Role of Functional Echocardiography in Preterm Infants in the Neonatology Unit

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ABSTRACT

Objective: To evaluate the role of functional echocardiography in preterm infants admitted to a Tunisian NICU.

Methods: This prospective, single-center study included 60 preterm infants (<37 weeks gestational age) over 12 months. Echocardiography was performed to assess structural and functional cardiac abnormalities and guide clinical management.

Results: Structural heart defects were observed in 15% of cases. Functional abnormalities, including systolic dysfunction, hemodynamically significant patent ductus arteriousus (hsPDA), and abnormal ventricular output, were detected in 42% of infants. Echocardiographic findings led to changes in therapeutic management in 23% of cases, primarily for PDA closure, inotropic support, and fluid optimization. In cases with systolic dysfunction, early identification allowed targeted interventions and favorable outcomes.

Conclusion : Functional echocardiography is a crucial tool in preterm infants, particularly for PDA evaluation and ventricular dysfunction. Functional echocardiography provides clinically meaningful information beyond routine examination and represents an essential tool for individualized hemodynamic assessment in preterm infants.

Keywords : Functional echocardiography, Structural echocardiography, Preterm infant, Neonate, Hemodynamic assessment

INTRODUCTION

Premature infants present unique cardiovascular challenges due to the immaturity of their cardiovascular system and the transitional changes occurring after birth. The preterm myocardium is structurally and functionally immature, characterized by reduced compliance, limited contractile reserve, and a diminished ability to adapt to fluctuations in preload and afterload. Consequently, cardiovascular adaptation in these infants differs substantially from that of term neonates, making them particularly vulnerable to hemodynamic instability during the early neonatal period. In addition, the persistence of fetal circulatory pathways, particularly patent ductus arteriosus (PDA) and, to a lesser extent, patent foramen ovale, is common in preterm infants. These shunts may significantly alter systemic and pulmonary blood flow, leading to pulmonary overcirculation, systemic hypoperfusion, impaired organ perfusion, and increased morbidity [1].

Clinical assessment alone is often insufficient to accurately characterize these complex hemodynamic disturbances, highlighting the need for bedside imaging tools capable of providing real-time cardiovascular evaluation.

Functional echocardiography has emerged as a valuable tool in neonatal intensive care units (NICUs), allowing clinicians to assess cardiac function, estimate systemic and pulmonary blood flow, evaluate the hemodynamic impact of PDA, and guide individualized therapeutic interventions [2-8]. Its use has expanded considerably over the past two decades, particularly in the management of critically ill preterm infants. However, most published studies include both term and preterm neonates, limiting the understanding of the specific indications and clinical utility of echocardiography in the preterm population.

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Therefore, this study aimed to evaluate the indications, echocardiographic findings, and clinical impact of echocardiography in preterm infants admitted to a Tunisian neonatal intensive care unit.

MATERIALS AND METHODS

This prospective, single-center study was conducted in a Level III NICU in Tunisia over a 12-month period to assess the indications, findings, and impact of functional echocardiography in preterm infants.

Participants

Infants with gestational age <37 weeks admitted for respiratory, hemodynamic, or suspected cardiac disorders were eligible. Exclusion criteria included major non-cardiac congenital malformations incompatible with survival and parental refusal.

Data Collection and Variables

Clinical data included gestational age, birth weight, sex, and admission diagnosis. Echocardiographic variables included:

- Structural abnormalities: Atrial septal defect (ASD), Ventricular septal defect (VSD), Hypertrophic cardiomyopathy (HCM)
- Ventricular dimensions (normalized for gestational age and weight)
- Left ventricular ejection fraction (LVEF)
- Fractional shortening (LVFS)
- Cardiac output
- Ductus arteriosus patency and hemodynamic significance.

All echocardiographic examinations were independently reviewed by an experienced pediatric cardiologist with expertise in neonatal echocardiography. Cardiac dimensions and Doppler-derived measurements were checked offline to ensure measurement accuracy, adherence to American Society of Echocardiography recommendations, and correct interpretation according to gestational age and body weight. Any discrepancy between the neonatologist and the pediatric cardiologist was resolved by joint review before final validation of the dataset.

Echocardiography Protocol

Functional echocardiography was performed according to standard neonatal protocols. Indications, findings, and subsequent management changes were recorded, including follow-up echocardiography when indicated.

Statistical Analysis

Data were entered and analyzed using SPSS software, version 22 (IBM Corp., Armonk, NY, USA). Descriptive statistics were applied. For qualitative variables, absolute frequencies and percentages (%) were calculated. For quantitative variables, means and standard deviations (SD) were computed.

Ethical Considerations

Given the non-invasive nature of the study, informed oral consent was obtained from the parents of all included infants. Patient anonymity and confidentiality were strictly maintained during data collection and analysis.

RESULTS

Demographic Characteristics

Table 1 : Demographic and anthropometric characteristics of the study population.

Characteristic	n = 60
Gestational age	
<28 weeks	3 (5%)
28-------32	17 (28%)
33-- 36	40 (67%)
Weight	
<1500 g	25 (42%)
1500---2499 g	25 (42%)
≥2500 g	10 (16%)

Pregnancy-related conditions were observed in 26 cases (43%), including gestational diabetes in 15 cases (58%) and gestational hypertension in 8 cases (31%). A combination of both disorders was reported in 3 cases (11%).

A fetal echocardiogram was available in 46 out of 60 cases; results were normal in 45 cases. One case of two muscular VSDs was identified antenatally and confirmed postnatally.

The main primary diagnosis at admission to the neonatology department was neonatal respiratory distress (43 cases, 72%), followed by growth anomalies (24 cases, 40%), infants of diabetic mothers (IDM) (15 cases, 25%), impaired transitional cardiovascular adaptation (10 cases, 17%), and suspected neonatal sepsis (4 cases, 7%).

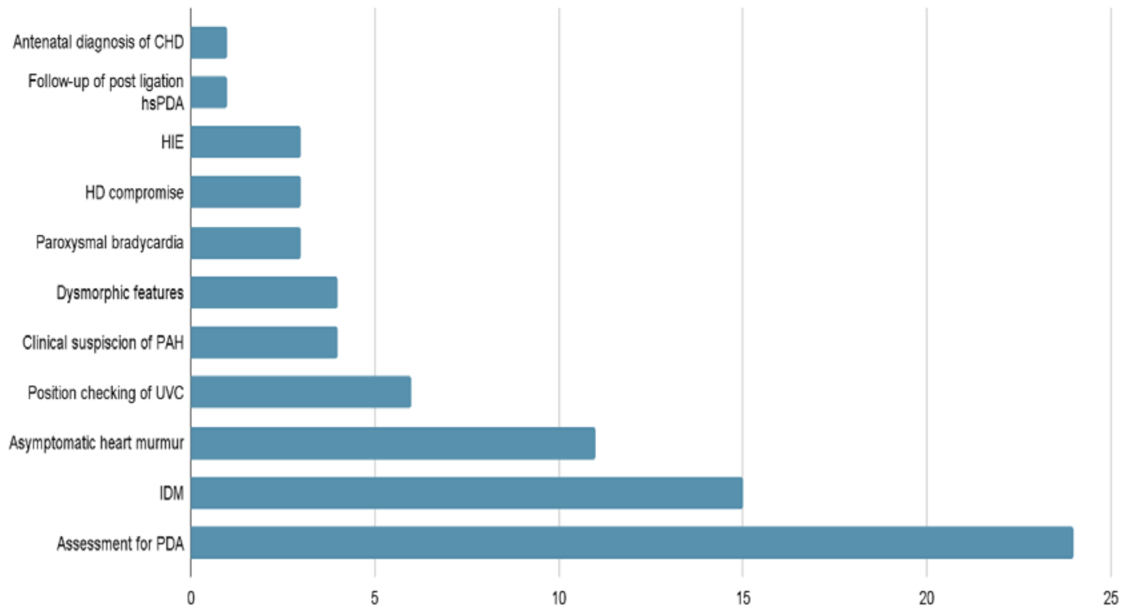
Timing of First Echocardiographic Evaluation

Most echocardiograms were performed after 72 hours of life, with timing ranging from 7 hours to 30 days. The median age at first examination was 8 days.

Indications for Echocardiography

The most frequent indication was assessment of PDA (n=24, 40%). The second most common indication, observed in equal proportion, was screening in infants of diabetic mothers (IDM) and hemodynamic evaluation in severe neonatal respiratory distress (n=15, 25% each). The presence of a cardiac murmur accounted for 11 cases (18%) of echocardiographic evaluation (Figure 1).

Figure 1 : Distribution of indications for echocardiography

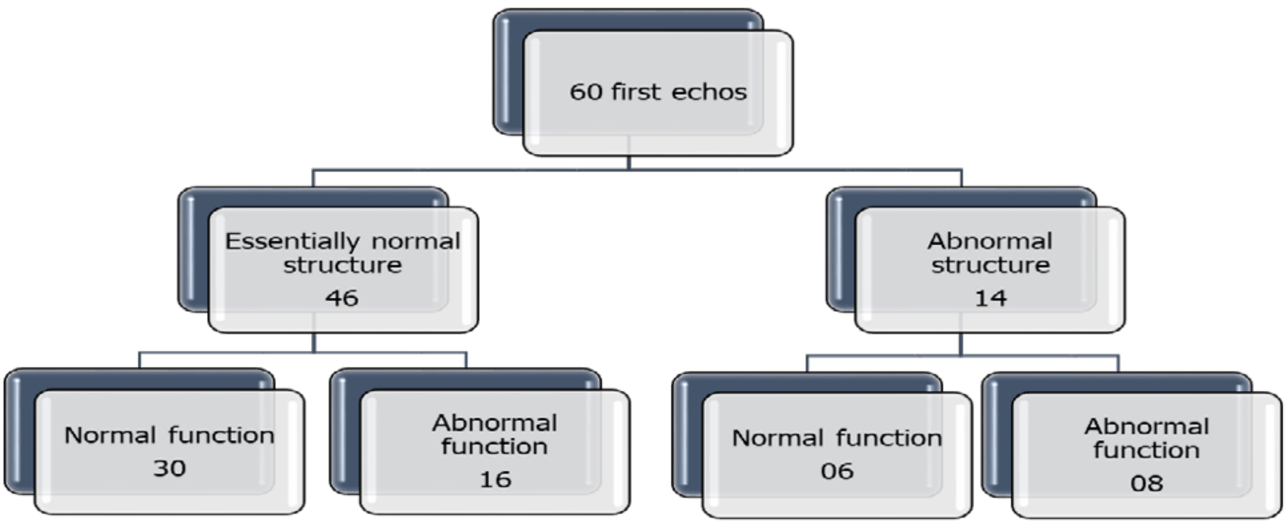


PDA = patent ductus arteriosus; IDM = infant of diabetic mother; PAH = pulmonary arterial hypertension.

Echocardiographic findings:

The distribution of main echocardiographic finding is highlighted in figure 2.

Figure 2 : Distribution of main echocardiographic findings



· *Cardiac dimensions:*

Tables 2 and 3 present the median values and ranges of echocardiographic parameters, stratified by gestational age categories and birth weight groups, respectively.

Table 2 : Echocardiographic measurements stratified by gestational age

Ranges of gestational age	LVEDD (range) Mm	LVESD (range) mm	LVEF (range) %	LVFS (range) %	IVS (range) Mm	LVPW (range) mm	SPAP (range) mmHg	Aortic annulus (range) Mm	Subaortic VTI (range) cm	LVO (range) ml/kg/min
32w - 36w+6d (N=40)	15 (11-22.5)	9 (6-14)	70 (50-80)	38.5 (23-47)	3.6 (1.5-8)	3 (2-6)	32 (8-80)	7 (4-10)	8.5 (6-12.5)	265 (150-472)
28w - 31w+6d (N=17)	12 (10-15)	7.3 (6.5-9)	74 (62-85)	39.5 (30-47)	3.5 (2.5-7)	2.9 (2-5)	38.5 (15-80)	6 (5-8)	8.2 (6-10)	272 (154-422)
< 28w (N=3)	11.4 (7.3-15)	7.1 (6-9.3)	66 (49-80)	35 (21-48	2.8 (2-3.2)	3 (2-4)	23 (15-30)	5 (4-8)	6.5 (4-8)	229 (88-435)

Abbreviations: IVS: Interventricular septum; **LVEDD:** Left ventricular end-diastolic diameter; **LVEF:** Left ventricular ejection fraction; **LVESD:** Left ventricular end-systolic diameter; **LVFS:** Left ventricular fractional shortening; **LVPW:** Left ventricular posterior wall; **LVO:** Left ventricular output; **N:** Number; **SPAP:** Systolic pulmonary artery pressure; **VTI:** Velocity–time integral

Table 3 : Echocardiographic measurements stratified by birth weight

Ranges of birth weight	LVEDD (range) Mm	LVESD (range) mm	LVEF (range) %	LVFS (range) %	IVS (range) mm	LVPW (range) Mm	SPAP (range) mmHg	Aortic annulus (range) Mm	Subaortic VTI (range) cm	LVO (range) ml/kg/min
> 2500g (N=12)	16.2 (12-22.5)	10 (8-14)	70 (58-76)	37.1 (28 -41)	4.9 (2-8)	3.7 (2-6)	42 (14-80)	7.8 (6-10)	8.8 (7.3-11	217 (154-355)
1500 - 2500g (N=25)	13.7 (11-19)	7.4 (6-13)	73.4 (63-85)	39.5 (32-47)	3.2 (1.5-6)	2.8 (2-4.5)	32 (8-67)	7.2 (5.5-8)	8.3 (6-12.5	253 (130-385)
< 1500g (N=23)	12.7 (7.3-17)	8 (6.2-11)	70 (49-82)	37.7 (21-48)	3.2 (2-6)	2.9 (2-5)	31 (10-80)	6 (4-8)	8 (6 -12)	217 (154-355)

Abbreviations: IVS: Interventricular septum; **LVEDD:** Left ventricular end-diastolic diameter; **LVEF:** Left ventricular ejection fraction; **LVESD:** Left ventricular end-systolic diameter; **LVFS:** Left ventricular fractional shortening; **LVPW:** Left ventricular posterior wall; **LVO:** Left ventricular output; **N:** Number; **SPAP:** Systolic pulmonary artery pressure; **VTI:** Velocity–time integral

· *Structural abnormalities*

The most observed congenital heart disease was ASD in 7 cases, followed by HCM in 5 cases, while VSD was diagnosed in 2 cases.

The mean diameter of ASDs, all of the ostium secundum type, was 6.7 mm (range: 4–10 mm). ASD was associated with transient PAH in 3 cases and persistent PAH in 1 case with a large VSD. The mean diameter of VSDs was 3.5 mm (range: 1.5–5.5 mm). One VSD was associated with a PFO, and another with a large ASD (10 mm) plus PAH. The latter infant had a fatal outcome, while the other was followed in the pediatric cardiology department.

In cases of HCM, gestational diabetes was noted in 4 cases. HCM was biventricular in 2 cases, septal in 2 cases, and left ventricular in 1 case. No LV outflow obstruction was observed. PAH was noted in 2 cases. All affected newborns were referred for monitoring by the hospital's pediatric cardiologist.

· *Functional abnormalities*

Functional abnormalities were noted in 23 cases (38.33%), one-third of which had structural defects. The most common functional anomalies were pulmonary hypertension in 13 cases, visual collapse of the IVC indicating hypovolemia in 6 cases, hemodynamically significant PDA in 3 cases, and LV systolic dysfunction in 2 cases.

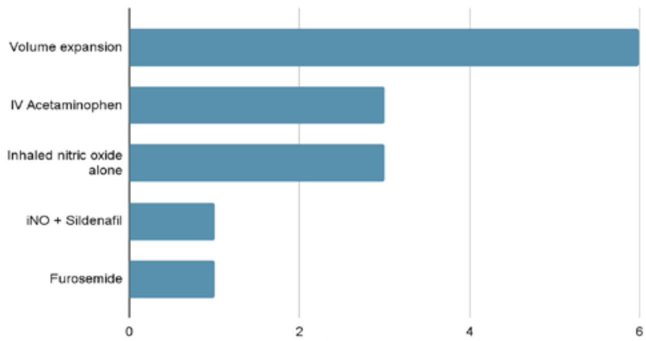
PAH was diagnosed in 13 patients, with a median Systolic PAP of 60 mmHg (range: 50–80 mmHg). PAH was classified as transient, persistent (refractory hypoxemia), or secondary to cardiovascular lesions (hsPDA, ASD, VSD).
Visual assessment of IVC collapse was observed in 6 cases. The mean IVC collapsibility index (IVCCI) in spontaneously breathing patients was 61% (range: 60–62%), and the mean IVC distensibility index in mechanically ventilated patients was 20.5% (range: 19–22%). Infants with echographic signs of hypovolemia had a favorable clinical outcome in 83% of cases.
Hmodynamically significant PDA was diagnosed in 3 patients, representing 5% of total cases and 13% of functional abnormalities.
Two cases of LV systolic dysfunction were identified:
- In an extremely preterm infant (26 weeks GA, BW 850 g) with severe hypoxic-ischemic encephalopathy, echocardiography at 18 hours of life showed LVEF 49%, LVFS 21%, and LV output 88 ml/kg/min. No specific therapy was administered due to the fatal prognosis; the infant died on day 1.
- In a moderately preterm infant (32 weeks GA, BW 790 g) with severe intrauterine growth restriction secondary to gestational hypertension, echocardiography on day 28 showed LVEF 50%, LVFS 23%, and a normal LV output of 301 ml/kg/min.

Therapeutic management guided by Echocardiography and clinical outcome

In the present study, echocardiographic findings modified medical management in 23% of total cases and 58% of functional abnormalities.
Specific management of structural heart defects consisted of expectant management, except for one case of a clinically suspected Patau syndrome, who had a large ASD associated with VSD and severe PAH and was treated with IV furosemide. However, the fatal outcome on day 34 after birth was inevitable due to the underlying chromosomal abnormality. This infant was included because the diagnosis of Patau syndrome was only suspected after enrollment and subsequently confirmed during hospitalization. Echocardiographic evaluation had already been performed according to the study protocol before the diagnosis was established. The surviving newborn with VSD had no symptoms at one-month follow-up, with a stable size on cardiac ultrasound examination.
In the case of ASD, the clinical outcome was fatal in 4 cases, and the remaining 3 cases were referred to the pediatric cardiology department for further follow-up with no symptoms.
In the case of HCM, two had a fatal outcome secondary to severe hypoxic-ischemic encephalopathy, whereas the three surviving infants had favorable echocardiographic follow-up at one and three months with no symptoms.
Therapeutic management of our preterm infants with PPHN consisted of inhaled NO (iNO) alone in 3 cases with clinically high oxygen needs, leading to favorable clinical outcomes in 2 cases; sildenafil in addition to iNO in 1 case; and diuretics in 1 case. Three patients with hsPDA treated with acetaminophen had a favorable echocardiographic outcome by day 4–5.
In the other cases of PAH, a spontaneous decrease in pulmonary pressure was observed, with a favorable clinical outcome in 7 cases, whereas death occurred in 2 cases due to hospital-acquired neonatal infection.
In our study, twelve preterm infants had a fatal outcome, which corresponding to an overall mortality rate of 20%

The graphical distribution of therapeutic interventions following echocardiography is represented in Figure 3.

Figure 3 : Distribution of therapeutic interventions



DISCUSSION

In our epidemiological work, the main primary diagnosis at admission to the neonatology department was neonatal respiratory distress. Our results were concordant with those reported by El-Khuffash and Hernandez et al., where the most common primary diagnoses were prematurity and respiratory distress syndrome, in 77% and 26.6% of cases, respectively [8,9].
In our study, the most frequent indication was PDA assessment (n=24, 40%), consistent with findings reported by Khamkar, El-Khuffash, and Corredera, at 50%, 51%, and 58% of cases, respectively [8-10]. Hemodynamic instability, which accounted for only 5% of our scans, was the second most frequent indication, compared to 22.2% in Corredera's study [11], 25% in Khamkar's [12], and 53.3% in Hernandez-Benitez's [9] (with sepsis). PAH screening and evaluation of pulmonary hemodynamics represented 7% of our echocardiograms, a result similar to those of Khamkar [10,12] and Hernandez-Benitez [9], both reporting 6.6% of cases.
The differences observed between studies are probably multifactorial. First, the gestational age distribution differed substantially across cohorts, with some studies including a higher proportion of ex-

tremely preterm infants requiring advanced cardiovascular support. Second, indications for targeted neonatal echocardiography are influenced by local clinical protocols, availability of trained operators, and the timing of echocardiographic assessment. Finally, the absence of universally standardized indications for neonatal functional echocardiography may explain part of the variability reported in the literature. Chioukh et al., in a Tunisian Level III NICU, conducted the first national study over an approximately 2-year period [13]. It was a prospective observational study of 675 echocardiograms performed by neonatologists under the supervision of referent pediatric cardiologists. The main indications were heart murmur followed by cyanosis. A definite diagnosis of CHD was made in 80 cases, with ASD and VSD being the most frequently observed, in 25 and 24 cases, respectively.

Regarding cardiac dimensions, the measurements included LVEDD, LVESD, and thickness of the IVS and LV posterior wall. In our results, The median values were as follows: mean LVEDD = 11.5 [7.3–15.2] vs. 12.7 [7.3–17]; mean LVESD = 7.5 [4.5–10.6] vs. 8 [6.2–11]; mean IVSd = 3.2 [1.6–5.0] vs. 3.2 [2–6]; mean Aortic root = 5 [3.8–7.2] vs. 6 [4–8]. Skelton et al. observed similar findings in the same birth weight group at 7 days of life [14]. The overall agreement between our measurements and those reported by Skelton et al. supports the internal consistency of our echocardiographic dataset despite differences in study populations and examination timing. In that study, mean values compared to ours were: median IVSd = 2.75 [1.4–4.2] vs. 3.2 [2–6]; median LVEDD = 11.85 [7.2–15.7] vs. 12.7 [7.3–17]; median LVESD = 8.2 [4.0–11.6] vs. 8 [6.2–11]; median LVPW = 2.65 [1.7–3.7] vs. 2.9 [2–5]; median Aortic root = 6.85 [5.1–9] vs. 6 [4–8].

The slight differences between our measurements and those reported by Skelton et al. may be explained by several factors. First, our study included echocardiographic examinations performed over a wide postnatal age interval (7 hours to 30 days), whereas ventricular dimensions undergo rapid physiological adaptation during the neonatal period. Second, differences in gestational age, birth weight distribution, loading conditions, and respiratory support may influence ventricular dimensions and Doppler-derived indices. Third, interobserver variability and differences in echocardiographic equipment may also contribute to these discrepancies despite standardized acquisition protocols. Importantly, all measurements in our study were independently verified by an experienced pediatric cardiologist, which strengthened the reliability of the reported data.

Beyond their descriptive value, these echocardiographic measurements have important clinical implications. Parameters such as LVEDD, LVESD, ventricular wall thickness, aortic annulus diameter, VTI and left ventricular output provide objective information regarding myocardial performance, preload, systemic blood flow and cardiovascular adaptation. Their interpretation assists clinicians in distinguishing physiological transitional changes from pathological conditions such as myocardial dysfunction, significant ductal shunting or hypovolemia. Since normative echocardiographic data for North African preterm infants remain scarce, our results may provide preliminary local reference values while awaiting larger multicenter validation studies.

Analysis of our echocardiographic measurements also demonstrated a progressive increase in LVEDD, aortic annulus diameter and left ventricular output with increasing gestational age and birth weight, reflecting normal myocardial growth and cardiovascular maturation. By contrast, left ventricular systolic indices (LVEF and LVFS) remained relatively stable across gestational age groups, suggesting preservation of global systolic performance despite changes in cardiac dimensions. These observations reinforce the physiological relevance of the measurements presented in Tables 2 and 3 and support their potential usefulness for bedside interpretation in preterm infants. Subaortic VTI showed only limited variation across gestational age groups, indicating relatively preserved stroke distance during transitional circulation. Left ventricular output tended to increase with gestational maturity, consistent with the expected improvement in systemic perfusion during postnatal cardiovascular adaptation. Nevertheless, the wide range of LVO values observed in our cohort underscores that this parameter should always be interpreted in conjunction with clinical findings and other echocardiographic indices. Therefore, the measurements reported in Tables 2 and 3 should not be interpreted as definitive reference values but rather as preliminary observational data requiring confirmation in larger multicenter studies.

Functional abnormalities in our study were noted in 23 cases (38.33%), the most common being pulmonary hypertension. Our study also showed echocardiographic signs of hypovolemia in 6 cases. The assessment of preload on bedside echocardiography is performed by examining the LV, IVC, and the right heart, which can be reliably made through qualitative "eyeballing" in the A4C view. Quantitative assessment consists of measuring LV volumes and the IVCCI. To evaluate the correlation between echocardiographic IVC measurements and central venous pressure (CVP) in neonates, Mugloo M et al. conducted a cross-sectional analytical study over 2 years on 50 newborns. A strong negative linear correlation was observed between the IVCCI and CVP, while no correlation was observed between IVCCI and GA or BW [15]. These findings support the use of IVC assessment as a simple bedside marker of preload in neonates. Nevertheless, IVC-derived indices should always be interpreted together with the overall clinical examination and additional echocardiographic parameters, since they may be influenced by respiratory mechanics, intrathoracic pressure and mechanical ventilation.

PPHN is a syndrome characterized by sustained elevation of PVR with severe hypoxemia due to extrapulmonary shunting of deoxygenated blood right-to-left across the PDA and PFO. The etiology of PPHN in preterm infants is usually secondary to hypoxemic respiratory failure related to severe lung pathology soon after birth, such as hyaline membrane disease, or pulmonary hypoplasia caused by premature rupture of membranes or oligohydramnios [16,17].

In the present study, PAH was echocardiographically diagnosed in 13 preterm infants, accounting for 22% of cases. Nakanishi et al. reported 8.1% cases of PAH among 12,954 extremely preterm Japanese infants in a retrospective multicenter cohort study across 202 tertiary perinatal centers, with the annual increase mostly seen in infants born at 22–24 weeks gestation [18]. Moreover, Nakwan et al. reported an incidence ranging from 1.2 to 4.6 per 1000 live births through a retrospective chart review of patients with documented PPHN from seven centers in six Asian countries [19].

The higher prevalence observed in our cohort probably reflects the high proportion of infants admitted for severe respiratory disorders requiring ventilatory support. Furthermore, pulmonary hypertension was actively investigated using targeted echocardiography rather than relying solely on clinical suspicion, which may have increased its detection. Differences in gestational age, timing of assessment and diagnostic criteria probably also contributed to the variability observed across published studies.

Patent ductus arteriosus, a common complication of prematurity, is one of the daily dilemmas in the management of this population. Its incidence is inversely proportional to gestational age, with 80–90% prevalence in extremely low birth weight neonates born before 26 weeks of gestation [20,21]. Furthermore, rates of spontaneous closure in preterm infants during the first week of life are lower than in full-term infants [20,22]. In our study, the prevalence of PDA was 23.3%, while Soliman et al. [23] reported a 57.2% prevalence among preterm infants born before 34 weeks of gestation. In addition, PDA was mostly non-hemodynamically significant in 78.5% of cases, with hsPDA found in 21.5%—a much lower number than those reported in the literature.

Several factors may explain this lower prevalence. Our study included moderately preterm infants in addition to extremely preterm neonates, whereas many published cohorts focused almost exclusively on very low birth weight infants. Moreover, echocardiography was frequently performed after the first 72 hours of life, when spontaneous ductal closure may already have occurred in some infants. Finally, differences in echocardiographic definitions of hemodynamically significant PDA may also contribute to the observed variability.

Our results are in agreement with Khositseth et al. [24], who reported a prevalence of hsPDA of 29.3% among preterm infants, with non-hsPDA in 20.7%, and no PDA in 50%. The diagnosis of hsPDA in our study was based on clinical and echocardiographic criteria. Clinical criteria mainly included elevated oxygen demand with or without other suggestive signs such as heart murmur, hyperactive precordium, bounding pulses, and widened pulse pressure, associated with radiographic cardiomegaly or pulmonary vascular overload. Echocardiographic criteria focused on ductal characteristics (diameter, flow pattern, shunt direction) associated with high LA/AO ratio and high LV output [25,26]. Soliman et al. [23] used the following criteria to diagnose hsPDA: wide pulse pressure > 25 mmHg, hypotension (blood pressure below 3rd centile for gestational age), serum lactate > 4 mg/dl, pulmonary edema, or radiographic cardiomegaly. Ductal size ≥ 3 mm and LA/AO ratio > 1.5 were used as echocardiographic criteria in the same study.

These findings further emphasize that ductal diameter alone is insufficient for clinical decision-making. Current recommendations advocate a comprehensive echocardiographic evaluation integrating ductal characteristics, shunt direction, left heart volume loading and systemic perfusion parameters before considering treatment.

In the present study, echocardiographic findings modified medical management in 23% of cases, a lower figure compared to those reported by Khamkar [10], El-Khuffash [8], and Corredera [11], at 42%, 39.6%, and 36.9%, respectively. The most common changes in our series were hemodynamic, involving systemic circulation with volume expansion. In the studies conducted by Corredera [11] and Kumar [27], the most common modifications involved the management of PDA (18.6% and 26.4%, respectively), followed by hemodynamic support (10.8% and 8.6%, respectively). By contrast, El-Khuffash [8] reported guiding inotropic therapy as the most frequent intervention (23.4%), followed by treatment of PDA (20.7%), fluid administration (6.8%), and iNO (6%). The lower therapeutic impact observed in our study probably reflects differences in case-mix and local clinical practice. A considerable proportion of our examinations confirmed normal cardiovascular adaptation or identified abnormalities requiring close monitoring rather than immediate intervention. In addition, resource limitations and differences in therapeutic strategies may have reduced the frequency of treatment modifications. Nevertheless, even when no therapeutic change was made, functional echocardiography contributed to clinical decision-making by excluding significant cardiovascular pathology, avoiding unnecessary treatments and improving clinicians' confidence in patient management.

Overall, our findings support the growing role of targeted neonatal echocardiography as an extension of clinical examination in preterm infants. Beyond the diagnosis of congenital heart disease, it pro-

vides real-time assessment of cardiovascular physiology and facilitates individualized hemodynamic management. In countries with limited resources such as Tunisia, the implementation of standardized training programs and close multidisciplinary cooperation are essential to optimize the clinical impact of this technique.
Although therapeutic management was modified in only 23% of patients, functional echocardiography had a broader clinical impact than suggested by this figure alone. In many infants, it confirmed normal cardiovascular adaptation, excluded significant structural or functional abnormalities and therefore avoided unnecessary pharmacological interventions. This diagnostic reassurance represents an important clinical benefit that is often underestimated when only therapeutic changes are considered.

STUDY LIMITATIONS

This study has several limitations. First, it was a single-center study with a relatively small sample size, which limits the generalizability of our findings. Second, echocardiographic examinations were performed over a wide postnatal age range during the transitional circulation period, potentially influencing physiological measurements. Third, despite independent review by an experienced pediatric cardiologist, echocardiography remains an operator-dependent technique. Finally, because normative echocardiographic data for preterm infants remain limited, particularly in North African populations, our measurements should be interpreted as preliminary observational data rather than definitive reference values.

CONCLUSIONS

This prospective study demonstrates that functional echocardiography provides clinically relevant information beyond routine clinical examination in preterm infants admitted to the NICU. It not only facilitates the diagnosis of structural cardiac abnormalities but also allows early identification of functional disorders such as pulmonary hypertension, hemodynamically significant patent ductus arteriosus, hypovolemia and ventricular dysfunction, thereby supporting individualized therapeutic decisions. The systematic verification of echocardiographic measurements by a pediatric cardiologist reinforces the reliability of the reported data. Although our cohort was limited, the echocardiographic measurements presented may constitute preliminary reference data for Tunisian preterm infants and could assist clinicians in daily practice. Future multicenter studies involving larger cohorts are required to validate these findings, establish regional reference values and further define the clinical role of targeted neonatal echocardiography in resource-limited settings.

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