Screening with Pulse Oximetry for Early Detection of Neonatal Hypoxemia

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Objectives  After completing this article, readers should be able to:

1. Apply early pulse oximetry newborn screening to identify diseases associated with neonatal hypoxemia.
2. Identify differences in screening protocols and algorithms.
3. Describe the impact of early detection of critical congenital heart defects and hypoxemic neonatal conditions.

Abstract

Neonatal hypoxemia is sometimes difficult to detect. Therefore, it is sometimes challenging to diagnose critical congenital heart defects and other hypoxemic conditions before the infant becomes seriously ill. Screening with pulse oximetry is a noninvasive and inexpensive valuable method for early detection of these conditions. Establishing a protocol for all newborns saves lives and decreases morbidity without increasing costs.

Education Gaps

1. Normal neonatal saturation values in room air at sea level and at high altitude varies after the period of transition from fetal to neonatal life and up to 48 hours of age.
2. Cyanosis is not a very reliable clinical sign to detect neonatal hypoxemia.
3. Technology is available for evaluation and screening of neonatal hypoxemia.

INTRODUCTION

Congenital heart disease is one of the most common types of birth defects, affecting approximately 8 in 1,000 live-born infants. Critical congenital heart defects (CCHD), including ductal-dependent lesions, occur in 1 to 3 per 1,000 live births,
and account for about 40% of deaths associated with congenital malformations occurring in the first year of age. It is estimated that 60% of neonatal deaths in the United States are preventable. Neonatal hypoxemia is potentially fatal if there is a delayed or missed diagnosis of CCHD, pneumonia, sepsis, or persistent pulmonary hypertension (PPHN). Earlier detection of these pathologic conditions leads to improved management and outcomes. Numerous references support these statements but, for the purposes of providing an overview, we have limited the number cited in this review.

The prevalence, epidemiology, and impact of delay in the diagnosis of hypoxemic newborn diseases have been described in several publications. (1)(2)(3)(4)(5)(6)(7)(8) More than 30% of infant deaths associated with CCHD have been attributed to a late or missed diagnosis, which raises a concern for neonatal safety. (6) In Great Britain, it was estimated that 25% of infants with CCHD were not diagnosed until after discharge from the hospital when the infant presented in critical condition. (9)(10)(11)(12) In developing countries, it is estimated that more than half of neonates with CCHD are diagnosed after the first week of age. (13)(14)(15) It is now understood that routine prenatal imaging or physical examination of the neonate is insufficient for the early detection of potentially lethal cardiac conditions and that the delay in diagnosis may increase the risk of death or permanent injury.

This concern about delayed diagnosis of CCHD led to exploring the value of early detection with pulse oximetry (SpO2) monitoring. SpO2 is a noninvasive method that allows for rapid measurement of saturation of hemoglobin in arterial blood. It can detect hypoxemia in asymptomatic newborns with severe health conditions. Pulse oximetry with signal extraction technology (SET) is very easy to perform, fast, noninvasive, and cost-effective, and has significantly improved the quality and safety of neonatal health care. There is currently sufficient evidence on the benefits of SpO2 CCHD screening, and many organizations such as the US Advisory Committee on Hereditary Diseases endorse this screening test. (16)(17)(18)(19)(20) In 2015, the Centers for Disease Control and Prevention (CDC) and the American Academy of Pediatrics (AAP) convened an interdisciplinary panel with the approval of the US Department of Health, to perform oximetry to evaluate all newborns for CCHD. (16)(17)(18) In addition to CCHD, several other serious hypoxemic conditions can be diagnosed early with SpO2 screening.

This article will review the recommendations for early SpO2 newborn screening to identify diseases associated with neonatal hypoxemia. The information is obtained from all the cited references and also from the IX Clinical Consensus of the Ibero-American Society of Neonatology (SIBEN). (15)(26) At SIBEN’s Annual 2016 Congress in Asunción, Paraguay, 39 neonatologists and 4 neonatal nurses from 18 Ibero-American countries met and published the recommendations listed herein.

The early evaluation of all newborns with SpO2 screening is a noninvasive, easy to perform, and low-cost method that can be performed between 8 and 48 hours of age. It has excellent clinical utility at detecting potentially serious diseases in asymptomatic infants. The universal implementation of this evaluation in clinical practice enhances cardiopulmonary assessment, increases patient safety, and reduces morbidity, sequelae, and mortality.

**WHAT ARE THE NEONATAL CONDITIONS FOR WHICH DETECTION OF HYPOXEMIA WITH SP O2 CAN BE USEFUL BEFORE SEVERE CLINICAL MANIFESTATIONS OCCUR?**

The SpO2 screening test is very useful for the early detection of neonatal conditions with hypoxemia. The specific cardiac defects that can be detected and which require intervention (ie, catheterization or surgery) during the first year of age are listed in Table 1.

It is important to recognize that, in addition to congenital heart disease, the following conditions can be identified with
**TABLE 1. Critical Heart Lesions Detected on Pulse Oximetry Screening**

<table>
<thead>
<tr>
<th>LEFT-SIDED LESIONS</th>
<th>RIGHT-SIDED LESIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypoplastic left heart syndrome</td>
<td>Pulmonary atresia (intact septum or with a ventricular septal defect)</td>
</tr>
<tr>
<td>Interruption of the aortic arch</td>
<td>Pulmonary valve stenosis</td>
</tr>
<tr>
<td>Coarctation of the aorta, severe</td>
<td>Tricuspid atresia</td>
</tr>
<tr>
<td>Aortic valve stenosis</td>
<td>Ebstein anomaly</td>
</tr>
<tr>
<td></td>
<td>Tetralogy of Fallot</td>
</tr>
<tr>
<td></td>
<td>Transposition of the great vessels</td>
</tr>
<tr>
<td></td>
<td>Anomalous pulmonary venous return</td>
</tr>
<tr>
<td></td>
<td>Truncus arteriosus</td>
</tr>
</tbody>
</table>

**Spo2 screening:** 1) early sepsis, 2) congenital pneumonia, 3) PPHN, 4) meconium aspiration, 5) transient tachypnea of the newborn, 6) pneumothorax, and 7) other less frequent varied neonatal conditions.

This method of screening is not a reliable indicator of obstruction of the airway (eg, choanal atresia, dysfunction of the vocal cords) because these airway lesions may be associated with alveolar hypoventilation, with an elevated PaCO2 but normal Pao2. However, if these newborns are hypoxemic, the Spo2 screening will also be abnormal.

**HOW SHOULD EARLY Spo2 SCREENING BE PERFORMED?**

**General Clinical Protocols**

Neonatal screening for the detection of pathologic conditions with hypoxemia has been used in clinical practice since 2011. Since then, studies and meta-analyses have shown that such screening meets the criteria for a population screening test.

The Spo2 screening is an easy technique, and should be performed in all apparently healthy newborns between 12 and 48 hours after birth or before discharge. (Note: the timing of the screening varies among protocols.) The clinician can perform this screen by placing 1 sensor in the palm of the newborn’s right hand (preductal) and another sensor on 1 of the newborn’s feet (postductal). For preductal measurements, all large investigations have placed the sensors on the palm and the US Food and Drug Administration has recommended palm placement when using pulse oximetry monitors. Although the left hand may be used for a preductal measurement, it is not the preferred site because it only reflects the preductal value 80% of the time. These 2 Spo2 readings can be obtained consecutively with 1 monitor or simultaneously with 2 monitors.

**Pre- and Postductal Spo2 Differences**

Spo2 screening requires both preductal and postductal measurements to avoid an increase in false-negative and false-positive results. Newborns with obstruction of the left outflow tract may not be diagnosed if a single-site measurement is used. Ewer (12) and de-Wahl Granelli et al (27) also observed that both measurements increase the chances of early diagnosis of other serious hypoxemic conditions in the neonate.

In healthy newborns without heart disease, the normal Spo2 value is usually greater than 94% in both locations and the difference between the preductal and postductal measurements is minimal. In 1 study, oxygen saturations were measured in 13,714 healthy newborns without cardiac or pulmonary disease at a median age of 25 hours using Spo2 monitors with SET, and with 8- to 10-second mean times and reusable probes. The preductal or postductal Spo2 was greater than or equal to 95% in 99.5% of the infants, with the mean postductal Spo2 value being higher than the preductal Spo2. (28) In 40% of these infants, the postductal Spo2 value was lower than the postductal Spo2, with 28% having equal pre- and postductal Spo2 values and 22% with postductal Spo2 values that were respectively lower than the preductal Spo2. However, any difference was clinically insignificant, with a mean difference of only 0.29%.

The definition of a significant difference between pre- and postductal Spo2 during screening varies based on the protocol chosen for screening. The recommendations endorsed by the Secretary’s Advisory Committee on Heritable Disorders in Newborns and Children of the USA, (16) which are based on the protocol of de-Wahl Granelli et al (23) consider a difference of more than 3% to be significant. However, in the UK protocol, which is based on the studies of Ewer et al, a difference of more than 2% was considered to be significant. (24) These differences are significant regardless of whether the preductal Spo2 value is higher than the postductal Spo2 value or vice versa and even if both preductal and postductal Spo2 measurements are normal (ie, 95%).

The differences in Spo2 measurements can occur with:
1) a normal Spo2 (>95%) in both the right hand and 1 foot;
2) an abnormal Spo2 (<95%) in both extremities; and 3) an abnormal Spo2 in 1 territory (ie, preductal or postductal) but normal in the other territory.

When the preductal Spo2 value is higher than the postductal Spo2 value, possible explanations include 1) obstructions to the left heart with a right-to-left ductal shunt, and 2) persistent PPHN of the newborn with a right-to-left ductal shunt.

When the postductal Spo2 value is higher than the preductal Spo2 value, possible reasons are 1) an error in the
monitor, or 2) transposition of the great vessels with a conotruncal abnormality (eg, obstruction due to aortic stenosis or an interrupted aortic arch).

In summary, a significant difference between pre- and postductal values (>2% or >3%) indicates the presence of a shunt at the ductal level, and points to an abnormality, regardless of which of the 2 territories is higher. Of course, there are abnormal cardiac conditions without a pre-/postductal SpO2 difference; this occurs when the blood mixture of deoxygenated and oxygenated blood (ie, “shunt”) occurs mostly at other levels (eg, anomalous venous return, atrial level, ventricular level) and there is very little or no shunt at the ductal level. However, in these cases, the SpO2 is usually less than 95%.

**Technology for Screening**

For accurate SpO2 screening, it is important to use equipment that provides reliable results during motion and in low perfusion situations; in addition, the technique should show the pulsed wave signal and the perfusion index (described later). de-Wahl Granelli et al, Ewer et al, and Zhao et al showed that about 200,000 nurses (23)(24)(25) were able to perform SpO2 screening using this technology without difficulty. Interestingly, 1 study found that SpO2 screening did not improve CCHD detection in 15,299 newborns (29); however, the monitor used in this study did not have the appropriate technology to obtain stable signals, which may explain the negative results of this study.

Evaluating the quality of the SpO2 signal is fundamental to correctly interpret the SpO2 reading; therefore, SpO2 screening should be performed with a monitor that is not altered by movements or affected by low perfusion.

**Interpretation of SpO2 Screening**

The cumulative published experience to date may be insufficient to draw conclusions about the ideal SpO2 screening.

The 2 protocols previously mentioned agree in defining the screen as abnormal or “fail” if either the preductal or postductal SpO2 value is less than 90%. (24)(27) This result would require prompt clinical evaluation by a pediatric provider and transfer to a NICU. However, the protocols differ in several areas: age at the time of screening; whether 1 or both territories need to be abnormal (defined as an SpO2 value of 90%–94%); the cutoff value that defines a significant pre-/postductal SpO2 difference (>2% or >3%); and the number of times (once or twice) that an abnormal test should be repeated in a healthy-appearing infant. Each of these parameters is discussed below.

**Age.** The variability of published false-positive rates is mostly related to the age at screening. Studies quoted in the list of references found that the false-positive rate is 0.035% when the screening is done after 24 hours of age compared with 0.9% in screenings performed at 4 to 6 hours of age and 0.09% for screenings done at about 24 hours of age. However, if the screening is planned for 24 hours of age or later, some infants may become acutely ill before the screening and the opportunity for early diagnosis is missed. The current evidence seems to favor screening at about 12 hours of age or, at the latest, by 12 to 24 hours of age.

**One or Both Territories.** The US recommendation states that both territories need to have an SpO2 reading of 90% to 94% to be considered a “fail” result. Thus, a “pass” or negative screening result could occur if only 1 territory has an SpO2 level of greater than or equal to 95%. The UK protocol, on the other hand, considers the screen abnormal if either the hand or the foot has an SpO2 reading of 90% to 94% and, therefore, a “pass” is designated only when both territories have an SpO2 value greater than or equal to 95%.

**Difference Between Pre- and Postductal Values.** As mentioned before, there are different views about the definition of an abnormal (ie, “fail”) SpO2 screening result. The pre-/postductal SpO2 difference of greater than 2% is favored by some authors. If this difference persists in 2 evaluations, the infant should be assessed.

**Repeating an Abnormal Screen Once or Twice.** Some clinicians firmly believe that if the SpO2 screening is abnormal on 2 assessments, it is not appropriate to wait and repeat a third screening test (as recommended by the US protocol) in an asymptomatic newborn.

With the aforementioned caveats, the Fig summarizes 1 approach to CCHD screening in an asymptomatic newborn, which is as performed in the UK based on the studies of Ewer et al. (9)(10)(11)(12)(24) An infant with any symptoms for cardiac, pulmonary, or infectious disease should be treated as usual, without delays, regardless of the SpO2 screening result.

This protocol is based on the UK recommendations. If the SpO2 is greater than or equal to 95% and there is a greater than 2% difference, this would fit into the middle scenario and the test should be repeated. The US protocol defines an abnormal result if the pre-/postductal SpO2 difference is greater than 3%. The US protocol also considers that it is not necessary for both pre- and postductal values to be greater than or equal to 95%; if only 1 of the SpO2 values is greater than or equal to 95%, the infant “passes” the screen. Also, the US protocol considers that for an asymptomatic infant to fail the screening evaluation, 3 test results need to be abnormal and therefore the test needs to be repeated a 3rd time.

Preductal values are obtained from the right hand in all screening protocols.
HOW SHOULD WE RESPOND TO AN ABNORMAL (POSITIVE) \( \text{SpO}_2 \) SCREENING IN A CLINICALLY WELL NEWBORN?

The answer to this question is: Do not ignore an abnormal test and humbly accept that we may be wrong in our clinical assessment. After an abnormal result, clinicians need to quickly evaluate the newborn with a detailed and complete examination. Absence of a murmur, the presence of normal femoral pulses, or normal blood pressures does not rule out CCHD. In addition, neonates with hypoxemia from noncardiac conditions may not have a murmur and the other parameters may initially be normal. Unfortunately, there are legal cases in the United States in which a positive ("fail") test result was "ignored," and the infant later became critically ill or died.

It is neither essential nor necessary to perform echocardiography in all infants with a "failed" screening \( \text{SpO}_2 \) test. In addition to careful observation, monitoring, and a detailed physical examination, other studies may be needed to ensure a timely and accurate diagnosis. A complete diagnostic approach may include blood cell counts, cultures, a blood gas, and chest radiography. Some newborns will require echocardiography, and in some, it may be necessary to immediately start an infusion of prostaglandin to maintain patency of the ductus arteriosus (even before echocardiography).

HOW DOES HIGH ALTITUDE INFLUENCE THE RESULTS AND INTERPRETATION OF \( \text{SpO}_2 \) SCREENING?

Data are insufficient to clearly define generalizable normal \( \text{SpO}_2 \) levels within the first 24 hours after birth for the 7% of infants around the world who are born at altitudes higher than 1,500 m (~4,921 ft) above sea level. However, understanding cardiopulmonary physiology during fetal life and the transition to extrauterine life, as well as the alveolar gas equation, can assist with establishing the best approach to these infants.

At the SIBEN clinical consensus meeting, (26) clinicians reported that, on average, \( \text{SpO}_2 \) values are not different in the first 12 to 24 hours of age in infants born in locations less than 2,500 m (~8,200 ft) above sea level. In a recent study, \( \text{SpO}_2 \) was measured in newborns at 1,800 m (~5,905 ft) above sea level using a non–motion-resistant \( \text{SpO}_2 \) monitor, which has not been validated in neonates. (30) The 5% and 95% range for \( \text{SpO}_2 \) values reported in this study were about 90% and 98%, with mean and median preductal and postductal \( \text{SpO}_2 \) values only slightly lower than those reported at sea level. The SIBEN consensus statement and others consider that at less than 2,500 m (~8,200 ft) above sea level, the same values as reported at sea level should continue to be used until different well-established evidence becomes available.

At the recommended postnatal age for screening, the mean normal \( \text{SpO}_2 \) value is lower at high altitudes (93%–96%), but with larger standard deviations. Therefore, if screening is performed as recommended herein, the values for positive and negative results for each asymptomatic infant could be the same as the values at sea level, bearing in mind that some newborns who are completely healthy can have an \( \text{SpO}_2 \) value of 91% to 94% at altitudes of more than 2,700 m (~8,858 ft) above sea level. For these infants, more detailed observation would be recommended, exercising...
caution and avoiding aggressive investigations to prevent an increase in the number of “false-positives.” Nevertheless, precise cutoff points for SpO2 values in moderate and high altitudes are not known to adequately balance sensitivity with false-positive rates.

**FALSE-POSITIVE AND FALSE-NEGATIVE SCREENING**

As mentioned, an infant with a positive screening test has a SpO2 value less than 90% or 2 consecutive SpO2 values of 90% to 94% and/or a pre-/postductal difference greater than 2%, based on the UK protocol. A false-positive result occurs when additional testing after a positive screen finds that the infant does NOT have any hypoxemic condition such as CCHD, PPHN, transient tachypnea of the newborn, sepsis, or meconium aspiration. This false-positive occurrence is extremely rare (<0.1%) if the screening method and protocol are followed rigorously. If SpO2 screening is performed before 12 hours of age, the false-positive rate is slightly higher but the diagnosis of infectious and respiratory causes of hypoxemia are obtained earlier.

A false-negative result occurs when the SpO2 value is normal (negative screening) but the infant is actually found hours or days later to have a hypoxemic condition. Most studies indicate that the most frequently undiagnosed lesions are left-sided obstructed lesions with obstruction to the outflow of the aorta (eg, coarctation of the aortic arch, hypoplastic left heart, aortic stenosis), which are not necessarily associated with hypoxemia. False-negative results can also occur if the technology is inadequate. The use of the preductal and postductal saturations, as described before, and the perfusion index, described later, can be of some value to improve detection but they are not infallible.

**HOW SHOULD WE CARE FOR THE FAMILY OF A NEWBORN WITH AN ABNORMAL OR POSITIVE SCREENING RESULT?**

In the first hours after birth, various events generate great emotional tension. Health care professional should make an effort to decrease this by all possible means. Families should always actively participate in the care of their newborn and they should also understand the rationale and specifics of SpO2 screening.

Studies have shown that parents who are well informed are mostly satisfied with SpO2 screening tests and perceive screening to be a valuable method to identify sick newborns. In addition, parents of neonates who had a false-positive result did not show greater anxiety than those with negative or normal screening results.

It is recommended that parents receive written information about the SpO2 screening test. This written information must be accompanied by clear verbal communication and clarification of any questions. If possible, the screening should be performed with the parents present. If the newborn passes the test, there will be no issue. However, if the result is abnormal, parents may be shocked to receive this information. As parents’ emotions change from joy to worry, they may not be able to concentrate on the information that is being discussed with them.

All members of the neonatal team (social workers, nurses, nurse practitioners, and physicians) should be trained to empathetically support parents of infants who test positive on SpO2 screening. If the infant appears to be completely healthy but the SpO2 screening result is abnormal, clinicians should discuss with the parents the possibility that this is a false-positive result.

Depending on the clinical situation, there may be a need to proceed more or less quickly, but any communication with families should occur in a calm and supportive way. It is imperative to avoid delays while parents are processing the information. Parental uncertainty while waiting for repeat testing or further investigations can alter the relationship of the parents with the infant, and disrupt breastfeeding and maternal recovery. It is therefore especially important that staff members performing these screening tests are prepared in advance about how to communicate and empathize with parents if the results are abnormal.

**PERFUSION INDEX**

Most studies report that the lesions most often missed on SpO2 screening are those causing obstruction to aortic outflow (eg, hypoplastic left heart syndrome, critical aortic stenosis coarctation, interrupted arch), which may not necessarily be detected with antenatal ultrasonography, physical examination, or abnormal SpO2 values. However, an additional SET pulse oximetry measurement may increase detection of CCHD caused by an obstruction to aortic outflow. This measurement is called the perfusion index (PI), which is an assessment of strength of perfusion at the monitored site. A reference value was described for 10,000 newborns with a median value of 1.70% and a fifth percentile of 0.70%.

Granelli and Ostman-Smith showed that the addition of an abnormal PI to SpO2 screening increases the sensitivity of identifying CCHD with an obstruction to aortic outflow. However, adding the PI to the screening criteria may also result in an increase in false-positive results.

The PI is normally higher than 0.70% in both preductal and postductal territories. If it is less than 0.70% in 1
treatment, the test should be repeated. After 3 abnormal results in a healthy infant, further evaluation is needed. When the PI is less than 0.45%, it is indicative of low perfusion, which could be due to the aforementioned lesions. If the PI is higher in the postductal territory, it could be due to hypoplastic left heart syndrome or critical aortic stenosis with right-to-left ductal shunting. In this case, the postductal SpO2 value will also be significantly lower than the preductal SpO2 value. On the other hand, if the preductal PI is higher than the postductal value, one must consider a diagnosis of interruption of the aortic arch or coarctation of the aorta. More studies are still needed, but a published review summarizes all aspects of the PI in neonates (32) and a recent publication shows that combining PI with SpO2 screening in nontertiary centers increased the detection rate to 71%. (33) Furthermore, PIs were measured using an automated data selection method in healthy newborns during CCHD screening at 24 hours. (34) The median PI in asymptomatic newborns 24 hours after birth was 1.8 with a narrow interquartile range of 1.2 to 2.7. The median preductal PI was significantly higher than the median postductal PI (1.9 vs 1.8, P=.03) but this difference may not be clinically significant.

DECREASE IN INFANT CARDIAC DEATHS

A study from December 2017 (35) shows that statewide implementation of mandatory policies for newborn CCHD screening was associated with a significant decrease in infant cardiac deaths between 2007 and 2013 compared with states without these policies. In the United States, CCHD deaths dropped 16.8%, while other/unspecified cardiac deaths dropped 13.2% after screening was instituted. The authors also looked specifically at the 8 states that implemented mandatory screening policies between August 2011 and June 2013. They found a 33.4% relative decrease in CCHD deaths relative to previous years and other states, a decrease of 3.9 deaths per 100,000 births. Deaths from other/unspecified cardiac causes decreased 21.4% in states with mandatory screening relative to other states, with an absolute decline of 3.5 deaths per 100,000 births. (35) Therefore, the evidence is now sufficient to declare newborn screening for CCHD a successful public health intervention. Nearly all states now have CCHD screening requirements for all term infants who appear healthy and are asymptomatic.

WHAT TO DO WITH PRETERM INFANTS

The approach of SpO2 screening in preterm infants is a somewhat separate issue, with individual provisos. If the preterm infant seems healthy, is asymptomatic, and does not require intensive care, screening should be conducted as described here, within 6 to approximately 24 hours, without delay or waiting for any specific postmenstrual age. On the other hand, if the preterm infant is sick and is admitted to an intensive care unit, the infant will have adequate continuous SpO2 monitoring and careful daily evaluations during the hospital

TABLE 2. Points to Remember About CCHD Screening

<table>
<thead>
<tr>
<th>Points to Remember About CCHD Screening</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CCHD is the most common birth defect, affecting approximately 8 in 1,000 live-born children; it is estimated that about 40,000 infants are born with CCHD per year in the United States, and 1.35 million worldwide, including ductal-dependent lesions that affect between one-quarter and one-third of these children.</td>
</tr>
<tr>
<td>• CCHD represents about 40% of deaths due to congenital malformations and most deaths from cardiovascular disease occurring in the first year of age. Unfortunately, some neonatal deaths in more than 30% of infants with CCHD have been attributed to errors in diagnosis or late diagnosis.</td>
</tr>
<tr>
<td>• The prenatal diagnosis of CCHD can improve perinatal outcomes for certain lesions. (45)(46) Recent evidence shows that prenatal detection of CCHD has progressively increased from 2006 to 2012, but also that prenatal detection is highly variable.</td>
</tr>
<tr>
<td>• Cyanosis is not a very reliable clinical sign to detect hypoxemia.</td>
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<tr>
<td>• The active approach of pulse oximetry with SET can achieve an improvement in the quality and safety of health care, as well as cost savings.</td>
</tr>
<tr>
<td>• Early diagnosis of CCHD in postnatal life significantly decreases morbidity and mortality rates.</td>
</tr>
<tr>
<td>• Early detection of CCHD and hypoxemic neonatal conditions not only reduces the suffering of children and families, but can also reduce associated costs and long-term neurologic compromise by not delaying admission to a specialized care unit. Early diagnosis is also associated with significant reductions in mortality, better surgical outcomes, less prolonged ventilation, and lower potential developmental problems.</td>
</tr>
<tr>
<td>• It is an obligation and responsibility of neonatal centers to improve care on a universal basis whenever possible, without waiting for laws or bureaucratic processes that often place other interests above the needs of the newborns.</td>
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</table>

CCHD=critical congenital heart defects; SET=signal extraction technology.
CONCLUSION

In summary, significant reductions in pediatric mortality, better surgical outcomes, less prolonged ventilation, and diminished potential developmental problems can occur if hospitals adopt SpO2 screening in neonates for early and timely detection of CCHD and other hypoxemic conditions. (11)(19)(26)(27)(28)(36)(37)(38)(39)(40)(41)(42)(43)(44) Table 2 lists the most important factors to remember about SpO2 screening. Clinicians can use the specific SpO2 screening protocol described herein or modify the approach to specific scenarios (eg, elevated altitude). At the beginning of establishing a screening program for CCHD, each center must use a clear protocol with a quality improvement process to establish a screening program for CCHD, each center must use a clear protocol with a quality improvement process to confirm that 100% of newborns are screened. The detection of non-CCHDs and other disorders, such as respiratory problems or early sepsis, should also be measured and reported as an additional benefit. Physicians should be aware that, even though the combination of early detection with pulse oximetry and other methods of evaluation reduces diagnostic errors, some infants might still be discharged without a proper diagnosis. Most studies indicate that the most frequently undiagnosed lesions are those that cause obstruction to the outflow of the aorta (eg, coarctation of the aortic arch), which are not necessarily associated with hypoxemia. The use of the preductal and postductal saturation difference and the PI improve detection rates, but published studies have warned that this combined technique is also not infallible. The combined approach of using SpO2 with SET, staff education, and a focus on family support can lead to an improvement in the quality and safety of health care for newborns along with lower associated costs.

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