and immature sympathetic innervations also restricts cardiac contractility in newborns.[1,2,5]

The measurement of local and global myocardial functions using non-invasive methods is a major aim in clinical cardiology. The tissue Doppler imaging method, which has recently allowed a detailed examination of cardiac functions, is widely used in children. Normal paediatric data of tissue Doppler echocardiography in different age groups were published.[6,7] Furthermore, the angle dependency

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of the method and the effects of preload and the translational motion of the heart were overcome by strain and strain rate echocardiography, which were then adopted as new models in the assessment of myocardial performance and deformation. Strain imaging based on speckle tracking, in particular, enabled the assessment of myocardial motion and deformation irrespective of angle and geometry, allowing an improved examination of myocardial mechanics.[8–10]

Knowledge of the normal range of echocardiographic data in each age group in childhood is a prerequisite for the evaluation of pathologic changes. Our knowledge of the changes in myocardial functions in early postnatal days and months is very limited. Determination of the changes in cardiac functions in response to the haemodynamic changes in healthy newborns and infants using new echocardiographic methods, such as strain and strain rate, which are not subjective, can provide more insights into these processes.

The aim of our study is to determine the changes in the neonate and infancy periods and to determine the normal reference values by conducting tissue Doppler, strain, and strain rate echocardiography using two-dimensional tissue-tracking methods in healthy newborns and infants.

Methods

The study included 149 healthy babies from 1 day to 3 months, with no systemic or cardiac pathologies. Newborn infants were selected from the well-baby nursery department. Infants were selected from paediatric clinics during routine visits for health maintenance. Infants referred to the paediatric cardiology unit for innocent murmurs were included in the selection. No babies were acutely ill or were on medications at the time of the study. Two-dimensional echocardiography showed no cardiac defects.

The infants were allocated to four groups: Group 1 was composed of 32 preterm infants whose gestational age was between 36 and 37 weeks and postnatal age was 1–3 days; group 2 was composed of 32 term infants whose postnatal age was 1–3 days; group 3 was composed of 37 infants whose age was 1 month; and group 4 was composed of 38 infants whose age was 3 months. The parents of all infants were informed about the study and their written consent was received. In accordance with the Helsinki Declaration, the approval of the Ethics Committee of Inonu University Medical School was obtained before the study. Patients who had a systemic disease, whose mothers had a history of systemic disease during pregnancy with a possible effect on the baby, and those who were found to have structural or functional cardiovascular system pathology by echocardiography were excluded.

Personal and family histories of all cases included in the study were collected and their detailed physical examinations were performed by the same person.

A standard echocardiographic evaluation, as well as pulsed wave Doppler, tissue Doppler, strain, and strain rate echocardiography, of all patients was performed by the same person using a Mylab 50 (Esaote, Florence, Italy) echocardiography machine (Esaote). Echocardiographic measurements were obtained in standard precordial positions according to recommendations by the American Society of Echocardiography.[11] Left ventricular ejection fraction, fractional shortening, cardiac output, and stroke volume were measured by M-mode echocardiography in the parasternal long-axis position.

Transmitral pulsed wave Doppler velocities were obtained from the apical four-chamber view with Doppler sample placed between the tips of the mitral leaflets. Early (E) and late (A) wave velocities, deceleration time, and E/A ratio were measured from the mitral inflow profile. The isovolumetric relaxation time was obtained from the apical five-chamber view with the Doppler sample placed between the left ventricular outflow and mitral inflows.

Myocardial velocities were measured in the apical four-chamber view, and myocardial systolic (S), early diastolic velocity (E′), and late diastolic velocities (A′) were obtained at the septal mitral annulus by placing a sample volume of Doppler tissue. Isovolumetric relaxation time, isovolumetric contraction time, and ejection time were subsequently determined. The isovolumetric relaxation time was measured from the end of the S wave to the onset of the E′ wave, and the isovolumetric contraction time was measured from the end of the A′ wave to the onset of the S wave. The ejection time was measured from the onset of the S wave to the end of the S wave. The Tei index was calculated according to the following formula: isovolumetric contraction time + isovolumetric relaxation time/ejection time.

For the strain and strain rate imaging, two-dimensional harmonic image cineloop recordings each containing three cardiac cycles of apical four-, three-, and two-chamber and parasternal short-axis views with good-quality electrocardiogram signals and a frame rate of 50–75 frames per second were acquired and stored for off-line analysis. The off-line analyses of the video clips stored in Esaote Mylab 50 equipment were performed using XStrain™ software (Esaote) installed on a Windows™-based computer workstation. On the basis of the algorithm of optical flow analysis especially designed to track

the endocardial border, XStrain™ is granted software that derives longitudinal and circumferential velocity, strain and strain rate from digitised 2D video clips. The velocities are calculated for each point and displayed both as vectors superimposed on the 2D images and as graphs plotted against time; the strain and strain rate displayed for each point are then analysed (Figs 1–3). The endocardial border was delineated as a sequence of points on a single frame by the same operator. The clip that showed the endocardial border in the best way was chosen for each patient and processed as follows: the starting frame was usually, but not necessarily, chosen in the end diastole for a better view of the endocardial border. In the left ventricle apical four-chamber imaging, tracking began at the septal side of the mitral annulus and three points were tracked for each segment. The points in the apical two-chamber view were tracked starting from the mitral annulus at the level of the inferior wall. Tracking in the short axis at the mitral valve level began at the mitral valve posteromedial commissure. The tracking in the short axis at the level of papillary muscles began at the posteromedial papillary muscle, and the distance between these points was automatically divided into equidistant segments. Velocity, strain, and strain rate graphs were obtained automatically (Fig 4).

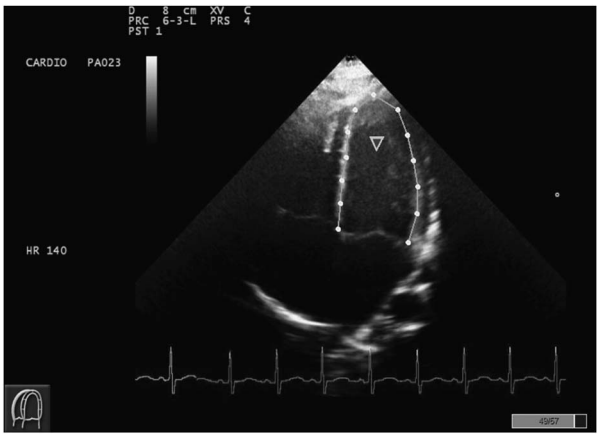

Figure 1.
Delineation of the left ventricular endocardial border in the apical four-chamber view.

Statistical analysis

The compatibility of the data with normal distribution was tested using the Kolmogorov–Smirnov test. A one-way analysis of variance (ANOVA) was used as the unidirectional variance analysis in the comparisons among groups. In cases where ANOVA showed a significant difference between groups, a Tukey HSD test was applied to the second test to find out which groups differed significantly. The wall segments within each group were compared by a paired t-test. The results were presented as mean ± standard deviation. The level of significance was set at $p < 0.05$.

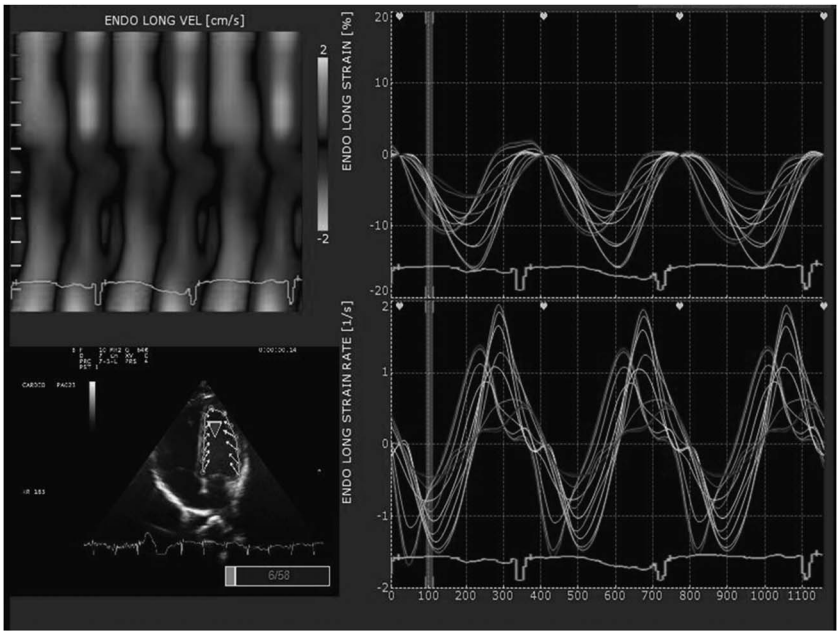

Figure 2.
Graph of the processing result of an apical four-chamber view. The vectors show the direction of displacement of any point selected. The upper left panel shows the colour scale analysis of systolic velocity, and the curves on the right side report strain and strain rate for any point selected.

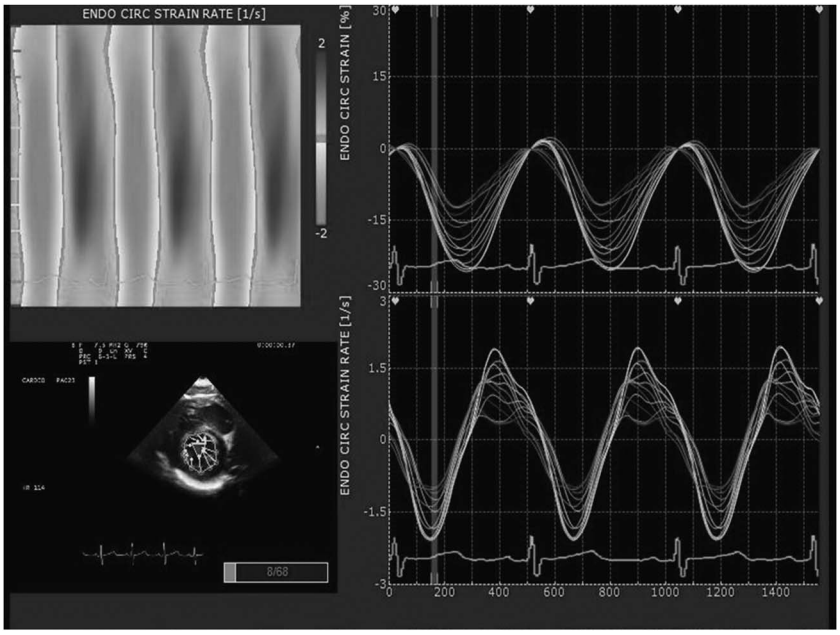

Figure 3.
Graph of the processing result of a short-axis view at mitral level. The upper left panel shows the colour scale analysis of circumferential strain rate, and the curves report the values for circumferential strain and strain rate for any selected point.

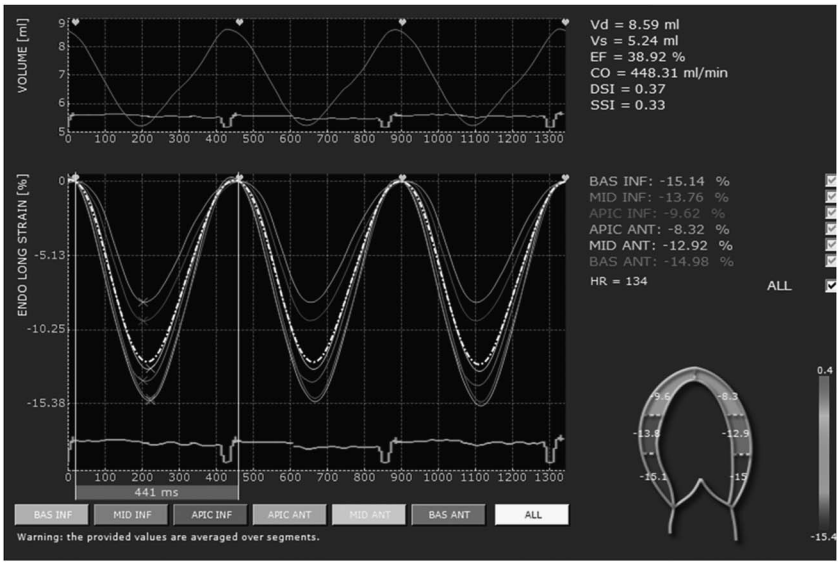

Figure 4.
Longitudinal strain values obtained in the left ventricle two-chamber view.

Results

Study population

The demographic characteristics of the subjects are listed in Table 1. Group 1 comprised 18 girls (56.3%) and 14 boys (43.8%); group 2 comprised 14 girls (43.8%) and 18 boys (56.3%); group 3 comprised 18 girls (33.8%) and 29 boys (61.7%); and group 4 comprised 22 girls (57.9%) and 16 boys (42.1%). No difference was found among the groups regarding gender ($p > 0.05$). The mean weight was 2516.25 ± 188.18 in group 1, 3544.38 ± 356.89 in group 2, 4598.19 ± 432.53 in group 3, and 6163.68 ± 419.78 in group 4. As expected, there was a statistically significant difference in weight among the study groups ($p < 0.001$). The results of two-dimensional standard grayscale and colour Doppler examinations were within normal limits.

Table 1. Demographic characteristics of subjects.

	Newborns		Infants	
	Preterm	Term	1-month-old	3-month-old
Gestational age (week)	36.61 ± 49	38.75 ± 0.80	38.39 ± 1.20	38.26 ± 1.11
Gender				
Male	14 (43.7%)	18 (56.3%)	29 (61.7%)	16 (42.1%)
Female	18 (56.3%)	14 (43.7%)	18 (38.3%)	22 (57.9%)
Weight (g)	2516.25 ± 188.18*	3544.38 ± 356.89*.	4598.19 ± 432.53*	6163.68 ± 419.78*
Delivery type				
Vaginal	5 (15.2%)	13 (40.6%)	19 (41.3%)	12 (31.6%)
Cesarean	28 (84.8%)	19 (59.4%)	27 (58.7%)	26 (68.4%)
5-minute Apgar score	9.56 ± 0.50	9.47 ± 0.51	9.62 ± 0.49	9.55 ± 0.50

*Between groups, $p < 0.001$

Table 2. Left ventricle Doppler findings of groups as measured by transmitral pulsed wave Doppler echocardiography.

	Newborns		Infants	
	Preterm	Term	1-month-old	3-month-old
Mitral E (m/sn)	0.59 ± 0.14*·**·***	0.64 ± 0.11****·*****	0.81 ± 0.12	0.86 ± 0.11
Mitral A (m/sn)	0.55 ± 0.11*·**·***	0.66 ± 0.11****·*****	0.77 ± 0.14	0.75 ± 0.11
Mitral E/A	1.04 ± 0.29	0.99 ± 0.18*****	1.07 ± 0.17	1.16 ± 0.15
Mitral E duration (msn)	100.13 ± 14.62***	99.25 ± 16*****	103.32 ± 14.80	110.87 ± 9.39
Mitral A duration (msn)	74.13 ± 12.49***	79.44 ± 9.75	79.15 ± 9.79	81.37 ± 10.79
DT (msn)	57.81 ± 10.62	61.09 ± 10.8	61.57 ± 10.72	64.18 ± 9.24
IVRT (msn)	44.72 ± 6.05***	44.84 ± 4.87*****	45.36 ± 5.62******	49.89 ± 4.74

A = mitral late diastolic velocity; E = mitral early diastolic velocity; E/A = E/A ratio; DT = mitral E-wave deceleration time; IVRT = mitral isovolumetric relaxation time
*Between preterm and term baby $p < 0.05$
**Between preterm and 1-month-old baby $p < 0.05$
***Between preterm and 3-month-old baby $p < 0.05$
****Between term and 1-month-old baby $p < 0.05$
*****Between term and 3-month-old baby $p < 0.05$
******Between 1-month-old and 3-month-old baby $p < 0.05$

Left ventricle M-mode echocardiographic measurements

The M-mode echocardiographic examination showed that left ventricular ejection fraction and fractional shortening were within the normal range in all groups. There was no significant difference in ejection fraction and fractional shortening among the groups ($p > 0.05$).

Left ventricle transmitral pulsed wave Doppler echocardiographic measurements

The left ventricle transmitral pulsed wave Doppler measurements of the groups are presented in Table 2. Mitral E and A velocities showed statistically significant increases from group 1 to 2 ($p = 0.02$; $p = 0.04$, respectively), from group 2 to 3 ($p = 0.001$; $p = 0.001$, respectively), from group 2 to 4 ($p = 0.001$; $p = 0.01$, respectively), from group 1 to 3 ($p < 0.001$; $p < 0.001$, respectively), and from group 1 to 4 ($p = 0.001$; $p = 0.001$, respectively). The mitral E/A ratio in group 4 was significantly higher than that in group 2 ($p = 0.005$). No significant difference was found in the E/A ratios of the other groups ($p > 0.05$). There was no difference between the deceleration times of the groups ($p > 0.05$). When the groups were compared with regard to their isovolumetric relaxation time, statistically significant differences were established between groups 1 and 4 ($p = 0.001$), groups 2 and 4 ($p = 0.001$), and groups 3 and 4 ($p = 0.001$).

Left ventricle tissue Doppler echocardiographic measurements

Table 3 presents a comparison of the values measured by tissue Doppler echocardiography.

Myocardial E′ velocities showed statistically significant increases from group 2 to 3 ($p = 0.001$), from group 2 to 4 ($p = 0.001$), from group 3 to 4 ($p = 0.001$), and from group 1 to 4 ($p = 0.001$). Myocardial A′ velocities showed statistically significant increases from group 2 to 3 ($p = 0.005$), from

group 1 to 3 ($p = 0.001$), and from group 1 to 4 ($p = 0.001$). With regard to the mitral E′/A′, statistically significant differences were found between groups 2 and 4 ($p = 0.001$), groups 3 and 4 ($p = 0.001$), and groups 1 and 4 ($p = 0.001$). In terms of mitral E/E′, there was a statistically significant difference between groups 2 and 4 ($p = 0.035$), but there were no differences among the other groups. The ejection time differed between groups 1 and 4 and groups 2 and 4 ($p = 0.001$, $p = 0.001$, respectively). With regard to the Tei index, statistically significant differences were established between groups 1 and 3 ($p = 0.002$), groups 1 and 4 ($p = 0.02$), groups 2 and 3 ($p = 0.001$), and groups 2 and 4 ($p = 0.005$).

Comparison of left ventricle systolic velocities, strain, and strain rate values

Evaluation of left ventricle four-, three-, and two-chamber views. A decrease was established from the basal segment to the apex in all segments in the systolic velocities, strain, and strain rate values of all groups ($p < 0.001$; Fig 4).

Left ventricle short-axis evaluation. A decrease was established from the basal segment to the apex in all segments in the systolic velocities, systolic strain, and strain rate values of all groups ($p < 0.001$).

Velocity, systolic strain, and strain rate values of the left ventricle in each group are presented in Tables 4–6.

Discussion

Tissue Doppler, strain, and strain rate echocardiography, which allow an accurate and reliable evaluation of cardiac functions, are relatively new echocardiographic techniques that recently have been used widely in both children and adults.[8,9,12,13]

Normal paediatric data of tissue Doppler echocardiography have been published for various age groups.[12,14] Studies involving neonates established that tissue velocities changed remarkably in the first few days of life, reflecting ventricular adaptation.[7,14,15] Negrine et al[16] established that mitral E and A velocities and mitral E/A ratio increased, whereas E/E′ values decreased parallel to increased gestational age. Myocardial E′ and A′ velocities also showed an increase with gestational age. Similar to Negrine et al, our study showed that mitral E and mitral A velocities increased with age. It was seen that mitral E/A ratio in 3-month-old infants was significantly high compared with that in term babies ($p = 0.005$). There was no significant difference in terms of E/A ratios among the other groups ($p > 0.05$), which was attributed to the fact that the premature cases in our study, whose gestational age was 36–37 weeks, were very close to full-term infants with regard to their gestational age. Myocardial E′ velocities showed an increase with gestational age. However, this increase did not differ statistically significantly between premature and mature babies, but was significant between other groups. With regard to mitral E/E′, the only statistically significant difference was found between mature infants and 3-month-old babies ($p = 0.035$), with no other difference among other groups.

When the groups were examined in terms of the Tei index, no difference was found between the premature and mature groups because of the closeness of the gestational ages or between 1-month-old and

Table 3. Findings of cases as measured by tissue Doppler echocardiography.

	Newborns		Infants	
	Preterm	Term	1-month-old	3-month-old
Mitral E′ (m/sn)	0.07 ± 0.02**·***	0.08 ± 0.02****·*****	0.09 ± 0.02******	0.12 ± 0.02
Mitral A′ (m/sn)	0.07 ± 0.02**·***	0.08 ± 0.02****	0.09 ± 0.02	0.09 ± 0.03
Mitral E′/A′	1.04 ± 0.29***	0.96 ± 0.25*****	1.05 ± 0.35******	1.35 ± 0.36
Mitral E/E′	8.14 ± 2.67	8.79 ± 2.39*****	8.38 ± 1.71	7.43 ± 1.64
IVCT	49.90 ± 10.81**	50.47 ± 8.63****	44.49 ± 7.27	46.74 ± 9.63
IVRT	44.78 ± 6.77	47.25 ± 9.38	42.66 ± 7.07	46.47 ± 8.23
ET	187.66 ± 14.32***	190.75 ± 11.41*****	196.62 ± 16.43	204.95 ± 17.53
Tei index	0.51 ± 0.08**·***	0.51 ± 0.08****·*****	0.45 ± 0.07	0.46 ± 0.06

A′ = myocardial late diastolic velocity; E′ = myocardial early diastolic velocity; E′/A′ = E′/A′ ratio; E/E′ = E′/E′ ratio; ET = ejection time; IVCT = mitral isovolumetric contraction time; IVRT = mitral isovolumetric relaxation time

*Between preterm and term baby $p < 0.05$

**Between preterm and 1-month-old baby $p < 0.05$

***Between preterm and 1-month-old baby $p < 0.05$

****Between term and 1-month-old baby $p < 0.05$

*****Between term and 3-month-old baby $p < 0.05$

******Between 1-month-old and 3-month-old baby $p < 0.05$

Table 4. Values for longitudinal and circumferential velocity of the left ventricle (cm/second).

			Newborns		Infants	
		Segment	Preterm	Term	1-month-old	3-month-old
Apical 4 C	Septal	Basal	1.51 ± 0.22	1,59 ± 0.19	1.49 ± 0.18	1.57 ± 0.17
		Mid	1.07 ± 0.14	1.14 ± 0.14	1.07 ± 0.15	1.12 ± 0.09
		Apical	0.49 ± 0.08*	0.57 ± 0.09	0.55 ± 0.13	0.55 ± 0.11
	Lateral	Basal	1.51 ± 0.19	1.59 ± 0.19	1.55 ± 0.19	1.60 ± 0.17
		Mid	1.05 ± 0.17	1.09 ± 0.14	1.05 ± 0.16	1.13 ± 0.19
		Apical	0.46 ± 0.14	0.47 ± 0.09	0.51 ± 0.13	0.52 ± 0.12
Apical 2 C	Anterior	Basal	1.78 ± 0.14	1.72 ± 0.23	1.82 ± 0.19	1.86 ± 0.25
		Mid	1.26 ± 0.15	1.29 ± 0.20	1.33 ± 0.21	1.35 ± 0.22
		Apical	0.77 ± 0.17	0.78 ± 0.23	0.83 ± 0.23	0.76 ± 0.21
	İnferior	Basal	1.77 ± 0.19	1.76 ± 0.34****	1.89 ± 0.27	2.03 ± 0.31
		Mid	1.25 ± 0.18***	1.28 ± 0.21****	1.34 ± 0.26	1.35 ± 0.19
		Apical	0.68 ± 0.15	0.72 ± 0.32	0.79 ± 0.24	0.69 ± 0.19
Apical 3 C	Posterior	Basal	1.41 ± 0.15	1.49 ± 0.20	1.49 ± 0.16	1.46 ± 0.17
		Mid	1.01 ± 0.11	1.04 ± 0.13	1.06 ± 0.19	1.06 ± 0.14
		Apical	0.59 ± 0.17	0.52 ± 0.15	0.51 ± 0.16	0.56 ± 0.19
	Anterior	Basal	1.28 ± 0.16	1.27 ± 0.14	1.33 ± 0.18	1.27 ± 0.13
		Mid	0.94 ± 0.19	0.95 ± 0.17	0.95 ± 0.14	0.91 ± 0.16
		Apical	0.47 ± 0.18	0.44 ± 0.10	0.48 ± 0.17	0.43 ± 0.16
Short axis	Basal	Anterior septal	1.55 ± 0.20	1.72 ± 0.25	1.74 ± 0.24**	1.77 ± 0.26***
		Anterior	1.23 ± 0.17	1.39 ± 0.19*	1.38 ± 0.18**	1.45 ± 0.24***
		Lateral	1.01 ± 0.17	1.12 ± 0.15	1.13 ± 0.25	1.14 ± 0.24
		Posterior	0.98 ± 0.16	1.08 ± 0.12	1.02 ± 0.16	1.02 ± 0.17
		İnferior	1.26 ± 0.18	1.34 ± 0.14	1.29 ± 0.13	1.37 ± 0.19***
		Septal	1.55 ± 0.24	1.72 ± 0.24*	1.68 ± 0.19	1.67 ± 0.22

*Between preterm and term baby $p < 0.05$
**Between preterm and 1-month-old baby $p < 0.05$
***Between preterm and 3-month-old baby $p < 0.05$
****Between term and 3-month-old baby $p < 0.05$

3-month-old infants because their ages were too close to affect the myocardial maturation process, whereas other groups differed statistically significantly. The isovolumetric contraction time was more prolonged in premature and term neonates than in 1- and 3-month old infants in our study. Thus, the results showed that the difference in the Tei index of the groups might have been caused by the isovolumetric contraction time. The longer isovolumetric contraction time in premature and term newborns was attributed to the inadequate maturation of the cardiac contractile elements in this period.

Strain and strain rate echocardiography is superior to tissue Doppler echocardiography in the evaluation of regional myocardial functions because it is not affected by the translation and stretching of neighbouring myocardial segments.[13,17] However, strain and strain rate imaging has some limitations. Owing to the fact that it is associated with Doppler imaging, it is not entirely independent of angle; however, the effect of the angle is more evident in apical myocardial segments.[18,19] In our opinion, the other limitations of strain and strain rate echocardiography as shown in our study were shifts in the left ventricle form caused by aberrant bands. In our study, 13 cases (8.72%) had left ventricular aberrant bands (Fig 5). We think that the aberrant bands may constitute a technical pitfall of speckle-tracking strain because of the deformation in the left ventricular shape. Therefore, we believe that aberrant bands may be considered in measurements.

Di Salvo et al[20] established a strong correlation between E′/A′ values and longitudinal systolic strain/strain rates with gestational age and concluded that diastolic functions and deformation properties increased according to maturation. In their study, it was determined that both right and left ventricle longitudinal strain and strain rate values were homogeneous throughout the foetal life and this homogeneity was attributed to the pressures of both ventricles being equal in the foetal life. The same study also found that longitudinal systolic velocities did not display a homogeneous distribution and were significantly higher on the lateral wall and on the right ventricle free wall. It was concluded that strain and strain rate imaging was less sensitive to global cardiac movement and the tethering effect of neighbouring segments.

Table 5. Values of longitudinal and circumferential strain (%).

			Newborns		Infants	
		Segment	Preterm	Term	1-month-old	3-month-old
Apical 4 C	Septal	Basal	−13.54 ± 2.67***	−13.89 ± 2.54****	−14.47 ± 1.91*****	−15.72 ± 1.49
		Mid	−10.41 ± 2.48***	−10.58 ± 2.60****	−11.40 ± 2.01	−12.56 ± 1.98
		Apical	−5.65 ± 2.05***	−6.28 ± 2.33****	−6.58 ± 1.71	−8.15 ± 2.11
	Lateral	Basal	−14.34 ± 2.56	14.69 ± 3.04	−15.21 ± 1.87	−14.89 ± 2.23
		Mid	−10.81 ± 2.34	−11.66 ± 3.03	−11.58 ± 1.63	−11.34 ± 2.24
		Apical	−6.29 ± 1.72	−6.76 ± 2.28	−7.06 ± 1.43	−7.24 ± 1.68
Apical 2 C	Anterior	Basal	−14.17 ± 2.80	−15.51 ± 2.34*	−15.89 ± 2.56**	−16.59 ± 2.59***
		Mid	−10.56 ± 2.21	−11.67 ± 2.33	−11.88 ± 2.19**	−12.72 ± 2.36***
		Apical	−6.26 ± 2.22	−7.48 ± 2.09	−7.48 ± 1.91	−8.31 ± 2.39**·****
	Inferior	Basal	−14.48 ± 2.95	−14.19 ± 2.67	−15.69 ± 2.41**	−16.22 ± 2.33**
		Mid	−10.32 ± 3.04	−11.44 ± 2.49	−12.07 ± 2.42	−12.29 ± 1.91**
		Apical	−5.69 ± 2.61	−7.56 ± 2.12	−7.33 ± 2.09	−7.43 ± 1.48
Apical 3 C	Posterior	Basal	−13.55 ± 2.59	−15.03 ± 3.04	−15.11 ± 2.25**	−15.86 ± 2.69**
		Mid	−10.78 ± 2.59	−11.66 ± 2.56	−11.94 ± 2.07	−12.51 ± 2.53**
		Apical	−5.94 ± 2.44	−7.78 ± 2.64	−8.15 ± 2.16**	−8.61 ± 2.58**
	Anterior	Basal	−14.94 ± 2.71	−16.23 ± 3.21	−15.67 ± 2.03	−16.59 ± 3.34
		Mid	−12.13 ± 2.44	−12.40 ± 2.84	−12.22 ± 2.04	−12.88 ± 2.86
		Apical	−7.02 ± 2.37	8.03 ± 2.72	−7.87 ± 2.03	−8.32 ± 2.41
Short axis	Basal	Anterior septal	−17.61 ± 3.39***	−18.17 ± 3.77****	−19.03 ± 2.99*****	−21.01 ± 3.33
		Anterior	−13.22 ± 2.57***	−13.81 ± 2,41	−13.44 ± 2.29	−14.89 ± 3.18
		Lateral	−8.49 ± 2.61***	−9.91 ± 2.53****	−8.82 ± 2.26	−10.97 ± 3.48
		Posterior	−9.22 ± 2.38	−9.66 ± 2.18	−9.38 ± 2.08	−10.34 ± 2.39
		İnferior	−14.07 ± 3.03	−12.87 ± 3.04****	−13.59 ± 2.52	−14.59 ± 2.45
		Septal	−18.02 ± 3.73	−17.75 ± 3.54	−18.67 ± 3.34	−19.40 ± 3.24

*Between preterm and term baby $p < 0.05$
**Between preterm and 1-month-old baby $p < 0.05$
***Between preterm and 3-month-old baby $p < 0.05$
****Between term and 3-month-old baby $p < 0.05$
*****Between 1-month-old and 3-month-old baby $p < 0.05$

In another study using 2D tissue-tracking strain echocardiography, Di Salvo et al[21] stated that Doppler-derived strain imaging had several properties, such as angle dependency, sensitivity to extra-cardiac motion, need for image quality, longer post-processing time, and low reproducibility. The strain values measured in this study were higher than those measured by Doppler-derived strain imaging, and this difference was attributed to the angle dependency of Doppler-derived strain imaging. Our study also used the 2D tissue-tracking method. Although there was no difference in the mitral E′/A′ ratios of premature and mature babies, this ratio was found to increase gradually starting in the 1st postnatal month. When premature and mature newborns whose age was closest to the age of the study population of Di Salvo et al were examined, no significant difference was found between the longitudinal systolic velocities of the two groups. With regard to systolic strain and strain rate values, there were differences between a few segments only, but no significant differences among all segments. In contrast to the cited study, in the present study systolic velocities, strain, and strain rate values were seen to display a heterogeneous distribution among segments in both groups. This difference may be attributed to the postnatal change in foetal physiology and transition from parallel to sequential circulation.

No difference was found between apical and basal segments in terms of strain and strain rate values.[22,23] However, Andersen et al[24] showed that values in the basal segment were higher than those in the mid- and apical segments in the left ventricular longitudinal measurements. Similarly, basal values were found higher than mid- and apical values in our study. This heterogeneity may be explained by the distribution of myocardial fibres among segments and different wall thicknesses.

Sun et al[25] suggested that strain and strain rate values increased from the basal to the apical segment in straight walls, but decreased in curved walls. The heterogeneity observed in our study is similar to the results in the above study. However, our study found a decrease from the basal to the apical segment in both strain and strain rate values in all segments. This difference might be explained by the fact that although our study group

Table 6. Values of longitudinal and circumferential strain rate (/second).

			Newborns		Infants	
		Segment	Preterm	Term	1-month-old	3-month-old
Apical 4 C	Septal	Basal	−1.23 ± 0.13	−1.27 ± 0.19	−1.24 ± 0.13	−1.26 ± 0.10
		Mid	−0.97 ± 0.14	−1.01 ± 0.15	−0.98 ± 0.12	−1.02 ± 0.09
		Apical	−0.59 ± 0.18	−0.65 ± 0.18	−0.58 ± 0.11	−0.62 ± 0.14
	Lateral	Basal	−1.22 ± 0.14	−1.32 ± 0.20*	−1.25 ± 0.13	−1.29 ± 0.13
		Mid	−0.96 ± 0.17	−1.02 ± 0.21	−0.99 ± 0.12	−1.02 ± 0.13
		Apical	−0.59 ± 0.19	−0.65 ± 0.21	−0.63 ± 0.10	−0.69 ± 0.12
Apical 2 C	Anterior	Basal	−1.58 ± 0.12	−1.55 ± 0.21	−1.55 ± 0.16	−1.52 ± 0.15
		Mid	−1.28 ± 0.09	−1.21 ± 0.10	−1.20 ± 0.12	−1.25 ± 0.11
		Apical	−1.05 ± 0.08*,***	−0.94 ± 0.11	−0.90 ± 0.15	−1.03 ± 0.08*****,******
	Inferior	Basal	−1.58 ± 0.10	−1.54 ± 0.19	−1.58 ± 0.12	−1.54 ± 0.11
		Mid	−1.31 ± 0.08	−1.24 ± 0.12	−1.24 ± 0.09	−1.26 ± 0.09
		Apical	−1.05 ± 0.08*,***	−0.93 ± 0.12	−0.91 ± 0.14	−1.02 ± 0.07*****,******
Apical 3 C	Posterior	Basal	−1.41 ± 0.22	−1.54 ± 0.18*	−1.49 ± 0.14	−1.53 ± 0.13***
		Mid	−1.06 ± 0.15	−1.17 ± 0.13*	−1.14 ± 0.13	−1.18 ± 0.13***
		Apical	−0.72 ± 0.21	−0.92 ± 0.15*	−0.89 ± 0.12**	−0.89 ± 0.15***
	Anterior	Basal	−1.46 ± 0.27	−1.57 ± 0.16	−1.56 ± 0.15	−1.65 ± 0.14***
		Mid	−1.12 ± 0.20	−1.20 ± 0.14	−1.23 ± 0.12**	−1.29 ± 0.12***
		Apical	−0.76 ± 0.25	−0.90 ± 0.16*	−0.91 ± 0.13**	−0.95 ± 0.12***
Short axis	Basal	Anterior septal	−1.67 ± 0.19	−1.81 ± 0.29	−1.72 ± 0.19	−1.69 ± 0.19
		Anterior	−1.33 ± 0.19	−1.37 ± 0.24	−1.34 ± 0.19	−1.39 ± 0.20
		Lateral	−0.96 ± 0.18*	−1.08 ± 0.14	−0.99 ± 0.14	−1.03 ± 0.19
		Posterior	−0.86 ± 0.15*,***	−1.09 ± 0.17	−0.97 ± 0.14****	−0.97 ± 0.19*****
		Inferior	−1.28 ± 0.18	−1.39 ± 0.21	−1.35 ± 0.19	−1.34 ± 0.27
		Septal	−1.60 ± 0.16*,***	−1.79 ± 0.25	−1.73 ± 0.18	−1.68 ± 0.23

*Between preterm and term baby $p < 0.05$
**Between preterm and 1-month-old baby $p < 0.05$
***Between preterm and 3-month-old baby $p < 0.05$
****Between term and 1-month-old baby $p < 0.05$
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******Between 1-month-old and 3-month-old baby $p < 0.05$

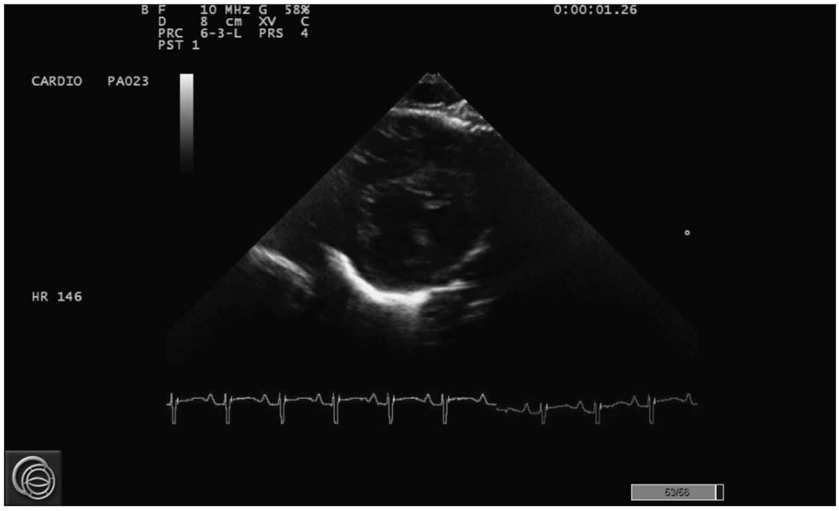

Figure 5.
Deformation of left ventricular shape due to aberrant band in the short-axis view.

consisted of newborn babies and young infants whose myocardial maturation was not completed, the study group in Sun et al study[25] included adults whose myocardial development was completed. We are of the opinion that the myocardial development process influences cardiac velocities, strain, and

strain rate values, as well as the difference between wall segments.

Using a two-dimensional tissue-tracking system, Bussadori et al[10] found that systolic velocities decreased from the basal segment to the apex in children and adults. Our study also used the two-dimensional tissue-tracking system and found that both longitudinal and circumferential systolic velocities decreased from the basal to the apical segment in all groups. Bussadori et al[10] found that left ventricle longitudinal strain values in children increased from the basal segment to the apex on the septal wall, whereas they were lower in the apex than they were in the basal segment on the lateral wall, and strain rate values increased from the basal segment to the apex. In the concerned study, global longitudinal systolic strain, global circumferential strain, and strain rate values in children were markedly higher than those in adults. We think that this might be because the image quality is better in children. Our study also found that systolic strain and strain rate values obtained by apical four-chamber and two-chamber imaging were lower in the apical segment. This might be explained by the effect of a high heart rate on the image quality in our age group, as presumed by Lorch et al,[26] or by the inadequacy of the insonation angle in the apical segment, the curvature structure in the apical region, or wall thinness as suggested by Pena et al.[27] It was shown that total collagen/total protein ratio and type I collagen/type III collagen ratio were quite high in newborns and that the total collagen/total protein ratio gradually decreased during the development process. On the basis of these data, it was concluded that the newborn heart was rigid and less compliant.[28] The data demonstrated the differences between the neonate and adult heart, and therefore helped to explain the difference between Bussadori et al[10] and our study regarding the segments.

In a study that compared values of healthy newborns in postnatal 24 hours and at 1 month showed a marked decrease in systolic strain values of the basal and mid-segments in the second examination, but no significant change in systolic strain rate values.[29] It was therefore argued that strain rate values that were influenced by haemodynamic changes to a lesser extent were more reliable. In our study, longitudinal and circumferential strain and longitudinal strain rate values in full-term neonates and 1-month-old neonates, who were similar to the study groups in this study,[29] showed no difference between these two groups. The comparison between circumferential strain rate values revealed a statistically significant decrease in 1-month-old infants, relative to newborns, only in the basal-posterior segment ($p = 0.004$). No differences were found among other segments. These results demonstrated that neither strain nor strain rate values are markedly affected by volume and pressure loadings in this 1-month period.

It was established that longitudinal strain values did not change markedly with age and heart rate, and they attributed the stability of left ventricle geometry from babyhood to adulthood in the balancing of torsion, which is the major cause of myocardial deformation.[26] It was argued that as strain values in particular are relatively independent of changes in maturation, they could be a critical tool in the cardiac evaluation of different ages in children. In our study, an examination of groups revealed that the major difference in the strain values was between the premature and 3-month-old group, and there was a significant increase in the basal, mid-, and apical segments of the septal wall from the premature group to the 3-month-old group ($p = 0.001$). However, similar to Pena et al[29] and Boettler et al,[30] there was no difference between the systolic strain rate values of the two groups. Therefore, it was thought that systolic strain rate values in particular might be relatively independent of changes in the maturation process.

In conclusion, the results of our study suggested that myocardial contraction and relaxation process undergo changes in the transition from foetal life to the postnatal period and then to early infancy. Tissue Doppler imaging, strain, and strain rate echocardiography, which have recently become increasingly more common in clinical practice, have proven quite useful in providing critical and objective information to understand the cardiac haemodynamic changes in the neonatal and early infancy periods. We think that because of its advantages over the tissue Doppler-derived method, the two-dimensional speckle-tracking method could produce results that are more reliable in clinical practice. However, despite its usefulness and reproducibility, the method has some limitations.

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