Impact of Pulse Oximetry Screening to Detect Congenital Heart Defects: 5 Years’ Experience in a Regional Neonatal Unit in the UK

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Research Article

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Abstract

Pulse oximetry screening (POS) has been shown to be an effective and non-invasive investigation that can detect up to 50-70% of previously undiagnosed congenital heart defects (CHDs). The aims of this study were to assess the accuracy of POS in detection of CHDs and its impact on the clinical practice. All the eligible newborn infants born between Jan 2015 and Dec 2019 in busy regional neonatal unit were included in the prospective observational study. Of the 25185 eligible infants, 189 (0.8%) infants had a true positive results: 6 had critical CHDs, 9 serious or significant CHDs, and a further 156/189 infants had significant non-cardiac conditions. 43 infants who had a normal POS were later (post-hospital discharge) diagnosed with following category of CHDs: 1 critical, 15 serious, 20 significant and 7 non-significant CHDs. POS sensitivity for detection of critical CHD was 85.7% and its specificity was 99.3%. However, its sensitivity for detection of all the major CHDs needing surgery during infancy was 33%.

Conclusion

Pulse oximetry screening showed moderate and high sensitivity in detection of undiagnosed critical CHDs, however it failed to detect two-third of the major CHDs. Our study further emphasises the significance of adopting routine POS to detect critical CHDs in the clinical practice. However, it also highlights the need to develop new, innovative methods to detect other major CHDs missed by pulse oximetry screening and other current screening tools.

Introduction

Globally, congenital heart disease, sepsis and lower respiratory tract infections remain the most common causes of neonatal mortality[1]. The prevalence of congenital heart defects (CHDs) is around 7–9 per 1000 live births[2]; they account for just under 50% of deaths from all congenital anomalies, and up to 10% of all infant deaths in the Western world[3], [4]. Critical CHDs (CCHDs), comprising up to 30% of all CHDs, are defined by conditions needing surgery, intervention, or resulting in death, within one month after birth[5]. Most of these defects can be corrected if diagnosed and intervened in a timely fashion; late diagnosis is associated with complications such as acute cardiovascular collapse upon closure of the duct dependent circulation. Poor clinical condition at the time of surgery furthermore worsens outcomes and mortality[6], [7].

Current screening strategies for detection of CHDs are limited, with a significant proportion of infants with CCHDs remaining undiagnosed before discharge from hospital[8], [9]. Fetal anomaly screening involving antenatal ultrasound at 20 weeks can detect only around 50% of all CHDs[10]; what is more concerning is that CCHDs such as coarctation of the aorta have an antenatal detection rate of just 22%[11]. Post-natal clinical examination to assess heart sounds and inspect for visible cyanosis is similarly poor, detecting only 31% of critical CHDs[12]–[14].

The addition of pulse oximetry screening (POS) can improve detection of CCHDs to around 75–90%[12], [13]. Previous studies have shown POS is accurate, cost effective and acceptable to both parents and
clinical staff[4], [12]–[17]. Pulse oximetry screening is based on the rationale that asymptomatic infants with CHDs will have some degree of hypoxaemia that may not be clinically ascertainable, or a difference in oxygen content between pre-and post-ductal circulations[14][18]. It can furthermore detect significant hypoxic non-cardiac conditions, such as sepsis or respiratory conditions[19].

As a result, routine pulse oximetry screening in neonates has been implemented in many countries globally, as well as in around 50% hospitals in the UK despite no recommendation from the UK National Screening Committee (UKNSC)[17][20], [21]. Many POS studies have been published, however studies on postnatal detection and presentation of all CHDs, the impact on clinical practice and what cardiac conditions lead to a false negative POS test result are still lacking. The paper is focused on assessing the accuracy of pulse oximetry screening and impact on clinical practice, including evaluation of postnatally diagnosed CHDs not detected by POS, over a 5-year period at the Rosie Hospital, Cambridge, UK.

Materials And Methods

This was a 5-year prospective observational cohort study involving all 27170 babies born at the Rosie Hospital between Jan 2015 and Dec 2019. Data were analysed retrospectively. Patients were excluded if they were < 35 weeks of gestation, if they were admitted to NICU before 4 hours of age (including babies symptomatic of congenital heart disease), or if they had an antenatal diagnosis of a CHD detected on fetal anomaly screening.

Screening was undertaken routinely by midwives and/or paediatricians on the postnatal ward between 4 to 12 hours of age using a pulse oximeter probe with Masimo's pulse oximeters. Oxygen saturations were taken from the baby's right hand and right foot to obtain preductal and post ductal saturations respectively. A saturation of < 95% in either pre- or post-ductal circulations, or a difference of > 2% between pre- and post-ductal oxygen saturations was classed as abnormal as per the hospital guideline.

Following an initial abnormal result, infants were assessed – pulse oximetry was repeated 1–2 hours later if they were otherwise well with no clinical concerns. The pulse oximetry result was classed as ‘positive’ if the oxygen saturations remained abnormal on a second screen, and these infants were evaluated by a paediatrician for further management. Further clinical details were obtained from the electronic record system, including data on investigations and interventions, respiratory support, infection markers, duration of antibiotics, length of stay, and any follow up in outpatient clinics. False negative tests were identified from a cardiac database of all babies with congenital heart defects born in the Rosie Hospital.

For the study analysis, CHDs were classified as: critical (requiring intervention or resulting in death within 28 days), serious (requiring intervention within 1 year after birth), significant (needing follow up for over 1 year) or non-significant (babies with conditions such as small muscular VSD who had follow-up for less than 12 months). Major CHDs were defined as critical or serious CHDs. Infants with isolated PDA and / or
PFO, expected normal findings on echocardiography at this age, were excluded. Definition for the non-cardiac conditions has been summarised in Table 1. The study was approved by the Clinical Audit department at Cambridge University Hospitals NHS Foundation Trust as per local arrangements for the quality improvement and service evaluation.

Table 1
Definitions of non-cardiac diagnoses in babies with test positive pulse oximetry

| Congenital Pneumonia | Raised inflammatory markers (CRP > 10 mg/L) +/- positive culture needing antibiotics for ≥ 5 days and radiological changes on chest x-ray (CXR) |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Sepsis               | Raised inflammatory markers (CRP > 10 mg/L) +/- positive culture needing antibiotics for ≥ 5 days                                                                 |
| Meconium aspiration syndrome (MAS) | History of meconium staining of liquor, respiratory distress, oxygen requirement for longer than 2 hours, radiological changes on CXR consistent with MAS |
| TTN requiring oxygen | Tachypnoea with radiological changes of fluid retention, oxygen requirement for more than 2 hours and no rise in inflammatory markers or positive culture |

Results

Of 27170 infants born during the study period, 25185 (92.7%) were eligible for pulse oximetry screening and 1985 (7.3%) were either admitted to NICU before screening or had an antenatal diagnosis of CHD. 23614 out of 25185 eligible infants had pulse oximetry screening performed (93.8% uptake). In 1571 eligible infants (6.2%), there were no documented pulse oximetry screening results before discharge from hospital.

Of the 23614 infants who had pulse oximetry screening, 1393 (5.9%) had an abnormal first pulse oximetry screening result. 1033 of the 1393 infants had a normal second pulse oximetry screening result. 360 infants (1.5%) had an abnormal second pulse oximetry screening result and therefore were classified as ‘positive’. 171/360 subsequently had a normal pulse oximetry screening result on further evaluation by the paediatrician, although 2 of these infants were later noted to have a CHD, detected via a heart murmur. The remaining 189 infants (0.8%) had a true positive result as summarised in Fig. 1.

Chds In Infants With Positive Pulse Oximetry Screening Test

Of the 189 infants with true positive pulse oximetry screening test, 64 (33.8%) had an echocardiogram performed, and 21 (11.1%) were found to have a previously undiagnosed cardiovascular abnormality (Table 2). 9 infants had a major CHD (6 CCHDs and 3 serious CHDs) while 6 infants had significant CHDs needing follow up for > 12 months after birth.
### Table 2
Echocardiographic findings and types of CHD in infants with a positive pulse oximetry screening test

| Critical CHDs (6) | Serious CHDs (3) |
|------------------|------------------|
| Hypoplastic left heart syndrome (HLHS) | 1 | Atrio-ventricular septal defects (AVSD) | 3 |
| Hypoplasia of aortic arch | 1 | |
| Interrupted aortic arch (IAA) | 1 | |
| Coarctation of aorta (CoA) | 1 | |
| Critical pulmonary stenosis (PS) | 2 | |

| Significant CHDs (6) | Non-significant CHDs (6) |
|---------------------|--------------------------|
| ASD alone | 1 | Small muscular VSD | 3 |
| Bicuspid aortic valve with ASD | 1 | RV hypertrophy | 2 |
| Ventricular septal thickening with PFO | 1 | Tricuspid regurgitation | 1 |
| Cardiomyopathy with PDA and PFO | 1 | |
| Dysplastic tricuspid valve with PFO | 1 | |
| Dextrocardia with PFO | 1 | |

In our cohort, CCHD cases included coarctation of the aorta (CoA) (1), hypoplastic left heart syndrome (1), hypoplasia of the aortic arch (1), interruption of the aortic arch (1), and critical pulmonary stenosis (2). 5 infants with critical CHD were transferred to a cardiac surgical centre, requiring surgery or medical intervention within one month after birth, most of them within a week after birth. One infant with the diagnosis of hypoplastic left heart syndrome went into palliative care after careful discussion with parents who did not wish for them to have any further surgical intervention. All 3 infants with serious category CHDs had surgical intervention within 12 months after birth.

In total, 21 infants with cardiovascular abnormality on initial echocardiography required followed up in the outpatient clinic, and of these, 11 have been discharged at a median age of 409 days (range 7 days – 3 years) whilst 10 are still under follow up. One baby with a significant CHD died in this cohort: this was attributed to a genetic TTN13 related cardiomyopathy.

### Chds In Infants With Negative Pulse Oximetry Screening Test

In total, 43 patients with a postnatal diagnosis CHD had a negative pulse oximetry screen. 21/43 were found to have a heart murmur on newborn physical examination. 9 of these infants had serious CHDs
such as CoA and Tetralogy of Fallot, requiring surgery within first year of life, while 8 had significant CHDs requiring follow up for >12 months.

22/43 infants had negative pulse oximetry screening and a normal physical examination of the newborn. Most of these infants were found to have a heart murmur on routine examination in the community within 8 weeks after birth or had an outpatient echocardiogram arranged for family history of CHD (Table 3). Fortunately, of these 22 infants, only 1 infant had a CCHD. This infant presented in a state of collapse at 12 days after birth and was found to have critical coarctation of aorta and VSD. 6/22 infants had serious CHD needing surgery within their first year of life, while 12/22 had significant CHDs needing follow up for >12 months (Table 4). There were no deaths amongst babies with a postnatally diagnosed CHD and negative pulse oximetry screen.

Table 3
Presentation of infants with postnatal diagnoses of CHDs and normal pulse oximetry screening test

| Severity of CHD | Critical | Serious | Significant | Non-significant | Total |
|-----------------|----------|---------|-------------|----------------|-------|
| Heart murmur detected on newborn physical examination | 0        | 9       | 8           | 4              | 21    |
| Heart murmur after discharge from hospital | 0        | 6       | 6           | 1              | 13    |
| Family history of CHD | 0        | 0       | 1           | 2              | 3     |
| Inpatient echocardiography (for other unrelated cause) | 0        | 0       | 1           | 0              | 1     |
| Pulse irregularity | 0        | 0       | 1           | 0              | 1     |
| Collapse | 1        | 0       | 0           | 0              | 1     |
| Outpatient echocardiography for syndromic screening (T21, William's) | 0        | 0       | 3           | 0              | 3     |
| Total | 1        | 15      | 20          | 7              | 43    |
Table 4
Postnatal diagnoses of CHDs in infants with normal pulse oximetry screening test

| Congenital heart diseases diagnosed in infants with a negative pulse oximetry screen |
|---------------------------------|-------------------------------------------------|-----------------|
| **Critical CHDs (1)** | **Serious CHDs (15)** |     |
| Coarctation of aorta (CoA) | 1 | Atrio-ventricular septal defects (AVSD) | 3 |
| Partial anomalous pulmonary venous connection (PAPVC) with sinus venous type large ASD | 1 |
| VSD | 5 |
| CoA | 1 |
| Tetralogy of Fallot (TOF) | 3 |
| Dysplastic pulmonary valve with pulmonary stenosis | 1 |
| Aortic stenosis | 1 |
| **Significant CHDs (20)** | **Non-significant CHDs (7)** |     |
| ASD | 2 | Small muscular VSD | 7 |
| VSD | 8 |
| Mild pulmonary stenosis | 7 |
| VSD with mild pulmonary stenosis | 1 |
| Aortic arch narrowing | 2 |

HLHS – hypoplastic left heart syndrome, CoA – coarctation of aorta, IAA – interrupted aortic arch, PS – pulmonary stenosis, ASD – atrial septal defect, VSD – ventricular septal defect, PDA – patent ductus arteriosus, PFO – Patent foramen of ovale, TOF – Tetralogy of Fallot, PAPVC - Partial anomalous pulmonary venous connection

Positive Pulse Oximetry And Significant Non-cardiac Conditions

156/189 neonates (83%), including 11 infants with CHDs, had a significant non-cardiac diagnosis needing further intervention (Table 5). Overall, 138/189 (73%) infants required admission to NICU (including 7/10 babies who had CHD alone).
### Table 5
**Respiratory support and antibiotic therapy in infants with a positive pulse oximetry screening test**

| Clinical parameters of NICU admission | Number of patients | Median length (days) | Minimum duration (days) | Maximum duration (days) |
|---------------------------------------|--------------------|----------------------|-------------------------|-------------------------|
| Mechanical ventilation                | 7                  | 3                    | 0                       | 6                       |
| CPAP/HFNC                             | 80                 | 2                    | 0                       | 18                      |
| Low flow oxygen                       | 34                 | 2                    | 0                       | 5                       |
| Antibiotics                           | 156                | 5                    | 2                       | 19                      |
| Days of hospital stay                 | 6                  | 2                    | 2                       | 26                      |

Of the 156 infants with non-cardiac conditions, 103 (66%) patients had a chest X-ray, and 103 (66%) required oxygen therapy during their stay for a median of 2 days (range 1–18 days). 7 (4.5%) infants required mechanical ventilation (median 3 days, range 1–6 days) while 80 (51%) patients required non-invasive respiratory support (continuous positive airway pressure (CPAP) or high flow nasal cannula (HFNC) therapy; median 2 days, range 1–18 days)) and 34 (22%) infants required low flow oxygen therapy (median 2 days, range 1–5 days).

Most infants had more than one significant documented problem: 126 had neonatal sepsis (with either a significant rise in inflammatory markers (CRP > 10) or required antibiotics for > 5 days), 7 patients had a positive blood culture, and 25 infants were found to have congenital pneumonia. 10 infants had a small pneumothorax (managed conservatively with no infant requiring a chest drain) while another 10 infants had a diagnosis of meconium aspiration syndrome. 9 infants were noted to have persistent pulmonary hypertension of newborn (PPHN). 22 infants were categorised to have respiratory distress syndrome and 13 to have transient tachypnoea of the newborn.

23/189 (12%) infants had symptoms of respiratory distress and were given antibiotics for 2 days but had no significant rise in inflammatory markers or any other significant pathology detected.

### Discussion

Globally, many research studies have been performed on pulse oximetry screening for detection of critical CHDs\[4], [12]–[14], [18], [19], [22]. Most have focused on the detection of CCHDs and non-cardiac conditions by POS: there remains a paucity of data on missed cases of CCHD and major CHDs not detected by pulse oximetry screening. The biggest strength of our study is that it describes the postnatal diagnoses of all types of CHDs in infants with both positive and negative pulse oximetry screening results over a 5-year period.
In our study of 23614 newborns, 0.8% had a positive POS result, consistent with previous studies\cite{12}, \cite{14}. In total, 64 infants had a postnatal diagnosis of CHDs, including 7 cases of CCHDs. Sensitivity of POS varied from 85.7% for detection of CCHD to just 33% for detection of major (critical and serious) CHD, and specificity was 99.3%. Pulse oximetry screening was able to identify 6/7 (85.7%) cases of CCHDs prior to discharge from hospital. When used in conjunction with physical examination of the newborn, 65.6% of major CHDs were diagnosed prior to discharge from the hospital.

Despite previous studies showing that POS is a low cost, effective measure\cite{13}, \cite{16}, \cite{23}, \cite{24}, routine pulse oximetry screening is not currently recommended by the UKNSC\cite{17}, \cite{21}, \cite{25}. Their argument was that most test positive babies did not have congenital heart disease, yet around half of these test positive babies were diagnosed with other significant clinical conditions such as respiratory problems or infections. In our cohort, pulse oximetry screening similarly detected a large number (156/189) of significant non-cardiac conditions, such as neonatal sepsis, requiring admission to NICU, respiratory support, antibiotics or other interventions. Earlier intervention in these cases is also likely to produce better outcomes in terms of morbidity and mortality, and thus early diagnosis of these conditions is likewise of importance\cite{12}. Pulse oximetry screening is therefore a valuable tool not only for the detection of CHDs but also for the early diagnosis of non-cardiac conditions in asymptomatic infants.

There has also been concern that POS may be difficult to implement in district general hospitals where echocardiography cannot be routinely performed and could significantly add to workload. In our study, echocardiography was performed in 33.8% test positive babies, and of these, 32.8% had a cardiac abnormality. Singh et al., 2014\cite{12} reported that echocardiography following a positive POS was more favourable for detection of CHD compared to echocardiography following murmur, with one critical CHD identified per 100 echocardiograms for murmur and one CCHD per 6.8 echocardiograms for pulse oximetry screening\cite{24}. Furthermore, a recent UK survey reported 78% neonatal units felt screening did not increase the number of unnecessary investigations, and 10% felt this increase was justified by the benefits of identifying considerable cardiac pathology\cite{17}.

However, as with any screening programme, POS has its limitations. Most importantly, not all CCHDs can be detected with pulse oximetry screening. Despite current screening practices (including POS), timely diagnosis is missed in approximately 900 (15%) infants with CCHD annually in the United States\cite{26}, \cite{27}. In our cohort, 1 case (14%) of critical CHD (critical coarctation of aorta) and 15 cases (83%) of serious CHDs had negative POS and were not detected before discharge. A simulation study estimates that of undiagnosed CCHD, 15% would be missed by pulse oximetry screening: acyanotic CHDs such as TOF and CoA are among the conditions most likely to be missed by POS as they do not cause hypoxaemia \cite{8}, \cite{26}. This was similarly demonstrated in our study population, where the major defects missed were TOF, VSD and CoA.

Another limitation of our study was the high false positive rate of 0.7%, compared to the rate of 0.14% in previous studies\cite{4}. This is likely explained by the fact that our screening programme involves performing pulse oximetry screening between 4–12 hours after birth. It is better to detect critical CHDs as soon as
possible after birth, but false positivity is also greatest when pulse oximetry screening is performed < 24h age: differential saturations may be falsely high < 24h owing to the high pulmonary artery pressure and patent duct[22], [28]. There remains a challenge in balancing optimal timing of screening with the increasing tendency to discharge apparently healthy babies before 24h age[22].

Further Research

Our study emphasises on the significance of adding routine pulse oximetry screening to detect CCHDs in clinical practice. However, two-thirds of major CHDs were not detected before discharge. Hence, further research is required to find optimal methods to enhance diagnosis of these missed cases, particularly for acyanotic serious congenital heart defects. Recently, Doshi et al., have published a promising role of adding non-invasive pulse oximetry measurements such as perfusion index (Plx), radiofemoral pulse delay (f-hTD), and waveform analysis in improve detection of such cases[29]–[33], but further study in larger trials is required to ascertain the clinical impact.

Conclusions

In conjunction with antenatal fetal anomaly screening and physical examination of newborn, pulse oximetry screening can play an important role in early detection of critical congenital heart defects, as well as non-cardiac conditions such as sepsis, pneumonia, and other significant pathologies. Our study adds further evidence for implementation of routine pulse oximetry screening to detect critical CHDs. However, there remain concerns that up to 15% of the critical CHDs and a significant proportion of other major CHDs may still be missed prior to discharge from hospital. There is an urgent need of further research in the role of innovative methods such as perfusion index, waveform or artificial intelligence to enhance early detection of these major CHDs that are missed by current screening tools of fetal anomaly screening, newborn physical examination and pulse oximetry screening.

Abbreviations

- CHD
  Congenital heart defects
- CCHD
  Critical congenital heart defect
- CoA
  co-arctation of the aorta
- CPAP
  continuous positive airway pressure
- CRP
  C reactive protein
- CXR
  chest X ray
Declarations

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Figures

Figure 1

Flow chart showing uptake of pulse oximetry screening and diagnoses of CHDs in infants with positive and negative pulse oximetry results.