

Cardiorespiratory and Pulse Oximetry Monitoring in Hospitalized Children: A Delphi Process

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abstract

OBJECTIVES: Cardiorespiratory and pulse oximetry monitoring in children who are hospitalized should balance benefits of detecting deterioration with potential harms of alarm fatigue. We developed recommendations for monitoring outside the ICU on the basis of available evidence and expert opinion.

METHODS: We conducted a comprehensive literature search for studies addressing the utility of cardiorespiratory and pulse oximetry monitoring in common pediatric conditions and drafted candidate monitoring recommendations based on our findings. We convened a panel of nominees from national professional organizations with diverse expertise: nursing, medicine, respiratory therapy, biomedical engineering, and family advocacy. Using the RAND/University of California, Los Angeles Appropriateness Method, panelists rated recommendations for appropriateness and necessity in 3 sequential rating sessions and a moderated meeting.

RESULTS: The panel evaluated 56 recommendations for intermittent and continuous monitoring for children hospitalized outside the ICU with 7 common conditions (eg, asthma, croup) and/or receiving common therapies (eg, supplemental oxygen, intravenous opioids). The panel reached agreement on the appropriateness of monitoring recommendations for 55 of 56 indications and on necessity of monitoring for 52. For mild or moderate asthma, croup, pneumonia, and bronchiolitis, the panel recommended intermittent vital sign or oximetry measurement only. The panel recommended continuous monitoring for severe disease in each respiratory condition as well as for a new or increased dose of intravenous opiate or benzodiazepine.

CONCLUSIONS: Expert panel members agreed that intermittent vital sign assessment, rather than continuous monitoring, is appropriate management for a set of specific conditions of mild or moderate severity that require hospitalization.



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Dr Schondelmeyer conceptualized and designed the study, contributed to the acquisition, analysis, and interpretation of data, and drafted the manuscript; Drs Dewan, Brady, and Bonafide conceptualized and designed the study and contributed to the acquisition, analysis, and interpretation of data; (Continued)

WHAT'S KNOWN ON THIS SUBJECT: Continuous cardiorespiratory and pulse oximetry monitors (commonly used to surveil for deterioration in children who are hospitalized) can negatively impact patient safety because of excessive monitor alarms. There are no national guidelines for using monitors in most common pediatric conditions.

WHAT THIS STUDY ADDS: Leveraging existing evidence, a national expert panel reached agreement that intermittent heart rate, respiratory rate, and pulse oximetry assessment, rather than continuous monitoring, is appropriate management for a set of specific conditions of mild or moderate severity that require hospitalization.

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Continuous cardiorespiratory (cCR) and continuous pulse oximetry (cSpO₂) monitoring of children who are hospitalized may identify deterioration in patients who are unstable, but using continuous monitors can also have a substantial negative impact. Specifically, overuse of continuous monitors can contribute to alarm fatigue (when clinicians become desensitized to alarms) and its associated morbidity and mortality.^{1,2} Excessive alarms from continuous monitors may be detrimental to hospital staff³⁻⁵ and may lead to poor sleep and anxiety for families of children who are hospitalized.⁶⁻¹⁰ Inappropriate monitoring may also capture normal physiology, such as brief nighttime desaturations in healthy infants,¹¹⁻¹³ leading to overdiagnosis and potentially increased length of hospital stay.¹⁴

Hospital-based clinicians commonly use monitors to measure the heart rhythms, heart rates, respiratory rates, and oxyhemoglobin saturation levels of children who are hospitalized,^{15,16} and there is wide variation in how clinicians monitor children who are hospitalized.¹⁵ This variation has important potential implications because it remains unclear which patients are better served by continuous monitoring modalities in addition to routine intermittent cardiorespiratory (measuring heart rate and respiratory rate) and intermittent pulse oximetry (SpO₂) assessments. Clinicians may also overestimate the contribution of continuous monitoring to patient care,^{17,18} making it difficult to objectively balance the harms associated with missing patient deterioration with the potential harms of over-monitoring.

To our knowledge, there are no published expert recommendations on the indications for continuous monitoring of the most common conditions seen in children's hospitals. There are few well-designed

trials addressing monitoring for children who are hospitalized, and there is an urgent need for a standardized approach. Standardizing clinical practice can reduce unnecessary use and improve patient outcomes,¹⁹⁻²⁶ and well-developed guidelines can improve practice.²⁷ We combined the best available evidence with the skills and insights of a diverse national expert panel to develop monitoring recommendations.

METHODS

Study Design

We followed the RAND/University of California, Los Angeles (UCLA) Appropriateness Method,²⁸ a widely applied technique for creating recommendations for medical practices.²⁹⁻³³ The RAND/UCLA Appropriateness Method is designed to develop recommendations when the scientific literature is limited and combines existing evidence with expert judgment through a structured rating process with strict definitions of appropriateness and necessity (Fig 1).

This study was reviewed by the hospital's institutional review board and determined to be exempt.

Expert Panel Recruitment

Our multidisciplinary research team invited leaders of relevant national professional organizations as well as a family advocacy organization to nominate expert panelists. We reviewed curricula vitae of nominees for applicable expertise and evidence of potential bias that could render a nominee unsuitable as a panelist. We then interviewed nominees to identify potential conflicts of interest. To maintain a manageable panel size²⁸ and to ensure broad representation of disciplines, we targeted approaching a subset of nominees with the plan to approach additional nominees as needed to ensure representation of those

perspectives. From the original nominees, we identified 14 willing panel members, of whom 12, representing a wide array of disciplines and experience, were ultimately able to participate in the full process (Supplemental Table 2). Panelists with clinical backgrounds held relevant experience in pediatric hospital medicine, pediatric critical care medicine, transport care, emergency medicine, and anesthesiology, including members with experience working in community settings and in large children's hospitals.

Comprehensive Literature Search and Recommendation Generation

The research team consulted a medical librarian, who constructed a comprehensive search strategy. Search terms included the most common diagnoses treated in children's hospitals, as identified by Keren et al,³⁴ combined with terms specific to monitoring (eg, SpO₂ monitor), and patient safety (eg, deterioration, apnea, cardiac arrest). Databases searched included PubMed, Cumulative Index to Nursing and Allied Health Literature, Scopus, Embase, and Evidence-Based Medicine Reviews (Ovid). At least 2 study team members screened titles for relevance. We considered titles focused on surgical or subspecialty-specific care (eg, oncology, neonatology) out of scope for this project and excluded them during screening.

We then reviewed abstracts of screened articles for pertinence and evidence quality. We identified additional articles by reviewing article reference lists and the authors' personal reference libraries. One study team member (A.C.S) reviewed selected full-text articles and extracted information about study design, population, and results using a structured review form. The group assigned a level of evidence for each study and an aggregate literature

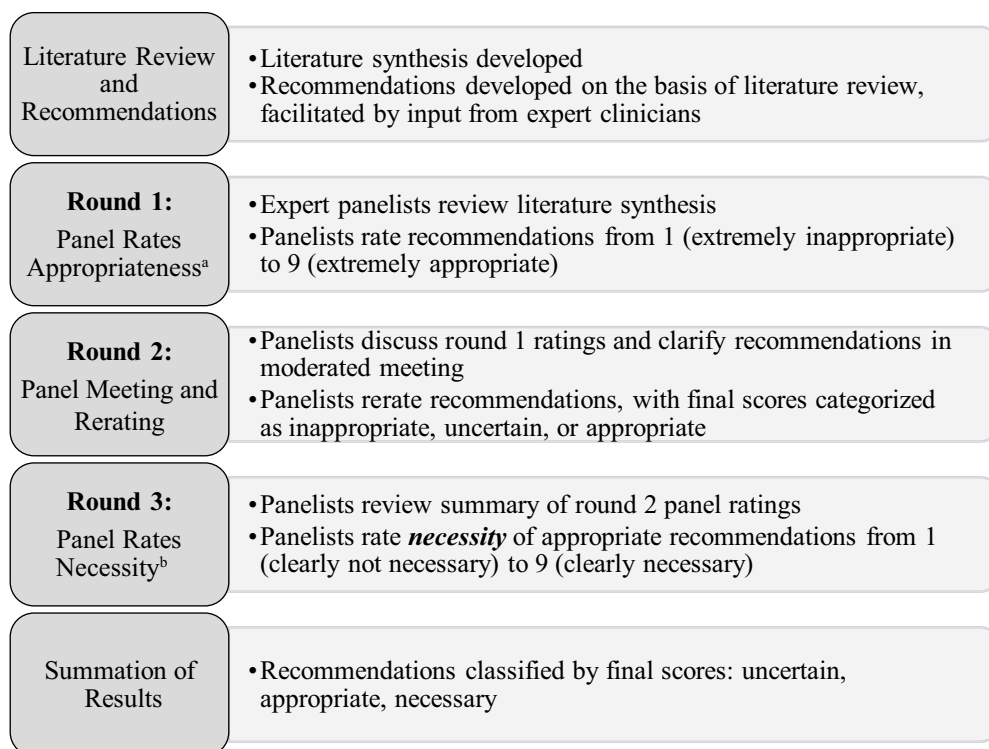


FIGURE 1

Steps in the RAND/UCLA Appropriateness Method. ^a The expected health benefit exceeds the negative consequences by a sufficiently wide margin that the recommendation is worth following, exclusive of the cost. ^b The recommendation is appropriate, there is a reasonable chance it will benefit the patient, the magnitude of expected benefit is not small, and it would be improper care to not follow the recommendation.

quality rating based on the Oxford Centre for Evidence-Based Medicine Levels of Evidence.³⁵

We then generated literature summaries organized by disease (eg, pneumonia, sepsis), type of therapy (eg, supplemental oxygen), and general information about monitoring (eg, accuracy and utility of monitors). We have included the search strategy in Supplemental Table 3 and the literature search results in Supplemental Fig 2.

Creation of Recommendations

We drafted potential indications for monitoring that included the specific diagnosis (eg, pneumonia), patient characteristics or symptoms, and severity of illness criteria drawn from the literature. We then, on the basis of the available literature, created a recommendation in each indication for whether cCR and cSpO₂ monitoring or intermittent

cardiorespiratory and SpO₂ assessment should be performed. Recommendations suggesting intermittent cardiorespiratory or SpO₂ assessment were treated as being at the exclusion of cCR or cSpO₂ monitoring for that indication. Therefore, as an example, in an indication for which the evidence suggests that only intermittent cardiorespiratory or SpO₂ assessment should be performed, we did not ask the panel to rate the appropriateness of recommendation for a continuous monitoring modality. The full list of recommendations is included in Supplemental Fig 3.

Study team members who were content experts in hospital medicine (A.C.S., P.W.B., and C.P.B.), patient safety (P.W.B. and C.P.B.), and the care of patients who are critically ill (M.L.D. and R.C.) reviewed recommendations in detail for clarity and completeness.

Recommendation Rating

Before the rating sessions, we briefed panelists on the RAND/UCLA Appropriateness Method and provided opportunity to clarify language in evidence summaries or recommendations or to suggest additional relevant literature. We also asked panelists to suggest additional recommendations.

In the first round, we provided evidence summaries reviewing key findings and studies that informed recommendations. Panelists then independently rated each recommendation on a standard 9-point Likert scale of appropriateness. We framed appropriateness as the degree to which the benefits of continuous monitoring outweighed the risks, exclusive of cost.²⁸ We assessed scores for disagreement on the basis of the median and range of ratings as previously described.²⁸

Recommendations for which there was agreement were considered appropriate if the median panelist rating was between 7 and 9, of uncertain appropriateness if the median was between 4 and 6, or inappropriate if the median was between 1 and 3.

After the first round, panelists participated in a moderated conference call, a previously published modification on the RAND/UCLA Appropriateness Method.^{29,30,32} During the call, panelists discussed round 1, focusing on ratings for which a final score was uncertain or for which there was disagreement. The moderator encouraged panelists to discuss areas of disagreement and unclear recommendations. Immediately after the call, we made suggested revisions to improve clarity of the recommendations, and panelists completed a second round of individual ratings using the same appropriateness scale. We assessed those scores for agreement and appropriateness.

We conducted a third round of ratings to assess the necessity of monitoring in situations that the panelists had already determined to be appropriate. In RAND/UCLA terms, necessary recommendations are those for which it would be improper care not to follow the practice.³⁶ Panelists were provided updated rating forms with recommendations rated as appropriate in the first 2 rounds. They rated recommendations on 9-point Likert scale, from completely unnecessary to completely necessary. Finally, we assessed necessity scores for disagreement, as described above, and recommendations were classified as necessary (median score of 7–9), of uncertain necessity (median score of 4–6) and appropriate but unnecessary (median score of 1–3 or presence of disagreement).²⁸

RESULTS

Of the 56 original scenarios, panelists reached agreement on appropriateness of 55 and reached agreement on the necessity of 52. For all indications below in which necessity is discussed, panelists rated either intermittent or continuous monitoring as appropriate. Recommendations for monitoring in patients requiring specific therapies (eg, supplemental oxygen) were addressed separately from recommendations for monitoring in respiratory conditions and are therefore discussed separately below. We condensed results for similar indications and for which the final recommendations were analogous. In Table 1, we provide a visual summary of the panel recommendations. We provide the list of recommendations with final panelist ratings in Supplemental Fig 3.

Therapies

Intravenous Opioids and Benzodiazepines

For children receiving a dose that they had previously tolerated without issue, panelists rated intermittent SpO₂ and cardiorespiratory assessment as necessary at the exclusion of cCR and cSpO₂ monitoring, with the exception of cCR monitoring for benzodiazepines, which was appropriate but of uncertain necessity. For children receiving an increased dose of a drug or a new drug or for those receiving patient-controlled analgesia with or without a basal infusion rate, panelists rated cCR and cSpO₂ monitoring as necessary.

Supplemental Oxygen

For children receiving supplemental oxygen, panelists rated cSpO₂ as necessary and intermittent cardiorespiratory assessment as appropriate but not necessary. We presented the threshold for discontinuing cSpO₂ within 1 hour of stable saturation levels $\geq 90\%$ to

panelists. We based this recommendation on the literature review, including a randomized trial in which intermittent SpO₂ was compared with cSpO₂,¹⁶ a quality improvement study aimed at reducing SpO₂ use in children with wheezing,³⁷ and a separate randomized trial assessing the effect of target saturation levels of $\geq 90\%$ in bronchiolitis³⁸ as well as multiple studies documenting the frequency of self-resolved desaturations in healthy patients during sleep^{11–13} and in children with viral lower respiratory illness³⁹ and the effect of SpO₂ on physician clinical practice and patient outcomes.^{40,41} When invited to provide input on this threshold, panelists agreed with the 1-hour time period and did not recommend any modifications. At the conclusion of ratings, panelists rated transition from cSpO₂ to intermittent SpO₂ within 1 hour of achieving stable saturation levels $\geq 90\%$ as necessary.

Specific Conditions

Asthma

For asthma, panelists rated severity-based recommendations referring to published guidelines classifying exacerbations.⁴² For patients with mild or moderate disease, indicated by dyspnea with activity or dyspnea that limits exertion, panelists rated intermittent cardiorespiratory and SpO₂ assessment as necessary, at the exclusion of cCR and cSpO₂ monitoring. For patients with more severe disease, indicated by dyspnea at rest that interferes with conversation, or for patients requiring continuous albuterol, panelists rated cSpO₂ monitoring as appropriate but not necessary and cCR monitoring as necessary.

Croup

Panelists rated recommendations based on published illness severity criteria.⁴³ For patients with audible stridor, mild or moderate retractions, and minimal distress, panelists rated

TABLE 1 Panel Results for Appropriateness and Necessity of Intermittent SpO₂ and Heart Rate and Respiratory Rate Assessment Versus cSpO₂ and cCR Monitoring

	Indication	Definition	Recommendation			
			Intermittent Assessment		Continuous Monitoring	
			SpO ₂	Cardiorespiratory	SpO ₂	Cardiorespiratory
Therapies						
Supplemental oxygen	—	Children weaned from supplemental oxygen should be transitioned to intermittent oximetry measurement within 1 h if oxygen saturation levels are stable at ≥90% unless otherwise indicated by diagnosis or condition	—	A	AN	—
Opioids or benzodiazepines	Stable dose	Previously received dosage without complications	AN	AN	—	—
	New drug, increased dose ± PCA	New medication or increased dose of a current medication (during drug peak effect and half-life); initiation of a patient-controlled analgesia with or without a basal rate	—	—	AN	AN ^a
Diagnoses						
Asthma	Mild or moderate	Dyspnea limiting activity	AN	AN	—	—
	Severe ± continuous albuterol	Dyspnea at rest interferes with conversation or too dyspneic to speak	—	—	A	AN
Croup	Mild or moderate	Audible stridor and mild-moderate retractions at rest, minimal distress	A	AN	—	—
	Severe	Prominent inspiratory or expiratory stridor, marked retractions, significant distress	—	—	AN	AN
Pneumonia	Routine	Cough, difficulty breathing, tachypnea	AN	AN	—	—
	Severe	Lower-chest indrawing, nasal flaring, grunting	—	A	AN	—
Bronchiolitis	Very severe	Cyanosis, severe distress, lethargy, unconsciousness	—	—	AN	AN
	Low risk	No apnea or cyanosis	AN	AN	—	—
Pertussis suspected or confirmed	High risk	Witnessed apnea or cyanosis	—	—	AN	AN
	Low risk	Children <4 mo or <1 y unimmunized with no witnessed apnea or cyanosis	—	—	—	AN
Brief resolved unexplained event	High risk	Children <4 mo or <1 y unimmunized with witnessed apnea or cyanosis	—	—	AN	AN
	Low risk	Well-appearing infant with no high-risk features, up to 24 h	—	—	—	—
Severe sepsis	—	<60 d or <45 wk corrected age, <32 wk gestation, multiple or prolonged events, CPR received	—	—	AN	AN
		Sepsis plus cardiovascular dysfunction, acute respiratory distress syndrome, or ≥2 other organ dysfunctions	—	—	AN	AN

Indications with similar recommendations for monitoring were merged. Panelists were advised to use the following definitions of appropriateness and necessity: appropriateness: the expected health benefit exceeds the negative consequences by a sufficiently wide margin that the recommendation is worth following, exclusive of the cost; necessity: the recommendation is appropriate, there is a reasonable chance it will benefit the patient, the magnitude of expected benefit is not small, and it would be improper care to not follow the recommendation. AN, appropriate and necessary; A, appropriate but not necessary or appropriate and of uncertain necessity; PCA, patient-controlled analgesia; —, not applicable.

^a Cardiorespiratory monitoring in patients receiving a new or increased dose of a benzodiazepine was rated as appropriate but of uncertain necessity.

intermittent SpO₂ assessment as appropriate but of uncertain necessity and rated intermittent cardiorespiratory assessment as necessary. For patients with prominent inspiratory and expiratory stridor, marked retractions, and/or significant distress, panelists rated cSpO₂ and cCR monitoring as necessary.

Pneumonia

Panelists referenced severity of illness recommendations adapted

from World Health Organization criteria⁴⁴ that have been used across multiple studies.^{45–48} For children with milder disease, characterized by cough, difficulty breathing, and tachypnea, panelists rated intermittent SpO₂ and cardiorespiratory assessment as necessary, at the exclusion of cCR and cSpO₂ monitoring. For children with more substantial distress, including retractions, nasal flaring, and grunting, panelists rated cSpO₂ as appropriate and intermittent

cardiorespiratory assessment as necessary. Finally, for children with cyanosis, severe distress, or changes in mental status (such as lethargy or unconsciousness), panelists rated cSpO₂ and cCR monitoring as necessary.

Bronchiolitis

Panelists rated recommendations based on the presence of witnessed apnea or cyanosis. For infants without witnessed apnea or cyanosis, panelists rated intermittent

cardiorespiratory and SpO₂ assessment as necessary, at the exclusion of cCR and cSpO₂ monitoring. For patients with witnessed apnea or cyanosis, panelists rated cCR and cSpO₂ monitoring as necessary.

Pertussis

Panelists rated recommendations for suspected and confirmed pertussis separately. For children <4 months (or unimmunized children <1 year) with no witnessed apnea or cyanosis, panelists rated the appropriateness of cSpO₂ monitoring as uncertain; panelists rated the recommendation for cCR monitoring for this indication as necessary. For children with witnessed apnea or cyanosis, panelists rated cSpO₂ and cCR monitoring as necessary.

Brief Resolved Unexplained Event

Panelists rated risk-based recommendations drawn from American Academy of Pediatrics guidelines.⁴⁹ For well-appearing, low-risk patients admitted to the hospital, panelists rated cSpO₂ of up to 24 hours' duration and intermittent cardiorespiratory assessment as appropriate but of uncertain necessity. For children with higher-risk features,⁴⁹ including those <60 days or those <45 weeks' corrected age, those who were born at <32 weeks' gestation, and those who had multiple or prolonged events or required cardiopulmonary resuscitation, panelists rated cSpO₂ and cCR monitoring as necessary.

Severe Sepsis

Severe sepsis was defined according to existing criteria as signs of sepsis with cardiovascular dysfunction, acute respiratory distress syndrome, or evidence of dysfunction in ≥ 2 other organ systems.⁵⁰ Panelists rated the recommendation for cSpO₂ and cCR monitoring in this indication as necessary.

DISCUSSION

After the RAND/UCLA Appropriateness Method and using a literature review and a national expert panel with diverse expertise, the panel reached agreement on recommendations for cSpO₂ and cCR monitoring and its alternative, intermittent cardiorespiratory and SpO₂ assessment, in children who are hospitalized. There are a few conditions for which the panel determined that continuous monitoring was appropriate and necessary. However, in many other conditions, the panel determined that intermittent cardiorespiratory and SpO₂ assessment were appropriate and necessary. These recommendations, combining available evidence and expert judgment, are intended to guide clinicians trying to balance the harms of over-monitoring with risks of under-monitoring and facilitate the development of rigorous, evidence-driven guidelines for monitoring children who are hospitalized.

Studies of the benefits and harms of continuous monitoring, in particular of SpO₂, have been primarily limited to bronchiolitis. The common occurrence of self-resolved desaturations in healthy children¹¹⁻¹³ and in those with viral lower respiratory illness³⁹ is well documented. In addition, the safety of lower oxygen saturation targets^{41,51} as well as the impact of intermittent oximetry monitoring¹⁶ have been explored in randomized trials. Drawing from a broader set of literature, the expert panel reached agreement on continuous monitoring practices for the most common respiratory illness in children who are hospitalized. These recommendations outline symptom-based criteria on which to base escalation of intermittent SpO₂ to cSpO₂, and the results of this process confirm the importance of considering intermittent SpO₂ over continuous monitoring for a broad

range of respiratory conditions and symptom-based criteria on which to base escalation of intermittent SpO₂ to cSpO₂ monitoring. On the basis of existing risk- and severity-stratification approaches, the panel consistently rated different monitoring approaches (ie, intermittent monitoring for lower severity and continuous monitoring for higher severity) as appropriate, noting that the approach to monitoring depends both on the child's underlying diagnosis and on the severity of illness.

The expert panel rated transitioning from cSpO₂ to intermittent SpO₂ within an hour of achieving saturation levels $\geq 90\%$ as necessary, similar to recommendations in a previous quality improvement study⁵² and a randomized trial.¹⁶ This recommendation in particular has the potential to reduce length of monitoring for children after supplemental oxygen has been weaned, decreasing the likelihood of capturing transient desaturations that are normal or expected as part of the disease course. Capture of this type of data might lead clinicians to unnecessarily restart oxygen therapy or prolong hospital stay. Reduced monitoring for children not requiring supplemental oxygen has the potential to reduce unnecessary care and length of hospital stay, which could apply to a broad segment of children who are hospitalized given that respiratory conditions count among the top 10 reasons for pediatric hospitalization.³⁴

The panel consistently endorsed continuous monitoring as necessary for severe presentations of diseases on the basis of the premise that continuous monitoring is more likely to detect true signs of deterioration. The first continuous monitors were used in adult coronary care units, where they helped reduce mortality from fatal arrhythmias⁵³; however, more recent evidence in adults suggests that cCR and cSpO₂ monitors

may not broadly improve patient outcomes.⁵⁴ Given the lower rate of deterioration among children who are hospitalized,^{18,55-58} it is reasonable to approach widespread continuous monitoring of children outside the ICU with skepticism that it will improve patient outcomes. However, rigorous assessment of patient safety and clinician and patient experience should be conducted during implementation of these recommendations to understand their impact. In addition, building on a foundation of standardized monitoring, further work can better delineate monitoring strategies that are sensitive to patient deterioration but do not overburden clinicians and patients and families with alarm data that may not be useful.

This study was limited by quality of evidence, which included mostly observational studies. However, the RAND/UCLA Appropriateness Method was designed for just this scenario because it engages an expert panel to interpret and adjudicate in situations in which evidence is sparse. The conditions included were limited to those addressed in existing literature, and the recommendations do not address the full range of conditions for which children are hospitalized. However, respiratory conditions remain among the top

reasons for hospital admission³⁴ and for in-hospital deterioration.^{59,60}

Thus, we estimate that these will be relevant for a majority of general pediatric admissions. Finally results of the RAND/UCLA process can be influenced on the basis of panel composition.²⁸ We therefore sought nominees from a broad array of professional organizations and possessing a range of clinical practice expertise and other backgrounds to ensure a broad representation of opinions.

Further work will be needed to improve patient care with respect to monitoring. Previous studies have demonstrated the efficacy of high-quality guidelines in improving patient care,²⁷ yet usability can hinder a clinician's use of guidelines.⁶¹ Work to better understand barriers to appropriate monitor use and develop reliable implementation methods will be critical. Measurement of baseline monitoring practices and implementation of these recommendations in multisite hybrid implementation-effectiveness trials^{62,63} may provide the opportunity to better delineate the best practices for implementation and measure the effect on quality and safety of care and on clinician and

family experience as these recommendations are implemented.

CONCLUSIONS

Using the RAND/UCLA Appropriateness Method, an expert panel reached agreement on appropriate and necessary monitoring strategies for children hospitalized with common diagnoses or receiving frequently administered therapies. The expert panel consistently endorsed that intermittent cardiorespiratory and SpO₂ assessment, rather than continuous monitoring, be performed for mild or moderate disease. Future work should be focused on understanding barriers to appropriate monitor use and developing best practices for implementing monitoring recommendations into clinical practice alongside rigorous measurement of patient outcomes and alarm fatigue.

ABBREVIATIONS

cCR: continuous cardiorespiratory
cSpO₂: continuous pulse oximetry
SpO₂: pulse oximetry
UCLA: University of California Los Angeles

Dr Britto, Ms Timmons, and Ms Cable contributed to the study design, and the analysis and interpretation of the data; and all authors reviewed and revised the manuscript for important intellectual content, approve the final manuscript as submitted, and agree to be accountable for all aspects of the work.

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