Clinical Decision Support for Pediatric Home Pulse Oximetry Orders

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Abstract

Objective: Home pulse oximetry is often prescribed to children with chronic disease upon hospital discharge. Children monitored at home may generate >20 alarms every 8 hours, contributing to premature discontinuation of monitoring. We aimed to improve the home oximetry ordering process using clinical decision support (CDS), supporting more liberal oxygen saturation (SpO₂) alarm limits.

Methods: Within a large single-center improvement project to increase informativeness of alarms in the hospital and in patients’ homes, we compared home care oximetry orders of discharged children pre-post CDS implementation. Order parameters included low SpO₂ limit, specification of intensity of use, an intervention plan, pulse oximetry probe prescription, and order completeness. We extracted order details 6 months pre-CDS and 6 months post-CDS with a one-month washout period. The CDS intervention used a letter template to include all required home oximeter order elements and provide more liberal age-specific default alarm limits.

Results: There were 100 orders in the pre-CDS epoch (7/1/2021-12/31/2021) and 112 orders in the post-CDS epoch (2/1/2022-7/31/2022). The median low SpO₂ alarm limit post-CDS implementation (87%, IQR 87%-90%) was significantly lower than pre-CDS (90%, IQR 90%-90%, p<0.001). In the post-CDS epoch significantly more orders included an intervention plan (80.4% versus 31%, p<0.001), prescribed pulse oximetry probes (85.7% versus 52.0%, p<0.001), and were complete (68.8% versus 13.0%, p<0.001). Conclusions: CDS implementation resulted in a significant decrease in median low SpO₂ limit and a significant increase in home oximetry order completeness. These changes may decrease home oximetry alarm burden and improve caregiver experiences with home oximetry.

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Contributor Statement:
Dr. Herrick conceptualized the design of the project; contributed to data collection; led data analysis, and interpretation; drafted the initial manuscript; critically reviewed and revised the manuscript; and approved the final manuscript. Mses. McNamara, Albanowski, and Pohl conceptualized the design of the project; conducted data collection, analysis, and interpretation; critically reviewed and revised the manuscript; and approved the final manuscript. Drs. DeMauro, Bonafide, and Muthu supervised the conceptualization and design of the study; supervised data collection, analysis, and interpretation; critically reviewed and revised the manuscript; and approved the final manuscript. Dr. Bonafide also obtained funding for the project.

Keywords: Clinical decision support, home pulse oximeter, pediatrics

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Results: There were 100 orders in the pre-CDS epoch (7/1/2021-12/31/2021) and 112 orders in the post-CDS epoch (2/1/2022-7/31/2022). The median low SpO₂ alarm limit post-CDS implementation (87%, IQR 87%-90%) was significantly lower than pre-CDS (90%, IQR 90%-90%, p=<0.001). In the post-CDS epoch significantly more orders included an intervention plan (80.4% versus 31%, p<0.001), prescribed pulse oximeter probes (85.7% versus 52.0%, p<0.001), and were complete (68.8% versus 13.0%, p<0.001).
**Conclusions:** CDS implementation resulted in a significant decrease in median low SpO\(_2\) limit and a significant increase in home oximetry order completeness. These changes may decrease home oximetry alarm burden and improve caregiver experiences with home oximetry.

**Introduction:**

Home pulse oximetry is often prescribed to pediatric patients discharged with respiratory support to ensure patient safety and monitor disease progression. Unfortunately, the current status of home oximetry may result in alarm fatigue, missed life-threatening alarms, and premature monitor discontinuation. In a study using home oximetry data from patients with chronic lung disease, typical discharge parameters predicted 23 alarms per 8 hours, and number of alarms decreased significantly with lower alarm limits. Frequency of alarms is a key driver of premature discontinuation of pulse oximetry, and thus liberalizing alarm limits may improve home oximetry adherence. Lower limits decrease alarm burden without increasing risk to the patient. Furthermore, 30% of home oximetry orders do not include intervention instructions for caregivers when alarms occur, which could result in caregivers being unprepared to manage home emergency situations.

To address these concerns, we focused on provider prescribing patterns for home oximetry. We employed clinical decision support (CDS) to improve home oximeter orders with the specific goals of more liberal oxygen saturation (SpO\(_2\)) alarm limits and increased order completeness.

**Methods:**

This project was conducted at an urban children’s hospital with >500 beds and almost 30,000 admissions per year including general pediatric admissions and national and international subspecialty referrals. Home pulse oximeters are prescribed across units from critical care to general pediatrics for multiple indications including chronic lung disease, obstructive sleep apnea, and cyanotic heart disease. Within a large improvement project to increase informativeness of alarms, we evaluated the impact of a single CDS intervention on home oximetry orders. Our primary outcome was low SpO\(_2\) limit. Secondary outcomes included specification of intensity of use, an intervention plan for alarms, prescription of pulse oximetry probes, and order completeness. Complete orders were defined as inclusion of these parameters as well as heart rate alarm limits. We extracted electronic medical record data for all children discharged with home oximeter orders 6 months before CDS implementation and 6 months after implementation with a one-month washout between epochs for CDS education. The hospital Institutional Review Board deemed this not human subjects research.

**CDS Iterative Design:**

Initial CDS development evaluated the current ordering process including provider perspectives for process improvement. We undertook an iterative design process with purposive recruitment of representative ordering providers across neonatology, cardiology, and pulmonology. We conducted think-aloud interviews with five individual users. We presented four patient scenarios asking users to discuss decision-making process for home respiratory support and monitoring. Wireframe mockups of home oximetry orders were introduced in the second half of the interviews, and users were asked to describe how they would complete the order and provide feedback. When interviews demonstrated reliance upon case manager collaboration for home orders, we expanded interviews to include four case managers. Case manager interviews revealed widespread use of a respiratory order letter template for home oximetry orders and inefficient communication between providers and case managers to complete the letter. We iterated further mockups within this order letter template based on user feedback and observed use of the order letter during walkthroughs.

**CDS Intervention:**

The CDS intervention modified the existing order letter template in two specific ways. First, the modified letter included all required home oximeter elements in drop-down menus: alarm limits, frequency of use, and intervention plans. Second, the drop-down menu provided age specific hospital default alarm limits as preset options(Figure 1). Non-default options were included for patients with cyanotic heart disease. The specific goals of these interventions were to provide more liberal alarm parameters to reduce home alarm burden,
improve order completeness, and enhance communication between prescribers and case management. CDS education consisted of an email update to all ordering providers within the hospital.

**Statistical Analysis:**

All analyses were conducted using Stata 16.1 (Stata Corp, College Station, TX). Summary statistics described patient, provider, and order characteristics. Pre- and post-CDS characteristics and outcomes were compared using \( \chi^2 \) or Fisher’s exact tests for categorical variables and Wilcoxon rank-sum tests for non-parametric variables. Patients with a diagnosis of cyanotic heart disease were excluded from the analysis of low SpO\(_2\) limit but included in other analyses. We performed multivariable regression for all outcomes, adjusted for patient and provider variables that were different \( (p<0.05) \) between epochs. Lastly, we performed a sensitivity analysis comparing low SpO\(_2\) limit between complete template use versus partial or non-use in the post-CDS epoch.

**Results:**

We implemented the CDS intervention in January 2022. The pre-CDS epoch was 7/1/2021-12/31/2021, and the post-CDS epoch was 2/1/2022-7/31/2022. There were 100 home oximetry orders in the pre-CDS epoch and 112 in the post-CDS epoch. In the post-CDS epoch, 68 orders (60.7%) had complete template use, 23 (20.5%) had partial template use, and 21 (18.8%) did not use the template.

Table 1 shows patient and prescribing provider characteristics by epoch. In univariable analysis, the median low SpO\(_2\) alarm limit post-CDS implementation was significantly lower than pre-CDS (87%, IQR 87%-90% versus 90%, IQR 90%-90%, \( p=0.001 \); Table 2). In the post-CDS epoch significantly more orders included an intervention plan (80.4% versus 31%, \( p<0.001 \)), prescribed pulse oximeter probes (85.7% versus 52.0%, \( p<0.001 \)), and were complete (68.8% versus 13.0%, \( p<0.001 \)). All four findings remained significant in multivariable regression models which included non-white race and the role of ordering provider: the post-intervention epoch was associated with a decrease in low SpO\(_2\) alarm (beta -1.44, 95% CI -2.04 to -0.85) and an increased adjusted odds ratio (aOR) of an intervention plan (aOR 8.19, 95% CI 4.27-15.69), a pulse oximeter probe prescription (aOR 6.25, 95% CI 3.07-12.73), and a complete order (aOR 14.87, 95% CI 7.08-31.20). In sensitivity analyses, complete template use was associated with a significantly lower SpO\(_2\) alarm limit in univariable (median 87% versus 90%, \( p<0.001 \)) and multivariable analysis (beta -1.27, 95% CI -2.16 to -0.38) as compared to partial or non-use.

**Discussion:**

This project examined the impact of CDS implementation for home oximetry orders on order parameters with a primary outcome of low SpO\(_2\) limit. The low SpO\(_2\) limit in the post-CDS epoch was significantly lower in both univariable and multivariable analysis. In the post-CDS epoch, significantly more orders included an intervention plan, prescribed pulse oximeter probes, and were complete.

The ultimate study goal was to improve the state of home oximetry for patients and their families by liberalizing SpO\(_2\) parameters to decrease alarms and by increasing order completeness. We successfully reduced the low SpO\(_2\) limit from a median 90% to 87% in the post-CDS epoch. While there are limited data with which to compare our results, decreasing low SpO\(_2\) alarm limits was associated with a significant decrease in predicted number of alarms per 8-hour period in a study using home oximetry data among patients with chronic lung disease. Given that alarm frequency contributes to premature discontinuation of home oximetry, decreasing the number of home alarms may encourage caregivers to continue home oximetry as prescribed, ultimately improving patient safety.

Patients in the post-CDS epoch were also more likely to have complete orders including an intervention plan and a prescription for additional pulse oximeter probes. The presence of an intervention plan for alarms may improve caregiver comfort with the home oximeter, empowering caregivers with a specific action plan. We hypothesize that ensuring a prescription of additional pulse oximeter probes enables caregivers to replace non-adherent probes, improving pulse oximetry quality and decreasing false alarms due to probe
malfunction. Additionally, improved order completeness has implications for case management workflow, potentially improving communication with the providers to finalize orders.

We achieved our goal of improving pediatric home oximetry orders through implementation of a simple CDS intervention. Systematic reviews of CDS have reported poor overall uptake and minimal changes in process or patient outcomes, but most of these reviews conceive of CDS as a standalone system or interruptive reminders. In this study, and in previous work, we demonstrated that subtle changes aligning existing electronic workflows with effective task performance can increase efficiency and improve clinical care. This work also highlights the limitation of the “five rights” clinical decision support framework, which assumes that there’s a single “right person” for display of decision support. In practice, healthcare delivery is often a collaborative exercise as demonstrated here where orders were generated jointly by case managers and ordering providers. Instead of focusing on providing the “right person” with the “right information”, a systems thinking approach suggests optimizing technology design for key interactions between people and work tasks.

We acknowledge study limitations. While the study demonstrates successful CDS implementation resulting in liberalized SpO\textsubscript{2} parameters and increased order completeness, the study does not directly measure rate of home alarms nor caregiver experience with home oximetry. Next steps for this project include a post-CDS effectiveness study on caregiver experience with home oximetry and creation of standardized indications for home pulse oximetry.

Conclusions:
Implementation of a simple CDS intervention resulted in a significant decrease in median low SpO\textsubscript{2} limit and a significant increase in home oximetry order completeness. These changes have the potential to decrease home oximetry alarm burden and improve caregiver experience with home oximetry leading to increased adherence.

Conflicts of Interest: The authors have no conflicts of interest to report.

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References:

Tables and Figures (see attachments for figures and tables):

Figure 1: Clinical decision support embedded in the template for home pulse oximetry orders.
1A. All pulse oximeter parameters required for a complete order are available in a dropdown menu. 1B. Once order parameters are selected, age-appropriate limit defaults are provided as well as free-text options for cyanotic heart disease and other.

Table 1: Patient and Provider Characteristics
Table 2: Pulse Oximeter Order Details by Epoch
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CDS Table 1.docx available at https://authorea.com/users/638174/articles/654062-clinical-decision-support-for-pediatric-home-pulse-oximetry-orders

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CDS Table 2.docx available at https://authorea.com/users/638174/articles/654062-clinical-decision-support-for-pediatric-home-pulse-oximetry-orders