The Alarm Burden of Excess Continuous Pulse Oximetry Monitoring Among Patients With Bronchiolitis

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Guidelines discourage continuous pulse oximetry monitoring of hospitalized infants with bronchiolitis who are not receiving supplemental oxygen. Excess monitoring is theorized to contribute to increased alarm burden, but this burden has not been quantified. We evaluated admissions of 201 children (aged 0-24 months) with bronchiolitis. We categorized time ≥60 minutes following discontinuation of supplemental oxygen as "continuously monitored (guideline-discordant)," "intermittently measured (guideline-concordant)," or "unable to classify." Across 4402 classifiable hours, 77% (11,101) of alarms occurred during periods of guideline-discordant monitoring. Patients experienced a median of 35 alarms (interquartile range [IQR], 10-81) during guideline-discordant, continuously monitored time, representing a rate of 6.7 alarms per hour (IQR, 2.1-12.3). In comparison, the median hourly alarm rate during periods of guideline-concordant intermittent measurement was 0.5 alarms per hour (IQR, 0.1-0.8). Reducing guideline-discordant monitoring in bronchiolitis patients would reduce nurse alarm burden. *Journal of Hospital Medicine* 2021;16:727-729. © 2021 Society of Hospital Medicine

Practice guidelines discourage continuous pulse oximetry (SpO_2) monitoring of patients with bronchiolitis who are not receiving supplemental oxygen.[1,2] Overuse of SpO_2 monitoring in this patient population has been associated with increased length of stay, unnecessary oxygen therapy, and excess hospital costs, without measurable patient benefit.[3-5] In spite of this evidence base and expert guidance, nearly half of the more than 100,000 infants admitted for bronchiolitis each year receive excess SpO_2 monitoring.[6,7]

Bronchiolitis guidelines suggest that guideline-discordant SpO_2 monitoring may result in excess alarms, which disrupt families' sleep and engender alarm fatigue among staff.[1] Pediatric nurses receive up to 155 alarms per monitored patient per day.[8,9] Frequent alarms are associated with slower nurse response times[10,11] and increased nurse subjective workload.[12] The rate of excess alarms occurring during guideline-discordant, continuously SpO_2 monitored time, compared to the rate of alarms occurring during guideline-concordant (intermittently measured SpO_2) time, has not been evaluated. The magnitude of this difference in alarm rates, if such a difference exists, will inform prioritization of guideline-discordant continuous SpO_2 measurement de-implementation. The objective of this study was to quantify the alarm burden associated with excess SpO_2 monitoring of bronchiolitis patients not receiving supplemental oxygen.

METHODS

Cohort

We retrospectively evaluated SpO_2 monitoring patterns and alarm rates of children 0 to 24 months old admitted to a general pediatrics service at a tertiary care children's hospital. We included patients who had a discharge diagnosis of bronchiolitis (*International Classification of Diseases, Tenth Revision* codes J45x, T17.2x, T17.3x, T17.4x, T17.5x, T17.8x, T17.9x, A37xx, J04x, J05x, J05.1x, J69.0x, J69.1x, J69.8x) between November 24, 2019, and January 21, 2020, the period of time during which alarm data and monitor data were concurrently available for analysis. In order to conservatively assure applicability of clinical practice guidelines, we excluded patients with discharge diagnoses that included other respiratory conditions (eg, reactive airway disease), patients with complex chronic conditions (CCC) as defined by the CCC version 2 classification system,[13] and patients with intensive care unit (ICU) stays during the admission.

Time

Flowsheet data detailing nursing respiratory assessments were extracted from the electronic health record (EHR) database (Clarity, Epic Systems). Using previously validated methodology,[14] we identified minutes during which patients received supplemental oxygen or high-flow nasal cannula (supplemental oxygen) based on the documented fraction of inspired oxygen

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(FiO_2), flow rate, and support devices. We then identified the final discontinuation of respiratory support during the hospital admission, and censored the 60 minutes after final discontinuation of supplemental oxygen based upon recent monitoring guidelines.[2] Minutes up to an hour after supplemental oxygen discontinuation were classified as receiving supplemental oxygen and not included in our analysis. Only minutes between the end of the censored period and hospital discharge were used in the analysis. For patients who never received respiratory support during the admission, we censored the first 60 minutes of the admission and analyzed the remainder of their stay.

SpO_2 Monitoring

We used device-integrated, physiologic-monitor, vital sign data sent each minute from the General Electric monitor network to the EHR to identify minutes during which patients were connected to physiologic monitors and transmitting signals from SpO_2 sensors. We extracted minute-level SpO_2 data from the hospital clinical data warehouse (CDW). Minutes in which SpO_2 data were present were classified as "monitored," an approach previously validated using in-person observation.[14]

To categorize time as "not receiving supplemental oxygen and continuously monitored (guideline-discordant monitoring)," or "not receiving supplemental oxygen and not continuously monitored (guideline-concordant intermittent measurement)," we evaluated the percent of minutes within an hour during which the patient received SpO_2 monitoring and applied an a priori conservative rule. Hours during which ≥90% of minutes had SpO_2 monitoring data were classified as "continuously monitored." Hours during which ≤10% of minutes had SpO_2 monitoring data were classified as "intermittently measured." Hours during which 11% to 89% of minutes included monitor data were excluded from further analysis. The number of continuously monitored hours was tabulated for each patient. The median number of continuously monitored hours was computed; results were stratified by prior receipt of respiratory support.

Alarm Counts

Minute-level monitor alarm counts (the absolute number of abnormal vital signs that triggered a monitor to alarm) were extracted from the CDW. Alarm counts were tabulated for each patient hour. For each patient, the alarm rate (total number of alarms divided by time) was computed for continuously monitored and intermittently measured time. Results were stratified by prior receipt of respiratory support.

The study was reviewed by the institutional review board and determined to meet exemption criteria.

RESULTS

Our cohort included 201 admissions by 197 unique patients (Table). We evaluated 4402 hours that occurred ≥60 minutes following final discontinuation of supplemental oxygen, the time period during which guidelines discourage routine use of continuous SpO_2 monitoring. This represented a median of 19 hours (interquartile range [IQR], 14-25) per admission. We excluded 474 hours (11%) that could not be classified as either continuously or intermittently measured.

TABLE. **Demographics by Admission**

Total admissions (N = 201)	No. (%)
Sex	
Male	112 (56)
Female	89 (44)
Race/ethnicity	
Non-Hispanic Black	85 (42)
Non-Hispanic White	61 (30)
Hispanic	26 (13)
Asian	13 (6)
Other	16 (8)
Age	
0-1 month	29 (14)
2-11 months	54 (27)
12-24 months	118 (59)

During time ≥60 minutes following discontinuation of supplemental oxygen, our cohort experienced 1537 hours of guideline-discordant continuous monitoring, a median of 6 hours (IQR, 3-12) per admission. Patients experienced a median of 12 hours (IQR, 5-17) of intermittent measurement. Among patients who received supplemental oxygen, 91% experienced guideline-discordant continuous SpO_2 monitoring, as compared to 68% of patients who did not receive supplemental oxygen. Among those who received guideline-discordant continuous SpO_2 monitoring, the duration of this monitoring did not differ significantly between those who had received supplemental oxygen during the admission and those who had not.

During classifiable time ≥60 minutes following discontinuation of supplemental oxygen, our cohort experienced 14,371 alarms; 77% (11,101) of these alarms were generated during periods of guideline-discordant continuous monitoring. The median hourly alarm rate during these periods of guideline-discordant continuous monitoring was 6.7 alarms per hour (IQR, 2.1-12.3), representing a median of 35 (IQR, 10-81) additional alarms per patient. During periods of guideline-concordant intermittent measurement, the median hourly alarm rate was 0.5 (IQR, 0.1-0.8), with a median of 5 (IQR, 1-13) alarms per patient.

Those who received supplemental oxygen earlier in the admission had higher alarm rates during continuously monitored time (7.3 per hour [IQR, 2.7-12.7]) than patients who had not received supplemental oxygen (3.3 per hour [IQR, 0.6-11.8]), likely reflecting clinical differences between these patient populations. The most frequent alarm type among continuously monitored patients who had previously received supplemental oxygen was "SpO_2 low."

DISCUSSION

Across 4402 patient hours, guideline-discordant continuous SpO_2 monitoring of patients with bronchiolitis resulted in 11,101 alarms, at a rate of approximately 1 additional alarm

every 9 minutes. Patients in our cohort received a median of 6 hours of guideline-discordant monitoring, which imposes a significant alarm burden that is potentially modifiable using targeted reduction strategies.[15]

Transient, self-resolved hypoxemia is a common feature of bronchiolitis and likely of little clinical consequence.[16] Therefore, this rate of hypoxemia alarms is not unexpected. Though we evaluated only the period of time following final discontinuation of respiratory support, this finding is in keeping with the literature associating excess physiologic monitoring of patients with bronchiolitis with unnecessary oxygen therapy and increased length of stay,[3-5] largely because clinicians may feel compelled to respond to hypoxemia alarms with either supplemental oxygen or longer monitoring.

Our findings must be contextualized in light of the limitations of our approach. We did not evaluate nurse workload associated with guideline-discordant continuous SpO_2 monitoring. Prior work conducted by our lab has demonstrated that when nurses experience more than 40 alarms within a 2-hour period, their measured subjective workload increases to a degree associated with missing important tasks, threatening the quality and safety of the care they deliver.[12,17] Given that nurses care for multiple patients, it is likely that the excess alarms introduced by guideline-discordant continuous monitoring contribute to increased nurse workload and alarm fatigue.

Similarly, we could not evaluate whether the alarms nurses experienced were actionable. Although our lab has previously reported that ≥99% of alarms occurring on non-ICU pediatric wards are nonactionable,[10,11] it is possible that some of the alarms during guideline-discordant monitoring periods required action. However, it is unlikely that any life-sustaining actions were taken because (1) we only evaluated time >60 minutes after final discontinuation of supplemental oxygen, so by definition none of these alarms required treatment with supplemental oxygen, and (2) none of the patients we included received ICU care during their admission.

The avoidable alarm burden identified in our analysis suggests that eliminating continuous SpO_2 monitoring overuse in bronchiolitis will likely reduce nurses' workload and alarm fatigue in hospital settings that care for children with bronchiolitis.

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References

1. Ralston SL, Lieberthal AS, Meissner HC, et al. Clinical practice guideline: the diagnosis, management, and prevention of bronchiolitis. *Pediatrics.* 2014;134(5):e1474-e1502. https://doi.org/10.1542/peds.2014-2742
2. Schondelmeyer AC, Dewan ML, Brady PW, et al. Cardiorespiratory and pulse oximetry monitoring in hospitalized children: a Delphi process. *Pediatrics.* 2020;146(2):e20193336. https://doi.org/10.1542/peds.2019-3336
3. Cunningham S, Rodriguez A, Boyd KA, McIntosh E, Lewis SC, BIDS Collaborators Group. Bronchiolitis of Infancy Discharge Study (BIDS): A multicentre, parallel-group, double-blind, randomised controlled, equivalence trial with economic evaluation. *Health Technol Assess.* 2015;19(71):i-xxiii, 1-172. https://doi.org/10.3310/hta19710
4. McCulloh R, Koster M, Ralston S, et al. Use of intermittent vs continuous pulse oximetry for nonhypoxemic infants and young children hospitalized for bronchiolitis: a randomized clinical trial. *JAMA Pediatr.* 2015;169(10):898-904. https://doi.org/10.1001/jamapediatrics.2015.1746
5. Schuh S, Freedman S, Coates A, et al. Effect of oximetry on hospitalization in bronchiolitis: a randomized clinical trial. *JAMA.* 2014;312(7):712-718. https://doi.org/10.1001/jama.2014.8637
6. Fujiogi M, Goto T, Yasunaga H, et al. Trends in bronchiolitis hospitalizations in the United States: 2000–2016. *Pediatrics.* 2019;144(6):e20192614. https://doi.org/10.1542/peds.2019-2614
7. Bonafide CP, Xiao R, Brady PW, et al. Prevalence of continuous pulse oximetry monitoring in hospitalized children with bronchiolitis not requiring supplemental oxygen. *JAMA.* 2020;323(15):1467-1477. https://doi.org/10.1001/jama.2020.2998
8. Schondelmeyer AC, Brady PW, Goel VV, et al. Physiologic monitor alarm rates at 5 children's hospitals. *J Hosp Med.* 2018;13(6):396-398. https://doi.org/10.12788/jhm.2918
9. Schondelmeyer AC, Bonafide CP, Goel VV, et al. The frequency of physiologic monitor alarms in a children's hospital. *J Hosp Med.* 2016;11(11):796-798. https://doi.org/10.1002/jhm.2612
10. Bonafide CP, Lin R, Zander M, et al. Association between exposure to nonactionable physiologic monitor alarms and response time in a children's hospital. *J Hosp Med.* 2015;10(6):345-351. https://doi.org/10.1002/jhm.2331
11. Bonafide CP, Localio AR, Holmes JH, et al. Video analysis of factors associated with response time to physiologic monitor alarms in a children's hospital. *JAMA Pediatr.* 2017;171(6):524-531. https://doi.org/10.1001/jamapediatrics.2016.5123
12. Rasooly IR, Kern-Goldberger AS, Xiao R, et al. Physiologic monitor alarm burden and nurses' subjective workload in a children's hospital. *Hosp Pediatr.* 2021;11(7):703-710. https://doi.org/10.1542/hpeds.2020-003509
13. Feudtner C, Feinstein JA, Zhong W, Hall M, Dai D. Pediatric complex chronic conditions classification system version 2: updated for ICD-10 and complex medical technology dependence and transplantation. *BMC Pediatr.* 2014;14:199. https://doi.org/10.1186/1471-2431-14-199
14. Kern-Goldberger AS, Rasooly IR, Luo B, et al. EHR-integrated monitor data to measure pulse oximetry use in bronchiolitis. *Hosp Pediatr.* 2021;11(10):1073-1082. https://doi.org/10.1542/hpeds.2021-005894
15. Schondelmeyer AC, Bettencourt AP, Xiao R, et al. Evaluation of an educational outreach and audit and feedback program to reduce continuous pulse oximetry use in hospitalized infants with stable bronchiolitis. *JAMA Netw Open.* 2021;4(9):e2122826. https://doi.org/10.1001/jamanetworkopen.2021.22826
16. Principi T, Coates AL, Parkin PC, Stephens D, DaSilva Z, Schuh S. Effect of oxygen desaturations on subsequent medical visits in infants discharged from the emergency department with bronchiolitis. *JAMA Pediatr.* 2016;170(6):602-608. https://doi.org/10.1001/jamapediatrics.2016.0114
17. Tubbs-Cooley HL, Mara CA, Carle AC, Mark BA, Pickler RH. Association of nurse workload with missed nursing care in the neonatal intensive care unit. *JAMA Pediatr.* 2019;173(1):44-51. https://doi.org/10.1001/jamapediatrics.2018.3619