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Influence of patent ductus arteriosus on left ventricular myocardial deformation in preterm neonates in the early neonatal period

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1. Introduction

The incidence of patent ductus arteriosus (PDA) in preterm neonates (PN) varies from 20% to 60%, depending on the diagnostic criteria applied and the population examined [1–3]. Low-weight PN with PDA are at higher risk of developing heart failure, bronchopulmonary dysplasia, renal failure, necrotizing enterocolitis, and eventual neurodevelopmental deficits, all of which impact morbidity and mortality of these infants [2,3].

Compared with older children and adults, systolic functional reserve and diastolic properties of immature neonatal myocardium are relatively impaired [4]. In both preterm and term neonates, myocardial cells display fewer contractile elements, higher water content, greater surface-to-volume ratio, and underdeveloped sarcoplasmic reticulum [5]. Besides, abrupt changes in left ventricular (LV) loading conditions that occur immediately after birth due to increased systemic vascular resistance and pulmonary venous return, the presence of left-to-right shunting through a PDA further burdens LV myocardium [6].

Evaluation of LV function in newborns is thus a difficult task, complicated not only by physiologic factors but also by a lack of standardized echocardiographic parameters [7].

Two-dimensional speckle tracking echocardiography (2DSTE) has proved to be a useful tool for detecting early ventricular systolic dysfunction in adults and in the pediatric population [8–12]. De Waal et al. [13] and Levy et al. [14] studied PN using 2DSTE and found speckle tracking analysis to be feasible in the very PN [13] and described maturational changes in systolic ventricular deformation mechanics [14]. However, in PN, there is still a lack of reference values for deformation parameters in different clinical conditions. The aim of this study is to evaluate the measures of myocardial deformation of the left ventricle using 2DSTE in stable preterm newborns with and without patent ductus arteriosus and providing reference values could help the clinical management of these patients.

2. Methods

2.1. Study population

This is an observational study and the data were collected prospectively in the Neonatal Intensive Care Unit, examining preterm infants at 24–34 weeks of gestation. Neonates with congenital heart diseases other than PDA, 5-minute Apgar scores < 5, sepsis, death within 72 h after birth, arrhythmias, pulmonary hypertension and those in need of inotropic support were excluded. Infants with poor quality echocardiographic images were also excluded. Parental informed consent was obtained for all participants, and the institutional Ethics Committee on Human Research approved the study protocol.

2.2. Clinical characteristics

Data on gestational age, birth weight, gender, Apgar score, systemic arterial pressure, number of patients under mechanical ventilation support and duration of oxygen therapy, and use of surfactant were recorded for each neonate in a standardized form.

2.3. Echocardiographic examinations

Comprehensive transthoracic echocardiographic examinations were performed by the same experienced pediatric echocardiographer (KFSA), according to the recommendations of the American Society of Echocardiography [15–18]. All PN were examined within 24 h to 72 h after birth, without the use of sedation. Two-dimensional real-time grayscale images were obtained using a MyLab 60 echocardiographic machine (Esaote, Florence, Italy), with a neonatal phased array PA 023 multi-frequency (5–7.5 MHz) transducer. Harmonic imaging was used to acquire cine-loop images of the heart from the apical four-chamber view and parasternal short-axis view at the level of papillary muscles, at a rate of 90–120 frames/s, with good quality ECG tracings.

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2.4. Echocardiographic parameters

LV diameters, as well as left atrial (LA) and aortic root (Ao) dimensions, LV ejection fraction was calculated from the apical 4-chamber view using Simpson's rule. S wave was measured at level of the mitral lateral ring by Tissue Doppler Index (TDI). LV output was calculated as LV outflow tract cross-sectional area × LV outflow Doppler velocity-time integral × heart rate / weight [19].

Imaging of the PDA was obtained from the high left parasternal view. The minimum diameter of the color flow jet closest to the entry to the main pulmonary artery was taken as the ductal diameter [20].

2.5. Hemodynamically significant PDA

In this study, the echocardiographic definition of hemodynamically significant PDA (hsPDA) was established based on the presence of a ductal diameter > 1.5 mm, with flow directed from left to right, and LA/Ao ratio ≥1.4. Additionally, at least one of the following Doppler flow patterns was required: reversal flow in the descending aorta or the presence of diastolic flow in the left pulmonary artery [20–24].

2.6. Two-dimensional speckle tracking echocardiography analysis

Two-dimensional speckle tracking echocardiography was used for the evaluation of the septal and lateral walls from the four-chamber apical view, and the anteroseptal, anterior, lateral, posterior, inferior and septal walls from the parasternal mid-ventricular short-axis view. Upon review, only those cine-loops with at least three consecutive measurable cardiac cycles were considered valid for study. The endocardial border, drawn by the operator on an arbitrary single frame, was identified as a sequence of points. Image data were digitally stored in cine-loop format for offline analysis using the XStrain software (Esaote, Italy), designed specifically to track endocardial border. Peak systolic longitudinal, radial, and circumferential myocardial strain and strain rate (SR) curves were generated automatically, and quantitative data for the various parameters were exported into a Windows TM-based computer workstation (Fig. 1).

2.7. Statistical analysis

Continuous variables were assessed for normality using the Shapiro-Wilk test. Normally distributed variables were expressed as mean ± SD and skewed data as median and interquartile range. A one-way analysis of variance (ANOVA) was used for comparisons among groups. In cases where ANOVA showed a significant difference between groups, a Tukey HSD test was applied to find out which group differed significantly.

Intra- and interobserver variability for strain measurements were evaluated using a 15-patient subset from each group. Intraobserver variability was assessed by a pediatric echocardiographer (KFSA) who performed offline analysis 6 weeks apart to reduce recall bias. To assess interobserver variability, a second pediatric echocardiographer (GNL), blinded to clinical infant status and unaware of prior analysis, examined LV deformation of the same patient subset offline. To test intraobserver and interobserver reproducibility of strain measurements (strain and SR), the intraclass correlation coefficient test and the Bland-Altman test were used. All computations relied on standard software (SPSS v 13.0; SPSS Inc., Chicago, IL, USA), setting statistical significance at $P < .05$.

3. Results

3.1. Clinical characteristics

Overall, 21 PN with hsPDA (Group I), 14 patients with PDA without hemodynamic repercussion (Group II) and 30 control subjects without PDA (Group III) were studied. Clinical characteristics of the three groups are summarized in Table 1.

Median gestational age was similar for the three groups ($P = .07$): 29 weeks (range, 25–33 weeks) for Group I, 30 weeks (range, 27–33 weeks) for Group II and for Group III, 31 weeks (range, 24–34 weeks); mean birth weight did not differ significantly either (1.3 ± 0.4 kg vs 1.3 ± 0.3 kg vs 1.5 ± 0.4 kg respectively for Groups I, II and III, $P = .07$).

No significant differences in 5-minute Apgar scores, gender, heart rate, systolic blood pressure, or mean blood pressure were evident. In Group I, diastolic blood pressure ($P = .007$), duration of required oxygen support ($P < .001$), ventilatory support ($P < .001$) and use of surfactant ($P < .001$) were significantly different (Table 1).

3.2. Echocardiographic parameters

Median values of the timing of echocardiographic assessment was similar among the groups ($P = .20$ – see Table 2). Group I: median 48 h (range, 26 to 69 h) compared to Group II, median 43 h (range, 27 to 70 h); $P = .32$ as well as Group I compared to Group III: median 46 h (range, 26 to 60 h); $P = .18$. Ductus diameter was 2.2 mm ± 0.4 mm for Group I and 1.2 mm ± 0.2 mm for Group II ($P = .01$).

Regarding the influence of PDA on the LV, median LV end-diastolic diameter (LVEDD) was larger in Group I (15.5 mm; range, 9.5–17.5 mm) compared to Group II (13.7 mm; range, 9–14 mm) and Group III (12 mm; range, 8–15 mm, $P = .009$). Similarly, LA/Ao ratio was greater in Group I ($P = .01$).

No differences on LV ejection fraction could be found among the groups; $P = .14$. The averages of S-wave measurements remained within normal values in all groups and there was no statistical difference between them; $P = .93$.

Median LV output was higher in PN with hsPDA (420 ± 123 mL/kg/min) compared to Groups II and III (278 ± 112 mL/kg/min and 235 ± 56 mL/kg/min respectively, $P = .001$).

3.3. Two-dimensional speckle tracking echocardiography analysis

Left ventricular longitudinal, radial, and circumferential strain and SR for each group are presented in Table 3. With regard to peak systolic longitudinal strain (PSLS), statistically significant differences were found between Group I (−19%; range, −9.1% to −26.6%) and Group II (−15.3%; range, −8% to −20%; $P < .004$), and Groups I and III (−12.7%; range, −7% to −18%; $P < .001$). Peak systolic radial strain (PSRS) was also increased in Group I compared to Group II ($P = .03$) and Group III ($P = .005$).

When the groups were compared regarding peak systolic circumferential strain (PSCS), higher values were also observed for Group I (−18%, range, −10% to −31%) compared to Group II (−15.9%, range, −11% to −27%); $P < .002$ and Group III (−12.6%, range, −12% to −24.8%); $P < .001$.

Mean values for peak systolic longitudinal SR (PSLSR) were higher in Group I: $-1.9\ s^{-1} \pm 0.4\ s^{-1}$ compared to those in Group II: $-1.4\ s^{-1} \pm 0.4\ s^{-1}$; $P = .005$, as well as between Group I and Group III: $-1.3\ s^{-1} \pm 0.2\ s^{-1}$; $P = .005$. Similarly, medians of peak systolic radial SR (PSRSR) were significantly higher in Group I: $2.9\ s^{-1}$ (ranging from $1.0\ s^{-1}$ to $4.5\ s^{-1}$) when compared to Group II: $2.2\ s^{-1}$ (ranging from $1.4\ s^{-1}$ to $4.2\ s^{-1}$) and Group III: $1.9\ s^{-1}$ (ranging from $1.3\ s^{-1}$ to $3.6\ s^{-1}$); $P = .007$.

Regarding the mean values of peak systolic circumferential SR (PSCSR), statistically significant differences were established between Group I: $-1.2\ s^{-1} \pm 0.6\ s^{-1}$ and Group II: $-1.8\ s^{-1} \pm 0.4\ s^{-1}$; $P = .005$ between Group I and Group III: $-1.5\ s^{-1} \pm 0.38\ s^{-1}$; $P = .004$ and between Group II and Group III; $P = .01$.

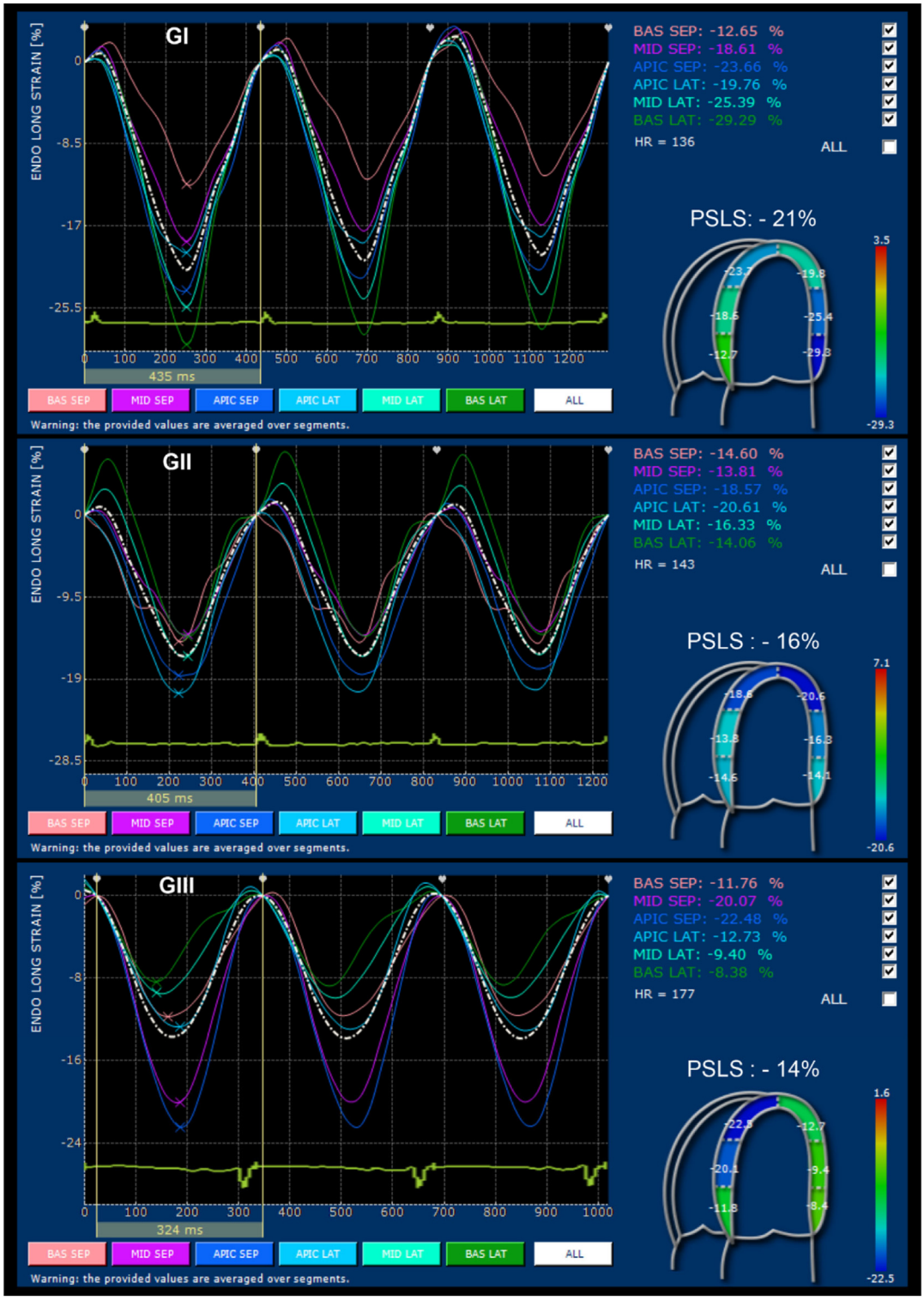

Fig. 1. Screen shots showing the peak systolic longitudinal strain (PSLS) for three different patients: (upper) from Group I (GI), (middle) from Group II (GII) and (lower) Group III (GIII).

3.4. Feasibility and reproducibility

Of the 150 initially eligible PN, 65 were excluded due to APGAR scores ≤5 (n = 5), congenital structural heart disease other than PDA (n = 6), need for inotropic support (n = 15), severe pulmonary hypertension (n = 15), death within the first 72 h of life (n = 20), arrhythmias (n = 4); according Fig. 2.

Of the 85 preterm infants studied, strain and SR measurements were therefore adequately performed in 65 individuals.

Inter and intraobserver variabilities analysis, including the percentage bias, 95% limits of agreements, intraclass and interclass correlation coefficient are summarized in Table 4.

4. Discussion

Unlike most studies published in the literature in which

Table 1
Patient demographics and clinical characteristics.

Variable	Group I	Group II	Group III	P value
Number of patients	21	14	30	–
Gestational age at birth (weeks)	29 (25–33)	30 (27–33)	31 (24–34)	.07
Birth weight (kg)	1.3 ± 0.4	1.3 ± 0.4	1.5 ± 0.4	.07
Male/female ratio	15/6	7/7	18/12	.97
APGAR score	8 ± 1.5	8 ± 1.1	8.4 ± 1.2	.40
Heart rate (beats/min)	157 ± 17	150 ± 11	147 ± 16	.90
SBP (mmHg)	61 ± 8	59 ± 7	66 ± 8	.90
DBP (mmHg)	26 ± 6*	33 ± 5*	31 ± 8*	.007
Mean BP (mmHg)	30 ± 5	32 ± 4	39 ± 7	.20
Patients use of surfactant	17*	4*	5*	< .001
Duration of required oxygen (days)	40*	32*	25*	< .001
Patients under respiratory support	14*	4*	9*	< .001

Data expressed as mean ± SD or as median (range).
SBP, systolic blood pressure; DBP, diastolic blood pressure; BP, blood pressure.
* P < .05% between group I versus group II and group I versus group III.

measurements of myocardial deformation in PN were performed from the third day of life onwards [25–28] and included in the control group both patients with PDA without hemodynamic repercussion and patients without PDA [19,23,28], our study population consisted of three selected groups of PN with gestational age ≤34 weeks, excluding the main factors that could influence the myocardial function of these patients. In addition, none of them underwent any drug therapy or surgery during the period of the echocardiographic exams.

These studied populations did not show statistically significant differences regarding gestational age, birth weight, gender or APGAR scores, confirming homogeneity of the groups. In the group of PN with hsPDA, a higher incidence of surfactant use, longer duration of oxygen therapy and invasive mechanical ventilation were observed. This is justified due to pulmonary hyperflow imposing systemic pressure on the pulmonary vascular bed, leading to pulmonary congestion and worsening respiratory function, already impaired by prematurity itself. These factors cause interstitial overload, diffusion of proteins in the alveolar bed, with risk of edema and decreased pulmonary compliance. The presence of interstitial and alveolar edema, in turn, inhibits the action of surfactant, aggravating respiratory stress.

We also found significantly higher values for LVDD, LA/Ao ratio and LV output measurements in the group with hsPDA. These differences observed are due to substantially higher preload and afterload in this group.

It is noteworthy that the LV output depends on preload, afterload, myocardial contractility and heart rate. In the presence of PDA, left-to-right blood diversion increases venous return from the pulmonary circulation to the LA, thus increasing LV preload, with a consequent increase in its final diastolic volume. However, in the presence of a hsPDA, left-to-right flow does not participate in effective systemic flow

Table 3
Strain and strain rate measurements.

Parameters	Group I	Group II	Group III	P value
PSLS (%)	−19.0 (−9.1 to −26.6)*	−15.3 (−8.0 to −20.0)*,#	−12.7 (−7.0 to −18.0)*,#	< .001
PSRS (%)	23.5 ± 10.0*	20.0 ± 8.1*	18.0 ± 4.3*	.040
PSCS (%)	−18.0 (−10.0 to −31.0)*	−15.9 (−11.0 to −27.0)*,#	−12.6 (−12.0 to −24.8)*,#	< .001
PSLSR (sec^{-1})	−1.9 ± 0.4*	−1.4 ± 0.44*	−1.3 ± 0.2*	.005
PSRSR (sec^{-1})	2.9 (1.0 to 4.5)*	2.2 (1.4 to 4.2)*	1.9 (1.3 to 3.6)*	.007
PSCSR (sec^{-1})	−2.2 ± 0.6*	−1.8 ± 0.4*,#	−1.5 ± 0.3*,#	.004

Data expressed as mean ± SD or as median (range).
PSLS, peak systolic longitudinal strain; PSRS, peak systolic radial strain; PSCS, peak systolic circumferential strain; PSLSR, peak systolic longitudinal strain rate; PSRSR, peak systolic radial strain rate; PSCSR, peak systolic circumferential strain rate.
* P < .05% between group I versus group II and group I versus group III.
# P < .05% between group II versus group III.

(PDA flow theft concept) [29]. In addition, in the postnatal setting, vascular bed resistance is low in the pulmonary and systemic circulations, reducing LV afterload and increasing systolic volume. Noori et al. [22] and El-Khuffash et al. [19], similarly to our study, demonstrated higher values of LV output in neonates with hsPDA.

The three studied groups presented mean and median values of LV ejection fraction and S wave by TDI, within the normal range and without statistical difference between the groups, proving that they had preserved LV systolic function.

The present study showed that PN with hsPCA presented significantly higher strain and SR values as determined by 2DSTE when compared to PN with PDA without hemodynamic repercussion and those PN without PDA. The differences observed are probably due to substantially higher preload and afterload in the presence of hsPDA. De Waal et al. [25] showed consistently higher longitudinal strain values in infants with PDA > 1.5 mm.

Likewise, El Khuffash et al. [19] and Levy et al. [14] observed that LV myocardial deformation was also higher in PN with hsPDA. However, El Khuffash et al. [19], observed that there was a reduction in the values of global deformation in patients after surgery to close the PDA. And in this study, patients using vasoactive drugs were included, a variable that we want to eliminate in order to study myocardial deformation more accurately. Levy et al. [14] observed that the myocardial deformation of the LV was also greater in PN with hsPDA. However, PN were assessed at 5 to 7 days of life, unlike our study, where we investigated the effect of studying earlier (24–72 h of life).

Similar to our study, Castaldi et al. [30] evaluated PN in the first hours of life and also observed higher values of longitudinal strain in individuals with PDA, which were attributed to a hyperdynamic state, showing that the deformation may be influenced by the preload [30].

In addition, El-Khuffash et al. [19], Amoogzar et al. [31] and Kang et al. [29] documented a significant reduction in overall longitudinal

Table 2
Conventional echocardiography values.

Parameters	Group I	Group II	Group III	P value
Postnatal time at initial echocardiographic examination (h)	48 (26–69)	43 (27–70)	46 (26–60)	.20
PDA diameter (mm)	2.2 ± 0.4	1.2 ± 0.2	–	.01
EF by Simpson (%)	75.0 (70.0–86.0)	74.0 (66.0–85.0)	73.0 (65.0–80.0)	.14
LVEDD (mm)	15.5 (9.5–17.5)*	13.7 (9.0–14.0)*	12.0 (8.0–15.0)*	.009*
LA/Ao ratio	1.6 ± 0.2*	1.3 ± 0.3*	1.2 ± 0.1*	.01*
S wave (cm/s)	4.9 ± 1	4.6 ± 1.1	4.5 ± 0.84	.93
LVO (mL/kg/min)	420 ± 123*	278 ± 112*	235 ± 56*	.001*

Data expressed as mean ± SD or as median (range).
EF, ejection fraction; LVEDD, left ventricular end-diastolic diameter; LVO, left ventricular output; S wave, peak systolic pulsed wave tissue Doppler velocity.
* P < .05% between group I versus group II and group I versus group III.

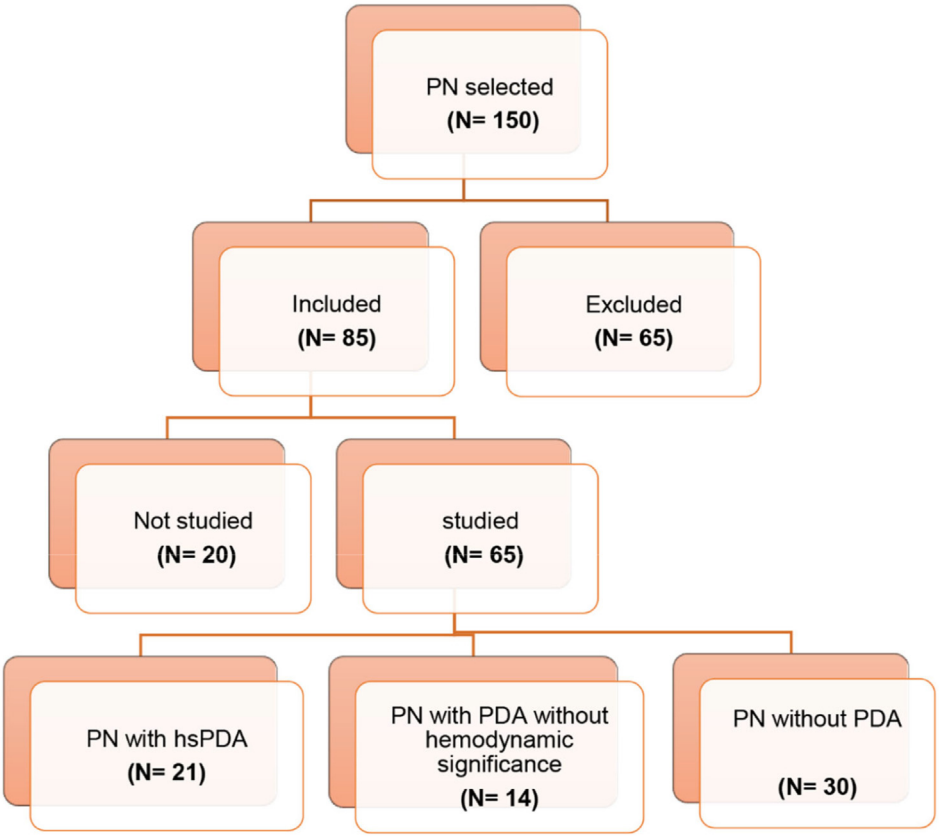

Fig. 2. Flow chart of the studied preterm neonates (PN). PDA: patent ductus arteriosus; hsPDA: hemodynamically significant PDA.

Table 4
Reproducibility analysis inter and intraobserver strain and SR.

Variable	Intraclass correlation			Bland-Altman		
	Bias	(95% LOA)	P value	Bias	(95% LOA)	ICC
Interobserver reproducibility						
PSLS	0.89	0.76 to 0.95	< .0001	0.77	0.23 (−0.73 to 2.33)	0.89
PSRS	0.99	0.99 to 0.99	< .0001	−0.25	0.12 (−0.9 to 0.19)	0.98
PSCS	0.95	0.89 to 0.97	< .0001	0.67	0.75 (−0.85 to 2.2)	0.95
PSLSR	0.82	0.63 to 0.91	< .0001	−0.33	0.03 (−0.03 to 0.09)	0.82
PSRSR	0.98	0.95 to 0.99	< .0001	−0.12	0.12 (−0.19 to 0.004)	0.98
PSCSR	0.83	0.65 to 0.92	< .0001	0.03	0.03 (−0.03 to 0.09)	0.83
Intraobserver reproducibility						
PSLS	0.88	0.74 to 0.94	< .0001	0.71	0.47 (−0.79 to 2.22)	0.88
PSRS	0.99	0.99 to 0.99	< .0001	−0.25	−0.09 (−0.07 to 0.20)	0.99
PSCS	0.95	0.90 to 0.98	< .0001	0.69	0.50 (−0.87 to 2.25)	0.95
PSLSR	0.84	0.67 to 0.92	< .0001	−0.04	0.01 (−0.07 to 0.02)	0.84
PSRSR	0.96	0.92 to 0.98	< .0001	−0.23	−0.30 (−0.09 to 0.04)	0.96
PSCSR	0.92	0.83 to 0.96	< .0001	0.02	−0.06 (−0.03 to 0.1)	0.92

PSLS, peak systolic longitudinal strain; PSRS, peak systolic radial strain; PSCS; peak systolic circumferential strain; PSLSR, peak systolic longitudinal strain rate; PSRSR, peak systolic radial strain rate; PSCSR, peak systolic circumferential strain rate; ICC, intraclass correlation coefficient.

systolic strain values immediately after PDA ligation, probably due to the reduction in LV volume loading and increased systemic vascular resistance.

In our study, the values of circumferential and radial strains and SR were also significantly higher in the PN with hsPDA. Laplace's law states that stress on the LV myocardial wall is directly dependent on the pressures and on the radius length divided by the free wall thickness.

In patients with PDA without hemodynamic repercussion or without PDA, as the preload is lower, the myocardial wall tension and LV radius length are lower, phenomena that lead to a lower contraction force of the circumferential fibers.

Comparing the absolute values of myocardial strain measurements in studies published in the medical literature, is difficult to come to any conclusion due to differences in the methodologies used for each author. In addition, differences in ultrasound systems, tracking software and frame rate may influence the results of myocardial deformation by 2DSTE [32–35].

There is also heterogeneity in the methodology regarding the gestational age, the time at which echocardiographic examination was performed, if a PDA was present or not or if vasoactive drugs was used or not [35,36].

Therefore, there is a lack of standardization of 2DSTE values in PN, as shown in previous studies [32–36].The variety of methodologies is summarized in Table 5.

We tried to overcome such a heterogeneity of clinical scenarios, analyzing the myocardial deformation in a more homogeneous group of PN. In the present study, the intraobserver and interobserver variations were satisfactory for the LV parameters analyzed, reinforcing that the strain and SR measured by 2DSTE is a viable tool for the detection of myocardial deformation in PN.

4.1. Study limitations

When performing echocardiography in PN, it is important to highlight the difficulties and challenges related to the examination. Some very small PN may present with limited echocardiographic windows, particularly if they are on mechanical ventilation; besides, they may be agitated and with high heart rate when they are not under sedation.

This study did not evaluate right ventricular deformation. The analysis of this parameter should improve our understanding of the physiopathology of PDA in PN. We also did not evaluate the therapeutic

Table 5
Studies comparing PSLS and PSLRS values by 2DSTE in PN.

Study	Year	n	GA (weeks)	Weight (kg)	Time of examination	PDA	Software	FR	PSLS (%)	PSLSR (sec^{-1})
El-Khuffash [19]	2012	19	24–30	0.6–0.8	GI) preoperative PDA GII) 1 h postoperative PDA GIII) 18 h postoperative PDA	W/o and with PDA	EchoPAC	80–100	GI) −19.7 (± 3.8) GII) −11.5 (± 3.5) GIII) −15.1 (± 2.9)	–
Elkiran [36]	2014	32	36–37	2.5 (± 0.2)	1–3 days	–	X Strain	50–75	−10.4% (± 2.8)	−1.11 (± 0.2)
De Wall [13]	2014	51	24–31	1.0 (± 0.3)	10 (11) days	W/o and with PDA < 1.5 mm	Tomtec	30	−18.7% (± 2.6)	−1.73 (± 0.28)
Hirose [9]	2015	30	27 (± 1.2)	1.1 (± 0.2)	28.2 (0.5) days	W/o and with PDA	EchoPAC	–	−16.0 (± 3.3)	−1.63 (± 0.26)
Schubert [11]	2016	25	27.7 (± 1.2)	1.1 (± 0.2)	–	W/o and with PDA	EchoPAC	187	−17.9 (± 2.5)	−2.33 (−2.9 to −2.1)
De Wall [27]	2017	GI) 30 GII) 77	< 30	–	3 days	GI) with PDA > 1.5 mm GII) with PDA < 1.5 mm or w/o PDA	Tomtec	90–110	GI) −23.4 (± 2.3) GII) −21.2 (± 2.1)	−2.5 (± 0.3)
Castaldi [30]	2018	39	≤39	1.3 (± 0.5)	96 h	W/o and with PDA	EchoPAC	60–100	−19 (± 3.1)	–
Almeida	2019	GI) 21 GII) 14 GIII) 30	≤34	1.3 (± 0.4)	24–72 h	GI) hsPDA GII) PDA w/o HS GIII) w/o PDA	X Strain	90–120	GI) −19 (−9 to −26.6) GII) −15.3 (−8 to −20) GIII) −12.7 (−7 to −18)	GI) −1.9 (± 0.40) GII) −1.4 (± 0.44) GIII) −1.3 (± 0.21)

N, number of patients; GA, gestational age; PDA, patent ductus arteriosus; FR; frame rate; PSLS, peak systolic longitudinal strain; PSLSR, peak systolic longitudinal strain rate; G, group; w/o; without; hsPDA, hemodynamically significant PDA; HS; hemodynamic significance.

effect and prognosis of PDA treatment on LV deformation, as it was not our aim.

The measurement of the LV deformation of a smaller number of myocardial segments, from apical four-chamber and mid-ventricular short-axis views, applied in this study may reflect less the LV myocardial deformation than the measurements of all myocardial segments (global deformation).

The frequency of ultrasound emission is a determining factor on the definition and quality of the echocardiographic images. Therefore, in the very PN the ideal transducer frequency should run between 8 and 12 MHz. In our work we used a transducer with slightly lower frequencies (5–7.5 MHz). However, we believe that the use of lower frequency transducers, with consequent higher frame rates, should have contributed to increase the capture sensitivity of acoustic markers. Proof of this was the low rate of patients excluded for inadequate quality of strain and SR tracing (only 3 patients).

As in other studies of this nature, the investigation was also restricted to a small number of patients in each group and further research with a larger number of individuals is clearly needed to corroborate our findings.

5. Conclusions

Peak systolic longitudinal, radial, and circumferential strain and SR measurements are significantly higher in a group of low-weight PN with hsPDA, possibly as a mean of compensating for PDA-imposed LV volume overload.

This values for the left ventricular deformation parameters in stable preterm infants with and without persistent ductus arteriosus in an attempt to provide new possible information for the clinical management of these patients.

CRediT authorship contribution statement

Kellen Freitas Silva de Almeida: Conceptualization, Methodology, Investigation. **Gabriela Nunes Leal:** Conceptualization, Methodology, Investigation. **Samira Saady Morhy:** Conceptualization, Methodology. **Ana Clara Tude Rodrigues:** Methodology, Writing - review & editing. **Giovanni G. Cerri:** Writing - review & editing. **Ulysses Doria-Filho:** Formal analysis. **Jose Lázaro de Andrade:** Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare no conflict of interest.

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