Received: 24 May 2018 | Revised: 13 July 2018 | Accepted: 27 June 2018
DOI: 10.1111/chd.12654

ORIGINAL ARTICLE

WILEY Congenital Heart Disease

Is pulse oximetry helpful for the early detection of critical congenital heart disease at high altitude?

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Funding information
The authors declare that the financial resources for the elaboration of the present investigation do not come from any fund, but from their self-management.

Abstract

Objective: To assess the pulse oximetry as a method for screening critical congenital heart disease (CHD) in newborns.

Study design: This is an observational, transversal, descriptive simple study. The preductal and postductal saturation were taken in term newborns that fulfilled the criteria of inclusion and exclusion in the Hospital Gineco-Obstetrico Isidro Ayora (HGOIA) in Quito. These measurements were performed between the 24 and 48 h after birth. Those newborns that saturated less than 90% on initial pulse oxìmetry underwent 3 successive measurements at 1-h intervals. Those who saturate less than 90% after 3 measurements or have a difference higher than 3% in preductal saturation and postductal saturation (positive screening) underwent transthoracic echocardiography evaluate for CHD.

Results: Pulse oximetry from 963 newborns was evaluated. In Quito, at an altitude of 2820 meters above sea level (9252 feet), the mean preductal saturation was 92.76% (SD ± 3) and the postductal saturation, 93.76% (SD ± 4.7). Pulse oximetry in 53 patients (5.5%) was classified as a positive screening. No critical congenital heart diseases were found. Atrial septal defect (ASD) was the most common finding in a 46.94% (n = 23), followed by the association of patent ductus arteriosus (PDA) and ASD with a 12.24% (n = 6).

Conclusion: In this cohort of patients who underwent screening pulse oximetry, no critical congenital heart diseases (CHD) were observed. However, identifying those with oxygen saturation less than 90% after 3 successive measurements or a pre- and postductal oxygen difference of > 3% resulted in successful identification of ASD and PDA. It is necessary to implement new cutoff points in saturation values to identify critical cardiac anomalies in cities placed at a high altitude. The use of pulse oximetry should be recommended in all the newborns.

KEYWORDS
critical congenital heart disease, early detection, Ecuador, high altitude, newborns, pulse oximetry

1 | INTRODUCTION

Reported prevalence of congenital heart diseases (CHD) at birth is 2 to 13 per 1000 live births[1,2]; of those, critical congenital heart defects (CCHD) represents 1.2–1.7 per 1000 live births (10%–15%).[2] It has been also estimated that 0.8% of newborns have specific cardiovascular defects.[3,4] All of them represent 10% to 25% of admissions to hospitals in Latin America (LATAM) during infant age, usually require invasive medical intervention within the first month of life and can lead to death or significant morbidity if are not diagnosed in a proper time.[5] Early detection may decrease the incidence of heart failure, growth retardation, neurodevelopment delay, even death, and it is important for reducing the mortality and improving the postoperative outcome.[6,7] Some countries have recommended neonatal pulse oximetry to identify critical CHD.[8,9]

CCHD are those which can cause death or require surgery within first 28 d of life, and they are: hypoplastic left heart syndrome (HLHS), pulmonary atresia (PA), transposition of great arteries (TGA), interrupted aortic arch, critical coarctation of the aorta (CoAo), critical aortic valve stenosis, tetralogy of Fallot (TF), Total anomalous pulmonary venous connection (TAPVC), tricuspid atresia (TA) and troncus arteriosus.[10]

Pulse oximetry (PO) is widely available, simple, safe, noninvasive and accurate method to objectively quantify oxygen saturations (SpO), and thereby identify the clinically undetectable hypoxaemia that occurs in the majority of neonates with CCHD.[9] Most of CCHD present some degree of hypoxemia which not necessarily produces visible cyanosis; therefore it cannot be detected by physical examination. PO has a sensitivity of 76.5% and a specificity of 99.9% to detect CCHD with a rate of false-positive of 0.14%. If the measurement of PO is taken after 24 h of life, false-positive cases decrease.[6,11,12]

In the other hand, echocardiography is considered the gold standard to identify CHD, but it is expensive and not always available, especially in low-income countries as Ecuador.[7,13] Routine fetal ultrasound screening has led to increased antenatal detection of around 50%–70% of all CCHD.[14–16] Early studies assessing neonatal PO screening for CCHD demonstrated proof of concept. This led to a recommendation in 2011 by the US Secretary of Health and Human Services to add CCHD screening to the recommended uniform screening panel, which was also endorsed by the American Academy of Pediatrics.[7,17–19] The aim of this paper is to assess PO as a method for screening CCHD in newborns, at high altitude, in Quito, at 2820 meters above sea level (masl) or 9252 feet.

2 | SUBJECTS AND METHODS

2.1 | Study design

Observational, cross-sectional study.

2.2 | Sampling

Term gestation newborns from 24 to 48 h of life were selected at Hospital Gineco-Obstetrico Isidro Ayora (HGOIA) in Quito, without sex distinction, during four months period. Inclusion criteria were: healthy newborn at 24–48 h of life; they could be borne by vaginal or cesarean mode; term gestation, 37 to 41 wk and 6 d, based on a trustable date of the last period or obstetric echography performed before 20 wk of gestational age; adequate weight using growth Babson curves in the Ecuadorian standards; without symptoms of respiratory distress, defined as tachypnea with 60 breaths per minute, nasal flaring, intercostal or subcostal retractions, or presence of respiratory grunting. Exclusion criteria were premature newborns of gestational age less than 37 wk, neonates with respiratory distress, congenital heart anomalies previously diagnosed, inadequate perfusion or presence of central cyanosis; with pulmonary, infectious, gastrointestinal diseases or previously known heart disease; with APGAR less than 7 in the first minute of life; with other major congenital defects, chromosomal disorders, or dysmorphic syndromes; all of them were excluded.

2.3 | Methods

Design and elaboration of the formulary in which data is collected; measure oxygen saturation to selected patients; PO measurement between 24 and 48 h of life. This strategy will help to avoid influence of the transition from fetal life to neonatal life and also the influence of the closure of ductus arteriosus on saturation levels. Preductal saturation was taken on the right superior limb at the palm of the hand and postductal saturation on the left lower limb at the sole of the foot. The value obtained was recorded when the oximeter plethysmographic waveform was stable. Levels of saturation were recorded after 30 seconds of having an adequate waveform Neonate needed to be in supine position during the saturation was taken. They needed to be calm, awake, and not crying or eating at that time. These strategies were placed to reduce the probability of low saturation levels due to hypoventilation during deep sleep or errors to get appropriate data of saturation levels. A vital signs monitor EDAN M3 (Edan Instruments, Shenzhen, China, 2010) that uses PO method was used. This monitor measures different absorption spectra of reduced hemoglobin and oxyhemoglobin. See Figure 1.

2.4 | Registry of saturation values

A negative screening was defined as oxygen saturation ≥ 90% in each extremity or when a difference ≤ 3% existed between preductal and postductal saturation. A positive screening was considered when a neonate saturated less than 90%; or if there was a difference of ≥ 3% between preductal and postductal saturation in 3 measures, each one separated by 1 h from the previous measurement. Newborns with positive screening underwent a transthoracic echocardiogram performed by a trained specialist with a Terason t3000 echocardiography machine (Teratech Corporation, Burlington, MA) to confirm the presence or absence of CCHD. Defects considered were: hypoplastic left heart syndrome, pulmonary atresia, tetralogy of Fallot, total anomalous pulmonary venous connection, transposition of great arteries, tricuspid atresia, troncus arteriosus, a critical coarctation of the aorta, critical aortic valve stenosis and Interrupted aortic arch.

2.5 | Data analysis

Data were analyzed using the software Statistical Package for the Social Sciences, SPSS, IBM, Armonk, New York. To each one of the selected variables descriptive and inferential statistics were calculated.

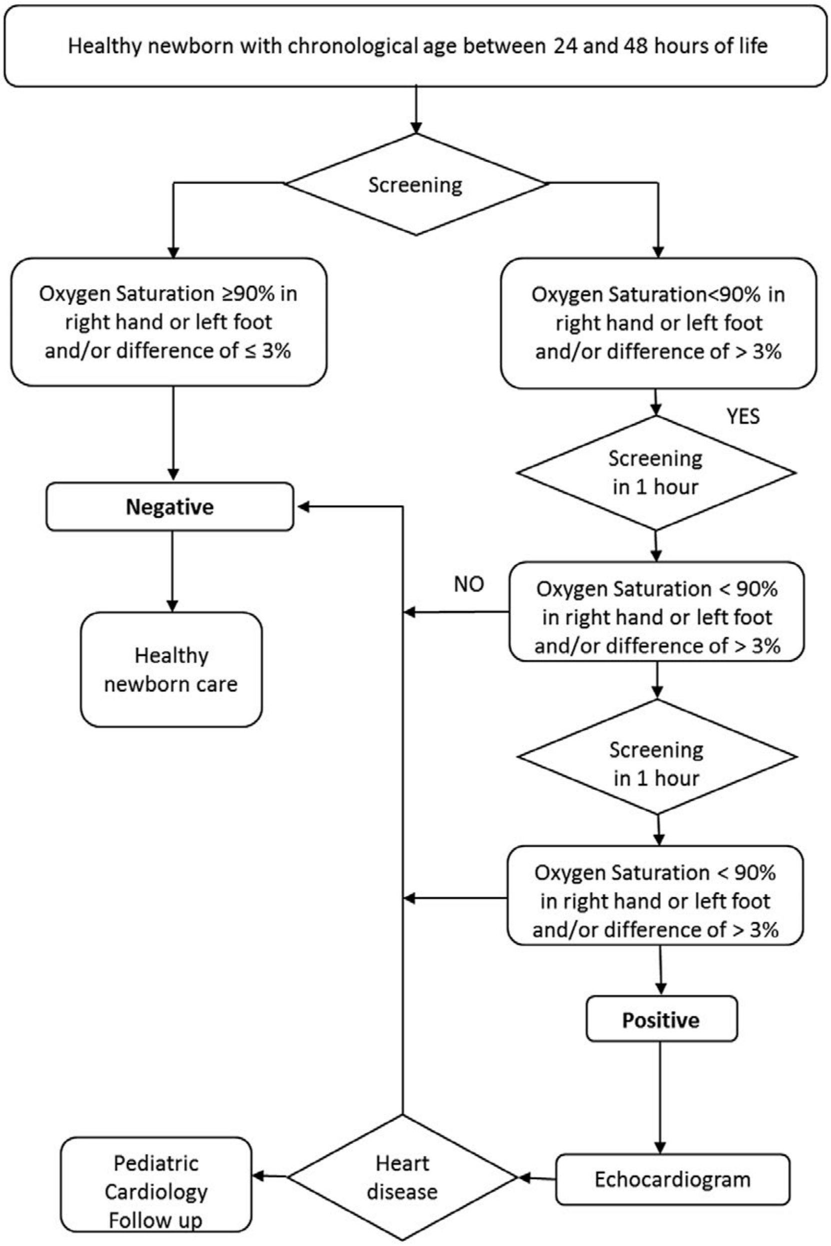

FIGURE 1 Pulse oximetry algorithm for healthy newborns at term at high altitude. Source: Study. Elaboration: Authors

To stablish an association between variables, correlation tests were performed. To calculate the statistical significance a value α of 1.96 ($P < .05$) was accepted. Results are presented in Tables 3 and 4.

2.6 | Ethical values

Autonomy principle was applied using the informed assent formulary previously approved by the authorities of Universidad Central del Ecuador and HGOIA in Quito. The authors interviewed mothers of all the newborns included in this study respecting their privacy right. The objective of the study was explained. Then it was indicated that a noninvasive method was going to be used and this was not going to cause any damage to detect possible heart anomalies with a clear and understandable language accomplishing with the principles of beneficence and nonmaleficence. Results of the screening were informed immediately to all the mothers keeping strict confidentiality of the names and data obtained accomplishing the principle of justice. In the same way, mothers whose newborns had a positive screening were notified to perform an echocardiogram in the following days. A written inform of the echocardiogram was delivered to parents of newborns and also to the secretary of neonatal care unit of HGOIA on digital and printed version. Follow-up of neonates with positive echocardiography was done by pediatric cardiology accomplishing with the principle of social and health responsibility.

3 | RESULTS

PO from 963 newborns was measured. Females represented 50.9% (n = 490). Gestational age presented more frequently corresponds

TABLE 1 Distribution of preductal and postductal oxygen saturations

	Preductal saturation 1st measurement (%)	Preductal saturation 2nd measurement (%)	Preductal saturation 3rd measurement (%)	Posductal saturation 1st measurement (%)	Postductal saturation 2nd measurement (%)	Postductal saturation 3rd measurement (%)
N	963	159	80	963	159	80
Mean	92.77	90.09	89.20	93.76	91.30	90.14
Stand. dev.	± 3.03	± 4.53	± 3.53	± 2.83	± 4.74	± 3.88
Median	93	91	89	95	93	89
Mode	94.0	92.0	88.0	95.0	93.0	89.0
Min value	76.0	60.0	79.0	79.0	50.0	79.0
Max value	100.0	98.0	96.0	100.0	98.0	96.0

Elaborated by: Authors.
[a] Source: Study data.

to a range between 39 to 40 wk and 6 d with 52.9% (n = 509). Vaginal delivery was predominant over births by cesarean with 38.3% (n = 369). Weight was mainly between 15th percentile and 90th percentile 15 and 50 percentile of the growth charts in 47% of subjects (n = 453). Oxygen saturation was measured between 24 and 36 h of life in 60.5% of the cases (n = 583).

In Quito at 2820 meters above sea level (9252 feet), preductal saturation had a mean value of 92.77% (SD 3) and postductal saturation had a mean value of 93.76% (SD 2.83). The minimum value of oxygen saturation presented in this study was 60% in preductal measurements and 50% in postductal measurements, see Table 1.

Patients who obtained negative screening were 910 (94.5%), positive screening 53 (5.5%) showed oxygen saturation less than 90% preductal or postductal or both in the three measurements recorded. The echocardiography was done to 49 neonates (92.5%) who met criteria for positive screening. Echocardiography was not done in four patients (7.5%). 14 of 49 (28%) had a 3% or greater saturation differential between pre- and postductal saturations newborns with a positive screening. Ten of them had a pathologic echocardiogram. Of the 35 neonates who did not present a differential saturation higher than 3%, 30 newborns had abnormal echocardiograms. There was no significant difference in these two groups with a $P = .258$ ($P < .05$, IC 95%)

Of the echocardiograms performed, nine (18.37%) presented normal cardiac anatomy and function, 40 (81.63%) show the evidence of noncyanotic heart defects. Atrial septal defect (ASD) occurred in 23 cases (46.96%), followed by PDA in 12.24% (n = 6). In 3 patients (6.12%) PDA with left to right shunt was visible. Three echocardiograms showed right to left shunt through a patent foramen ovale, one of them (2.04%) associated to mild pulmonary insufficiency and the remaining two only had foramen ovale (18.37%). There were no cases of critical congenital anomalies found, see Table 2

Of the 963 neonates included in this study, 583 were saturated within 24–36 h of life. From this last group 28 presented positive screening and 555 negative screening to detect CHD. There was no significant difference in these groups $P = .377$ ($P < .05$, IC 95%). There was light female predominance versus male among neonates

TABLE 2 Main findings

Finding	n= (%)
Normal	9 (18.37)
Foramen ovale	2 (4.08)
Foramen ovale + mild pulmonary insufficiency	1 (2.04)
PDA	3 (6.12)
ASD	23 (46.94)
ASD + PDA	6 (12.24)
ASD + rhythm disorder	2 (4.08)
ASD + false tendon in LV	2 (4.08)
Mitral insufficiency	1 (2.04)
Total	49 (100)
Critical congenital heart diseases	0

Abbreviations: ASD, atrial septal defect; LV, left ventricle; PDA, patent ductus arteriosus.
Elaborated by: Authors.
Source: Study data.

with negative screening (n = 464 vs n = 446) and male vs female among neonates with positive screening (n = 27 vs n = 26). There was no significant difference in these groups $P = .784$ ($P < .05$, IC 95%). Neonates with negative screening born by vaginal delivery were n = 560. From the group of 53 neonates with positive screening, 34 were born by vaginal delivery and 19 by cesarean section. There was no significant difference in these groups $P = .704$ ($P < .05$, IC 95%). The majority of the screened newborns belong to the group of 39 to 40 wk 6 d of gestational age (n = 483 and n = 26 negative and positive screening, respectively). There was a significant statistical difference among the groups of gestational age compared with the screening results $P = .027$ ($P < .05$, IC 95%), see Table 3.

Most of the neonates with positive screening for CHD was found in the group of preductal saturation of less than 90% (n = 44), only 9 neonates were found in the group of more than 90%. There was a significant difference in the groups $P = .0001$ ($P < .05$, IC 95%). Regarding postductal saturation, those with positive screening were found in the group of less than 90% (n = 32), 21 of them in the group

TABLE 3 Comparison of the findings of the screening for critical congenital heart diseases with sex, way of birth, gestational age, and weight percentiles

		Screening for CCHD			
		Positive	Negative	Total	*P* <.05
Age in hours	24–36 h	28	555	583	.337
	37–48 h	25	355	380	
	Total	53	910	963	
Sex	M	27	446	473	.784
	F	26	464	490	
	Total	53	910	963	
Way of birth	Vaginal	34	560	594	.704
	Cesarean	19	350	369	
	Total	53	910	963	
Gestational age	37–38,6	15	329	344	.027
	39–40,6	26	483	509	
	41–41,6	12	98	110	
	Total	53	910	963	
Weight (percentiles)	3–15	6	215	221	.160
	15–50	28	425	453	
	50–85	18	239	257	
	85–97	1	31	32	
	Total	53	910	963	

Elaborated by: Authors.

Source: Study data.

TABLE 4 Comparison of the screening findings for CHD values of preductal and postductal oxygen at high altitude

	Preductal saturation 1st measure			
Screening for CHD	Less than 90 %	Equal or higher than 90 %	Total	*P* <.05
Positive	44	9	53	.0001
Negative	72	838	910	
Total	116	847	963	
	Postductal saturation 1st measure			
	Less than 90 %	Equal or higher than 90 %	Total	p
Positive	32	21	53	.0001
Negative	42	868	910	
Total	74	889	963	

Elaborated by: Authors.

Source: Study data.

of more than 90%. There was significant difference in the groups *P* = .0001 (*P* <.05, IC 95%), see Table 4.

4 | DISCUSSION

Quito is located at high altitude, at 2820 meters (9252 feet). 963 neonates were evaluated with PO to detect CCHD. The distribution corresponding to each sex was equitable, although there is a slight predominance of females. The measurements were done more often in the group of children who were born at 39–40 wk and 6 d of gestational age, who were born through vaginal canal, within percentiles 15–50, and those who were 24–36 h of life.

Data published in the last Ecuadorian population census elaborated by INEC (Statistics and census Ecuadorian National Institute) in 2010 shows predominance of female over male in ecuadorian population, which corresponds to this study results. In the same way, this study data matches with statistics information of HGOIA regarding info about vaginal way of birth which occurs more frequently. There are studies about the use of oxygen saturation to detect CHD in healthy newborns in which saturation was taken within 6–12 h of life, or the study, that saturated newborns within 2–24 h of life. Unlike the studies previously described, regarding chronological age, a proposed protocol to saturate within 24–48 h of life to detect critical CHD was fulfilled. This protocol acknowledges that it is better to perform the screening after 24 h of life and before 48 h of life. In this way, the number of false-positive cases diminishes because initial neonatal adaptation to the environment could affect early measurement of oxygen saturation as well as the closure of the patent ductus arteriosus in late measurement.

4.1 | Preductal and postductal oxygen saturation values in Quito

All the neonates included in this study were born in Quito at 2820 meters above sea level (9252 feet). They presented a mean preductal oxygen saturation of 92.77% (SD 3) and 93.76% (SD 2.83) of postductal saturation. The levels of oxygen saturation found in this study are lower than those found at sea level. It is known that oxygen saturation is lower at high altitude. This is because the barometric pressure lowers as the elevation increases and this produces reduction of the partial oxygen pressure, so there is a proportional inverse relationship between altitude and oxygen saturation. The study carried out in neonates at term, established that the saturation at 150 meters above sea level (492 feet) is 91.10% ± 0.5% at 15 min of age and at 4340 meters above sea level (14 238 feet) is 87.56% ± 1.19% at 30 min of life. Other researchers, at 2640 meters above sea level (8661 feet), published saturation values of 93.3%; Salas and cols. in La Paz, Bolivia in 2008 at 3665 meters above sea level (12 024 feet) evidenced values of saturation in healthy newborns of 88.2% at 24 h of life. In El Alto, Bolivia at 4018 meters above sea level (13 182 feet) a saturation of 87.3% among infants younger than 5 months old was described. In other study that healthy newborns at term in Quito saturate 91.05% ± 2.06% (88.99%–93.11%) between 6 and 48 h of life. If the results in this study are correlated with the studies previously showed, similitudes might be seen. It is completely feasible that healthy newborns at term saturate less than 90%, proving that at high altitude, oxygen saturations will be lower.

4.2 | Differential saturation between preductal and postductal saturation

This study did not find significant statistical difference between preductal and posductal saturation. This is because the cardiology findings did not find critical congenital heart diseases ductus-dependent of systemic circulation. This means those heart diseases with right to left shunt, like CoAo, aortic stenosis or aortic arch interruption. For the clinical suspicion of these congenital heart anomalies, ductus-dependent, there should be a differential higher than 3% between preductal and postductal saturation. In a study with 200 healthy newborns, about the viability of pulse oximetry to detect critical ductus-dependent CHD reported the utility of such difference for the diagnosis, especially in cases of aortic coarctation ductus dependent with a sensitivity of 82.4% and specificity of 96.0%.

4.3 | Echocardiography findings

This study did not find critical congenital heart diseases using oxygen saturation. Some studies reflect low incidence in this type of heart diseases. The study performed with 39 821 neonates reported incidence of 1.3 per each 1000 newborns. Another study performed in California with a total of 13 714 neonates reported 8 cases with positive screening, 2 of them showed critical congenital heart disease, tetralogy of Fallot and Ebstein anomaly. In Saxony, Germany, with 41 445 neonates researchers presented 14 cases of critical congenital heart disease detected by screening. In one study published with 1069 patients did not find critical congenital heart disease. In a prospective study with 122 738 newborns detected 185 cases of critical congenital heart diseases. A published systematic review and a meta-analysis of 13 studies gathering 229 421 neonates reported 118 cases of critical congenital heart diseases. All these studies explain the low incidence of critical congenital heart diseases that is been sought by the oxygen saturation protocol proposed in this study. This also explains that the number of cases obtained in this study was insufficient to find any of these heart diseases, nevertheless, this does not mean that oxygen saturation is not useful to screen for critical heart diseases. This is because it has been demonstrated in some studies the usefulness of this protocol to detect this heart diseases in early stages of life. Some organizations have recommended the use of pulse oximetry to detect critical heart diseases with the objective to minimize nondetected cases and lower the sequels by late detection· It is important to mention that this study detected noncyanotic congenital heart diseases, that while these are not sought by the screening, they deserve follow up because of the long-term repercussions and the morbidity of patients.[20]

4.4 | Screening for critical heart disease and chronological age

This study did not find significant statistical difference regarding time (hours of life) in which the screening was performed. The screening was done between 24 and 48 h of life to diminish the number of false-positive therefore dropping high costs of nonjustified echocardiograms. International protocol to search for congenital heart diseases recommends doing it not before 24 h of life and it must be completed at the second day of life. Early screening is the cause of false-positive cases. Therefore, false-positive cases would be neonates who saturate less than 90% not for cardiac cause but due to the transition from fetal circulation to neonatal circulation because of the establishment of systemic saturation levels and decrease in vascular pulmonary resistance. On the other hand, late screenings, those taken after 48 h of life are affected by the closure of ductus arteriousus. This issue was indicated by a systematic review and meta-analysis, in which it was found to increase the number of false-positive cases in screenings performed before 24 h since birth compared to those performed after 24 h of life.

4.5 | Screening for critical heart disease and gestational age

Regarding gestational age in which saturation measurements were taken, this study found significant statistical difference. A researcher with 189 healthy newborn at term and preterm older than 34 wk of gestational age did not find significant statistical difference between preductal and postductal saturation compared to gestational age.

Opposite to other studies findings, this study found significant statistical difference in gestational age. This fact is striking because screening was performed only in neonates at term. There is not a clear explanation for such finding. It is difficult to extrapolate this fact because pathologies detected in this study are not sought by screening. There is the need to research more specifically about this subject.

4.6 | Screening for critical heart disease and weight at birth

This study demonstrated absence of significant difference in birth weight compared to screening. Other studies also showed there is no significant difference of the saturation values and the weight at birth. This agrees with this study establishing that weigh at birth is not determinant in saturation. This is due, like it was explained before, oxygen saturation depends on reduced hemoglobin absorption and it is affected by factors like altitude, anemia, and increase in red cells concentration.

4.7 | Screening for critical heart disease and sex

There was not significant statistical difference regarding sex in this study. Results published previously revealed the absence of significant difference between values of saturation and sex of the newborn. Like these studies, it is stablished that sex does not intervene in oxygen saturation values, given that the difference in anatomical condition does not influence in reduced hemoglobin percentages.

4.8 | Screening for critical heart disease and type of delivery

There was not significant statistical difference to compare the way of birth with the results of positive or negative screening. Researcher also found that preductal saturation values in those individuals who were born by cesarean were higher than those who were born by vaginal way. Postductal saturation was not affected. They did not find significant differences for both groups of neonates at term, although, they report lower postductal saturation values in preterm compared with neonates at term.

In this research, we did not find differences regarding the type of birth given that selected neonates for the study were all at term and healthy, therefore, adaptation mechanisms to the environment at birth are different from the preterm newborn.

4.9 | Screening for critical heart disease and preductal and postductal saturation

This investigation found significant statistical difference between levels of preductal and postductal saturation in comparison with the result of the screening. The validity of preductal and postductal saturation to detect heart diseases has been addressed in previous studies. It showed the importance of postductal measurement. This is due some congenital heart diseases have predominantly right to left shunt in the ductus arteriosus that cannot be detected if only preductal saturation is measured. In a systematic review and a meta-analysis published did not find significant difference when saturation was taken postductal alone versus both of them. However, they conclude that sensitivity for both groups in their study was imprecise, so they recognize that using both zones for saturation is more feasible to find individual heart defects than only if postductal saturation was used. Both values are important to detect congenital heart diseases, although like it was mention before, it is difficult to extrapolate findings in this study. This is explained because heart diseases detected in this study are not critical. This study found congenital noncyanotic heart diseases with left to right shunt that do not affect systemic saturation; therefore they should have not been detected with pulseoximetry. Moreover, the majority of studies made internationally are performed at sea level. We coincide with other authors about that screening threshold must be adjusted to high altitude populations. With 189 neonates in two locations of Jerusalem with different altitude (at sea level and at 780 meters above sea level/2559 feet) researchers concluded that small differences in altitude is enough to provoke 3.5 times more false-positive results, so they concluded that oxygen saturation cutoffs for the screening of heart diseases need to be modified according to the altitude. In this context new values of saturation at high altitude populations should be established. Unfortunately there is little data available from infants born at high altitudes as Quito. A study published by Bossano and colleagues in 1997, performed in Quito with 50 neonates reported as preductal saturation values of 92.1% ± 1.86% and postductal of 91.8% ± 1.86%.[5] Nevertheless, that study takes into account neonates up to 72 h of life unlike this present study.

5 | CONCLUSION

This study did not find critical congenital heart diseases using pulse oximetry due to the number of patients included. These factors influenced for not detecting this type of heart diseases which are of low prevalence. In Quito, Ecuador, placed at high altitude to 2820 meters above sea level (9252 feet), values of preductal oxygen saturation in healthy neonates is 89.74%–95.8%; and postductal saturation of 90.93%–96.5%. This demonstrates that measurements of oxygen saturation at high altitude are lower than those found at sea level. Pulse oximetry is an easy method, safe and noninvasive that can be done by any member of health services. To perform the measurement after 24 h and before 48 h of life diminishes the number of screening cases affected by fetal to neonatal life transition and the closure of the ductus arteriosus. Determination of preductal and postductal saturation, especially the existence of a difference higher than 3% between them, allows detecting severe aortic coarctation, interrupted aortic arch and severe aortic stenosis. Echocardiography in this study found noncyanotic congenital heart diseases like ASD and PDA, that while they are not considered critical, they count as morbidity causes and long term potential complication.

AVAILABILITY OF DATA AND MATERIALS

The data supporting this manuscript are available upon request to the corresponding author.

CONSENT FOR PUBLICATION

The identity of the individuals participating in the study is anonymous and confidential, specific informed consent was obtained for its publication.

CONFLICTS OF INTERESTS

The authors declare that they have no conflicts of interest with the contents of this article.

CONTRIBUTION OF THE AUTHORS

The research protocol and its design, data collection, statistical analysis, evaluation and interpretation of the data, critical analysis, discussion, writing and approval of the final manuscript were carried out by all authors, who they contributed in the same way in the whole process. The corresponding author represents the group of authors.

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REFERENCES

1. Khoshnood B, Lelong N, Houyel L, Thieulin AC, Jouannic JM, Magnier S, et al. Prevalence, timing of diagnosis and mortality of newborns with congenital heart defects: a population-based study. *Heart*. 2012;98(22):1667-1673.
2. Roberts T, Barton P, Auguste P, Middleton L, Furmston A, Ewer A. Pulse oximetry as a screening test for congenital heart defects in newborn infants: a cost-effectiveness analysis. *Arch Dis Child*. 2012;97:221-226.
3. Thangaratinam S, Daniels J, Ewer A, Zamora J, Khalid K. Accuracy of pulse oximetry in screening for congenital heart diseases. *Arch Dis Child Fetal Neonatal*. 2007 Marzo 7; 92:176-180.
4. Frank L, Bradshaw E, Beekman R, Mahle W, Martin G. Critical congenital heart disease screening using pulse oximetry. *J Pediatr*. 2013;162(3):445-453.
5. Tennant P, Pearce M, Bythell M, Rankin J. 20-year survival of children born with congenital anomalies: a population-based study. *Lancet*. 2010;375(9715):649-656.
6. Kuehl K, Loffredo C, Ferencz C. Failure to diagnose congenital heart disease in infancy. *Pediatrics*. 1999;103:743-747.
7. González F, López R. Ecuador Congenital malformations in Ecuadorian children: urgent need to create a National Registry of Birth Defects. *The Application of Clinical Genetics*. 2010;3:29-39.
8. Bird T, Hobbs C, Cleves M, Tilford J, Robbins J. National rates of birth defects among hospitalized newborns. *Birth Defects Res A Clin Mol Teratol*. 2006;76(11):762-769.
9. Canfield M, Honein M, Yuskiv N, Xing J, Mai C, Collins J, et al. National estimates and race/ethnic-specific variation of selected birth defects in the United States, 1999–2001. *Birth Defects Res A Clin Mol Terato*. 2006;76(11):747-756.
10. Wren C, Reinhardt Z, Khawaja K. Twenty-year trends in diagnosis of life-threatening neonatal cardiovascular malformations. *Arch Dis Child Fetal Neonatal Ed*. 2008;93(1):F33-F35.
11. Wren C, Irving C, Griffiths J, et al. Mortality in infants with cardiovascular malformations. *Eur J Pediatr*. 2012;171(2):281-287.
12. Ishikawa T, Iwashima S, Ohishi A, Nakagawa Y, Ohzeki T. Prevalence of congenital heart disease assessed by echocardiography in 2067 consecutive newborns. *Acta Paediatr*. 2011;100(8):e55-e60.
13. Gournay V. Screening for severe congenital heart diseases by pulse oximetry in asymptomatic newborns. *Arch Pediatr*. 2015; 22(5 Suppl. 1):75-76.
14. Reller M, Strickland M, Riehle T, Mahle W, Correa A. Prevalence of congenital heart defects in metropolitan Atlanta, 1998–2005. *J Pediatr*. 2008;153(6):807-813.
15. Tanner K, Sabrine N, Wren C. Cardiovascular malformations among preterm infants. *Pediatrics*. 2005 Diciembre;116(6): e833-e838.
16. Ferencz C, Rubin J, McCarter R, Brenner J, Neill C, Perry L, et al. Congenital heart disease: prevalence at livebirth. The Baltimore-Washington Infant Study. *Am J Epidemiol*. 1985;121(1):31-36.
17. Ewer A, Furmston A, Middleton L, Deeks J, Daniels J, Pattison H, et al. Pulse oximetry as a screening test for congenital heart defects in newborn infants: a test accuracy study with evaluation of acceptability and cost-effectiveness. *Health Technol Assess*. 2012;16(2):1-184.
18. AbdullaR. *Heart diseases in children. A pediatrician's guide*. New York: Springer; 2011.
19. Echeverría D, Alejandro L, Chávez M, Echeverría O. Malformaciones congénitas encontradas en el servicio de neonatología del Hospital Provincial General Docente Riobamba año 2008. *Rev Ecuat Pediat*. 2009;10(2):13-21.
20. Samánek M, Slavík Z, Zborilová B, Hrobonová V, Voríšková M, Skovránek J. Prevalence, treatment, and outcome of heart disease in live-born children: a prospective analysis of 91,823 live-born children. *Pediatr Cardiol*. 1989;10:205-211.

How to cite this article: González-Andrade F, Echeverría D, López V, Arellano M. Is pulse oximetry helpful for the early detection of critical congenital heart disease at high altitude?. *Congenital Heart Disease*. 2018;13:911–918. https://doi.org/10.1111/chd.12654