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Society Position Statement

Canadian Cardiovascular Society/Canadian Pediatric Cardiology Association Position Statement on Pulse Oximetry Screening in Newborns to Enhance Detection of Critical Congenital Heart Disease

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See editorial by Harris, pages 209–210 of this issue.

ABSTRACT

Congenital heart disease is the most common congenital malformation and approximately 3 in 1000 newborns have critical congenital heart disease (CCHD). Timely diagnosis affects morbidity, mortality, and disability, and newborn pulse oximetry screening has been studied to enhance detection of CCHD. In this position statement we present an evaluation of the literature for pulse oximetry screening. Current detection strategies including prenatal ultrasound examination and newborn physical examination are limited by low diagnostic sensitivity. Pulse oximetry screening is safe, noninvasive, easy to perform, and widely available with a high specificity (99.9%) and moderately high sensitivity (76.5%). When an abnormal saturation is obtained, the likelihood of having CCHD is 5.5 times greater than when a normal result is obtained. The use of pulse oximetry combined with current

RÉSUMÉ

La cardiopathie congénitale qui constitue la malformation congénitale la plus fréquente compte environ 3 nouveau-nés sur 1000 atteints d'une cardiopathie congénitale grave (CCG). Son diagnostic précoce influence la morbidité, la mortalité et l'incapacité. De ce fait, le dépistage par oxymétrie de pouls chez le nouveau-né a fait l'objet d'une étude afin d'améliorer la détection de la CCG. Dans le présent énoncé de position, nous présentons une évaluation de la littérature sur le dépistage par oxymétrie de pouls. Les stratégies de détection actuelles, dont l'examen prénatal par échographie et l'examen physique du nouveau-né, sont limitées par leur faible sensibilité diagnostique. Le dépistage par oxymétrie de pouls est sûr, non effractif, facile à réaliser et largement accessible, et montre une spécificité élevée (99,9 %) et une sensibilité modérément élevée

Congenital heart disease (CHD) is the most common congenital malformation with a prevalence of approximately 12 per 1000 in Canada, and approximately 25% have critical CHD (CCHD).[1] CCHD includes severe lesions that require intervention early in life to optimize health outcomes, and are commonly duct-dependent.[2] Although a reduction of 67% in mortality has been shown for children with severe forms of CHD in Quebec from 1987 to 2005, CHD remains a leading cause of infant death.[3,4] It has been reported that 30% of cases of CCHD are diagnosed more

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The disclosure information of the authors and reviewers is available from the CCS on their guidelines library at www.ccs.ca.

This statement was developed following a thorough consideration of medical literature and the best available evidence and clinical experience. It represents the consensus of a Canadian panel comprised of multidisciplinary experts on this topic with a mandate to formulate disease-specific recommendations. These recommendations are aimed to provide a reasonable and practical approach to care for specialists and allied health professionals obliged with the duty of bestowing optimal care to patients and families, and can be subject to change as scientific knowledge and technology advance and as practice patterns evolve. The statement is not intended to be a substitute for physicians using their individual judgement in managing clinical care in consultation with the patient, with appropriate regard to all the individual circumstances of the patient, diagnostic and treatment options available and available resources. Adherence to these recommendations will not necessarily produce successful outcomes in every case.

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strategies has shown sensitivities of up to 92% for detecting CCHD. False positive results can be minimized by screening after 24 hours, and testing the right hand and either foot might further increase sensitivity. Newborns with abnormal screening results should undergo a comprehensive assessment and echocardiography performed if a cardiac cause cannot be excluded. Screening has been studied to be cost neutral to cost effective. We recommend that pulse oximetry screening should be routinely performed in all healthy newborns to enhance the detection of CCHD in Canada.

(76,5 %). Lorsqu'une saturation anormale est obtenue, la probabilité de CCG est 5,5 fois plus élevée que lorsqu'un résultat normal est obtenu. Il a été démontré que la combinaison de l'utilisation de l'oxymétrie de pouls et des stratégies actuelles avait une sensibilité de détection de la CCG allant jusqu'à 92 %. Le dépistage après 24 heures peut minimiser les résultats faux positifs, et les mesures réalisées à la main droite et à un pied augmenteraient davantage la sensibilité. Les nouveau-nés montrant des résultats anormaux au dépistage devraient subir une évaluation exhaustive et une échographie si une origine cardiaque ne peut être exclue. L'étude a montré que le dépistage était neutre par rapport au coût à rentable. Nous recommandons que le dépistage par oxymétrie de pouls soit systématiquement réalisé chez les nouveau-nés en santé afin d'améliorer la détection de la CCG au Canada.

than 3 days after birth in the United States and 25% are diagnosed after discharge in Northern England.[5,6] In addition, deaths from unrecognized CCHDs accounted for 4.6 per 100,000 live births in Sweden.[7] The burden of disease in Canada should be similar to these countries. Early diagnosis of CCHD continues to be important because delay in diagnosis increases morbidity, mortality, and disability,[7] and emphasizes the need to improve the process for timely diagnosis.

Pulse oximetry has been studied as a newborn screening test to enhance the detection of CCHD (Table 1).[2,7-11] Although many programs and groups around the world have recommended and adopted this screening, newborn pulse oximetry is not currently routine practice in Canada. The aim of this Position Statement is to present an evaluation of the literature for pulse oximetry screening and determine a best practice in Canada.

Methods

Expert representatives from the Canadian Cardiovascular Society (CCS) and Canadian Pediatric Cardiology Association (K.K.W., A.F., D.S.F., D.G.H., J.L.R.), Canadian Pediatric Society (M.N.), and College of Family Physicians of Canada (L.G.) were identified and made up the primary writing panel, with additional representation from nursing, midwifery, and rural physicians in the secondary writing panel (see the *Acknowledgements* section). Relevant literature was identified by searching Ovid MedLine and then EMBASE with MeSH headings "congenital heart," "neonatal screening," and "oximetry" by a research coordinator starting in June 2015. The co-chairs assessed all titles and abstracts for relevance and 2 members of the primary writing panel using the Grading of Recommendations Assessment, Development and Evaluation system for evidence classification reviewed pertinent articles and published guidelines. The primary writing panel wrote the document, followed by peer review from the secondary writing panel with combined expertise to address our recommendations in the Canadian context that affects urban and rural births in and out of hospital. The CCS Guidelines Committee reviewed and approved the statement. There are no randomized controlled trials for this topic, but high-quality observational studies formed the basis of our recommendations. Grading the quality of evidence for each recommendation was on the basis of whether we believed that further research was very unlikely (high quality), likely (moderate quality), or very likely (low quality) to have an important effect on our confidence in the estimate of effect. The recommendations represent the consensus opinion of the primary writing panel authors, endorsed by the CCS/Canadian Pediatric Cardiology Association, and the Canadian Pediatric Society.

Table 1. Examples of CCHD lesions detectable using pulse oximetry screening

Most consistently cyanotic
Hypoplastic left heart syndrome
Pulmonary atresia with intact ventricular septum
Total anomalous pulmonary venous return
Tetralogy of Fallot
Transposition of the great arteries
Tricuspid atresia
Truncus arteriosus
Might be cyanotic
Coarctation of the aorta
Double outlet right ventricle
Ebstein anomaly
Interrupted aortic arch
Other single ventricles

CCHD, critical congenital heart disease.

Assessment of Current Detection Strategies

Current screening for CCHD includes offering all pregnant women a prenatal ultrasound examination between 18 to 22 weeks' gestation followed by newborn physical examination.

Prenatal ultrasound examination

The prenatal ultrasound examination can be limited by low diagnostic sensitivity. In Alberta between 2007 and 2010, only 50% of newborns with CHD requiring surgery by 1 year of age were diagnosed prenatally.[12] There was significant variation in detection rates depending on the type of CHD: 85% if the abnormality is easily noted on a standard 4-chamber view such as a hypoplastic ventricle, down to 29% for transposition of the great arteries.[12] Detection rates were also influenced by ultrasound expertise.[6,12,13] The Society of Thoracic Surgeons Congenital Heart Surgery Database noted

an average prenatal detection rate of only 42% for infants operated on at ≤ 6 months of age in 2012 with significant variation between states (11.8%-53.4%).[13] In the United Kingdom (UK), the average detection rate among regions ranged from 20% to 55%.[6]

More contemporary prenatal detection rates are likely higher with routine imaging of the outflow tracts and other quality improvement practices. In 2016, a single tertiary perinatology referral centre in Ireland showed that a 91% prenatal CCHD detection rate can be achieved[14]; however, there appears to be a ceiling in prenatal detection when applied to the larger population because the necessary knowledge, expertise, and experience has yet to be optimally regionalized. Continued efforts to improved prenatal detection are encouraged because this is the preferred method for detecting CCHD, but until prenatal detection rates improve significantly, there is a role for additional strategies to enhance the detection of CCHD.

When prenatal ultrasound examination is used to detect or raise suspicion for CHD, this should lead to a detailed fetal echocardiogram with very high accuracy in the diagnosis of CCHD. This then allows for delivery and management of the newborn at an appropriate centre.

Newborn physical examination

Critics of pulse oximetry screening argue that important hemodynamic lesions will present clinically before discharge, and question the value added with screening. However, some types of CCHD might not present with abnormal clinical findings before decompensation while the ductus arteriosus remains patent. There are also limitations related to expertise, confidence, and experience of the individual who performs the newborn physical examination.[2] A study from Norway by Meberg et al. showed that hospitals without pulse oximetry screening were only able to diagnose 77% of CCHD according to clinical features before discharge, and another study showed that 7 of 24 newborns with CCHD (including 2 with hypoplastic left heart syndrome and 2 with transposition of the great arteries) had a normal examination at the time of screening, highlighting these limitations.[9,15] In one study, the false positive detection rate for CCHD was 10 times higher for physical examination alone compared with pulse oximetry (1.91% vs 0.17%; $P < 0.0001$), and was associated with a larger number of referrals for echocardiogram examinations (729 vs 69, respectively).[7]

Newborn echocardiography

When CHD is suspected, newborn echocardiography is the gold standard for diagnosis, but applying this as a screening test is neither cost effective nor feasible in a geographically large country like Canada. It has been estimated that using echocardiography as a screening tool would cost 10 million dollars per additional timely detection of a serious CCHD case.[4]

Assessment of Pulse Oximetry to Screen for CCHD

Pulse oximetry provides the ability to screen for levels of hypoxemia otherwise undetectable on clinical examination. Most studies define an oxygen saturation ≥ 95% as normal, with 95% representing the 2.5 percentile (−2 SD) in a study of 1000 newborns, supported by an analysis of distributions from another study.[7,16,17]

Pulse oximetry as a screening test

Pulse oximetry is safe, noninvasive, easy to perform, and widely available. Early studies using pulse oximetry were too small to define the benefits of screening, but this evolved as larger studies were performed. In a systematic review by Thangaratinam et al., which included 13 studies and 229,421 newborns, pulse oximetry screening for CCHD had a high specificity (99.9%; 95% confidence interval [CI], 99.7%-99.9%) and a moderately high sensitivity (76.5%; 95% CI, 67%-83.5%). With an abnormal saturation, the likelihood of having CCHD was 5.5 times higher than a normal result.[11] Increasing the saturation cutoff to above 95% to increase the detection of cyanotic cases (higher sensitivity) also increases the false positive rate (lower specificity). One challenge to achieving higher sensitivity is the varying degrees of severity within the same type of CCHD, which might influence the degree of cyanosis. Studies using the lower abnormal saturation limit of 92%-95% have been reported, and are limited by further decreasing the sensitivity and increasing the false negative rate.[11]

Pulse oximetry screening has features comparable with current established newborn screening practices. The prevalence of CCHD is similar to that of cystic fibrosis (CF) (0.5/1000), and hypothyroidism (1/3000-4000). There are challenges in comparisons of sensitivity and specificity for CF and thyroid screening because of different cutoffs for abnormal results and second-line testing that is performed. The sensitivity for CF screening (95%) is higher than for pulse oximetry with comparable specificity (CF, 99.5%). The false positive rates are also comparable for pulse oximetry (0.05%-0.5%) and newborn thyroid screening (0.3%).

Value added with pulse oximetry testing

Pulse oximetry screening for CCHD, in isolation, should not be considered a replacement for current detection methods. Alone, pulse oximetry identified only 66% (12 of 29) of CCHDs in 1 study[7]; the concept of a "diagnostic gap," introduced by Riede et al., describes pulse oximetry as an adjunct to the current practice of prenatal ultrasound examination and newborn physical examination, to enhance the detection of CCHD.[18] The use of pulse oximetry in addition to these current practices has shown sensitivities of 82.8%-92% (Fig. 1).[7,15,18] The positive predictive value for pulse oximetry has been shown to be 7 times greater than for newborn physical examination in a large multicentre Swedish study (20.69% vs 3.06%, respectively) and provides a significantly greater likelihood ratio for detecting CCHD (344.8 vs 32.4, respectively).[7]

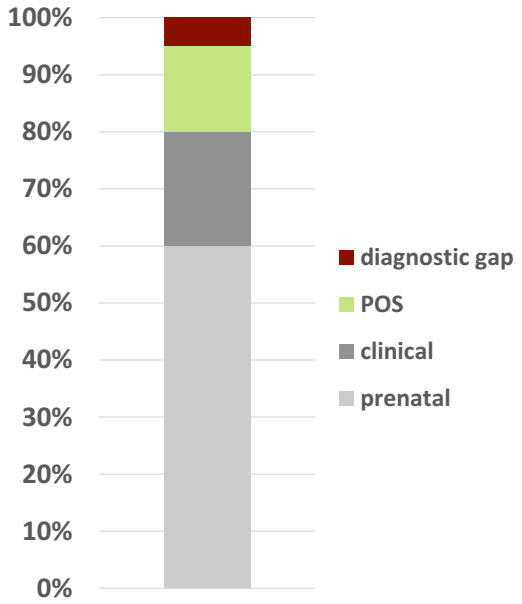

Figure 1. Reducing the diagnostic gap for detecting critical congenital heart disease with the addition of pulse oximetry screening (POS). Reproduced from Reide et al.[18] under the Creative Commons Attribution Noncommercial License.

If the prenatal detection rate of CCHD is assumed to be 50%, information from a large prospective observational study suggests that pulse oximetry would detect an additional 35 per 100,000 newborns with CCHD.[15] Applying this to the total annual births in Canada of 388,729 (2014-2015 Statistics Canada) and an incidence for CCHD of 3 per 1000, 583 infants with CCHD would be born without prenatal diagnosis; 136 additional cases of CCHD per year could be detected earlier with routine newborn pulse oximetry screening in Canada.

RECOMMENDATION

1. We recommend that pulse oximetry screening should be routinely performed in all newborns to enhance the detection of CCHD in Canada (Strong Recommendation; Moderate-Quality Evidence).

   Values and preferences. This recommendation places emphasis on achieving timely detection of CCHD through the use of pulse oximetry screening, thereby avoiding newborn discharge before diagnosis and later presentation in circulatory shock.

Practical tip. With a normal saturation, health care providers should not ignore other important signs of CCHD or CHD. Some types of CCHD, in particular left heart obstructive lesions, remain a challenge to diagnosis even with the use of pulse oximetry screening. The presence of weak or absent femoral pulses, abnormal auscultation findings, or respiratory distress might also point to a cardiac abnormality that requires further evaluation.

RECOMMENDATION

2. We recommend that the optimal screening for CCHD includes prenatal ultrasound examination, physical examination, and pulse oximetry screening (Strong Recommendation; Moderate-Quality Evidence).

   Values and preferences. This recommendation places emphasis on the use of pulse oximetry screening in addition to prenatal ultrasound and physical examination to achieve the highest detection rates for CCHD in all newborns. The value added from screening is influenced by current detection methods. Regions with very high prenatal detection rates might find fewer additional cases from screening and benefit less than the average centre in Canada.

Effect on Families

In a questionnaire to 119 mothers in Birmingham, UK whose newborn had a false positive pulse oximetry screening result, reported anxiety levels were not significantly different from those with true negative results, and both groups had anxiety scores within the normal range for women.[19] Pulse oximetry screening was perceived as quick, safe, noninvasive, painless, and nondistressing for the newborn, and reassuring for the parents. Many parents reported newborn screening to be acceptable, and placed high importance on the potential for earlier detection of CCHD. Participants with false positive pulse oximetry results reported less satisfaction with the screening, which likely reflected uncertainty when given a positive result and the need for further testing. Improved prescreening education would address this issue, because better understanding of the screen correlated with higher satisfaction.[19] This study did not involve long distance transport of newborns for cardiac assessment, which might further affect anxiety levels and be a very important issue for families, which needs further study.

Addressing False Positive Results

There might be important regional challenges to providing diagnostic testing with pediatric cardiology consultation and newborn echocardiography for abnormal screening results. Accessing these resources, because of distance from the delivery hospital, might necessitate patient transport and might be facilitated using telehealth for live remote viewing and interpretation of an echocardiogram performed by a local pediatric and/or adult sonographer.

The transitional fetal circulation with elevation of the pulmonary vascular resistance can result in varying degrees of right to left shunting at the ductus arteriousus and foramen ovale causing desaturation, despite a structurally normal heart. The duration of this transition varies in newborns and is a common cause of false positive results. Studies have identified several strategies to decrease the false positive rate.

The Timing of Screening Matters

Pulse oximetry screening can be performed any time after birth. Earlier screening has the benefit of detection before any signs or symptoms develop. A large multicentre prospective

study in China screened 122,738 newborns and showed that screening at 6-24 hours had 10% higher sensitivity compared with after 24 hours,[10] but a higher false positive rate.[9,10] A meta-analysis showed that detection of CCHD using pulse oximetry screening after 24 hours was associated with a 10-fold reduction in false positive rate (0.05%; 95% CI, 0.02%-0.12%) compared with earlier screening (0.50%; 95% CI, 0.29%-0.86%), without a significant effect on screening sensitivity.[11] This information suggests that 2-12 per 10,000 newborns would have a false positive pulse oximetry screen for CCHD if performed after 24 hours. For smaller or remote centres in Canada, on the basis of their birth rate, this might result in 1 false positive result every couple of years.

All studies report screening time interval rather than screening at an exact time from birth. Screening between 24 and 36 hours allows for flexibility in the timing of screening so that screening can become part of a daily schedule for appropriate utilization of resources. Some centres coordinate pulse oximetry screening with newborn hearing assessment, the first bath, or other routinely scheduled evaluations.

Pulse oximetry screening protocols for hospital discharges occurring before 24 hours, or freestanding birthing centres and births occurring at home, require additional consideration. Accommodations made to manage early discharges for existing newborn screening tests could apply to pulse oximetry screening. Screening before 24 hours, which is associated with higher false positive rates, is preferable to no screening. A normal screen at any time is normal even if it occurs before 24 hours. In-hospital reassessment or assessment by public health nurses at 24-36 hours for newborns discharged early would be an acceptable alternative. Similarly, midwives could screen at the time of the routine home visit at approximately 24 hours. It is critical whatever the locally approved practice, that it be consistent, well communicated, and have a tracking system in place to ensure no loss to follow-up screening.

RECOMMENDATION

3. We recommend that pulse oximetry screening should be performed between 24 to 36 hours of age (Strong Recommendation; Moderate-Quality Evidence).

   Values and preferences. This recommendations places emphasis on reducing false positive rates by performing screening after 24 hours compared with screening before 24 hours.

Practical tip. For early discharges and home births, consider applying accommodations for existing newborn screening tests.

Pulse Oximetry Enhances Detection of Other Disease States

An abnormal pulse oximetry screen might detect other causes of hypoxemia, including important infections and respiratory disorders that require intervention. Pulmonary pathology has been identified in 39% of abnormal CCHD screen results,[16] and 29% of false positive results have required further follow-up and neonatal intensive care admission.[7] It is estimated that pulse oximetry could detect 199 per 100,000 newborn cases of respiratory or infective illness that require treatment.[15]

Addressing False Negative Results

Newborns with normal screening results at any time in testing, and therefore negative pulse oximetry screening, are unlikely to have one of the 12 types of CCHD (Table 1). It is important to recognize that pulse oximetry screening does not exclude all forms of CCHD or CHD. Because of the varying severity within a particular type of CCHD, the degree of cyanosis might be variable or even absent. For example, a newborn with hypoplastic left heart syndrome could have an initial foot saturation of 84% or 100% on the basis of variations in the pulmonary vascular resistance and anatomy (aortic and mitral atresia vs stenosis).[15] Severe cases of coarctation might present with right to left ductal shunting resulting in abnormal screening results, but some cases of coarctation with or without associated defects like a ventricular septal defect might have normal screening results and not decompensate until the ductus closes. Although screening can detect some cases of coarctation, studies have shown that coarctation and other left heart obstructive lesions remain a challenge to diagnose.[7] Although the false negative rate is low, ongoing assessment of femoral pulses and signs of cardiac disease should continue as part of the normal newborn care.[11] Additionally, pulse oximetry will not detect a ventricular septal defect that is of no hemodynamic significance in a newborn, but could cause congestive heart failure during the first few weeks of life as the pulmonary vascular resistance decreases.

Testing the Right Hand and Either Foot

Studies have used protocols that test 1 foot alone or sequentially the right hand and either foot. Differences in saturations of $> 3\%$ between the right hand and either foot is also abnormal (> 2 SD of measurement variability).[17]

Many types of CCHD require a patent ductus arteriosus to secure adequate systemic or pulmonary blood flow, and the degree of right to left shunting across the ductus arteriosus will result in different saturations in preductal (right hand) and postductal (either foot) sites. Use of the left hand for pulse oximetry is not recommended because of its proximity to the ductus arteriosus. Because both feet are postductal, checking either foot is adequate. Although a meta-analysis did not show a significant difference in sensitivity ($P = 0.22$) or false positive rates ($P = 0.66$), regardless of the site tested, other studies have shown that CCHD would have been missed with screening the foot alone: 4 newborns in one study with 2 newborns with hypoplastic left heart syndrome, 1 with coarctation, 1 with truncus arteriosus, and 1 newborn in another study with interrupted aortic arch.[7,11,15] The number of additional cases detected by checking the right hand and either foot is small for each reported series, but might be significant when applied across a population. The additional time to obtain the pulse oximetry result from the right hand is estimated to take < 1 minute.

RECOMMENDATION

4. We recommend that pulse oximetry screening should be performed using the right hand and either foot (Strong Recommendation; Moderate-Quality Evidence).

   Values and preferences. This recommendation places emphasis on increasing screening sensitivity by performing pulse oximetry on the right hand and either foot rather than the foot alone.

Review of the Pulse Oximetry Screening Protocol

The American Academy of Pediatrics protocol should be used.[20] Studies report a median of 5 minutes to perform and document screening using this protocol.[7,21] The protocol with modifications is summarized in Figure 2, and presents a management plan for newborns screened between 24 and 36 hours of age on the basis of pulse oximetry results. Newborns with pulse oximetry $\geq$ 95% in the right hand OR foot and $\leq$ 3% difference between the right hand AND either foot at any time of testing have a normal result, and require no further testing.

A failed pulse oximetry screen is a saturation in any limb $<$ 90%, and requires evaluation for CCHD. The 90% threshold is supported by data showing a median postductal saturation of 90% in the CCHD group.[7,17]

A borderline screening result is a saturation in the right hand AND foot of 90%-94% or $>$ 3% difference between the right hand and either foot, and has greater potential to be a false positive than do saturations $<$ 90%, and therefore benefit from rescreening. Studies that used repeat screening usually allowed 1 hour between screens to provide more time for the transitional circulation to adapt and decrease false positive results. The optimal timing between screening and frequency of rescreening has not been studied, but a 1-hour interval is practical. After the third screen, a persistently borderline result is considered a failure, because continued rescreening or longer intervals between screening might prolong the screening process and there might be clinical decompensation. A group in Wisconsin has coined the phrase "2 sites/3 strikes" to help people remember this part of the protocol.[22]

For the newborn population, taped or wrap-on probes allow closer skin contact, and are more effective than clamp-on probes.[20] The largest pulse oximetry studies used wrapped probes around the palm of the hand and the foot. Saturations obtained when babies were quiet or sleeping were slightly higher than when babies were fussy or crying (by 0.44%, $P = 0.0001$ and 0.98%, $P = 0.001$, respectively).[23] Local expertise should guide the use of pulse oximetry equipment and practices.

A newborn who develops clinical signs of cardiorespiratory decompensation during the protocol should be considered to have failed screening and undergo further evaluation.

Protocol interpretation

Limitations of this multistep protocol include inaccurate documentation and misinterpretation. Oster et al. asked clinical staff to interpret a series of right hand and foot pulse oximetry results; staff who used a paper-based protocol made more errors than those who used a computer-based tool (81.6% vs 98.3% correct; $P < 0.001$). Failed screen results were correctly identified 96.7% of the time using the computer and only 65.4% using the paper flow chart, and increased the false negative rate. Interpreting the difference between extremities and management after the third screen were additional sources of error. To minimize these errors, a computer-assisted Web-based program was developed (www.pulseoxtool.org).[24] In Appendix 1 an alternative method for the interpretation of pulse oximetry results is presented. The benefits of other technologies that integrate the screening protocol into the software of the pulse oximetry machine have not been determined.

Managing abnormal results

The management of failed screen results require a comprehensive assessment by the most responsible health care provider, which could be midwives, nurses, nurse practitioners, or physicians. Echocardiography is required as the gold standard for diagnosing CCHD in these cyanotic newborns, and many studies used echocardiography as the next test to assess newborns after an abnormal screening result. This process might be efficient and cost effective in a tertiary centre with on-site pediatric cardiology and echocardiography services from a work flow perspective. However, in many centres in Canada without these cardiac services, the practicality of requiring ground or air transport to obtain an echocardiogram examination warrants additional evaluation in an attempt to further reduce the false positive results. Further consultation between the most responsible health care provider and local expertise (a more experienced health care provider, pediatrician, or neonatologist) to exclude noncardiac causes might be helpful. A comprehensive evaluation, including upper and lower limb blood pressures, electrocardiogram, and chest x-ray, might be beneficial. If the most likely cause remains cardiac or unclear, consultation with pediatric cardiology followed by an echocardiogram is required to rule out CCHD. After consultation with pediatric cardiology, it might be reasonable to keep a newborn in hospital for further observation and retesting rather than immediately initiate a long distance transport to further reduce false positive results.

RECOMMENDATION

5. We recommend that newborns with an abnormal screening result should undergo a comprehensive evaluation by the most responsible health care provider. If a cardiac diagnosis cannot be confidently excluded, referral to a pediatric cardiologist for consultation and echocardiogram is advised (Strong Recommendation; Moderate-Quality Evidence).

   Values and preferences. This recommendation places emphasis on ruling out noncardiac causes of cyanosis to further decrease the number of false positive results that might require transportation for cardiology consultation and echocardiography.

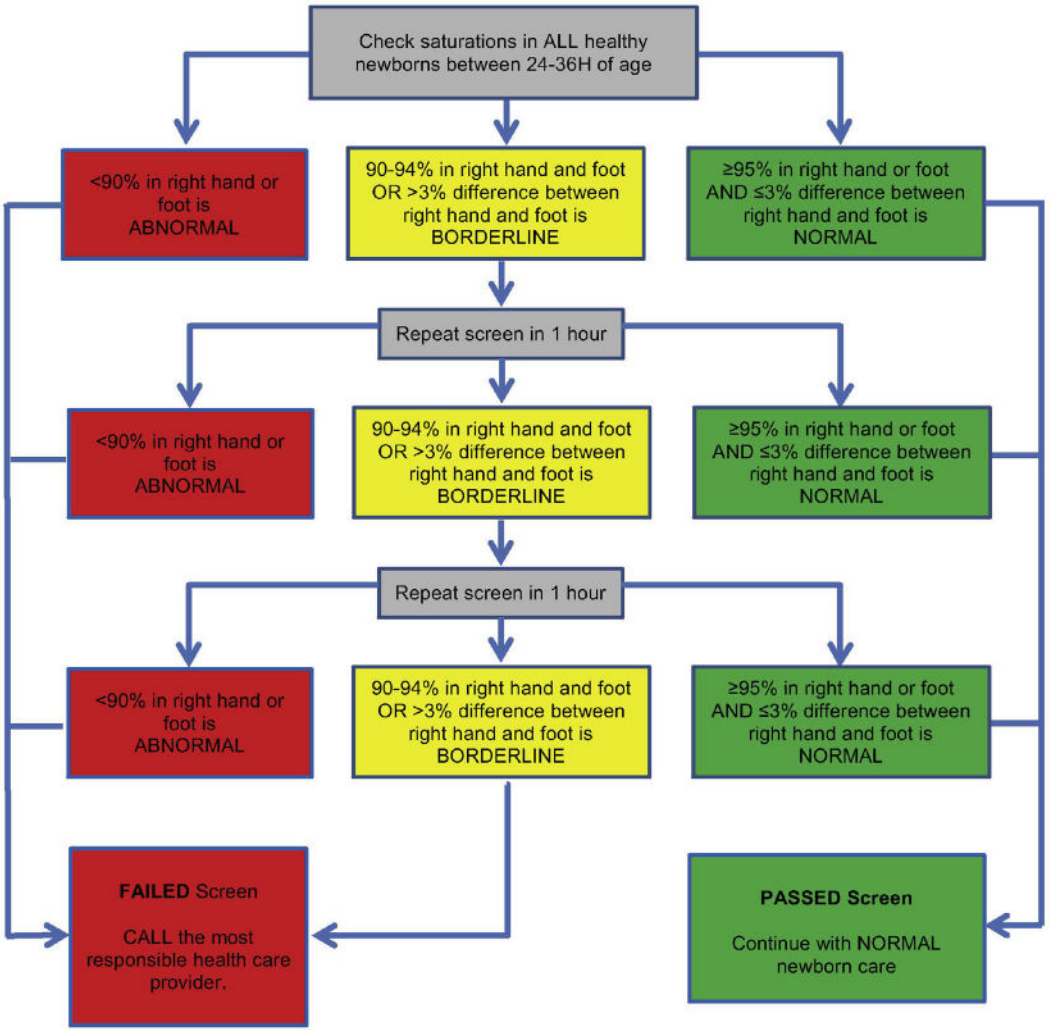

Figure 2. Pulse oximetry screening protocol. Modified from Kemper et al.[20]. Reproduced with permission from *Pediatrics*, Vol. 128:e1259-67. Copyright © 2011 by the AAP.

Practical tip. For centres without cardiology or echocardiography services, consultation with local expertise (a more experienced provider, pediatrician, or neonatologist) and additional testing (electrocardiogram, chest radiography) might be helpful to further reduce false positive screening results.

Pulse Oximetry Equipment Selection

Studies have evaluated a variety of devices for pulse oximetry screening; there is no clear distinction in superiority according to manufacturer. All equipment should meet relevant Health Canada and/or US Food and Drug Administration approval for clinical use and have the latest firmware updates. The use of oximeters that measure functional oxygen saturations, are motion-tolerant, accurate, and function well in lower perfusion conditions is recommended.

Cost Considerations

In a time of limited health care resources, there are challenges to implementing a new screening program. However, this should be paired against evidence that shows that pulse oximetry screening can enhance detection of CCHD, and the cost savings associated with decreasing morbidity and mortality with earlier diagnosis. There is no Canadian data regarding costs with pulse oximetry screening. The 2011 Neonatal Resuscitation Program guidelines states that a pulse oximeter should be available for every birth so equipment and expertise for performing pulse oximetry is already available. The implications related to false positive results has already been discussed, and the use of pulse oximetry screening does not change the current practice that all newborns found to be cyanotic are thoroughly evaluated, which might include consultation with cardiology and the potential need for transportation for further testing.

Studies from the United States and the UK report that pulse oximetry screening for CCHD is cost neutral to cost effective.[7,21,25,26] Costs for screening are variable, with potential costs associated with equipment (pulse oximetry machines, probes), personnel (nursing and physician time), transportation, and additional testing. Net estimated costs

including equipment and labour have been reported to be from $14.09 per newborn screened in New Jersey to $5.10 in Minnesota.[25,26] Estimated costs with reusable probes were considerably less than for use of disposable probes.[25,26]

In New Jersey, pulse oximetry screening costs less than the $20 for newborn metabolic screening and $36-$39 for hearing screening.[26] The estimated cost of a false positive screen requiring transport and echocardiogram examination added only 3% to the cost per newborn, because false positive rates are low.[27] The estimated cost to detect 1 newborn with CCHD was $20,862, and a favourable cost effectiveness of $42,385 per life year gained was estimated if 20 infant deaths were prevented in the New Jersey region per year.[26]

Generalization of the cost benefit of pulse oximetry screening across all regions of Canada is challenging because of varying prenatal ultrasound detection rates and access to newborn echocardiography. Regions with very high prenatal detection rates will benefit less from pulse oximetry screening. One study that applied a cost effectiveness decision analysis model estimated that costs increase steeply when the prenatal ultrasound detection rates reach 85%-90%; this level of detection and cost assessment has yet to be widely reported in clinical practice.[28] Future studies are required to refine the cost effectiveness of screening in Canada.

Pulse Oximetry Screening in Different Settings

Out of hospital screening

Lhost et al. studied the application of pulse oximetry screening to out of hospital births with only 37.5% (449 of 1196) screened. In some communities, only 13% of pregnant women had prenatal ultrasound examinations, highlighting an opportunity for enhanced detection with pulse oximetry. Screening between 24 and 48 hours of age occurred in only 77% of newborns and showed a higher false positive rate of 0.9%.[22] This highlights a need for closer study of factors that limit screening in out of hospital births and a greater awareness of screening protocols.

A survey conducted with licensed midwives in Washington state indicated that 98% were aware of screening recommendations, 52% were currently performing screening, and 21% were in the process of implementing a program. Of those who used screening, 94% did so between the local protocol recommendation at 24-48 hours as opposed to < 24 hours, leading the authors to hypothesize that current midwifery practice for routine follow-up of newborns at 24-48 hours of life allows for this timely assessment.[29] The cost effectiveness of equipping midwives with pulse oximetry equipment has not been studied.

Screening at altitude

With increasing altitude, there is less available oxygen, which results in generally lower mean oxygen saturations. Bakr and Habib[30] reported a mean oxygen saturation of 95.4% at 24 hours in healthy newborns at 1640 m (5380 feet).[2] Altitude might also delay the natural decrease in pulmonary vascular resistance, and lead to lower saturation levels in healthy newborns, and a higher false positive rate; these differences might require modifications to the standard protocols. At 806 m (2643 feet), Han et al. screened 1069 newborns using the standard protocol and identified no significant increase in the false positive rate (0.094%).[31] At 1694 m (5557 feet), Wright et al. observed abnormal screen results in 1.1% of newborns, but did not correlate with echocardiogram data to define true and false positive rates.[32] Pulse oximetry screening can be applied at altitude, accepting higher false positive rates until further studies define the normal saturation threshold at different altitudes.

Implementation Priorities

Successful implementation of pulse oximetry screening requires an organized education program for families and health care providers. Family education should focus on the benefits and limitations of screening, including what to expect if the screen is positive, and signs and symptoms of CCHD to observe for in the case of a false negative result. Health care provider education should be aimed at achieving a high uptake of the screening as well as ensuring correct performance, interpretation, and recording of the screen results. Online education modules have been developed and used with success. Education materials are required to be culturally competent and available in languages that meet the needs of the population.

Successful national implementation of pulse oximetry screening will also depend on the appropriate capture of screening results on a population basis. In the Canadian context, this is best achieved using the provincial newborn screening program resources that are currently in place. The recorded information will need to be sufficient to determine whether all eligible infants are screened and the outcome associated with the screen result, and allow appropriate determination of true and false positive rates. Information about requirements for infant transfer for evaluation and/or treatment should also be collected to evaluate the effect on families and the costs of the program, and to guide implementation of telehealth or related solutions. For negative screen results, it will be essential to capture any subsequent diagnosis of CCHD and the outcomes for such cases to examine the false negative rate and the consequences.

Summary

Pulse oximetry screening has been shown to enhance the detection of CCHD. Pulse oximetry is widely available, noninvasive, easy to perform, and should be viewed as another vital sign. The use of pulse oximetry screening in addition to prenatal ultrasound examination and the newborn physical examination provides optimal screening and best practice for detecting CCHD. Although the false negative rate is very low, with a normal saturation, health care providers should not ignore other signs of CCHD or CHD that require further evaluation. The timing of screening should occur between 24 and 36 hours to decrease false positive results that might have significant implications if transport is required for further evaluation. A rigourous system should be in place to ensure that newborns are screened, and that follow-up occurs for positive or borderline screening results. Pulse oximetry

screening removes the subjective assessment for cyanosis and should be part of newborn screening in Canada. We wish to raise awareness and advocate for the implementation of routine pulse oximetry screening.

Summary of Recommendations

1. We recommend that pulse oximetry screening should be routinely performed in all healthy newborns to enhance the detection of CCHD in Canada (Strong Recommendation; Moderate-Quality Evidence).
2. We recommend that the optimal screening for CCHD should include prenatal ultrasound, physical examination, and pulse oximetry screening (Strong Recommendation; Moderate-Quality Evidence).
3. We recommend that pulse oximetry screening should be performed between 24 and 36 hours of age (Strong Recommendation; Moderate-Quality Evidence).
4. We recommend that pulse oximetry screening should be performed in the right hand and either foot (Strong Recommendation; Moderate-Quality Evidence).
5. We recommend that newborns with an abnormal screening result should undergo a comprehensive evaluation by the most responsible health care provider. If a cardiac diagnosis cannot be confidently excluded, referral to a pediatric cardiologist for consultation and echocardiogram examination is advised (Strong Recommendation; Moderate-Quality Evidence).

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Appendix 1. Chart to aid in the interpretation of pulse oximetry results from the right hand and one foot.

		RIGHT HAND											
		100	99	98	97	96	95	94	93	92	91	90	89
ONE FOOT	100	PASS	PASS	PASS	PASS	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	99	PASS	PASS	PASS	PASS	PASS	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	98	PASS	PASS	PASS	PASS	PASS	PASS	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	97	PASS	PASS	PASS	PASS	PASS	PASS	PASS	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	96	REPEAT	PASS	PASS	PASS	PASS	PASS	PASS	PASS	REPEAT	REPEAT	REPEAT	FAIL
	95	REPEAT	REPEAT	PASS	PASS	PASS	PASS	PASS	PASS	PASS	REPEAT	REPEAT	FAIL
	94	REPEAT	REPEAT	REPEAT	PASS	PASS	PASS	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	93	REPEAT	REPEAT	REPEAT	REPEAT	PASS	PASS	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	92	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	PASS	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	91	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	90	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	FAIL
	89	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL