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It Is Time for Routine Neonatal Screening by Pulse Oximetry

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Key Words
Pulse oximetry · Critical congenital heart disease · Neonatal screening tests · Cost-benefit analysis

Abstract
Most pediatric cardiologists believe that pulse oximetry helps to diagnose critical congenital heart disease in neonates who might otherwise be discharged from the newborn nursery undiagnosed. Some of these patients develop catastrophic cardiac and multi-system failure after the ductus closes and die or suffer severe morbidity. Nevertheless, pulse oximetry is not universally used in the newborn nursery. Some pediatricians believe that they can always detect these patients from physical findings, many believe that oximeters are unreliable, and others are concerned about costs of investigating false positive tests. Recent studies, however, show that even cardiologists miss critical congenital heart defects, modern oximeters are stable and reliable, and that the false positive rate is very low, lower than the false positive rate based on physical examination. The benefits probably exceed the cost, and evidence is provided to confirm this. There is no reason not to use pulse oximetry routinely in the newborn nursery.

Introduction

Congenital heart defects (CHD) are among the most common major congenital anomalies, and they occur worldwide with an incidence of about 8–12/1,000 live births [1] (this figure excludes bicuspid aortic valves and trivial lesions such as small atrial or ventricular septal defects). Most of these defects are mild or moderate. They either do not need treatment or treatment is needed only after infancy. Other defects are severe and require early treatment in infancy, often in the neonatal period; patients needing treatment in the neonatal period are often defined as having critical CHD (CCHD).

Many of these defects are ductus dependent, and because the ductus arteriosus may not close until after the infant has left the newborn nursery, the diagnosis may not be made in hospital. In the US, most full-term newborn infants leave the nursery 36–48 h after normal vaginal delivery, and 3–4 days after delivery by cesarean section. A well-known example of delayed onset of critical heart disease is the neonate without signs or symptoms who goes home, and returns a week later with shock and heart failure due to a tight coarctation of the aorta. Even though the treatment of the defect may be the same whether diagnosed early or late, the consequences of delaying treatment until the infant becomes critically ill are often higher operative mortality, much longer stay in the intensive care unit, and higher incidence of serious complications such as neurological dysfunction [2–6]. A pre-

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Table 1. Missed or undiagnosed critical congenital heart disease

First author	Years	CCHD				Missed CCHD		
		live born		/1,000 live births	deaths	n	% CCHD	% deaths
		prenatal Dx	postnatal Dx					
Aamir [19]	1999–2004	18	94	0.2	–	47	50	–
Abu-Harb [22]	1985–1990	–	–	–	185	56	–	30
Brown [4]	1999–2002	56	230[1]	–	–	73	32	–
Chang [21]	1989–2004	–	–	–	898	152	–	17
de Wahl-Granelli [6]	2004–2007	2	60[2, 3]	1.3		19	32	
		9	109[4]	1.0		28	28	
Koppel [16]	1989–1999	9	11	1.8		3	27	
Kuehl [20]	1981–1989	–	4,390	–	800	76		9.5
Liske [17]	2000–2002	–	62[5]	2.78	–	15	25	–
			110[6]	–		–	–	
Meberg [23]	2005–2006	31	50[7]	1.2	–	6	12	–
		7	48[8]			11	23	
Mellander [24]	1993–2001	–	259[9]	–	–	51	20	–
Schultz [25]	2000–2003	31	45[10]	–	–	12	27	–
Wren [15]	1985–2004	55	614	0.97	–	198	32	15[11]

The numbers of live-born infants with CCHD detected by fetal echocardiography were excluded from the denominator used to estimate the percentage of missed diagnoses. Some additional data and smaller series are listed in table 3 in Mahle et al. [31].

[1] Defined as needing neonatal intervention; [2] West Götaland screened; [3] duct dependent; [4] other referral hospitals in the region without screening; [5] ductus dependent systemic circulation; [6] cyanotic heart disease; [7] postnatal diagnosis, screening; [8] postnatal diagnosis, no screening; [9] defined as needing early intervention; [10] defined as significant physiologic compromise; [11] percent missed CCHD diagnosed after death.

mium is therefore placed on diagnosing all severe CHD before the patients leave the nursery, but this is often not possible. In theory, such defects could be detected by fetal ultrasound that is becoming universally performed, but unfortunately at present fetal ultrasound detects <50% [7–10] (see also table 1).

Causes of Missed Diagnosis

Many newborn infants with CCHD are diagnosed while in the nursery because of symptoms, abnormal murmurs or cyanosis. Murmurs are often nonspecific, and indeed most newborn infants have some type of murmur. Furthermore, about half the neonates in the nursery who have CHD have no distinctive murmur [11]. This applies particularly to the common ductus-dependent defects such as coarctation of the aorta, interrupted aortic arch, hypoplastic left heart syndrome, d-transposition of the great arteries, and also to total anomalous pulmonary venous connection. Even if there is a ventricular septal defect, as in an interrupted aortic arch, the high postnatal pulmonary vascular resistance minimizes the left-to-right shunt that, passing through a large defect, produces little or no murmur. Cyanosis may be difficult to detect if desaturation is mild, lighting is inadequate, or the skin color is dark [12, 13]. In fact, in a major Swedish study, d-transposition of the great arteries was often missed without oximetry [6]. As a result of these problems, in an excellent unit in the UK, 30–50% of children with CHD left the nursery undiagnosed [11, 14, 15].

Magnitude of the Problem

About 25–40% of CHD have been estimated to cause early severe heart disease [1, 3, 16, 17], and most of these severe lesions are ductus dependent. The risks for specific lesions are discussed in detail by Hoffman [18].

How frequently is CCHD missed in newborn nurseries? This number must vary by place, time, and the expertise of the staff caring for the neonates. Data collection is

Table 2. Data from selected studies on unrecognized critical CHD found by screening

Ductus-dependent systemic circulation		Right-to-left shunts, some with ductus-dependent pulmonic circulation	
Coarctation of the aorta	138[1]	d-TGA[2]	49[1]
Interrupted aortic arch	14[1]	Truncus arteriosus	27
Aortic stenosis	41[1]	Tetralogy of Fallot[3]	8
Hypoplastic left heart	84[1]	TAPVC[3]	25[1]
Miscellaneous	21	Miscellaneous[3]	15
Total	298		124

d-TGA = d-Transposition of the great arteries; TAPVC = total anomalous pulmonary venous connection.

[1] Benefit by early treatment.

[2] Ductus closure affects entry of desaturated blood into the pulmonary circulation.

[3] Only some ductus dependent.

Table 3. Mandated chemical screening tests in California

Disease	Incidence
Hemoglobinopathy	1/2,000
Cystic fibrosis	1/2,000
Hypothyroidism	1/4,000
Phenylketonuria	1/10,000
Adrenal hyperplasia	1/12,000
MCAD deficiency	1/17,000
Galactosemia	1/50,000
Biotidinase deficiency	1/100,000
Tyrosinemia	1/100,000
Homocystinuria	1/150,000
Maple syrup urine disease	1/180,000
Miscellaneous amino acid, fatty acid, organic acid, and lysosomal abnormalities	1/50,000 to <1/100,000

MCAD = Medium-chain acyl-CoA dehydrogenase. Incidence data are taken from standard texts.

inconsistent, and there are several ways of making these estimates:

(1) Examine records of birth certificates and hospital discharge and readmission records [19].
(2) Examine records of deaths from CHD and establish how many were undiagnosed [20, 21].
(3) Collect all patients with CHD over a given period and determine how many had CCHD or died, and how many were missed (whether they survived or not) [15, 16, 22, 23].
(4) Report numbers of patients with CCHD (some differences in definition) and determine how many were missed [6, 24, 25].

Some of the larger patient series reporting missed diagnoses are given in table 1.

Despite considerable variation in the way data were gathered, it appears that about 30% (range 13–48%) of patients with CCHD may leave hospital undiagnosed. Using a figure for total CHD incidence of 1%, there will be 10,000 with CHD per million live births, about 4,000 with severe or CCHD, and therefore 1,200 (range 520–1,920) with missed CCHD.

The types of CCHD that were missed in the absence of oximetry screening are presented in table 2 [5, 6, 16, 19, 20, 22, 24–28].

Ductus-dependent systemic circulation predominates. The numbers with tetralogy of Fallot are low because most patients with this defect do not have a right-to-left shunt in the neonatal period or are detected because of a prominent murmur. Two items in this list were surprising to me. One was the high number with transposition of the great arteries, but as many of these were reported from excellent institutions I have to accept that some of these patients have a high enough ductus flow immediately after birth that cyanosis is not conspicuous. The other was that I had not considered previously that even before they presented clinically, neonates with severe coarctation of the aorta might have a right-to-left shunt.

Data from the large study by Mellander and Sunnegardh [24] showed that at 2 days of age (by which time most infants in the US have been discharged from the nursery), 75% of those with a ductus-dependent pulmonary circulation and 60% of those with a ductus-dependent systemic circulation or other right-to-left shunt had not been diagnosed. Furthermore, for those with a ductus-dependent systemic circulation, 75% with coarctation of the aorta, 45% with interrupted aortic arch, 40% with aortic stenosis, and 25% with hypoplastic left heart syndrome were undiagnosed at 2 days. Similar data were presented by Wren et al. [14, 15] and by Knowles et al. [3]. The high incidence of coarctation of the aorta and its late presentation make it the most important lesion in this group.

Oximetry Performance and Standards

There are differences between different brands of oximeters, different software versions for each oximeter, and sometimes between the results from different insti-

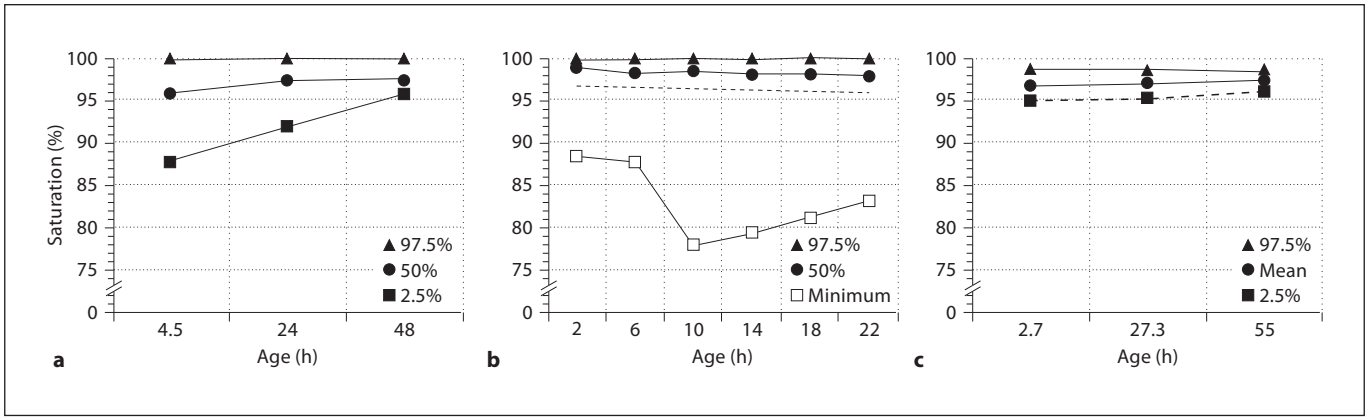

Fig. 1. Normal oxygen saturations in newborns under 60 h of age. At each age, the times are averaged over a few hours. **a** Data from Hoke et al. [33], using a Nellcor 50 pulse oximeter, showing 97.5th, 50th (median) and 2.5th percentiles of 2,876 healthy newborns. **b** Data from O'Brien et al. [32], using a modified Nellcor 200 pulse oximeter, in 90 healthy infants, showing maximal, median, and minimal saturations in the absence of apneic spells. It is not possible to derive the 2.5th percentile from their data, but the dashed line is an approximation. **c** Data from Levesque et al. [34], using a Novametrix Oxypleth pulse oximeter, in 718 healthy newborns showing 97.5th percentile, mean, and approximate 2.5th percentile based on standard deviation.

tutions using the same oximeter and software version [29, 30]. Nevertheless, with modern oximeters these differences rarely exceed 3% saturation, and provided that each institution derives its own normal standards, all modern oximeters will provide useful information. The probes should be placed on a foot to record post-ductus oxygen saturation. The child should be awake but not struggling, and should have regular breathing. The recording should be stable for at least 2 min, and accurate recording of the heart rate verifies correct function of the oximeter. Bilirubinemia or dark skin pigmentation has no affect on oximetry results if saturations are over 90% [31]. Nurses, technicians, or residents who have been well trained can perform the pulse oximetry.

Formal studies of normal oxygen saturations soon after birth (fig. 1) [32–34] show that saturations are fairly stable over the first 48 h with a slight tendency to rise after 12–24 h after birth.

The episodic minimal saturations recorded by O'Brien et al. [32] were detected on continuous recordings. They were not associated with any particular patient, and were often but not always associated with short episodes of apnea. Their oximeter was an older model, and de Wahl-Granelli et al. [35] who compared an older with a newer oximeter observed minimal saturations of 94% with the newer but 68% with the older oximeter. All the values shown in figure 1 are slightly higher than those obtained in 1991 by Dimich et al. [36] who found that in 100 newborns the oxygen saturation at 24 h had a mean of 95.2% and a standard deviation of 2.3%.

Different institutions have used a cutoff value for the lower limit of normal saturation between 92 and 96% [37], with most using 95%. In one large study, Meberg et al. [28] in Norway used a value of 95% saturation in the foot as the 2.5th percentile based on data from another 1,000 healthy newborns. In another study, de Wahl-Granelli et al. [35] in Sweden found a 2.5th percentile of 95% in 156 healthy newborns. The value of 95% was also used as a cutoff by other investigators [26, 27, 38–40]. A lower cutoff will be needed for children born at high altitude. At an altitude of 1,610 m above sea level (Denver and Taif City, Saudi Arabia), oxygen saturations averaged 92–95% in the first 2 days [41, 42], and mean values of 91–94% were observed in infants born 3,100–3,685 m above sea level in Leadville and Lhasa [43, 44].

Some investigators have placed a probe on the right hand as well so as to determine any difference, and regard a difference of >3% as abnormal [33, 35, 39]. Using two probes can avoid an error in the rare instances of a transposition with a large ductus arteriosus in which the leg saturation may exceed 95%, or even more rarely with a coarctation or interrupted aortic arch in which the arm saturation is 99% and the leg saturation is 95%. In one study in Sweden, there were 2 patients whose diagnosis would have been missed if only the foot saturation had been recorded.

Most investigators perform pulse oximetry between 24 and 48 h after birth. Although oxygen saturations are usually stable within 4 h after birth, oximetry in the first 24 h has a slightly higher incidence of false positive results secondary to transient pulmonary hypertension or retention of lung fluid. There is a trade-off. Oximetry on the 1st day after birth detects CCHD and serious pulmonary disease earlier at the expense of more false positives as compared with oximetry on the 2nd day. On the other hand, serious pulmonary disease has symptoms that draw attention to the patient, and as long as the patient is not sent home on the 1st day without an oximetry screen, there is little to be lost in waiting an extra day. Further studies are needed to determine the optimal timing of the screen.

The usual practice is to perform an initial pulse oximetry screen. Those with saturations above the cutoff point, say 95%, are regarded as having a negative screen; naturally, they will also have had a normal routine physical examination. Those with saturations below 90% are referred for cardiological consultation and echocardiography. Those with saturations between 90 and 95% have a second pulse oximetry screen 6–12 h later. By this time, most will have negative screens; the patients with positive screens are referred to the cardiologist.

In several studies, oximetry performed between 2 and 72 h after birth found abnormal saturations in 2–5% of patients screened, 95% of whom were normal on the second screen. Asymptomatic potentially severe CHD was found in 0.0–0.5% (median 0.07%) of newborns, equivalent to 1/14 with any form of CHD or about 1/4 with severe CHD.

Results of Screening

In a meta-analysis reported by Valmari [45], CCHD missed by physical examination alone occurred in 467/300,102 live births for a rate of 1/643. When patients were screened by pulse oximetry, however, missed diagnoses occurred in 10/42,286 for a rate of 1/4,209. This represented a reduction in missed diagnoses from 1.56/1,000 to 0.25/1,000, about a sevenfold reduction. In the very large Norwegian study by Meberg et al. [28] of pulse oximetry in the 1st day after birth, 50,008 apparently normal newborns were screened at a median age of 6 h. 324 (0.6%) failed the screen. Of these, 43 had CHD, 27 being critical, another 134 had pulmonary disease, and the remaining 147 were normal with a transitional circulation.

In the very large Swedish study [6], a comparison was made between five district hospitals in one health region that used oximetry screening of 38,429 asymptomatic newborns with a cohort of surrounding hospitals that did not use oximetry screening but also referred their infants for surgery to the same tertiary centre for pediatric cardiac surgery. The study found that a missed diagnosis occurred in 5/60 with screening but in 28/100 without screening. Tellingly, 11/25 patients with transposition of the great arteries were missed by hospitals that did not screen as compared to 0/18 when screening was used. There were no deaths in the 60 screened patients who would have been undiagnosed at discharge compared to 5/100 who were not screened. These findings were confirmed by the recent publication of Meberg et al. [23] who compared, for the whole of Norway, those hospitals that used oximetry screening with those that did not. CCHD were detected before discharge in 44/50 (88%) of hospitals that used oximetry (46/50 or 92% if 2 patients with failed screens had not been overlooked) as compared to 37/48 (77%) in the unscreened population.

Pulse Oximetry as a Screening Test

Basic Requirements

In several medical centers, pulse oximetry has been used to screen infants with the hope of detecting these severe defects so that they can be treated early. As for all screening tests, certain requirements must be met:

(1) The disease is not apparent on physical examination.
(2) The disease has mortality or severe morbidity if not diagnosed early.
(3) The disease must be treatable, with results better for early than for late treatment.
(4) The test should be sensitive, that is, it should detect a high proportion of the affected infants.
(5) The screening test should be cost effective. That is, in addition to the cost of the screening test, the cost savings due to early detection should outweigh the costs of late treatment plus the costs of secondary screening of the false positives that will inevitably occur.

For CCHD, requirements 1–3 are certainly met. Requirement 4 is met in part. Pulse oximetry is not expected to detect lesions that are not ductus dependent and do not have right-to-left shunts; for example, ventricular septal defect, atrial septal defect, patent ductus arteriosus, or mild or moderate aortic or pulmonic stenosis that in aggregate make up most of CHD. The crucial question is whether pulse oximetry will detect all who have critical

heart disease, and this will be discussed below. The fifth requirement is the most difficult to establish.

Primary Costs of Tests

Most neonatal units in developed countries have pulse oximeters that are used for other purposes, so this is not charged to the test. In addition, nurses are well trained in the use of oximeters, and the simple test takes little time, so that in each nursery there is no need for training costs or added staff. On the other hand, the disposable probes that are used for each test have a cost. In the US, each probe costs about USD 11, so that if a new probe is used for each infant, the screening cost begins at USD 11,000,000 per million live births. It is not clear that new probes must be used for each neonate, and the risk of infection by using a cleaned reusable probe is probably minimal, but has not been evaluated formally. However, such probes have been reused in several hospitals without any known ill effect [16, 23]. Reusable probes will reduce the primary cost to <5% of the above amount.

The cost savings from early treatment will vary considerably, but considering the high cost of stay in intensive care units that in the US can run to hundreds of thousands of dollars for a single patient, almost certainly there will be savings. This does not even take into account the enormous personal and societal cost of rearing a child with severe brain damage. It is true that any direct cost is nonexistent if the child dies at home before being diagnosed and treated, but we hope to prevent this from happening. To be practical, too, the financial damages incurred by a malpractice suit may amount to millions of dollars.

The biggest unknown is the cost of verifying false positives. That is, if pulse oximetry suggests that there is a critical form of CHD, this will require additional time in hospital, cardiology consultation, and almost certainly echocardiography to make a definitive diagnosis. Because even a small false positive rate applied to 99% of the neonates will produce a large number of false positives to be investigated, the added costs involved depend upon the number of normal people studied and the costs of these studies. These costs will vary from country to country.

Cost-Benefit Relationship

For this, we need to consider separately true and false positives, and true and false negatives.

True Positives

The cost of finding these is relatively low. It is useful to compare pulse oximetry with the conventional metabolic screening used in most hospitals. Table 3 gives some data about mandated chemical screening tests in California; the list is similar in other states and countries.

These metabolic disorders have a cumulative incidence of about 1,600 per million live births, or about 6,400 born annually in the USA. The cost of the primary metabolic screen in California is about USD 110 per infant, leading to an estimate of USD 68,750 primary cost per patient diagnosed. This should be compared with an incidence of CCHD of about 4,000/million live births, perhaps about 1,200 (range 520–1,920) of whom might be undiagnosed in the nursery with sometimes serious consequences. This leads to an estimate of USD 9,167 (range USD 5,729–21,153) primary cost per asymptomatic CCHD patient diagnosed. A similar conclusion was presented by Koppel et al. [16]. Should reusable probes become standard, this primary cost will drop to 10% or less of the above estimated value.

True Negatives

No cost beyond those for the primary screen. There is intangible but real benefit of knowing that a critical disorder has not been missed.

False Negatives

This has not been well studied. In the Swedish study [6], 5 out of 60 ductus-dependent lesions were not detected by screening; all had coarctation of the aorta. This is to be expected, because patients with coarctation of the aorta can present late [14, 28]. In the large Norwegian study [28], there were 8 false negatives out of 49,684 who had saturations by pulse oximetry of 95% or more, and 4 of these were diagnosed clinically before discharge. The false negative rate was therefore 4/49,684 or 0.008%.

There is obviously a cost to missing the diagnosis. The Swedish study observed that neonates who left the hospital undiagnosed had a higher proportion of severe acidosis than did those diagnosed while in hospital, resulting in longer stay in the intensive care unit and a higher operative mortality. A similar conclusion has been reached by others [2, 4, 5]. Inasmuch as false negatives are much higher without screening [6, 45], this per se suggests that there would be a significant personal and financial benefit due to screening.

False Positives

This is the main basis for secondary costs because it leads to cardiology consultation and echocardiography.

These costs vary tremendously from country to country, but realistically should be compared with the costs of cardiology consultation and echocardiography done based on a mistaken clinical suspicion of serious heart disease. In Sweden [6], the false positive rate was 729/38,249 (1.91%) by clinical examination as compared to 69/38,249 (0.18%) for pulse oximetry alone. A few patients with critical heart disease who were not detected by pulse oximetry were detected by clinical examination. In that study, although costs were not precisely defined, the investigators concluded that the cost-benefit balance of screening was either neutral or in favor of screening. The meta-analysis by Valmari [45] cited above also found a marked reduction in false positive diagnoses when pulse oximetry screening was used in addition to clinical examination. A similar meta-analysis performed by Thangaratinam et al. [37] estimated a false positive rate of 0.2%, with 95% confidence limits of 0–1%. In the Norwegian study [28], the false positive rate for pulse oximetry was 0.6%, but this was done at a median of 6 h after birth. About half of these had pulmonary hypertension or lung disease (that one might argue need to be detected) and the rest had transitional circulation that might not have been present had the test been done 24 h later. In a recent report by a joint committee of the American Heart Association and the American Academy of Pediatrics [31], the false positive rate averaged 0.87% for all studies surveyed, but averaged 0.035% for studies done after 24 h. If this figure is correct, then there will be one unnecessary echocardiogram done for this reason for every 3,000 births. At a false positive rate of 0.2% [37], unnecessary echocardiograms will be done in 2/1,000 births, and even at the high rate of 0.6% false positives [23, 28], unnecessary echocardiograms would be done in only 6/1,000 births. To put this in perspective, in a hospital with 2,000 births per year, a false positive rate of 0.6% will result in 1 unnecessary echocardiogram per month.

Referral for cardiology consultation and echocardiography may not be immediately available. Mahle et al. [31] cited studies to show that about 15% of the US population live in nonmetropolitan areas where subspecialty referral is not immediately available. The choices then are to observe the patients who fail the test in hospital for a few more days or to transport them to a regional center for further investigation or treatment. Both of these options add to costs. On the other hand, suspicion of critical heart disease based on physical examination leads to the same options, and false positive results are more frequent for physical examination than for pulse oximetry. Furthermore, in smaller hospitals without expertise in pediatric cardiology or pediatric echocardiography, pulse oximetry offers an inexpensive and more reliable way of detecting asymptomatic patients with CCHD.

Discussion

Not all investigators favor pulse oximetry screening, either because they regard the benefits as insignificant or the costs excessive or inadequately assessed. A recent survey of Pediatric Cardiologists by Chang et al. [46] showed that only 55% supported routine pulse oximetry screening. The dissenters cited poor sensitivity, too many false positives, and technical difficulties with oximeters as their major reasons for not using oximetry. Today modern pulse oximeters are much more stable than they were. Furthermore, it is illogical to refuse to use pulse oximeters to detect CCHD on the basis of unreliability, but to use the same pulse oximeters to monitor neonates in the intensive care unit.

Those who found no benefit to pulse oximetry include Sendelbach et al. [47] from Dallas who reported that in a study of 15,233 admissions to a newborn nursery who had pulse oximetry, 4 patients had CCHD but all were diagnosed clinically. The false positive rate was high, possibly because screening was done at 4 h of age. In their study, follow-up of neonates with and without positive oximetry screens was incomplete, and the study is continuing. Patton and Hey [48] in Northumberland observed that no CCHD was undetected after 1998, based on clinical examination and careful follow-up.

Most other investigators have found that some patients with CCHD are not detected by clinical examination, but some of them do not advise routine pulse oximetry. Reich et al. [49] considered that technical and human factors associated with oximetry made it unreliable. Liske et al. [17] in a report of the Tennessee Task Force on Screening Newborn Infants for Critical Congenital Heart Disease agreed with the benefits of screening, but did not recommend it because of potential flaws in oximetry and because the cost-benefit ratio could not be assessed. Their major concern was the cost incurred if the false positive rates were high.

There is no doubt that those responsible for the clinical examination of newborns should be trained better to detect possible CHD. In 2000, Gaskin et al. [50] found that residents' auscultatory skills were suboptimal, and this is still true today. Examining skills can be improved by paying attention to mild cyanosis and also, in addition to cardiac murmurs, paying attention to abnormal pulsation of

the ventricles, and the splitting and position of maximal intensity of the components of the second heart sound. Feeling for weak femoral arterial pulsations is essential, and in the Swedish study [6] there were 2 newborns who had coarctation of the aorta with weak femoral pulses but normal pulse oximetry. Until everyone in all nurseries can confidently detect these abnormalities, however, there will still be a need for pulse oximetry. Pulse oximetry demands care and expertise, as well as the use of the best current equipment and software, but that is no different from the requirements for any test. At present, pulse oximetry is capable of detecting otherwise undiagnosed CCHD with a low false positive rate and costs that are less than those of currently mandated screening tests.

There is little doubt that the major impediment to the use of pulse oximetry as a screening test for CCHD is the justified concern about the costs of investigating false positives. The cost-benefit balance has never been precisely quantified, and will obviously differ in different countries with their different cost and reimbursement structures. Nevertheless, there is good reason to believe that screening will produce cost savings in most countries even if dollar amounts are not invoked. Cost savings accrue from a reduction in false negative diagnoses (based only on clinical examination) because of early treatment of infants with CCHD before they become acutely ill. Even one critically ill infant diagnosed so late that there is a several weeks' stay in the intensive care unit due to multiple organ failure and long-term neurological dysfunction will incur costs equivalent to those for echocardiography for several hundred false positive diagnoses. Cost savings also accrue because the false positive diagnosis rate in most institutions is lower for screening by pulse oximetry than by clinical examination.

Conclusions

I think we are in a similar position to the one a few years ago in the Back to Sleep campaign to reduce the mortality of sudden infant death syndrome. Despite convincing evidence provided by investigators in Norway and the UK of the benefit of sleeping on the back, many pediatricians delayed implementing the recommendations. Some did not believe the results, others were concerned about the risk of increased gastrointestinal reflux and inhalation pneumonitis, and yet others considered other mechanisms that might cause SIDS to be more important. Nevertheless, when sleeping on the back became more generally used, the benefits were confirmed.

Given the likely benefits and relatively low costs of primary pulse oximetry screening, the fact that we do not have good estimates of secondary costs is not a good argument against routine pulse oximetry screening. Whatever the secondary costs of dealing with false positive results may be, they are certainly less than the costs of the more numerous false positive diagnoses based on physical examination or the human and financial costs of missing these patients.

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