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ORIGINAL ARTICLE

Establishing outcome-driven vital signs ranges for children in the prehospital setting

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Abstract

Background: Vital signs are frequently used in pediatric prehospital assessments and guide protocol utilization. Common pediatric vital sign classification criteria identify >80% of children in the prehospital setting as having abnormal vital signs, though few receive lifesaving interventions (LSIs). We sought to identify data-driven thresholds for abnormal vital signs by evaluating their association with prehospital LSIs.

Methods: We evaluated prehospital care records for children (<18 years) transported to the hospital during 2022 from a large, national repository of emergency medical services (EMS) patient encounters. Predictors of interest were heart rate (HR), respiratory rate (RR), systolic blood pressure (SBP), and pulse oximetry. HR, RR, and SBP were converted to *Z*-scores using age-based distributional models. Our outcome was potential LSIs, defined as performance of selected respiratory procedures, resuscitative interventions, or medication administrations. Using cut point analysis, we identified higher specificity (maximal specificity with a minimum of 25% sensitivity) and higher sensitivity (maximal sensitivity with a minimum of 25% specificity) ranges for each vital sign and evaluated measures of diagnostic accuracy.

Results: We included 987,515 children (median age 10 years, IQR 2–15 years). An LSI occurred in 4.3% (2.1% with respiratory procedures, 1.2% with resuscitative interventions, and 2.0% with medication administration). HR, RR, and SBP demonstrated a U-shaped association with LSIs. Specificities ranged from 84.1% to 93.7% for higher specificity criteria, with RR demonstrating the best performance (sensitivity 84.6%, specificity 27.0%). Sensitivities ranged from 62.3% to 84.4% for higher sensitivity criteria.

Conclusions: Cut points for pediatric vital signs were associated with LSIs. Specific age-adjusted ranges can identify children at higher and lower risk for receipt of LSI. These ranges may be combined with other objective measures to improve the assessment of children in the prehospital setting, assist in optimizing protocol utilization, improve transport decision making, and guide destination selection.

See related article on page 210

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INTRODUCTION

Children account for approximately 6% of emergency medical services (EMS) encounters in the United States.[1,2] The ability to triage patients accurately from the field to an emergency department (ED) is a cornerstone of emergency and disaster response. Prior qualitative research suggests that EMS clinicians are uncomfortable with pediatric care[3,4] and have difficulty identifying children with the potential for deterioration.[5] Vital signs provide objective measures that are essential to EMS protocol utilization, guide treatment decisions, assess response to interventions, direct patients to specialty centers, and initiate hospital processes, such as trauma team activation, to optimize patient evaluation, stabilization, and treatment in the ED. EMS protocols commonly reference the pediatric advanced life support (PALS) vital sign thresholds,[6] which include vital sign criteria largely derived from healthy populations. These criteria identify >80% of children in the prehospital setting as having abnormal vital signs,[7] though few receive advanced interventions.[8,9] Frequently, vital signs in the prehospital setting are altered beyond physiological norms derived for healthy populations because of pain, anxiety, or fever, leading to overclassification of patients as seriously ill. This may represent a limitation of current vital sign thresholds for children in prehospital triage protocols.

As an alternative approach, the classification of vital signs based on their association with potentially lifesaving interventions (LSIs) may allow for more accurate assessments of children in need of advanced prehospital or ED care. We recently described a distributional approach for centiles of pediatric prehospital vital signs[7] and have compared these to other expert and centile-based approaches for pediatric vital sign classification when using arbitrarily defined cutoffs occurring below the 10th or above the 90th percentile.[1] However, by leveraging the continuous nature of these age-adjusted vital signs and by applying cut point identification techniques with a clinically meaningful outcome, the resultant cut points can be applied to further enhance prehospital assessments. This approach also may be useful to inform specific criteria to identify children at higher risk of requiring potentially LSI and those who are likely safe for nontransport, refusal, or alternative destination protocols.

In this study, we sought to describe the association between vital signs for children in the prehospital setting and their receipt of potentially LSIs by EMS. In addition, we aimed to further characterize cutoffs for vital signs that may be used to risk stratify children receiving prehospital care using a large, prehospital data set.

METHODS

Data source

We performed a retrospective cross-sectional analysis of EMS encounters from 2022 using the National Emergency Medical Services Information System (NEMSIS, v.3.4.0). NEMSIS is a national repository that includes patient care records submitted prospectively by U.S. EMS agencies. The 2022 release contains data on 51,379,493 EMS activations submitted by 13,946 EMS agencies servicing 54 states and territories. Approval of this study was obtained by the institutional review board of Ann & Robert H. Lurie Children's Hospital of Chicago.

Inclusion

We included all pediatric (>0 days and <18 years) encounters, excluding those with a missing age. From this sample, we identified encounters from the scene (e.g., 9-1-1 calls) that had an Advanced Life Support (ALS) or critical care response. We limited our sample to those with an ALS or critical care prehospital clinician as most of our outcome measures were outside the scope of practice for Basic Life Support clinicians.

Exposure

Our exposures of interest were vital signs: heart rate (HR), respiratory rate (RR), systolic blood pressure (SBP), and pulse oximetry. We evaluated the first recorded value of each vital sign among the included encounters as our primary exposure of interest on the basis that these measures may have the greatest use in formulating EMS assessments and could potentially be incorporated within prediction models to identify children at the greatest risk of critical illness or injury. For HR, RR, and SBP, we applied *Z*-scores for age using our previously derived and validated distributions.[1,7] Pulse oximetry was considered as a continuous, unadjusted measure. Diastolic blood pressure is unavailable within the NEMSIS data set.

Outcome

Our outcome of interest was LSI during the encounter we adapted these from previously defined criteria[10] and categorized them within subgroups as respiratory interventions, resuscitative procedures, and medication administrations. Respiratory interventions were defined as endotracheal intubation, supraglottic airway placement, or positive pressure ventilation. Resuscitative procedures included cardiopulmonary resuscitation, bolus fluid administration of at least 20 mL/kg or 1 L, intraosseous line placement, control of major bleeding, or electrical therapy (defibrillation, cardioversion, or pacing). Medication administration was defined as administration of atropine, adenosine, epinephrine, naloxone, norepinephrine, dopamine, or milrinone. When estimating dosing of bolus fluid administration, we used the "best guess" formula to approximate patient weight for age.[11] Specific medication and procedure codes in the NEMSIS data set used for the identification of LSI are provided in Table S1.

Data analysis

We described demographic and treatment characteristics of the study sample. We constructed univariable analyses for each vital sign with our composite outcome using a tail-restricted cubic spline function with knots at each quartile and at the 5th and 95th percentiles and fit using the maximum likelihood function. We separately identified cut points for each vital sign for their high and low values. To identify the diagnostic value of different cut points to define bradycardia, bradypnea, and hypotension, we constructed a receiver operator characteristic (ROC) curve of the subset of all encounters where the *Z*-score for HR, RR, and SBP was <0 and evaluated the performance of cut points ranging from −0.2 to −2.0 at intervals of 0.2 with the metrics of sensitivity and specificity. We performed the opposite set of steps to evaluate cut points for tachycardia, tachypnea, and hypertension. We did not perform this step for pulse oximetry as this vital sign was not adjusted for age. Instead, we described the association of differing cut points for a lower limit of pulse oximetry with LSI in increasing 2% increments, from a starting threshold of 80%.

We next developed two age-based criteria for vital sign thresholds that were tested for their prediction of children who received LSI. We determined *higher specificity* criteria by identifying the highest cut point of specificity for each vital sign while keeping the sensitivity constrained to 25%. We next determined *higher sensitivity* criteria by identifying the cut point with the highest sensitivity while keeping the specificity constrained to 25%. As we established the upper and lower limits of each of these criteria from ROC curves constructed within subsets of patients with a high ($Z>0$) and low ($Z<0$) measure, respectively, we were able to identify separate criteria for these ranges rather than cut points equidistant from the *Z*-score of 0 (Figure 1). We then converted the *Z*-score cutpoints for each vital sign back to age-specific vital signs measures and summarized these using the median within the age groups of 0–3 months, >3–6 months, >6–9 months, >9–12 months, >1–3 years, >3–6 years, >6–9 years, >9–12 years, and >12–18 years. Among the subset of patients with all documented vital signs (HR, RR, SBP, and pulse oximetry), we evaluated the diagnostic accuracy of the higher specificity and higher sensitivity vital signs criteria in aggregate, in which the presence of at least one abnormal vital sign within this sample was considered as a positive result. To evaluate the association with multiple vital sign abnormalities on the performance of an LSI, we constructed a univariable and multivariable logistic regression models for this outcome using the higher sensitivity and higher specificity cutoffs. We expressed these results as univariable and multivariable odds ratios (OR) with a 95% confidence interval (CI). Using the higher specificity model, we next assigned the predictor in the multivariable model with the lowest absolute adjusted OR value as 1 point, while the remaining predictors scored according to the comparative magnitude of their adjusted ORs.[12] We constructed an ROC curve and calculated the sensitivity, specificity, and likelihood ratios, to evaluate the performance of the multivariable model at differing cutoffs.

As younger children are more challenging for EMS clinicians to assess,[13,14] we separately evaluated the performance of these cut points among infants. Analyses were performed using the *rms* (v6.7-0)[15] and *cutpointr* (v1.1.2)[16] packages in R, version 4.3.1 (R Foundation for Statistical Computing).

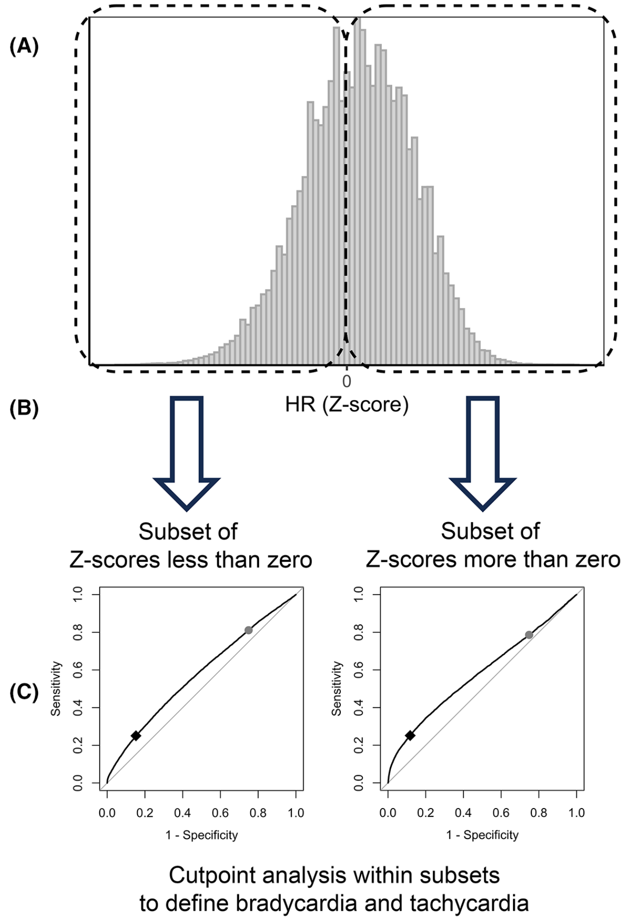

FIGURE 1 Summary of analytic approach to identify high and low cutpoints for each vital sign. (A) Age-based *Z*-scores for each vital sign were assessed. (B) Following this, separate subsets were taken for both low (all *Z*-scored vitals <0) and high (all *Z*-scored vitals >0) vital signs. (C) Within each subset, cutpoint analysis was done to identify higher sensitivity (maximal sensitivity when keeping the specificity to a minimum of 25%) and higher specificity (maximal specificity when keeping the sensitivity to a minimum of 25%) vital sign cutpoints. These steps were performed for HR (shown here), respiratory rate, and systolic blood pressure. HR, heart rate.

Additional analyses

As a *sensitivity analysis*, we evaluated the performance of the higher specificity and higher sensitivity vital signs criteria for each measure within the composite outcome of LSI. We performed an *exploratory* analysis to evaluate potential changes in vital signs over multiple assessments. We evaluated for the presence of additional vital signs within the first 10 min of their initial vital sign documentation and identified the proportion of encounters with a high vital sign measurement, low vital sign measurement, high and low vital sign measurements, or neither a high nor low vital sign measurement. Within each of these four groups, we reported the proportion who had an LSI performed. This was separately performed when using the higher sensitivity and higher specificity vital sign cutoffs. We recorded the number of vital signs documented within the first 10 min of the encounter and used the Wilcoxon rank-sum test to evaluate whether the documentation of more vital signs was associated with an LSI (e.g., reflective of greater concern for a patient at higher risk of critical illness or injury).

RESULTS

Inclusion

Of 51,379,493 encounters in the data set, we identified 2,763,594 pediatric encounters. After limiting to only ALS or critical care 9-1-1 scene encounters and applying exclusions, 987,515 encounters were available for analysis (Figure 2). The median patient age was 10 years (IQR 2–15 years). Demographics of the study sample are provided in Table 1.

Vital sign availability

Among children with at least one vital sign documented, the median number of vital sign assessments was 2 (IQR 2–3) per encounter. A high proportion of children had a documented HR (*n* = 956,045, 96.8%) and RR (*n* = 946,130, 95.8%). A lower proportion of children had a documented pulse oximetry (*n* = 889,173, 90.0%) or SBP (*n* = 807,336, 81.8%).

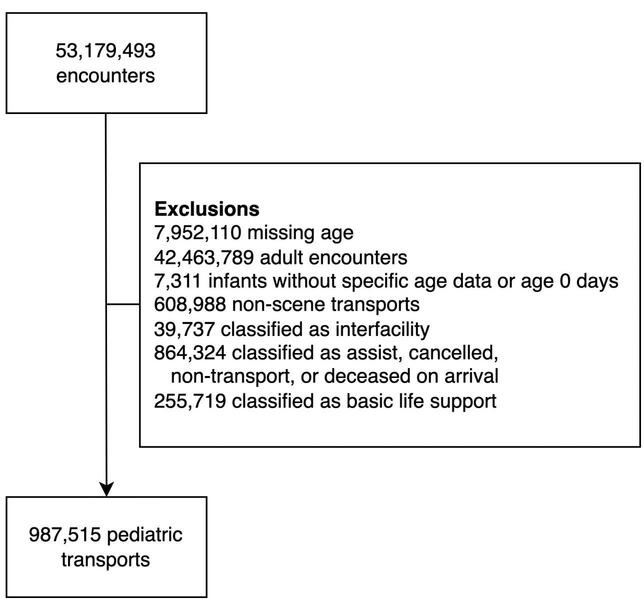

FIGURE 2 Patent inclusion.

TABLE 1 Demographics and transport characteristics.

Variable	*N* = 987,515
Age (years)	10 (2–15)
Male sex	505,237 (51.2)
Type	
ALS	961,822 (97.4)
Specialty critical care	25,693 (2.6)
Census region	
Midwest	229,565 (23.2)
Northeast	158,607 (16.1)
South	410,019 (41.5)
West	189,051 (19.1)
Weekend	137,499 (13.9)
Time of day	
Daytime	385,768 (39.1)
Evening	441,597 (44.7)
Overnight	160,150 (16.2)
Trauma[a]	307,034 (31.1)

Note: Data are reported as *n* (%) or median (IQR). Sex missing in 3718 (0.4%), and Census region, in 273 (0.0%).

Abbreviation: ALS, advanced life support.

[a]Based on dispatch complaint.

LSI

An outcome of LSI occurred in 42,609 (4.3%) encounters. This included 20,406 (2.1%) with respiratory interventions, 12,338 (1.2%) who had a resuscitative procedure, and 19,295 (2.0%) with medication administration. Detailed outcome data within these groups are provided in Table S2.

Univariable analysis and vital sign evaluation at interval cutpoints

Plotted as splined predictors, HR, RR, and SBP demonstrated a U-shaped association with LSI (Figure 3). The performance of varying cutoffs for high and low measures of these vital signs with LSI is provided in Table 2 and demonstrate a dynamic tradeoff between sensitivity and specificity at differing thresholds. *Z*-score cutoffs that were closer to 0 had greater sensitivities with lower specificities, whereas those further from 0 had greater specificity but lower sensitivity. When using pulse oximetry, overall accuracy was high at lower thresholds and declined rapidly at cut points over 92% (Table S3).

Higher specificity and higher sensitivity criteria

Ranges for higher specificity and higher sensitivity vital signs criteria for HR, RR, and SBP are provided in Table 3. The higher specificity

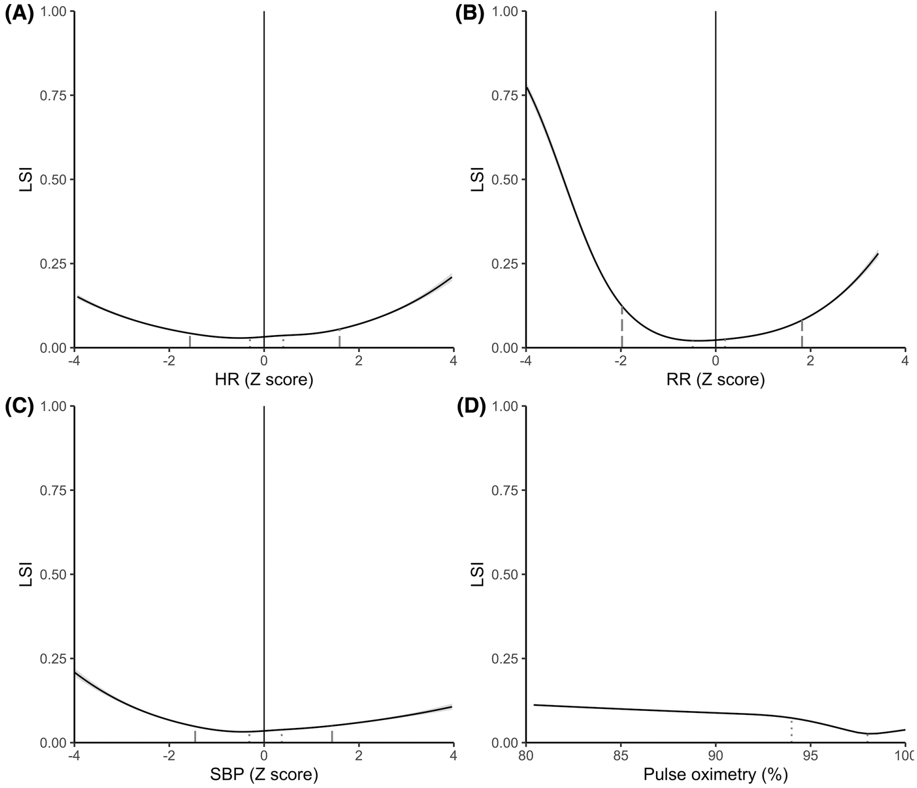

FIGURE 3 Spline-based probabilities of an LSI for each vital sign. HR, heart rate; LSI, lifesaving intervention; RR, respiratory rate; SBP, systolic blood pressure.

criteria had specificities ranging from 84.1% to 93.7%. The higher sensitivity criteria had sensitivities ranging from 78.2% to 84.4%. RR had the best overall performance for both higher specificity criteria (specificity 93.7%, sensitivity 25.1%) and higher sensitivity criteria (sensitivity 84.6%, specificity 27.0%). However, ranges for some of the vital signs were narrow in older age groups (e.g., 16–18 breaths/min for children >12–18 years of age). When evaluating pulse oximetry, a higher specificity cut point was identified at 94%, resulting in a sensitivity of 26.3% and a specificity of 90.6%. The higher sensitivity cut point was identified at 98%, which yielded a sensitivity of 62.3% and a specificity of 46.6%. The performance of the described cut points among infants was similar to the performance of the overall study sample (Table S4).

Among the subset of children with complete vital signs ($n = 714{,}426$), 32,244 (4.5%) had an LSI. When using all four vital signs, the higher specificity criteria had a sensitivity of 35.0% and a specificity of 68.4%. The higher sensitivity criteria had a sensitivity of 98.9% and a specificity of 1.2%. In multivariable models using higher specificity vital signs cutoffs, the greatest effect size was noted with a low respiratory rate (OR 5.83, 95% CI 5.55–6.13), followed by a high respiratory rate (OR 2.97, 95% CI 2.87–3.08) and low pulse oximetry (OR 2.57, 95% CO 2.49–2.66; Table S5). In multivariable models using higher sensitivity vital signs cutoffs, the greatest effect sizes were with a high respiratory rate (OR 2.13, 95% CI 2.06–2.20), low pulse oximetry (OR 1.69, 95% CI 1.65–1.73), and low respiratory rate (OR 1.58, 95% CI 1.52–1.63; Table S6).

When assigning points to the higher specificity criteria, a high and low HR and a high and low SBP were each 1 point. A high RR and a low pulse oximetry were each 2 points, and a low RR was 4 points. The maximum number of points a patient could receive was 8 points. Performance of this model at differing point thresholds demonstrated a progressive rise in likelihood ratios, as demonstrated in in Table S7.

Vital signs within subgroups of the LSI

Prediction plots for univariable splines with subgroups of LSI are provided in Figure S1. While HR, RR, and SBP demonstrated a U-shaped association with all of the LSI, this was more pronounced for respiratory LSI. When evaluating the ranges within the three types of interventions (respiratory, procedures, and medications), findings were similar to the overall composite outcome (Table S8).

Multiple vital sign assessments

HR was documented once in 48.9%, twice in 37.8%, three times in 9.0%, and four or more times in 4.3% within the first 10 min of the first HR documentation. RR was documented once in 55.8%, twice in 36.7%, three times in 5.9%, and four or more times in 1.5%. SBP was documented once in 53.3%, twice in 39.7%, three times in 6.5%,

TABLE 2 Performance of differing *Z*-score based cut points for low and high of each vital sign for the subset of encounters with a low vital sign (*Z*-score < 0) and a high vital sign (*Z*-score > 0).

Z-score	Lower limits of HR		Lower limits of RR		Lower limits of SBP	
	Sens	Spec	Sens	Spec	Sens	Spec
−2.0	16.0	95.1	24.0	97.5	13.7	95.3
−1.8	20.0	92.3	34.0	93.9	16.9	93.4
−1.6	24.3	89.1	37.4	92.1	21.2	90.5
−1.4	29.5	84.5	41.4	88.0	26.4	85.9
−1.2	35.7	78.5	51.7	78.8	32.3	79.9
−1.0	43.0	70.6	57.6	72.5	41.6	70.5
−0.8	50.8	60.8	62.4	64.0	50.7	60.0
−0.6	61.7	47.4	80.8	33.5	60.7	47.5
−0.4	72.6	33.1	85.4	24.0	73.0	32.4
−0.2	85.7	16.1	93.9	11.8	85.9	16.4
	Upper limits of HR		Upper limits of RR		Upper limits of SBP	
	Sens	Spec	Sens	Spec	Sens	Spec
0.2	90.8	12.8	84.0	29.5	89.4	13.2
0.4	81.3	24.9	80.6	35.8	78.2	26.6
0.6	71.0	36.9	73.4	46.9	67.1	38.9
0.8	60.8	48.9	69.5	52.4	55.5	51.9
1.0	50.9	59.8	56.5	68.1	44.9	62.9
1.2	40.9	70.0	50.5	73.9	35.2	72.2
1.4	32.6	77.8	41.4	81.1	26.1	80.5
1.6	24.6	85.1	34.4	86.0	18.6	86.7
1.8	18.4	90.0	25.8	90.9	12.7	91.5
2.0	12.5	94.0	17.9	94.4	8.3	94.8

Abbreviations: HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; sens, sensitivity; spec, specificity.

and four or more times in 0.6%. For each vital sign, there was an association between the number of vital sign assessments and the presence of an LSI (Wilcoxon $p < 0.01$). Patients with an abnormality in their vital sign assessments as measured within the first 10 min more frequently had an LSI performed when using either the higher sensitivity or the higher specificity vital sign criteria (Table S9).

DISCUSSION

We performed a retrospective study of a large, national, multiagency EMS data set to develop cut points of pediatric vital sign ranges for an outcome of LSI. First measured vital signs above the high cutpoints for HR, RR, and SBP and below the low cutpoints for all vital signs were associated with receipt of a potential LSI. While an individual vital sign cannot be used as a sole criterion to determine patients at risk of severe outcomes, our findings suggest that data-driven vital sign thresholds should be integrated into a multimodal strategy to identify children at the highest risk of requiring LSI.

These findings represent an advance in our prior work by pairing empirically derived age-adjusted vital signs with a composite outcome measure of LSI to identify children at high risk of receiving key interventions during their EMS encounter. Rather than using extremes of vital signs (such as above the 90th percentile and below the 10th percentile), these cutoffs allow for dynamic prioritization of metrics of diagnostic accuracy to optimize case identification for differing applications. This in turn can facilitate a more nuanced interpretation of vital signs by prehospital clinicians and within decision support systems. Used in this way, criteria can be more reliably used to identify children at greater risk of LSI, improving the real-time differentiation of patients, particularly for clinicians who must interpret vital signs of children who may be in pain, febrile, or anxious. This differs from other approaches toward vital signs, such as in PALS, which are based on physiologic criteria from healthy

TABLE 3 Ranges and performance of higher specificity and higher sensitivity vital signs criteria for HR, RR, and SBP.

	Higher specificity criteria			Higher sensitivity criteria		
	HR	RR	SBP	HR	RR	SBP
0–3 months	89–184	11–62	67–146	136–152	28–36	88–105
>3–6 months	101–180	13–59	74–131	135–149	27–33	93–105
>6–9 months	101–178	15–53	77–132	131–145	26–31	96–107
>9–12 months	98–179	15–51	79–134	129–144	25–30	98–109
>1–3 years	92–175	14–44	84–136	123–140	23–27	102–113
>3–6 years	82–153	14–36	88–134	108–123	20–23	104–114
>6–9 years	75–141	13–32	93–135	99–112	19–21	109–117
>9–12 years	72–136	12–29	97–140	94–108	18–20	113–122
>12–17 years	66–133	12–26	102–150	88–103	16–18	120–131
Sensitivity	24.2	25.1	24.8	79.6	84.6	78.7
Specificity	86.5	93.7	84.1	25.3	27.0	25.4

Abbreviations: HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure.

children in ambulatory or outpatient settings.[17,18] Differentiating higher sensitivity versus higher specificity cut points is important for different applications within prehospital care. Higher specificity cutpoints aim to identify the sickest children with the highest likelihood of deterioration or need for advanced interventions, which can be integrated into hospital alert mechanisms or EMS protocols aimed to identify patients in need of closer monitoring, such as by more frequent ongoing vital signs assessments. Alternately, higher sensitivity cutpoints can facilitate the refinement of EMS protocols related to non-transports, as well as those who may be transported to the hospital by basic instead of ALS, by identifying patients at lowest risk of requiring advanced interventions administered by EMS.

The performance of the studied vital signs demonstrated a greater role for RR compared to HR and SBP. This finding is likely driven by the high frequency of children having a respiratory intervention to meet LSI criteria compared to medication administration or procedures. This finding also parallels other research demonstrating a role for RR among children[19] and adults[20] to identify the presence of critical illness. A challenge with the use of RR in practice includes its difficulty in ascertainment (which frequently requires manual counting, and may be more subject to rounding errors compared to other vital signs) and its moment-to-moment variability. In addition, ranges to establish low-risk patients (i.e., higher sensitivity criteria) were notable for very narrow ranges deployed for this vital sign in practice.

To date, little research has been reported on the prediction of critical illness among children with out-of-hospital emergencies, with one study demonstrating limitations when using expert-derived cutoffs for vital signs.[21] Prediction models of critically ill adults have been incorporated into medical alert systems to identify patients who require immediate attention upon hospital arrival. One model combined hypotension and bradypnea with other variables acquired in the prehospital setting to identify adults with sepsis, mechanical ventilation, or in-hospital mortality.[22] Another study in adults demonstrated that a model including HR and RR had superior performance for identifying patients with sepsis compared to clinical gestalt.[23] The use of empirically derived cutoffs for vital signs may additionally inform future research focused on the prediction of children at risk of critical illness and injury following hospital arrival. The limitations of using vital signs alone, as suggested within the multivariable models for this outcome, demonstrate the need for the incorporation of other clinical factors to better predict critical illness and injury in this setting.

Our findings in combination with extant literature from adult patients suggest a role for future research based on developing models to identify critically ill children or children at risk of deterioration among those encountered by EMS. These models may combine age-adjusted vital signs with other clinical factors to accurately predict risk of consensus-based, composite outcome measures based on hospital interventions. Potentially, if vital signs are incorporated into a well-performing multivariable model, they may be used in a tiered manner, with greater points allocated for more severe abnormalities, as used in the Pediatric Early Warning Score.[24]

At the other end of the continuum, as mentioned above, our findings have potential for use in the identification of low-risk patients. While research has suggested that pediatric nontransports generally have lower acuity illness compared to those transported from the scene to the hospital,[25] clinicians report challenges in the identification of children who are lower acuity. If combined with other criteria, including behavioral and social assessments, these findings may serve as a starting point for objective criteria for the identification of lower risk patients who are amenable to not being transported to the ED. An important consideration in this study is that we excluded nontransports from the study sample as the interventions studied may have been specifically refused in these patients. However, the LSI that we studied are likely infrequently refused given their critical nature. In future work, these findings may facilitate a robust evaluation of these criteria in the consideration of pediatric nontransports or those who may be transported by Basic Life Support ambulances, leaving ALS practitioners available within EMS systems for other 9-1-1 responses.

LIMITATIONS

Our findings are subject to limitations. This was a retrospective study of data charted during standard EMS care and may be subject to inaccuracies. Individual vital sign assessments are subject to differences with measurement and equipment (e.g., cuff size for blood pressure or method of HR measurement using palpation, auscultation, or a monitor). Not all patients had all vital signs acquired, a finding that has been reported in previous work and may be associated with lower patient acuity, younger patient age, and lack of pediatric-sized equipiment.[26,27] We were unable to evaluate the necessity for each intervention categorized as lifesaving for our analysis: prior work has suggested, for example, that EMS frequently undertreats children with bradycardia.[28] Additionally, some of the interventions studied are inherently driven by vital sign measures (e.g., adenosine for supraventricular tachycardia or respiratory therapies for hypoxemia), leading to confounding by indication. The NEMSIS data set may be subject to reporting bias and other limitations of large data sets. Despite these limitations, however, this study demonstrates important associations with vital sign abnormalities in children and potential LSI delivered by EMS, supporting the need for future research to develop meaningful and clinically sensible guidelines to enhance EMS-based assessments.

CONCLUSIONS

Using a large, multiagency sample of pediatric prehospital transports, we evaluated the association of pediatric prehospital vital signs with lifesaving interventions and used cut point analyses to derive ranges for children at higher and lower risk of lifesaving intervention. Once prospectively validated and implemented within emergency medical services systems, these criteria may be combined with other assessment modalities to improve the assessment of children in the prehospital setting, assist in optimizing protocol utilization including nontransport decision making, and be incorporated into destination selection and hospital-based medical alert systems, such as the activation of trauma or extracorporeal membrane oxygenation teams.

AUTHOR CONTRIBUTIONS

Sriram Ramgopal conceptualized and designed the study, collected data, carried out the initial analyses, drafted the initial manuscript, and reviewed and revised the manuscript. Robert J. Sepanski assisted in the analyses and critically reviewed and revised the manuscript for important intellectual content. Michelle L. Macy, Rebecca E. Cash, and Christopher M. Horvat designed the data collection instructions and critically reviewed and revised the manuscript. Christian Martin-Gill designed the study, contributed to data analysis, and reviewed and revised the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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