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BRIEF RESEARCH REPORT

Pediatrics

Age-based centiles for diastolic blood pressure among children in the out-of-hospital emergency setting

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Abstract

Objective: To compare Pediatric Advanced Life Support (PALS) diastolic blood pressure (DBP) criteria to empirically derived DBP criteria for the prediction of out-of-hospital interventions in children.

Methods: We performed a retrospective study of pediatric (<18 years) encounters from the ESO Data Collaborative, which includes approximately 2000 Emergency Medical Services agencies in the United States. We developed age-based centile curves for DBP using generalized additive models for location, scale, and shape. We compared the proportion of encounters with a low DBP when using empirically derived and PALS criteria and calculated their associations with the delivery of out-of-hospital interventions (advanced airway management, cardiopulmonary resuscitation, cardiac epinephrine, any systemic epinephrine, defibrillation, and bolus intravenous fluids).

Results: We included 343,129 encounters. When using PALS criteria, 155,564 (45.3%) were classified as having abnormal DBP, including 120,624 (35.2%) with high DBP and 34,940 (10.2%) with low DBP. When using empirically-derived criteria, 18.6% had an abnormal DBP (ie, a DBP <10th or >90th centile). The accuracy of low DBP for out-of-hospital interventions between the two criteria was similar.

Conclusion: PALS criteria for DBP classified a high proportion of children as having abnormal vital signs, particularly with diastolic hypertension. Empirically derived DBP thresholds more accurately predict the delivery of key out-of-hospital interventions. If externally validated, correlated to in-hospital outcomes, and combined with thresholds for other vital signs, these may better predict the need for out-of-hospital interventions.

KEYWORDS
blood pressure, child, emergency medical services, emergency medicine, hypertension, hypotension, pediatrics

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1 | INTRODUCTION

1.1 | Background

Combined with structured physical assessment tools, the age-based interpretation of vital signs can facilitate the identification of a child with significant illness or injury in the out-of-hospital setting.[1] This is particularly relevant given the infrequency with which emergency medical services (EMS) clinicians encounter children in the out-of-hospital setting.[5] An appropriate classification of vital signs may assist in prediction modeling and decision aids to identify critically ill children, similar to those developed in adults.[3] The Pediatric Advanced Life Support (PALS) algorithm provides the most commonly used criteria for the age-based classification of pediatric vital signs in the United States for out-of-hospital emergencies.[4]

1.2 | Importance

Our prior work evaluating heart rate, respiratory rate, and systolic blood pressure when using a large out-of-hospital database demonstrated that the PALS criteria classified three-quarters of children as having at least one abnormal vital sign.[5] Cutoffs derived from the empiric modeling of vital signs with age, in contrast, demonstrated a lower proportion of children classified as having abnormal vital signs, and that patients with abnormal vital signs using these cutoffs had a greater frequency of important out-of-hospital interventions.[5] A limitation of this prior work lies in the absence of models for diastolic blood pressure (DBP), which was unavailable in the dataset used for modeling; this limitation also extends to other investigations evaluating pediatric vital signs.[6] DBP has been predictive of clinical outcomes in children in other settings. In one prospective multicenter cohort study of children admitted to the intensive care unit with cardiac arrest, a normal diastolic blood pressure was associated with survival.[7] Other studies have identified a predictive role for DBP in pediatric sepsis[8] and mortality in critically ill children.[9] DBP, in conjunction with other vital signs data may serve a useful role in identifying patients with critical illness, which may affect treatment and transport decisions.

1.3 | Goals of this investigation

More data are needed for the appropriate modeling of DBP and identifying its association with out-of-hospital interventions. We sought to construct an age-based model for DBP and derive centile curves for this vital sign among children in the out-of-hospital setting, and to compare these to PALS for out-of-hospital interventions.

2 | METHODS

2.1 | Study design and data source

We performed a retrospective cross-sectional study using out-of-hospital patient care records from 2020 and 2021 using the ESO Data Collaborative, a large, National Emergency Medical Services Information Systems-compliant electronic health record provider for approximately 2000 US-based EMS agencies. This investigation was approved by the Ann & Robert H. Lurie Children's Hospital institutional review board.

The Bottom Line

Pediatric vital signs are commonly used to identify the acuity of ill children. Using 343,000 observations from a national emergency medical services (EMS) dataset, this study augments prior approaches by introducing empiric diastolic blood pressure thresholds. These findings may lead to more specific guidance for EMS interventions.

2.2 | Selection of participants

We included pediatric (<18 years) patients with at least one DBP recorded. We did not make exclusions based on response type or disposition in the interest of acquiring maximally generalizable data, consistent with our prior methods.[5]

2.3 | Data abstraction

From each encounter we acquired age, first-recorded DBP, and for the performance of the following 6 out-of-hospital interventions: advanced airway management, cardiopulmonary resuscitation, defibrillation, any systemic epinephrine, systemic epinephrine concentrated for cardiac arrest (0.1 mg/1 mL), and provision of a fluid bolus. We classified age into mutually exclusive groups by months (for infants) and years (for older children).

2.4 | Outcomes

Our primary outcome was the classification of pediatric vital signs as normal versus abnormal (above or below the assessed criteria). Our secondary outcome was performance of 1 of the 6 studied EMS interventions.

2.5 | Analysis

We modeled DBP using data from the 2021 ESO dataset and validated them on encounters from the 2020 dataset. We selected these years as they were the most recently available at the time of this investigation. We constructed centile curves for each vital sign using the Generalized Additive Models for Location, Scale, and Shape (GAMLSS, v 5.4-1) package in R, version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria). The GAMLSS package uses a distributional regression approach where all the parameters of the conditional distributions of the response variable are modeled using explanatory variables to develop smoothened centile-based curve and in the generation of

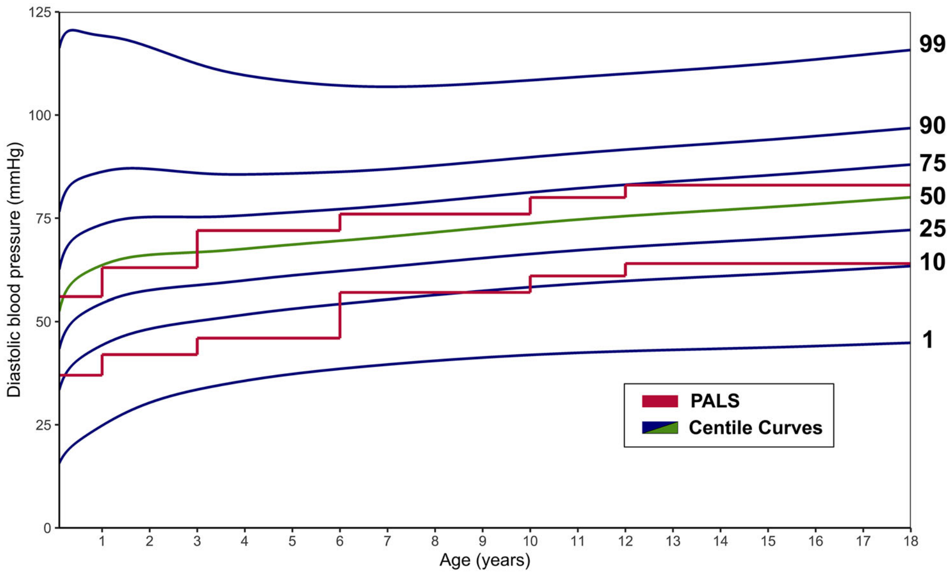

FIGURE 1 Comparison of calculated centiles for diastolic blood pressure for age derived from 343,129 pediatric encounters. The superimposed red lines indicate cutoffs when using Pediatric Advanced Life Support criteria.

predictions following the provision of new data. We developed our age-based DBP in a sequential pattern similar to our modeling of other vital signs.[5] We selected models on the Box-Cox Power Exponential (BCPE) distribution on the basis of previous work modeling this variable.[10–12] BCPE is well suited for characterizing differences in location (median), scale, skewness, and kurtosis.[13] DBP was modeled in a stepwise manner to create optimal age-specific fits for each of these measures, with an additive term which generated smooth centile curves using penalized B-splines. We rose the age to exponents between 0.01 and 1 to better optimize model fit. We used the Bayesian Information Criterion to determine the optimal model.[14,15]

We identified the proportion of children having abnormal empirically derived (<10th or >90th centile) or PALS-based DBP. We compared the total proportion of children with at least one abnormal vital sign (heart rate, respiratory rate, and blood pressure) when using empirically derived[5] and PALS criteria. We used the derivation subset to generate centile cutoffs and compared the proportion of encounters in the validation dataset that exceeded thresholds in the >99th, >95th, <5th, and <1st percentile. We characterized the proportion of children with abnormal low DBP when using empirically derived vital signs (<10th centile) and when using PALS criteria. We compared the accuracy, sensitivity, and specificity of low DBP for out-of-hospital interventions.

3 | RESULTS

3.1 | Study inclusion

A total of 11,074,469 encounters were present in the 2021 ESO database. After removal of encounters without age ($n = 1{,}504{,}437$) and adults ($n = 9{,}063{,}484$), 506,548 pediatric encounters were identified. DBP data were available for 343,129 pediatric encounters (67.7%). We identified 280,663 encounters in the validation sample. Characteristics between the derivation and validation samples were similar (Table S1). Within the derivation sample, the median age of included encounters was 13.5 years (interquartile range, 7.4–16.2 years). EMS interventions included the following: advanced airway management in 909 (0.3%), CPR in 553 (0.2%), cardiac epinephrine in 260 (0.1%), any epinephrine in 1938 (0.6%), defibrillation in 50 (0.0%), and bolus fluids in 6022 (1.8%).

3.2 | Empiric derivation of DBP centiles and comparison to PALS

The centile curves for DBP demonstrated a sharp rise, followed by a more gradual increase through the early childhood and adolescent years (Figure 1). A centile table for DBP for age is provided in the Table 1. Classified using empirically-derived criteria, 18.6% had an abnormal DBP. When classified using PALS, 155,564 (45.3%) were classified as having an abnormal DBP (Table 2). PALS criteria classified a higher proportion of patients as having abnormally high DBP (35.2%) than having abnormally low DBP (10.2%). Among 330,110 patients with a documented heart rate, respiratory rate, systolic blood pressure, and DBP, 171,562 (53.3%) had at least 1 abnormal sign when using empirically derived centile curves and 266,742 (80.8%) had at least 1 abnormal vital sign when using PALS criteria. The distribution of DBP in the validation sample demonstrated similar characteristics to those in the derivation sample for all vital signs, with observed differences of ≤0.3% at each cutoff (Table 3).

TABLE 1 Diastolic blood pressure for age at selected centiles.

Age	1	2.5	5	10	25	50	75	90	95	97.5	99
Neonate	14	19	24	30	40	48	58	72	83	95	112
1 month	16	22	28	34	45	54	64	78	89	101	117
2 months	18	24	30	37	47	56	67	81	92	103	120
3 months	19	26	32	38	49	58	69	82	93	105	120
4 months	20	27	33	39	50	59	70	83	94	105	121
5 months	21	28	34	40	51	60	71	84	95	106	120
6 months	21	28	34	41	52	61	71	85	95	106	120
7 months	22	29	35	42	52	62	72	85	95	106	120
8 months	23	30	36	42	53	62	72	85	95	106	120
9 months	23	30	36	43	53	63	73	86	96	106	120
10 months	24	31	37	44	54	63	73	86	96	106	119
11 months	25	31	37	44	54	63	73	86	96	106	119
1 year	28	35	40	47	56	65	75	87	96	106	118
2 years	32	38	43	49	58	66	75	86	95	103	114
3 years	35	40	45	51	59	67	75	86	93	101	111
4 years	37	42	47	52	61	68	76	86	93	100	109
5 years	38	44	48	54	62	69	77	86	93	99	108
6 years	39	45	50	55	63	70	78	87	93	99	107
7 years	40	46	51	56	64	71	79	87	93	99	107
8 years	41	47	52	57	65	72	80	88	94	100	107
9 years	42	48	53	58	66	73	81	89	95	101	108
10 years	42	48	53	59	67	74	82	90	96	102	109
11 years	43	49	54	59	68	75	83	91	97	103	110
12 years	43	49	55	60	68	76	83	92	98	103	110
13 years	43	50	55	61	69	77	84	93	99	104	111
14 years	44	50	56	61	70	77	85	94	99	105	112
15 years	44	51	56	62	70	78	86	94	100	106	113
16 years	44	51	57	62	71	79	87	95	101	107	114
17 years	45	52	57	63	72	80	88	96	102	108	115

Note: Numbers represent millimeters of mercury.

3.3 | EMS interventions among encounters with low DBP

The accuracy of identifying the studied out-of-hospital interventions for encounters with low recorded DBP was similar between the 2 criteria (Table 4).

4 | LIMITATIONS

Our findings are subject to limitations. The data used from this study were derived from retrospectively collected data. Vital signs may have been collected in different ways (such as auscultation versus automated measurements). However, this use of pragmatic data may better characterize "real world" collection of these vitals. Not all encounters had a recorded DBP; these data are likely missing disproportionately more in younger and/or well appearing children. We were unable to link our results to hospital-based interventions or ascertain the necessity of out-of-hospital interventions being performed. Despite these limitations, our findings demonstrate a practical approach toward the modeling of DBP that may have important implications in the future of this vital sign for pediatric assessments and predictive modeling.

5 | DISCUSSION

We constructed and validated empiric vital sign centile curves for DBP using a large out-of-hospital dataset and compared these to PALS criteria. These demonstrated a lower proportion of encounters classified as

TABLE 2 Classification of abnormal diastolic blood pressure and of any abnormal vital sign (systolic blood pressure, diastolic blood pressure, heart rate, and respiratory rate) using pediatric advanced life support criteria.

Age, years	Diastolic blood pressure (*n* = 343,129) Abnormal high	Abnormal low	Any abnormal vital sign (*n* = 330,110)[a]
Infant (<1 year)	6831 (55.8)	731 (6.0)	10,139 (86.1)
1	8034 (55.1)	593 (4.1)	12,224 (87.6)
2	7512 (58.7)	343 (2.7)	10,837 (87.9)
3	3532 (31.4)	401 (3.6)	8288 (76.5)
4	3686 (35.2)	299 (2.9)	8007 (79.5)
5	3796 (36.8)	225 (2.2)	7897 (79.6)
6	2974 (28.7)	1129 (10.9)	7959 (79.9)
7	3290 (32.3)	941 (9.2)	7822 (79.8)
8	3799 (36.1)	826 (7.9)	8202 (81.0)
9	4546 (39.4)	796 (6.9)	9202 (83.0)
10	3500 (28.2)	1670 (13.4)	9813 (81.9)
11	4568 (30.7)	1790 (12.0)	12,041 (83.8)
12	4783 (25.5)	2860 (15.2)	14,287 (78.8)
13	6698 (27.5)	3349 (13.8)	18,209 (78.0)
14	8993 (29.1)	4118 (13.3)	23,304 (78.3)
15	11,266 (31.7)	4569 (12.9)	26,995 (79.1)
16	14,812 (34.4)	5109 (11.9)	33,270 (80.5)
17	18,004 (36.7)	5191 (10.6)	38,246 (81.1)
Overall	120,624 (35.2)	34,940 (10.2)	266,742 (80.8)

[a]Among encounters with a recorded systolic blood pressure, diastolic blood pressure, heart rate, and respiratory rate; using cutoffs described in Ramgopal et al.[5]

TABLE 3 Comparison of the proportion of vital signs for diastolic blood pressure below the 1st and 5th percentiles and above the 95th and 99th percentiles between the derivation (ESO 2021) and validation (ESO 2020) datasets

Metric	Derivation, N = 343,129	Validation, N = 280,663
<1st centile	2742 (0.8)	2192 (0.8)
<5th centile	13,886 (4.0)	10,786 (3.8)
>95th centile	14,940 (4.4)	11,570 (4.1)
>99th centile	3900 (1.1)	2757 (1.0)

having abnormal DBP. When considering solely hypotension, the performance between the empirically derived and PALS criteria had similar accuracy for identifying important out-of-hospital interventions. The use of empirically derived vital sign cutoffs, derived directly from children in the out-of-hospital setting may provide a meaningful and more granular way to inform appropriate assessments for children with out-of-hospital emergencies than compared to criteria derived from healthy subjects.

Our findings add to our previously described work evaluating the performance of empirically derived heart rate, respiratory rate, and systolic blood pressure centile curves.[5] Vital signs in the out-of-hospital setting may be abnormal due to physiologic derangements (eg, fever or shock) or anxiety. For this reason, applying samples of normal vital signs derived from healthy samples of patients may be more limited among children with a gradient of disease severity, particularly as clinicians make the distinction between critically and non-critically ill children. As such, a vital signs system specifically designed for this setting may serve a greater role in differentiating patients who need immediate interventions as well as for medical alert systems to notify hospitals of at-risk patients.

Notably, a similar proportion of patients (~10%) were classified as having abnormally low DBP using both the PALS and empirically derived criteria, resulting in similar accuracy for out-of-hospital interventions. The use of a granular, centile-based DBP in combination with other vital signs and other clinical characteristics may play an important role in risk-stratifying children with out-of-hospital emergencies, allowing for data-driven approaches toward refusal protocols, destination protocols, and hospital-based alert systems. Although a high sensitivity is generally prioritized in these contexts, optimizing specificity is also critical to avoid false positive alerts and unnecessary resource utilization. Ideally, specific cutoffs would be generated through multidisciplinary stakeholder input to identify optimal trade-offs to derive a model with greatest utility. A recently published consensus-based criteria to identify children encountered by EMS who

TABLE 4 Accuracy, sensitivity, and specificity of prehospital interventions in the derivation dataset among patients identified to have abnormally low diastolic blood pressure when using empirically derived vital signs and PALS criteria

	Empiric			PALS		
	Accuracy	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity
Advanced airway	90.3	23.4	90.5	89.7	21.9	89.8
CPR	90.4	25.5	90.5	89.7	25.0	89.8
Systemic epinephrine 1:10	90.4	33.1	90.5	89.8	30.0	89.8
Any systemic epinephrine	90.1	15.8	90.5	89.4	16.4	89.9
Defibrillation	90.5	20.0	90.5	89.8	24.0	89.8
Bolus intravenous fluids	89.4	19.3	90.6	88.8	20.7	90.0

Abbreviations: CPR, cardiopulmonary resuscitation; PALS, Pediatric Advanced Life Support.

should be transferred to higher-level pediatric facilities, for example, noted abnormal vital signs in a medically complex child as a reason for this higher level of care.[20] Another Delphi-based approach toward the development of a destination tool specifically noted challenges with currently used vital sign specifications for this purpose.[16] These examples demonstrate a potential role toward empirically derived vital signs to achieve these aims without increasing resource utilization.

The high proportion of children with abnormal DBP as classified by PALS criteria may limit the ability of this system to identify the sickest patients in this setting. Notably, the upper limits of blood pressure in the PALS guidelines account for the greatest proportion of vital sign abnormalities. This is perhaps more representative of "noise" to the emergency clinician and be more likely related to anxiety or pain than indicative of a more serious underlying pathology requiring early intervention. In addition to data from the National Heart, Lung and Blood Institute,[17] data used to construct blood pressure norms for younger children are derived from a study of 514 healthy children[18] and a study of 207 neonates in the first 12 h of life.[19] None of these primary sources that have been used to create current standard normal and/or abnormal vital signs tables for children has evaluated a population of patients presenting for acute care in the out-of-hospital or emergency department settings.

We constructed empiric vital sign centile curves for DBP, augmenting our prior work modeling other vital signs among children in the out-of-hospital setting. These criteria may more meaningfully represent the distribution of vital signs in the emergent setting. Following external validation and prospective evaluation, these may provide a useful way toward more accurate out-of-hospital assessments and other decision support tools.

AUTHOR CONTRIBUTIONS

Sriram Ramgopal conceived of the study, analyzed, and interpreted the data, and drafted the work. Robert Sepanski and Remle P. Crowe analyzed and interpreted the results of the work and critically revised the work for intellectually important content. Christian Martin-Gill conceived of the study, interpreted the data, and critically revised the work for intellectually important content. All authors provided final approval of the version to be published and agree to be accountable for all aspects of the work.

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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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