Detection of hypoxemia and hyperoxemia by pulse oximetry in neonates and children

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Abstract

Objective To assess the validity of pulse oximetry for detecting hypoxemia and hyperoxemia in neonates and children.

Methods This was a diagnostic test study conducted in Neonatal Intensive Care Unit (NICU). The subjects of the study were neonates of 0-28 days and children aged one month to 14 years in Pediatric Intensive Care Unit (PICU) of Sardjito Hospital. Hypoxemia and hyperoxemia were obtained by using Nellcor® pulse oximetry, at the same time as blood gas analysis was obtained as a gold standard.

Results There were 240 neonates and 268 children enrolled in this study. Pulse oximetry test with cut-off point 91% (neonates) and 90% (children) for detecting hypoxemia had sensitivity of 81% and 80%, specificity of 79% and 95% positive predictive value of 54% and 82% negative predictive value of 93% and 93% positive likelihood ratio of 3.79 and 14.20 and negative likelihood ratio of 0.25 and 0.24. Pulse oximetry test with cut-off point 95% (neonates) and 97% (children) for detecting hyperoxemia had sensitivity of 78% and 81% specificity of 66% and 79%, positive predictive value of 77% and 76% negative predictive value of 66% and 83% positive likelihood ratio of 2.26 and 3.84 and negative likelihood ratio of 0.34 and 0.24.

Conclusion Pulse oximetry has a fairly good validity in detecting hypoxemia in neonates and children and in detecting hyperoxemia in children to however, it is not good enough to be used to detect hyperoxemia in neonates. [Paediatr Indones. 2008;48:346-9].

Keywords: blood gas analysis, pulse oximetry, oxygen saturation, hypoxemia, hyperoxemia, diagnostic test

Hypoxemia is one of the causes that can increase the risk of mortality while hyperoxemia can be toxic leading to a condition that damages tissues. Blood gas analysis (BGA) is the gold standard of examination but since it is invasive, it causes risk and complications due to needle pricks.

Pulse oximetry is a non-invasive tool to measure oxygen saturation and is frequently used to replace BGA examination. It is inaccurate to be used in low saturation because it may give high biases; on the contrary, high saturation will give saturation measurement by pulse oximetry that exceeds from the actual result.1 The results of the correlation between BGA and pulse oximetry vary with r = 0.4 which compared BGA with pulse oximetry in neonates,2 while pulse oximetry gives a high correlation result (r = 0.95) in a study by Razi and Akbari.3 Those illustrated conditions become the background of this study to investigate the diagnostic value of pulse oximetry in assessing oxygen saturation.
Methods

We conducted a diagnostic test study to investigate the diagnostic value of pulse oximetry with Nellcor® in detecting hypoxemia and hyperoxemia in neonates and children. Capillary BGA was the gold standard for neonates and arterial BGA was for children.

We recruited consecutively neonates aged 0–28 days admitted to Neonatal Intensive Care Unit (NICU) and children of one month to 14 years old admitted to Pediatrics Intensive Care Unit (PICU) of Dr. Sardjito Hospital in need of BGA examination from April 2006 to June 2007. We excluded patients with shock, hypotension or peripheral vasoconstriction, congenital heart disorder, wound or phlebitis on the skin where probe was put, anemia <5 g/dl, or those who declined to join the study.

Before the study was conducted, the field attendants (residents) were trained on how to use pulse oximetry, place probe, and write note in recording forms. They did not receive any explanation about the definition of hypoxemia or hyperoxemia intended by the investigators. The results were read and noted by other attendants. The neonates and children who needed BGA examination also underwent the assessment of oxygen saturation with pulse oximetry at the same time. Hypoxemia in neonate was defined as PaO₂ capillary was < 35 mmHg⁴ and in children when PaO₂ from arterial BGA was < 60 mmHg.⁵ Hyperoxemia was defined as PaO₂ from capillary BGA of > 50 mmHg⁶ to whereas in children when arterial PaO₂ was > 100 mmHg.⁷ By using Receiver Operator Curve (ROC), the cut-off point of hypoxemia and hyperoxemia detection to get the best diagnostic was determined.

Results

During the period of April 1st – June 30th 2007, 240 specimens of neonates capillary BGA and 268 specimens of children’s arterial BGA were collected. Table 1 shows the characteristics of the neonate group. Of 240 subjects, 152 (63.3%) were male with mean of age was seven days, and the greatest number of term gestational age (37 - ≤42 weeks) was 126 (58.3%).

The characteristics of children group are shown in Table 2. Of 268 subjects, 176 (65.7%) were male with mean age of 31.6 months. The most prevalent underlying disease was pneumonia (24.2%).

From hypoxemia prediction variant, saturation of 91% and 92% gave fairly good sensitivity and specificity as the lowest cut-off points in determining

| Table 1. Characteristics of the neonates |
|----------------------------------------|
| Characteristics                        |
| Sex (n%)                               |
| Male                                   | 152 (63.3) |
| Female                                 | 88 (36.7)  |
| Age, days, mean (range)                | 7 (0-62)   |
| Gestational age (n%)                   |
| < 28 weeks                             | 17 (7.1)   |
| 28 - < 37 weeks                        | 69 (28.8)  |
| 37 – ≤ 42 weeks                       | 140 (58.3) |
| >42 weeks                              | 14 (5.8)   |
| Pulse rate, per minute, mean (range)   | 146 (100-213) |
| Respiratory rate, per min., mean (range)| 53 (30-98)  |
| Temperature, °C, mean (range)          | 37 (36.5-40) |
| Hemoglobin, g/dl, mean (range)         | 15.2 (10-21.6) |
| Diagnosis, n (%)                       |
| Asphyxia                               | 106 (44)   |
| Meconium aspiration syndrome           | 36 (15)    |
| Pneumonia                              | 37 (15.4)  |
| HMD (hyaline membrane disease)         | 29 (12.1)  |
| Apnea of prematurity                   | 15 (6.2)   |
| ARDS (acute respiratory distress syndrome) | 13 (5.4)  |
| Hydrocephalus                          | 2 (0.8)    |
| Aspiration                             | 2 (0.8)    |

| Table 2. Basic characteristics of the children |
|-----------------------------------------------|
| Characteristics                               |
| Sex, n (%)                                   |
| Male                                         | 176 (65.7) |
| Female                                       | 92 (33.3)  |
| Age, mo, mean (range)                        | 31.6 (1.5-156) |
| Heart rate per minute, mean (range)          | 153 (92-205) |
| Resp. rate per minute, mean (range)          | 42 (20-80)  |
| Temperature, °C, mean (range)                | 37.6 (36.5-40) |
| Systolic blood pressure, mmHg, mean (range)  | 113 (80-160) |
| Diastolic blood pressure, mmHg, mean (range) | 66 (40-114)  |
| Mean arterial pressure, mmHg, mean (range)   | 82 (52-126) |
| Hemoglobin, g/dl, mean (range)               | 11 (9-20)   |
| Diagnosis, n (%)                             |
| Pneumonia                                    | 58 (24.2)  |
| Bronchial asthma                             | 43 (16)    |
| ARDS (acute resp. distress syndrome)         | 33 (12.3)  |
| Encephalitis                                 | 40 (16.7)  |
| CLD (chronic lung disease)                   | 26 (9.7)   |
| Meningoencephalitis                          | 19 (7.1)   |
| Wheezy infant                                | 15 (5.6)   |
| Intracranial bleeding                        | 14 (5.8)   |
| Bronchiolitis                                | 12 (4.5)   |
| Renal failure                                | 6 (2.3)    |
| Pleural effusion                             | 2 (0.7)    |
hypoxemia in neonates, and saturation of 95% and 96% gave better sensitivity and specificity as the highest cut-off points in determining hyperoxemia in neonates. The sensitivity and specificity in neonates are shown in Table 3.

| Lowest cut-off point SpO2 (%) | Sensitivity (%) | 95% Confidence Interval (%) | Specificity (%) | 95% Confidence Interval (%) |
|-------------------------------|----------------|-----------------------------|----------------|-----------------------------|
| 90                            | 70             | 58 to 82                    | 81             | 75 to 87                    |
| 91                            | 81             | 70 to 91                    | 79             | 73 to 85                    |
| 92                            | 84             | 70 to 91                    | 77             | 73 to 85                    |

* Capillary BGA was used as reference

In children, saturation of 90% and 91% presented fairly good sensitivity and specificity as the lowest cut-off point in determining hypoxemia, and saturation 97% and 98% exhibited better sensitivity and specificity as the highest cut-off point in determining hyperoxemia. These can be seen in Table 4.

| Lowest cut-off point SpO2 (%) | Sensitivity (%) | 95% Confidence Interval (%) | Specificity (%) | 95% Confidence Interval (%) |
|-------------------------------|----------------|-----------------------------|----------------|-----------------------------|
| 89                            | 69             | 58 to 80                    | 96             | 93 to 99                    |
| 90                            | 80             | 58 to 80                    | 95             | 93 to 99                    |
| 91                            | 77             | 67 to 87                    | 95             | 91 to 98                    |
| Highest cut-off point SpO2 (%)|                |                             |                |                             |
| 96                            | 73             | 65 to 81                    | 88             | 82 to 93                    |
| 97                            | 81             | 74 to 88                    | 79             | 72 to 86                    |
| 98                            | 89             | 84 to 95                    | 67             | 59 to 74                    |

* Arterial BGA as gold standard

The magnitude of sensitivity and specificity to detect hypoxemia and hyperoxemia tended to be lower in neonates in our study. This might be because the gold standard that was used was not from the analysis of arterial blood gas that described the actual level of PaO2 in blood, but from the analysis of capillary blood gas while it was known that the correlation between artery and capillary varied for PaO2 \( r = 0.657,11 \), \( r = 0.92,2 \) and \( r = 0.65,4 \).

In conclusion, pulse oximetry has a fairly good validity in detecting hypoxemia in neonates and children, and in detecting hyperoxemia in children; however, it is not good enough to be used to detect hyperoxemia in neonates.

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