ORIGINAL RESEARCH ARTICLE

Prevalence of undiagnosed hypoxemia in adults and children in an under-resourced district hospital in Zambia

Mark Foran · Roy Ahn · Joseph Novik · Lynda Tyer-Viola · Kennedy Chilufya · Kasseba Katamba · Thomas Burke

Abstract

Background In adequately resourced clinical environments, diagnosis of hypoxemia via pulse oximetry is routine. Unfortunately, pulse oximetry is rarely utilized in under-resourced hospitals in developing countries.

Aim The prevalence of undiagnosed hypoxemia among adults and children with illnesses other than pneumonia in these environments remains poorly described.

Methods This cross-sectional analysis of the prevalence of hypoxemia was conducted in Kapiri Mposhi, Zambia, at the 60-bed District Hospital, which serves a population of 320,000. The resting room air oxygen saturations of two consecutive samples of all adult and pediatric inpatients were measured in December 2008 and March 2009 using handheld pulse oximetry. Hypoxemia was defined as resting room air SpO_2 less than 90%.

Results A total of 192 patients were enrolled: 68 young children (<5 years old), 15 older children (5–17 years old), and 109 adults (≥18 years old). Five young children (7%), 0 older children (0%), and 10 adults (9%) were hypoxemic. No hypoxemic patients were receiving oxygen therapy at the time of diagnosis. Pneumonia, tuberculosis, and malnutrition were the most common conditions among those with hypoxemia. Oximetry data changed clinical management in all observed cases of hypoxemia and several cases of normoxemia, leading to application of supplemental oxygen, initiation of further diagnostic testing, prolongation of inpatient stay, or expedited discharge home.

Conclusions Undiagnosed hypoxemia is present among inpatients at this district hospital in rural Zambia with high prevalence in both adults and young children. These results support routine screening for hypoxemia in similar facilities in both age groups. Further investigation is warranted into the clinical impact and cost-effectiveness of pulse oximetry, provision of oxygen concentrators, and training on their use in developing countries.

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Introduction

Pulse oximetry is a technology that is used routinely for diagnosis of hypoxemia in high-income countries [1]. Pulse

oximetry has been shown in large trials to be more effective than clinical judgment in the detection of hypoxemia [2] and is well established in developed countries as the fifth vital sign in patients of all ages [3, 4].

Unfortunately, pulse oximetry is often unavailable in resource-limited clinical settings. The potential benefit of introducing the technology has been recognized by the field of anesthesiology, which has recently launched the Global Oximetry Initiative to promote oximetry utilization and reduce oximetry costs in low-income countries [5]. This effort focuses on increasing the availability of oximetry in perioperative settings, though randomized controlled trials in high-income countries have yet to demonstrate that oximetry reduces morbidity or mortality in this setting [6, 7].

Retrospective analysis has suggested that oximetry might improve the ability to predict clinical failure of oral amoxicillin therapy for children with WHO-defined severe pneumonia [8]. Preliminary studies in Egypt and Papua New Guinea have also shown that implementation of pulse oximeters, oxygen concentrators, and a training program on their use can reduce mortality in pediatric pneumonia [9–11]. Pulse oximetry in emergency triage has also been shown to save costs in a hospital in Kenya by enabling staff to target oxygen therapy more accurately [12]. However, overall, the literature evaluating the impact of pulse oximetry in resource-limited settings is sparse, and the prevalence of hypoxemia among adults in low-income countries remains largely unknown.

To date, most data collected on the clinical impact of pulse oximetry have been collected in high-income countries. For example, utilization of oximetry at patient triage has been shown to significantly reduce pediatric emergency department length of stay in the US, by expediting the identification and treatment of patients with hypoxemia [13]. Of those studies conducted in low-income countries, most report the prevalence of hypoxemia exclusively among children with pneumonia (acute lower respiratory infection) [14]. The few published studies that report data on other disease processes have found high prevalence of hypoxemia among pediatric patients with malaria, meningitis, diarrhea, malnutrition, anemia, tuberculosis, and neonatal illnesses [15–17]. To our knowledge, few data have been reported on the prevalence of hypoxemia among adults in resource-limited settings, and no data have been reported on the prevalence of hypoxemia at any clinical site in the country of Zambia [14].

The goal of this study was to determine the prevalence of hypoxemia at Kapiri District Hospital (KDH) in Kapiri Mposhi, Zambia, among both adults and pediatric inpatients. Characterization of the epidemiology of hypoxemia there is an important step in the design of subsequent interventions that aim to improve health outcomes. We hypothesized that a significant burden of hypoxemia was present and regularly remained undiagnosed at this hospital among both adults and children, and across a variety of illnesses.

Methods

Study design

A cross-sectional study was conducted to determine the prevalence of hypoxemia at this rural district hospital in Zambia. Prior to initiation of data collection, IRB approval was obtained from the Partners Human Research Committee and the Kapiri Mposhi District Health Office. There are no relevant financial disclosures for any of the authors involved in this project.

Study setting and population

KDH is a 60-bed, government-run district hospital serving the Kapiri District population of 320,000 [18]. Kapiri District is located in Zambia's Central Province. At the time of this study, the hospital did not regularly measure patient oxygen saturations, and used therapeutic oxygen sparingly. Two consecutive samples of all adult and pediatric inpatients at KDH were measured in December 2008 and March 2009. All patients older than 30 days were eligible for enrollment. All patients seen during daily rounds with the local physician were considered for enrollment. Outpatients did not meet inclusion criteria. There were no exclusion criteria.

Study protocol

Resting oxygen saturations were measured by an emergency physician from the US, who rounded with the local hospital physician each day. At the end of each patient evaluation, the local physician asked the patient whether he or she would like to participate, and if the patient did wish to participate, obtained verbal consent, explaining the purpose of the study and potential risks. Because risks were felt to be minimal, the requirement for written consent was waived by the IRB. If the patient was too young or ill to consent, a family member was asked regarding desire to participate. Oxygen saturation was then measured by placing a handheld pulse oximeter (Masimo Corporation, Irvine, CA) on the right index finger and allowing the signal to equilibrate for 5 sec. When the waveform was high quality and the saturation reading had been stable for 5 s, the level was recorded. If the saturation was less than 70% SpO_2, a value of <70% was recorded given known decreased accuracy below these levels. All measurements were obtained at rest while breathing room air. Measurement of the oxygen saturation level of the physician obtaining the measurement was taken at the beginning of each day of data collection to serve as a control and confirm that the oximeter was functioning appropriately.

Data collection was performed Monday through Saturday, when the local physician rounded and was available to

translate and obtain verbal consent. After the oxygen saturation was measured, the local physician and visiting physician used the data to adjust clinical plans as appropriate. Patient demographic data obtained from the medical record was limited to age, gender, bed number, and presumed diagnosis. No personal identifiers were recorded. Data were initially written on paper datasheets, which were kept locked at all times and later transferred to an electronic database on a secure laptop computer.

Data analysis

The study hypothesis was that clinically significant hypoxemia (SpO_2 <90%) was present among the inpatient population at this hospital. For statistical analysis, the null hypothesis was prevalence of hypoxemia at this hospital is less than 1%. The prevalence of hypoxemia was first calculated and analyzed for the entire sample population. Patients were then divided into three groups: age less than 5 years (a standard in the literature), age 5–17 years, and age 18 or older. Data were entered into Excel 2008 (Microsoft Corporation, Redmond, WA) and analyzed using Stata/IC 10.0 (Stata Corp., College Station, TX). Hypoxemia was defined as SpO_2 less than 90%, the accepted threshold in the existing literature [14]. Descriptive statistics were performed. The proportion of patients who met criteria for hypoxemia from the entire sample population and for each age group was calculated and reported with 95% confidence intervals of the proportion. One-sided, one-sample tests of proportion were performed at α level 0.05 to assess whether the observed prevalences of hypoxemia for the entire population and each age group were statistically higher than 1%. A one-sided test was necessary because negative values of oxygen saturation are not possible, and there was only one alternate hypothesis, prevalence is greater than 1%. The Kruskal-Wallis equality-of-populations rank test was performed using an α level 0.05 to assess whether there was a statistically significant difference between the distribution of oxygen saturation levels among the three age groups. This test was chosen based on the single independent variable with three categories (age groups) and a non-parametric continuous outcome variable (saturation levels).

Results

One hundred ninety-two patients were enrolled: 68 young children (<5 years old), 15 older children (5–17 years old), and 109 adults (≥18 years old). Six patients declined consent and were not enrolled. The mean age of the participants was 24.4 years, with an interquartile age range of 2 to 38.5 years and absolute range of 1 month to

75 years. There were 92 male and 100 female participants (see Table 1).

The majority of patients had measured oxygen saturation levels of greater than 90% (see Fig. 1). Five young children (7%), 0 older children (0%), and 10 adults (9%) were hypoxemic at time of measurement of saturation level. The one-sided, one-sample tests of proportion indicated that the prevalence of hypoxemia was greater than 1% for the entire population, for young children, and for adults, though not for older children (see Table 2). The Kruskal-Wallis equality-of-populations rank test indicated that there was a statistically significant difference between the oxygen saturation levels of the three age groups (p=0.018). The data suggest that the age group 5–17 years, which had a measured sample prevalence of zero, likely has a significantly lower prevalence of hypoxemia than the other two age groups (see Fig. 2).

None of the 15 hypoxemic patients were receiving oxygen therapy at the time they were identified as hypoxemic. Six of the 15 patients had oxygen saturations less than 70%, all of whom subsequently died during their hospitalization. These patients were generally ill-appearing, though not all were in acute distress—some were terminally ill-appearing and had been declining steadily for days or weeks.

Pneumonia, tuberculosis, and malnutrition were the most common diagnoses among those with hypoxemia. Other diagnoses included dilated cardiomyopathy of unclear etiology in a 26-year-old male, and presentations of fever and dyspnea of unclear etiologies. (see Table 3).

Oximetry data changed management in all cases of hypoxemia, leading to application of supplemental oxygen, initiation of further diagnostic testing such as x-rays, or prolongation of inpatient stay. Oximetry data also changed management in several cases where the saturation was normal, leading to the safe discontinuation of oxygen therapy (e.g., in pediatric respiratory illness) or expedited discharge home earlier than planned (e.g., transition to outpatient care in adult pulmonary tuberculosis). The

Table 1 Study sample population demographics

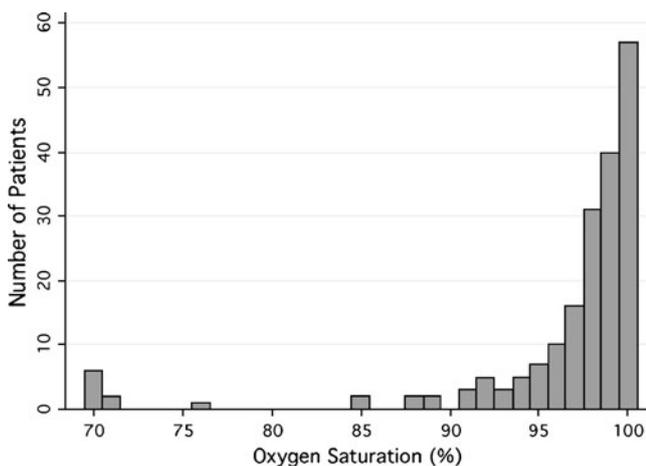| Characteristics of study participants	
Number enrolled	192
Declined to participate	6
Mean age	24.3 years
Interquartile age range	2–38.5 years
Age range	1 month–75 years
Male	92 (48%)
Female	100 (52%)
<5 years old	68 (35.4%)
5–17 years old	15 (7.8%)
≥18 years old	109 (56.8%)

Fig. 1 Histogram of inpatient resting room air oxygen saturation levels at Kapiri District Hospital (all ages)

proportion of cases in which oxymetry data changed management or any difference in outcomes was not recorded as part of this preliminary observational study.

Discussion

Hypoxemia was present in this under-resourced district hospital in Zambia with alarming prevalence. Numerous patients (n=15, 8%) were found to be hypoxemic, despite a conservative definition for hypoxemia of $SpO_2 < 90\%$ and measuring saturation at rest. Many more patients with resting SpO_2 90–94% (n=15, 8%) would have met criteria for treatment with therapeutic oxygen in developed countries, where exposure to saturations of 90–94% has been associated with adverse cognitive and behavioral outcomes [20, 21]. Hypoxemia was found among patients with a variety of diagnoses, though pulmonary infections accounted for the majority of cases. The prevalence of hypoxemia in adults (≥18 years) was at least as high as in young children (<5 years), indicating a need for more research and interventions aimed at understanding, diagnosing, and treating hypoxia in adults in resource-limited settings. Although the literature has previously focused on children with pneumonia, these data suggest that both
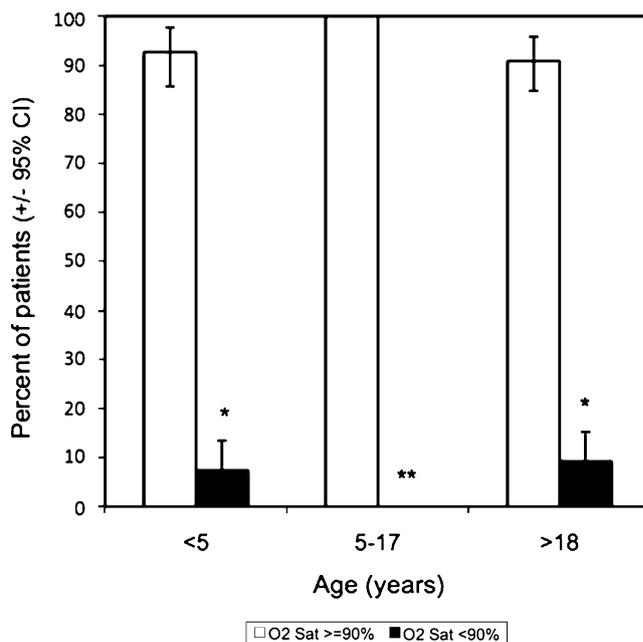

Fig. 2 Prevalence of hypoxemia (resting room air $SpO_2 < 90\%$) at Kapiri District Hospital by age group with 95% confidence intervals of proportions. *Denotes statistical significance for prevalence ≥1% via one-sided, one-sample test of proportion at $\alpha = 0.05$. **Denotes statistical significance for difference in distribution of oxygen saturation levels among the three groups via Kruskal-Wallis equality-of-populations rank test at $\alpha = 0.05$

adults and young children may benefit from routine screening for hypoxemia in similar under-resourced settings. The groups most likely to benefit from targeted screening include adults and young children with presumptive diagnoses of pneumonia, tuberculosis, and malnutrition.

Pneumonia (acute lower respiratory infection) currently accounts for more deaths in children under 5 worldwide than HIV, tuberculosis, malaria, and measles combined [22]. At Kapiri District Hospital, pneumonia was the leading cause of death in children under 5 and the third highest cause of death among adults [23]. Given the potential for impact on mortality, hospital length of stay, and cost-effective utilization of limited resources such as therapeutic oxygen, further implementation and evaluation are warranted in programs that provide under-resourced facilities with pulse oximeters, oxygen concentrators, and training in their use.

Table 2 Prevalence of hypoxemia (resting room air $SpO_2 < 90\%$) at Kapiri District Hospital. P-value represents probability of obtaining the observed value due to random chance under the null hypothesis that prevalence of hypoxemia is less than 1%, using a one-sided, one-sample test of proportions at $\alpha = 0.05$

Age group	Prevalence of hypoxemia (%)	95% confidence interval of proportion	P-value
All ages	7.8	(3.8, 14.6)	<0.0001
<5 years	7.4	(1.1, 13.5)	<0.0001
5–17 years	0.0	(0.0, 0.0)	0.652
≥18 years	9.2	(3.8, 14.5)	<0.001

Table 3 Etiologies of hypoxemia at Kapiri District Hospital

Age	Gender	Diagnosis	O₂ Saturation (room air)
3 months	Female	Pneumonia	88%
4 months	Male	Fever	<70%
13 months	Female	Pneumonia	85%
16 months	Female	Malnutrition	89%
3 years	Female	Malnutrition	89%
26 years	Male	Cardiomyopathy	88%
27 years	Female	Tuberculosis	71%
32 years	Male	Tuberculosis	<70%
34 years	Male	Pneumonia	76%
39 years	Male	Tuberculosis	<70%
45 years	Male	Tuberculosis	85%
52 years	Female	Dyspnea	<70%
62 years	Male	Pneumonia	<70%
69 years	Male	Tuberculosis	<70%
79 years	Male	Dyspnea	71%

Limitations

This study was cross-sectional and therefore cannot provide longitudinal data about hypoxemia at this hospital. There may be seasonal variation in prevalence in this area, though no significant differences were observed between the data collected in December and March. All data were collected in a single district hospital in a single country, which may limit the generalizability of our findings. In order to estimate hypoxia, hypoxemia alone was measured with no determinations of hemoglobin concentration, cardiac output, or mixed central venous O₂ saturation to truly calculate oxygen delivery to tissues. This use of hypoxemia as a surrogate marker of hypoxia is well established in both clinical and research settings [19]. The study does not specifically demonstrate improvement in patient outcomes due to identification and treatment of hypoxemia, which must be investigated further in subsequent research.

Conclusion

Undiagnosed and untreated hypoxemia (resting room air SpO₂ <90%) was found in both adults and young children (<5 years) and in a variety of illnesses at this under-resourced district hospital. The most common diagnoses of those with hypoxemia were pneumonia, tuberculosis, and malnutrition. Measurement of O₂ saturation altered the management of all hypoxemic and several normoxemic patients. Diagnosis of hypoxemia via pulse oximetry should be expanded in similar under-resourced settings.

Further investigation is warranted into the clinical impact and cost-effectiveness of pulse oximetry, provision of oxygen concentrators, and training on their use in developing countries.

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