

Pulse Oximetry Screening at 4 Hours of Age to Detect Critical Congenital Heart Defects

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What's Known on This Subject

POx has been advocated by some investigators as a useful tool for detecting congenital heart disease. Others have indicated that additional large studies are needed.

What This Study Adds

This is the largest single-center study in which screening with POx was performed. Screening at 4 hours of age was performed. Our study indicates that such screening does not detect CCHDs over and above clinical assessment.

ABSTRACT

OBJECTIVE. The purpose of this prospective study was to assess the feasibility and reliability of pulse oximetry screening to detect critical congenital heart defects in a newborn nursery.

METHODS. The study was performed in a large urban hospital with an exclusively inborn population. Stable neonates who had a gestational age of ≥ 35 weeks and birth weight of ≥ 2100 g and in whom a critical congenital heart defect was not suspected were admitted to the newborn nursery. When the 4-hour pulse oximetry reading was $<96\%$, pulse oximetry was repeated at discharge, and when the pulse oximetry reading remained at persistently $<96\%$, echocardiography was performed.

RESULTS. Of 15 299 admissions to newborn nursery during the 12-month study period, 15 233 (99.6%) neonates were screened with 4-hour pulse oximetry. Pulse oximetry readings were $\geq 96\%$ for 14 374 (94.4%) neonates; 77 were subsequently evaluated before discharge for cardiac defects on the basis of clinical examination. Seventy-six were normal, and 1 had tetralogy of Fallot with discontinuous pulmonary arteries. Pulse oximetry readings at 4 hours were $<96\%$ in 859 (5.6%); 768 were rescreened at discharge, and 767 neonates had a pulse oximetry reading at $\geq 96\%$. One neonate had persistently low pulse oximetry at discharge; echocardiography was normal. Although 3 neonates with a critical congenital heart defect had a 4-hour pulse oximetry reading of $<96\%$, all developed signs and/or symptoms of a cardiac defect and received a diagnosis on the basis of clinical findings, not screening results.

CONCLUSIONS. All neonates with a critical congenital heart defect were detected clinically, and no cases of critical congenital heart defect were detected by pulse oximetry screening. These results indicate that pulse oximetry screening does not improve detection of critical congenital heart defects above and beyond clinical observation and assessment. Our findings do not support a recommendation for routine pulse oximetry screening in seemingly healthy neonates. *Pediatrics* 2008;122:e815–e820

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Key Words

pulse oximetry, newborn, congenital heart disease, screening

Abbreviations

CCHD—critical congenital heart defect

POx—pulse oximetry

NBN—newborn nursery

PHHS—Parkland Health and Hospital System

AABR—automated auditory brainstem response

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CONGENITAL CARDIOVASCULAR MALFORMATIONS are the most common category of birth defects, occurring in 6.6 to 8.1 per 1000 live births.^{1,2} Approximately 25% of these lesions are associated with cyanosis; untreated, they lead to significant morbidity and mortality. Lesions that traditionally have been considered noncyanotic but involving impairment of left ventricular development or outflow also can result in poor outcomes when not recognized before hospital discharge. Although many lesions are diagnosed antenatally by ultrasonography,³ serious and potentially lethal critical congenital heart defects (CCHDs) may not be apparent on prenatal ultrasound, on subsequent physical examination after birth, or on follow-up after discharge.⁴ When detected early, CCHDs are either cured or ameliorated by surgery in the vast majority of cases; therefore, a universal screening test for CCHD would be beneficial if it were demonstrated to have acceptable sensitivity and specificity and to offer information that could not be provided by routine examination and observation.⁵

Several published studies have suggested that performing pulse oximetry (POx) on all newborns before hospital discharge is an effective screening tool for detection of CCHD,^{5–14} and parents' groups have advocated routine screening.¹⁵ Reich et al⁶ screened 2114 neonates for cyanotic congenital heart defects with POx and found 99.9%

specificity. Koppel et al⁷ screened 11 281 asymptomatic neonates with POx and reported a sensitivity of 60% and a specificity of 99.9%. Information regarding these and other studies was reported in meta-analyses by Thangaratnam et al¹⁶ and Valmari.¹⁷ Although not a study of POx screening, Aamir et al¹⁸ confirmed that a significant number of cases of CCHD were missed in New Jersey, and these investigators speculated that routine POx would have detected most of these neonates.

In contrast, the Tennessee Task Force on Screening Newborn Infants for Critical Congenital Heart Disease¹⁹ concluded that mandatory POx screening should not be implemented until a large prospective study is performed and the sensitivity and false-positive rates of POx in the asymptomatic newborn population is better defined. Knowles et al⁵ systematically reviewed this issue in the United Kingdom and concluded that additional evaluation of all forms of screening for congenital heart defects is needed before large-scale implementation of screening programs. A similar concern was raised in the meta-analysis by Valmari.¹⁷

Previous studies have varied widely, in both timing of POx screening and inclusion of other clinical factors in combination with POx screening. The American Academy of Pediatrics recommends careful observation during stabilization and transition of the neonate but has not issued a formal opinion on the use of POx as a screening tool.²⁰ Because several studies have determined that normal oxygen saturation in the first few hours of life in the term newborn is $\geq 96\%$,^{21,22} 4 hours after delivery may be a suitable and optimal time to perform POx screening. The purpose of this study was to determine whether routine POx screening at 4 hours of age, with rescreening before discharge as needed, is feasible and effective for detecting clinically silent CCHD.

METHODS

The study population consisted of term and late preterm neonates who were admitted from March 1, 2006, through February 28, 2007, to the newborn nursery (NBN) of a large public hospital (Parkland Health and Hospital System [PHHS]) in Dallas, Texas, that serves a primarily indigent Hispanic population. After delivery, stable neonates who did not have major malformations, weighed ≥ 2100 g, and were ≥ 35 weeks' gestation were triaged to the NBN. Neonates who met the birth weight and gestational age criteria but were initially triaged to the NICU were transferred to the NBN if stable at 4 hours of age. Neonates who were directly admitted to the NBN were monitored in an observation area for ~ 4 hours, per our routine, and then underwent routine hearing screening by use of automated auditory brainstem response testing (AABR) before transfer to either the mother's room or another room within NBN. Neonates transferred from the NICU to the NBN underwent AABR shortly after arrival. The average length of maternal and newborn hospitalization for the screened population was 2.2 days, and the minimum stay for all neonates is 36 hours.

We elected to perform POx screening immediately after AABR screening. POx was measured with the Nell-

cor N-395 (Boulder, CO) pulse oximeter by trained technicians who were not involved with direct patient care. Probes were held manually on either foot without the use of Velcro straps, and results were recorded once a consistent pulse wave form was established. When the POx reading was $<96\%$ or an adequate wave form was not acquired, probes were repositioned and warm blankets were applied to the feet to increase perfusion to the extremities; when a different result was obtained, the higher value was recorded. For assessment of the natural history of neonates who might be evaluated for cardiac disease as a result of clinical signs or symptoms, patient care providers were blinded to POx results. Neonates who were transferred to a higher level of care from the observation area were excluded from screening because POx monitoring was required for their clinical care.

We defined CCHD as lesions that include cyanotic defects such as tetralogy of Fallot, pulmonary atresia, truncus arteriosus, transposition of the great vessels, total anomalous pulmonary venous return, and tricuspid atresia, as well as left-sided obstructive lesions, including coarctation of the aorta, critical aortic stenosis, interrupted aortic arch, and hypoplastic left heart syndrome. Neonates who developed signs or symptoms suggestive of a cardiac defect during their hospitalization were evaluated according to our standard practice. This included a 15-lead electrocardiogram, chest radiograph, 4-extremity blood pressures, and POx. Echocardiography was performed when deemed appropriate by the consulting cardiologist. All providers remained blinded to the 4-hour POx screening results for neonates for whom a cardiac evaluation was performed.

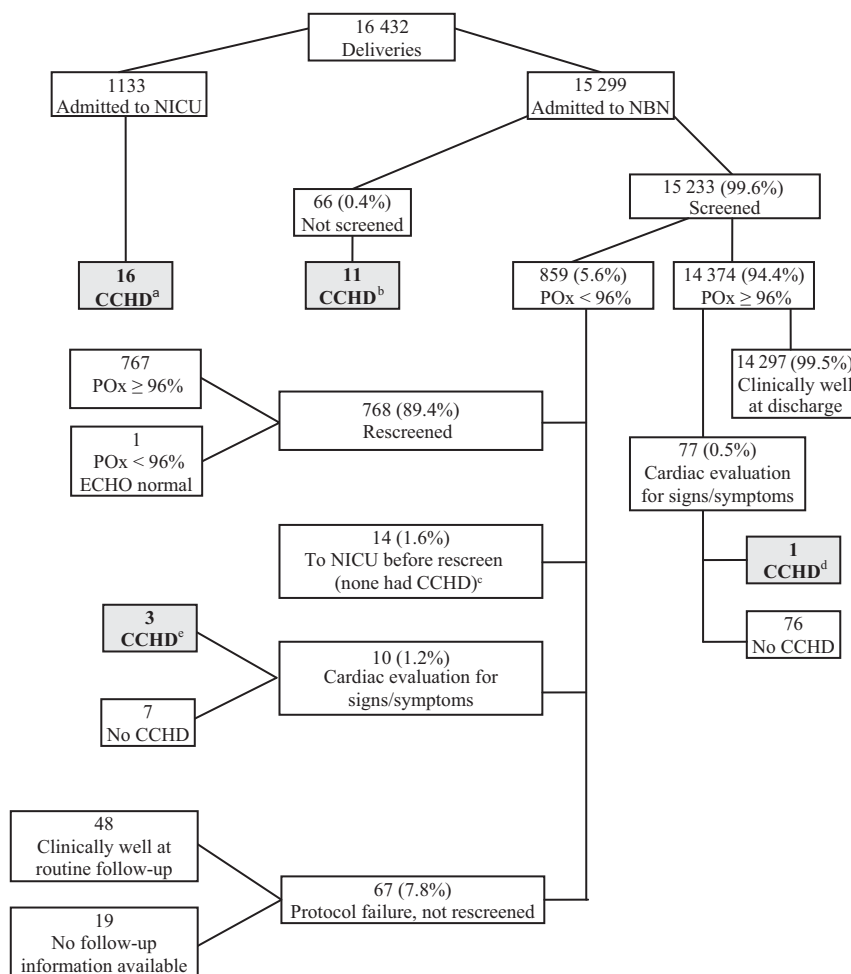
On the day of discharge, the 4-hour POx result was made available to the provider. A POx result of $\geq 96\%$ was considered normal and was not repeated. For neonates who failed to achieve $\geq 96\%$ on the 4-hour screen, a follow-up POx reading was performed by either the nursing staff or the medical provider by using the procedure described above. When the discharge POx reading was $<96\%$, echocardiography was performed.

Medical charts were reviewed for all neonates who were transferred to the NICU before 4 hours of age and for those who were admitted directly to the NICU and received a diagnosis of CCHD. Information regarding clinic attendance after discharge was collected on protocol failures (neonates with initial POx $<96\%$ but missed rescreening at discharge). Sensitivity and specificity were calculated for POx screening by using (1) only the 4-hour results and (2) the 4-hour results in combination with the discharge POx (when performed).

Before study initiation, we made the following assumptions: (1) an anticipated minimum incidence of 1.7 cases of CCHD per 1000 live births (assuming that $\sim 25\%$ of 6.6 per 1000 congenital cardiovascular malformations are cyanotic¹); (2) 0.5 per 1000 diagnosed prenatally or by symptoms in the newborn period; (3) a screening sensitivity of 60%⁷; and (4) 16 000 admissions to the NICU and NBN during a 12-month period. On the basis of these assumptions, we anticipated that 28 neonates with CCHD would be born at PHHS during the 12-month study period and that 11 to 12 of these (~ 1 per

FIGURE 1

POx screening outcomes during the 12-month study period. ^aPatients 1 to 16 (Table 1); ^bpatients 17 to 27 (Table 1), clinically decompensated before screening and transferred to the NICU; ^cexamples of transfer diagnoses included pneumonia, sepsis, transient tachypnea of the newborn, apnea, and seizures; ^dpatient 28 (Table 1); ^epatients 29 to 31 (Table 1). ECHO indicates echocardiography.



1400 neonates admitted to the NBN) would be detected by screening. This study was approved by the institutional review board at UT Southwestern Medical Center, and informed consent was waived.

RESULTS

During the study period, 16 432 neonates were born at PHHS, and 1133 were admitted directly to the NICU and not subsequently triaged to the NBN (Fig 1). For 16 of these neonates, CCHD was suspected at delivery, 12 of whom had an abnormal prenatal sonogram (Table 1). A total of 15 053 neonates were directly admitted to the NBN from the delivery room; an additional 246 neonates were transferred from the NICU after a 4-hour observation period. Of these 15 299 neonates, 66 (0.4%) were not screened primarily because of respiratory distress and/or cyanosis before 4 hours of age; 11 of these were transferred to the NICU and received a diagnosis of CCHD. A total of 15 233 (99.6%) were screened with POx at 4 hours of life. For 14 374 (94.4%), POx was $\geq 96\%$. Seventy-seven of the neonates with normal 4-hour POx underwent cardiac evaluation for clinical signs, and 1 of these neonates had CCHD (Fig 1; patient 28 in Table 1).

A total of 859 (5.6% of neonates screened) infants

had an initial POx reading of $<96\%$ (Fig 1). Of these, 768 (89.4%) were rescreened before discharge; 767 (99.9%) of 768 had normal POx. One neonate had a rescreen POx $<96\%$, and the echocardiogram was normal. Fourteen neonates were transferred to the NICU before rescreening for reasons other than a suspected cardiac defect, and none received a diagnosis of CCHD. Ten of the 859 neonates who failed 4-hour screening were evaluated for a heart defect before discharge on the basis of clinical signs. Three of these 10 neonates had CCHD (Table 1), and 4-hour screening POx results ranged from 83% to 93%; the other 7 did not have CCHD, and POx during cardiac evaluation was $\geq 96\%$. Sixty-seven (7.8%) neonates who failed the initial screening did not have a discharge POx result obtained as specified in the study protocol. Forty-eight were seen on subsequent clinic visits and were considered to be healthy. Follow-up information was unavailable for the other 19 (0.1% of the original population and 2.2% of those who failed the initial screening).

Considering only the initial 4-hour POx screening, sensitivity was 0.75 and specificity was 0.94. Of 859 neonates with abnormal POx screening results, 3 had CCHD (clinically apparent soon after the 4-hour POx screening) and 856 were false-positive screens. When

TABLE 1 Neonates Who Received a Diagnosis of CCHD

Patient	Birth Weight, g	Gestational Age, wk	Gender	POx, % ^a	Diagnosis
Neonates admitted directly to the NICU					
1	3195	37	M	90	PA, tricuspid atresia
2	2728	33	M	78	D-TGV, restrictive ASD
3	3230	39	M	70	D-TGV, ASD, VSD
4	1565	36	M	86	TOF, VSD, PA
5	3635	36	M	92	D-TGV, DORV
6	698	28	F	88	TOF, VSD
7 ^b	3270	38	F	95	HLHS
8	3615	37	M	68	DILV, Coarc, L-TGV
9	4563	39	M	96	HLHS
10	3488	37	F	93	AVSD, D-TGV
11 ^b	955	28	M	98	TOF
12 ^b	3230	43	M	42	AVSD, L-loop DORV, PS
13	3825	39	M	75	TGV, VSD
14	3065	39	M	92	HLHS
15	3655	37	F	84	AVSD, TAPVR
16 ^b	2910	35	M	82	TAPVR, ASD, Coarc
Neonates transferred from the NBN to NICU					
17	3965	39	M	88	L-looped ventricle, PA
18	2680	41	F	82	TOF, VSD, PA
19	3825	42	M	60	D-TGV
20	2525	39	M	91	TOF, VSD
21	3100	40	M	89	TOF with PA, ASD
22	3065	40	F	77	HLHS variant
23	3900	41	F	78	TOF, ASD, PS
24	3750	40	M	52	D-TGV
25	2590	40	M	94	PA, VSD
26	2560	40	F	73	DILV, HYPO RV, VSD
27	2995	38	M	85	D-TGV, VSD, Coarc
28	2970	39	F	97 (97)	TOF with discontinuous pulmonary arteries
29	4260	41	F	78 (87)	PS, PDA, PFO
30	4290	41	M	83 (94)	HLHS
31 ^c	3135	38	F	94 (93)	Moderate PDA, small VSD, subvalvular and PS (Down syndrome)

PA indicates pulmonary atresia; ASD, atrial septal defect; D-TGV, dextro-transposition of the great vessels; VSD, ventricular septal defect; TOF, tetralogy of Fallot; DORV, double-outlet right ventricle; HLHS, hypoplastic left heart syndrome; DILV, double-inlet left ventricle; AVSD, atrial ventricular septal defect; Coarc, coarctation of the aorta; TAPVR, total anomalous pulmonary venous return; PS, pulmonary stenosis; HYPO RV, hypoplastic right ventricle; PDA, patent ductus arteriosus; PFO, patent foramen ovale.

^a Most of the POx values were obtained during workup before 4 hours of age; when a 4-hour screening value was obtained, it is the value in parentheses.

^b Not diagnosed by prenatal ultrasound.

^c Remained in the NBN.

considering both the initial 4-hour POx screening coupled with the repeat POx screening at discharge (for neonates for whom both POx results were available), sensitivity was 0.00 and specificity was 0.99. Of 15 141 neonates with a negative screening result, 1 had CCHD.

Thirty-one neonates received a diagnosis of CCHD during the study period (1.9 cases per 1000 live-born neonates). Sixteen were admitted directly to the NICU, and 15 were initially admitted to the NBN (Table 1). Although 3 of these 15 neonates had 4-hour POx <96%, they all developed signs and symptoms of heart disease and received a diagnosis on the basis of clinical findings before discharge. No neonate received a diagnosis of CCHD on the basis of screening.

DISCUSSION

Since publication of several large studies that used POx to screen for congenital heart defects in the newborn, POx screening has generated considerable interest

among patient care providers and parents' groups.⁵⁻¹⁵ These studies suggested that POx screening is feasible, cost-effective, and useful in the detection of cardiac lesions that might otherwise have been missed. In general, these investigators focused on "critical" or "significant" heart defects and included neonates with cyanotic defects and left-sided obstructive lesions, as noted in "Methods."

In contrast, the systematic review and cost-effectiveness analysis performed by Knowles et al⁵ concluded that additional research is required to define the role of POx in screening for CCHD and that the potential negative psychosocial effects of newborn screening for congenital heart defects deserve additional investigation. Similarly, the Report of the Tennessee Task Force on Screening Newborn Infants for Critical Congenital Heart Disease questioned the utility of oximetry screening because of (1) the unclear false-positive rates of a screening program, (2) the questionable reliability of current

oximeter technology in the asymptomatic population, and (3) the inability to generate a reasonable cost/benefit estimate.¹⁹ It is important to note that this task force considered that left-sided obstructive cardiac lesions (eg, aortic stenosis, coarctation of the aorta [~ 1 in 1000 live births]) were the primary potential targets for a screening program, because “cyanotic lesions typically present with severe cyanosis recognized very early, a murmur, or cyanosis that is well tolerated.” Neonates with left-sided obstructive lesions typically seem clinically well until the ductus arteriosus closes, at which time systemic blood flow is severely compromised. Because ductal flow before closure in these lesions is a mixture of poorly oxygenated and well-oxygenated blood, one might expect subtle decreases in lower extremity POx; however, Liske et al¹⁹ noted that higher pulmonary/systemic flow ratios associated with decreasing pulmonary vascular resistance after birth may lead to false-negative POx results. This suggests that if POx screening were implemented, then 4 hours may be an optimal time to screen neonates in whom increases in pulmonary blood flow that might affect the POx results have not yet occurred.

In this study, we found that neonates with CCHD were or would have been detected clinically within several hours of birth. Twenty-seven neonates with CCHD were detected as a result of prenatal ultrasound abnormalities or clinical cyanosis and/or murmur before the 4-hour POx screening. Three of the other 4 patients with CCHD had 4-hour POx values below our cutoff value of 96% (sensitivity: 0.75). One of these 3 neonates had Down syndrome, and he would have undergone cardiac echocardiography as part of his routine evaluation. The other 2 were noted to have clinically apparent cyanosis soon after the 4-hour screening, the results of which were unknown to providers. The fourth neonate with CCHD had a screening POx $\geq 96\%$ and was detected as a result of signs of heart disease.

One limitation of this study is the lack of extended follow-up data, both for neonates with a normal 4-hour POx screening and for neonates who were protocol failures. Although the incidence of CCHD in our study corresponds closely to published incidence (1.9 per 1000 inborn neonates), we do not have definitive follow-up information on each neonate. If some neonates were missed by POx screening, then this would further underscore the lack of utility for such screening. The state of Texas maintains a Birth Defects Registry linking birth certificate data to subsequently diagnosed birth defects. The time between data collection, analysis, and availability of registry information is 3 to 4 years. We plan on determining whether any cases of CCHD were missed during the study period as soon as registry data are available.

Another potential limitation is that we did not evaluate POx in both the upper and lower extremities, which may be a concern in the detection of transposition of the great vessels; however, as noted, neonates with this type of CCHD will manifest clinically. It is noteworthy that we did not identify any patient with isolated coarctation of the aorta or isolated total (or partial)

anomalous pulmonary venous return. This study may not have a significant number of patients to state definitively whether these defects are amenable to detection by POx.

This study represents the largest single-center study of POx screening to date, and the results indicate that POx screening is not an effective strategy to detect CCHD in seemingly healthy neonates. We demonstrated that POx screening does not increase identification of CCHD above and beyond a complete physical examination, close clinical observation, and prenatal ultrasound. Although POx screening at 4 hours is feasible and can be done with minimal additional time expenditure, we did not detect a single patient with CCHD solely by POx screening. Furthermore, the false-positive rate (5.6%) in this study raises the concern that additional evaluation and observation will generate economic costs (eg, echocardiogram expense). POx screening might identify self-limited problems such as transient pulmonary artery hypertension, generating additional concern and intervention. Other reasons for avoiding adoption of routine POx without adequate clinical evidence include a false sense of assurance, additional reliance of clinicians on technology rather than physical examination skills, and potential medicolegal complications. In addition, we share the concerns of Knowles et al⁵ regarding potential for harm as a result of separation of mother and infant and to a parent's lingering perception that his or her infant is vulnerable.²³

CONCLUSIONS

Our failure to identify any neonate with CCHD by POx screening alone suggests that this intervention has limitations in the detection of CCHD when prenatal ultrasound, close clinical observation during the transitional period, and thorough physical examination are used. This study does not support recommending routine POx screening in seemingly healthy neonates.

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