Heart Rates in Hospitalized Children by Age and Body Temperature

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abstract

BACKGROUND AND OBJECTIVES: Heart rate (HR) is frequently used by clinicians in the hospital to assess a patient's severity of illness and make treatment decisions. We sought to develop percentiles that characterize the relationship of expected HR by age and body temperature in hospitalized children and to compare these percentiles with published references in both primary care and emergency department (ED) settings.

METHODS: Vital sign data were extracted from electronic health records of inpatients <18 years of age at 2 large freestanding children's hospitals from July 2011 to June 2012. We selected up to 10 HR-temperature measurement pairs from each admission. Measurements from 60% of patients were used to derive the percentile curves, with the remainder used for validation. We compared our upper percentiles with published references in primary care and ED settings.

RESULTS: We used 60 863 observations to derive the percentiles. Overall, an increase in body temperature of 1°C was associated with an increase of ~10 beats per minute in HR, although there were variations across age and temperature ranges. For infants and young children, our upper percentiles were lower than in primary care and ED settings. For school-age children, our upper percentiles were higher.

CONCLUSIONS: We characterized expected HR by age and body temperature in hospitalized children. These percentiles differed from references in primary care and ED settings. Additional research is needed to evaluate the performance of these percentiles for the identification of children who would benefit from further evaluation or intervention for tachycardia.

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WHAT'S KNOWN ON THIS SUBJECT: Heart rate (HR) increases with increasing body temperature. Previous studies have characterized the relationship among HR, age, and temperature for patients in primary care and emergency department settings but not in hospitalized children.

WHAT THIS STUDY ADDS: Our data demonstrate an overall increase in HR by ~10 beats/minute for each 1°C increase in body temperature. Expected heart rates for hospitalized children differ from those for primary care and emergency department patients at the same age and temperature.

Heart rate (HR) is frequently used by clinicians in the hospital to aid in determining a patient's severity of illness and in making treatment decisions. HR is an important component of many pediatric care guidelines and clinical tools including early warning scores and medical emergency team calling criteria,[1–8] criteria for the diagnosis of systemic inflammatory response syndrome and sepsis,[9] emergency department (ED) triage scores,[10,11] and Pediatric Advanced Life Support guidelines.[12] Although it is well established that HR increases with increasing body temperature, there is little guidance available to clinicians regarding how to account for this relationship, if at all, when using tools and guidelines that include HR cut points.

The relationship between HR and body temperature has been characterized in 2 nonhospitalized populations: pediatric primary care patients age 3 months to 10 years with suspected acute infection[13] and in 2 cohorts of children presenting to the ED.[14,15] In this study, we sought to characterize the relationship of HR and body temperature in hospitalized children, which has not been done previously. Our first objective was to derive reference values for HR according to both age and body temperature that could be used by clinicians at the bedside and to facilitate future research aimed at guiding medical decision-making in acutely ill children. Our second objective was to compare our reference values to HR, age, and temperature references developed in primary care and the ED.

METHODS

Data Collection

Vital sign data were extracted from electronic health records of all inpatients <18 years of age at the Children's Hospital of Philadelphia (CHOP) and Cincinnati Children's Hospital Medical Center (CCHMC) from July 1, 2011, to June 30, 2012. Vital signs obtained while subjects were in any intensive care or cardiac unit were excluded. General medical and surgical patients, as well as patients of all noncardiac subspecialties were included.

The vital sign observations had been previously entered into the electronic health records at each hospital (Epic Systems, Verona, WI) by nurses or nursing assistants in the course of clinical care at a frequency prescribed by the medical team. Over the study period for oral, axillary, and rectal temperatures CHOP used the Welch Allyn SureTemp Plus 692 thermometer Welch Allyn, Skaneateles Falls, NY) and CCHMC used the Alaris Turbo Temp thermometer (CareFusion, San Diego, CA). In practice, heart rate measurement was done using a mix of electronic (via pulse oximetry or electrocardiographic leads) and manual (via auscultation or pulse palpation) methods. The method of assessment is not documented in the chart and thus could not be included in the analysis.

Data Preparation

Only observations with simultaneous recording of both HR and temperature were included. The primary analysis was restricted to observations with a temperature taken either orally or rectally (referred to as "core" from this point forward). Other temperature measurement methods have variable degrees of error when compared with core temperatures, and we were concerned that including these observations could lead to less accurate and precise percentiles.[16,17] The most common method of temperature measurement for young children in our sample was axillary, a method that, on average, underestimates body temperature.[16]

For each observation we determined HR *z* scores by age (HRZ_{age}) using a reference for expected HR in hospitalized children previously developed by our team.[18] We excluded observations with extreme values for temperature (<35° or >40.5°C), HR (<30 or >240 beats per minute), or HRZ_{age} (<–5, >5, or not calculable) because we suspected that these values were likely to represent data entry errors or rare clinical conditions. A small proportion (0.1%) of temperature measurements were >40°C, and only 91 observations had a core temperature between 40.5°C and 41°C. Reference values are presented only up to 40°C because of the small sample of observations above this range.

We divided data at the patient level into derivation (60%) and validation (40%) data sets after using bootstrapped samples to determine the minimum sample size that would produce stable estimates of outer percentiles. Within each dataset we selected 10 observations from each admission for evaluation, to avoid undue influence by patients with long admissions. We selected observations with more extreme temperatures first to ensure adequate numbers of these observations for analysis. For each admission, we selected up to 3 observations with a body temperature in each of the following ranges, in order, until a maximum of 10 observations were selected for a given admission: 40 to 40.5, 39.5 to 39.9, 39.0 to 39.4, 38.5 to 38.9, 38.0 to 38.4, 35.0 to 35.4, 35.5 to 35.9, and 36 to 37.4. Within each temperature range for each admission, selection of observations was random.

Percentile Curve Development

Analysis was done using Stata 13.1 (Statacorp, College Station, TX) and R 3.0.2 (R Foundation for Statistical Computing, Vienna, Austria). Percentile curves were created by using the Box Cox Power Exponential distribution in the GAMLSS (generalized additive models for location scale and shape) package in R.[19,20] After preliminary analyses confirmed a similar relationship between HRZ_{age} and temperature across ages, we created a single set of age-nonspecific percentile curves using temperature as the independent variable and HRZ_{age} as the dependent variable. Model fit was evaluated using diagnostics available in the GAMLSS package, including QQ plots and worm plots. The age-nonspecific percentile curves were used to create 9 age-specific curves describing expected HR by temperature. This method allowed for increased stability of the outer percentiles at extreme temperatures compared with creating individual age-based percentile curves.

Validation

Using the newly created age-nonspecific reference, we calculated HR *z* scores and percentiles for age and temperature ($HRZ_{agetemp}$ and $HRP_{agetemp}$) for observations in the validation data set. We determined the overall proportion of observations <5th and >95th percentile. To evaluate the fit of our model across subgroups, we stratified observations into 18 groups based on our 9 age groups and 2 body temperature groups (<38°C and ≥38°C). In each of the 18 groups, we compared the observed proportions <5th or >95th percentile to the expected proportion (5%) and evaluated the statistical significance of differences using the binomial test with α = .0014 (.05 corrected with the Sidak method for 36 comparisons).

Evaluation of Non–Core Temperatures

We evaluated the difference in expected HR for observations with core and noncore body temperatures using linear regression, controlling for recorded body temperature and age. We expected the HR for observations with noncore body temperatures to be higher because of the potential for axillary temperatures, the most common form of noncore temperature measurement, to underestimate true body temperature.[16]

Analyses by Hospital

We compared the overall proportion of observations <5th and >95th percentile by hospital, evaluating statistical significance of the differences between hospitals with χ^2 tests. To explore the extent to which differences in temperature distributions between the hospitals were driven by the thermometer used, we then evaluated the temperature distribution in data obtained from CCHMC from July 1, 2012, to June 30, 2013, when CCHMC was in the process of transitioning to the same Welch Allyn thermometer used at CHOP. We used linear and logistic regression to compare differences in temperature between units at CCHMC that switched to the new thermometer earlier or later during the time period of the secondary data set. To further evaluate differences in the relationship between HR, age, and body temperature by hospital, we created separate percentile curves using only data from (1) CHOP, (2) the CCHMC primary data set in 2011–2012, and (3) the CCHMC secondary data set from 2012–2013, and compared each of these to the percentiles from the primary analysis.

Comparison With Primary Care and ED Patients

We compared the 90th percentiles from our primary analysis with the Thompson primary care percentiles at the medians of the age groups used in that reference (7 months, and 1.5, 3.5, and 7.5 years) at a temperature of 39.5°C.[13] We also compared the 95th percentiles for our reference with the Davies ED reference at 39.5°C for the above ages as well as at 12 and 15 years.[14] The Thompson reference did not include published values for the 95th percentile, and the Davies reference did not include the 90th percentile. The Hanna et al reference included means and confidence intervals but no percentiles for comparison.[15]

Ethics

Because deidentified data were used, the study was deemed to be not human subjects research and exempt from review by the institutional review boards of both CHOP and CCHMC.

RESULTS

The extracted data contained 684 749 observations with a HR and body temperature simultaneously recorded. Of these, 596 (0.1%) were excluded because of a temperature, HR, or HRZ_{age} that was out of range. There were 16 273 patients with 21 997 admissions from CHOP and 7572 patients with 10 345 admissions from CCHMC (Tables 1 and 2).

Percentile Curve Development

The derivation data set included 60 863 observations; 8.6% of

TABLE 1 Subject Demographics

Characteristic	*n* (%)
Age	
0 to <6 mo	3086 (13)
6 to <12 mo	1437 (6)
1 to <3 y	4133 (17)
3 to <5 y	2739 (11)
5 to <7 y	2053 (9)
7 to <9 y	1775 (7)
9 to <11 y	1692 (7)
11 to <14 y	2747 (12)
14 to 18 y	4183 (18)
Race	
American Indian/Alaska Native	14 (0.06)
African American or Black	7363 (31)
Asian	527 (2)
Multiracial	354 (1)
Native Hawaiian/Pacific Islander	15 (0.06)
White	13 294 (56)
Other	2218 (9)
Unknown/Refused	60 (0.3)
Gender	
Male	12 870 (54)
Female	10 975 (46)
Total	23 845

TABLE 2 Number of Observations by Age, Temperature (°C), and Temperature Source

Age	35–35.9	36–36.9	37–37.9	38–38.9	39–39.9	40–40.5	Total
0 to <6 mo							
C	165	991	2247	903	296	26	4628
NC	7560	42 378	14 386	683	158	19	65 184
6 to <12 mo							
C	55	358	629	412	165	27	1646
NC	9852	32 308	8486	893	208	36	51 783
1 to <3 y							
C	122	671	989	523	199	30	2534
NC	20 799	65 741	21 928	3289	1034	186	112 977
3 to <5 y							
C	249	3382	2833	450	149	20	7083
NC	15 141	39 532	14 018	2053	668	130	71 542
5 to <7 y							
C	617	8211	6404	960	305	22	16 519
NC	8954	27 027	8636	1137	372	60	46 186
7 to <9 y							
C	566	10 543	7319	871	311	20	19 630
NC	4343	14 829	5210	598	156	32	25 168
9 to <11 y							
C	1032	14 551	8665	930	345	28	25 551
NC	3572	11 140	4001	469	113	33	19 328
11 to <14 y							
C	2261	33 581	15 912	1688	561	28	54 031
NC	4496	15 271	6157	686	249	59	26 918
14–18 y							
C	5566	68 068	26 437	2315	660	16	103 062
NC	5099	16 963	7152	863	267	39	30 383
Total	90 449	405 545	161 409	19 723	6216	811	684 153

C, core temperature; NC, non–core temperature.

these had a temperature ≥38°C. Age-nonspecific percentile curves for HRZ_{age} by temperature were created (Fig 1). We used the age-nonspecific curves to develop HR by temperature curves for each of 9 age groups (Fig 2). Tables to calculate $HRZ_{agetemp}$ are available upon request from the authors.

Validation

In the validation data set (n = 40 096), the proportion of vital signs <5th percentile was 4.9%, and the proportion >95th percentile was 5.3%. In the subgroup analysis, the proportion <5th ranged from 2.1% to 8.4%, and the proportion >95th percentile ranged from 3.5% to 10.4%. The proportion <5th or >95th was statistically different from the expected value of 5% for 4 of 36 comparisons, 2 of which were in infants aged <6 months old (Supplemental Table 4). The group with the most deviation from the expected fit was febrile infants aged <6 months old (n = 374), with 2.1% <5th percentile (P = .008) and 10.4% of febrile infants >95th percentile ($P < .001$).

Evaluation of Non–Core Temperatures

Controlling for body temperature and age, linear regression showed that the expected HR for observations with a non–core body temperature was 3 beats per minute higher than for observations with a core body temperature.

Analyses by Hospital

The HR distributions were similar for both hospitals (mean HR: CHOP 109, CCHMC 107; mean HRZ_{age} CHOP: 0.10, CCHMC: 0.03). The distributions of core temperature differed more substantially (mean temperature: CHOP 36.9°C, CCHMC 36.4°C), with a large difference in the proportion of observations with a core body temperature <36°C (CHOP 0.2%, CCHMC 11.6%; Fig 3). The core temperature distribution of the secondary CCHMC dataset from 2012 to 2013 was intermediate between the CHOP and primary CCHMC data sets (mean temperature: 36.8°C; 8.3% <36°C). Five CCHMC units that switched to the new thermometer earlier in the time period of the secondary data set had a larger increase in mean body temperature and a larger decrease in the proportion of temperatures <36°C, compared with 3 units that switched later. The proportion of observations

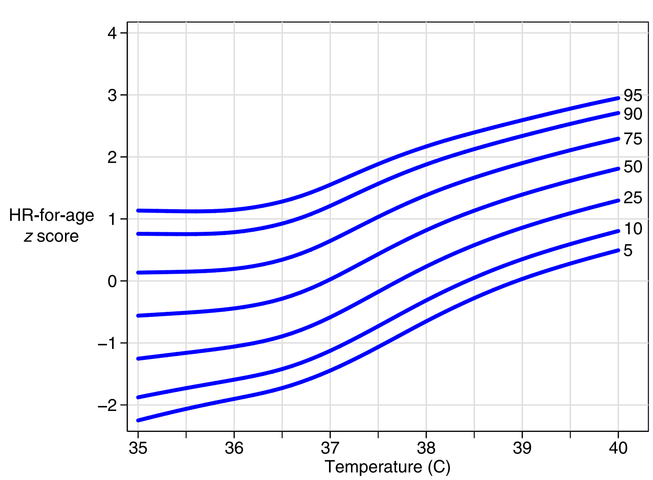

FIGURE 1
HR-for-age z score percentiles by temperature (age-nonspecific curves).

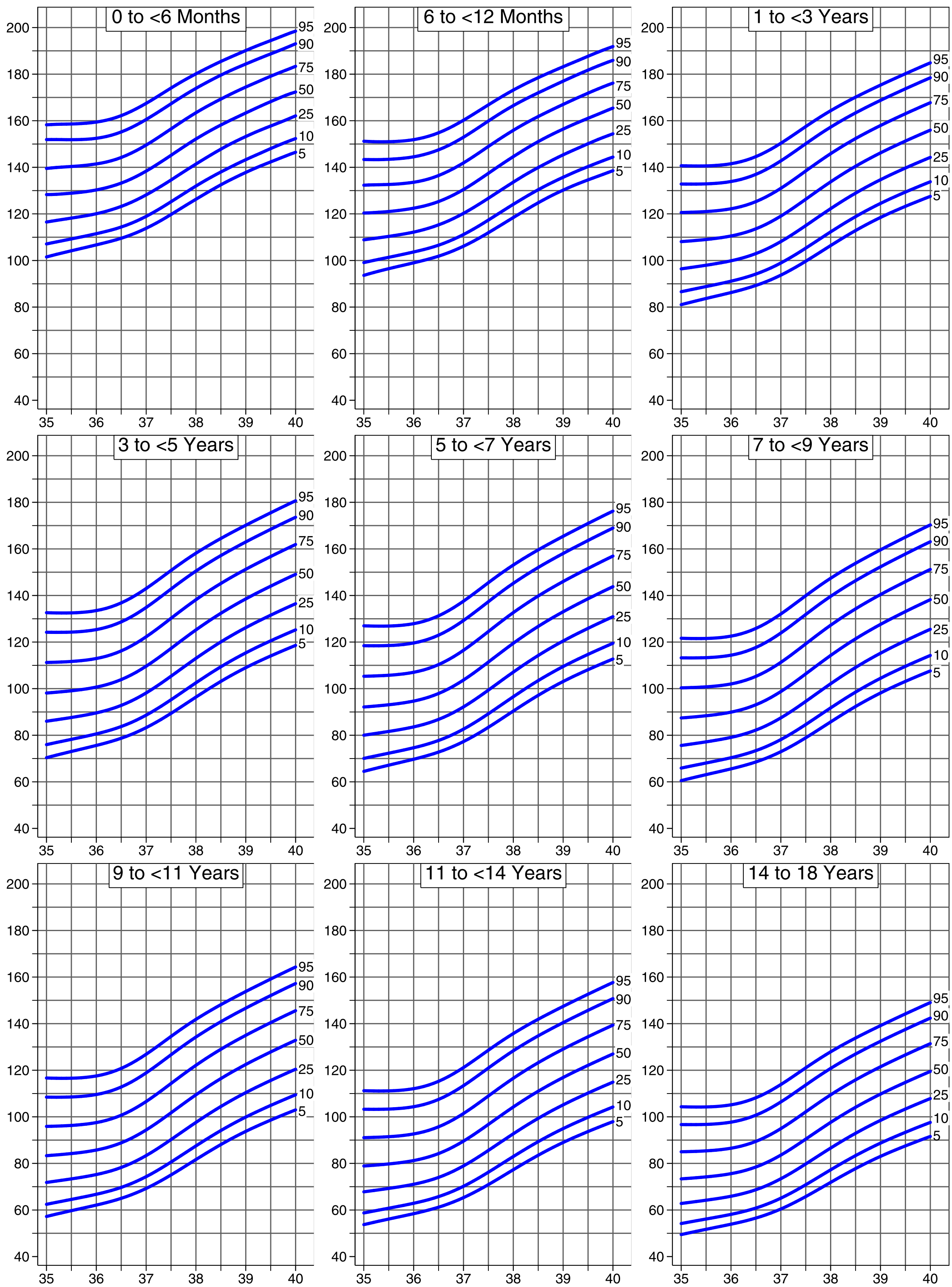

FIGURE 2
Heart HR-for-temperature percentiles by age group (age-specific curves).

with a core temperature ≥38°C was similar for both hospitals (CHOP 4.7%, CCHMC 2011–2012 6.0%, CCHMC 2012–2013 5.0%). There were small differences by hospital in the proportion of observations <5th percentile (CHOP 5.3%, CCHMC 4.2%, $P < .001$) and >95th percentile (CHOP 5.5%, CCHMC 5.0%, $P = .04$). The percentile curves created from individual hospital data sets were similar to the

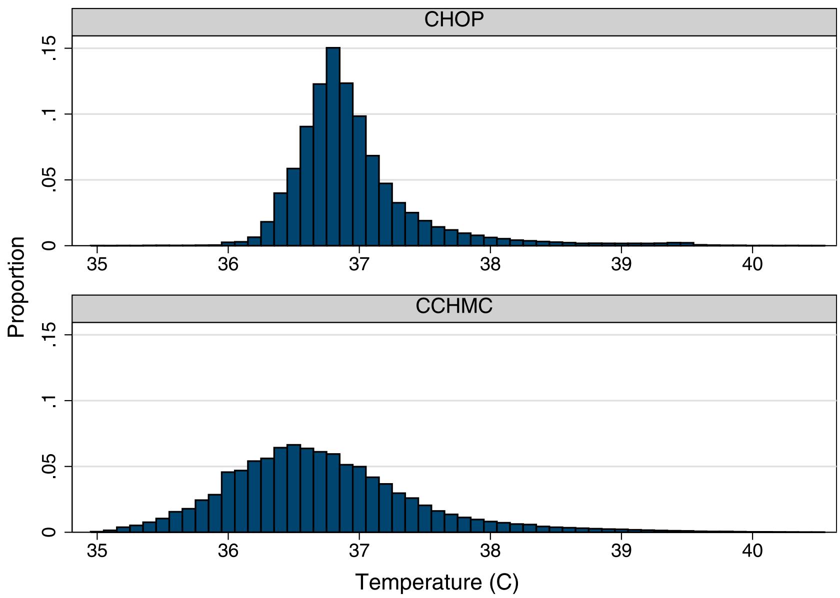

FIGURE 3
Histogram of core temperatures by hospital.

primary analysis percentiles at temperatures from 36° to 40°C (Fig 4).

Comparison With Primary Care and ED Patients

Our 90th and 95th percentiles were lower than primary care and ED percentiles at 7 months, 1.5 years, and 3.5 years. Our percentiles were higher than those for nonhospitalized children at 7.5 and 12 years (Table 3).

DISCUSSION

We created percentiles that characterize expected HR in hospitalized children by age and body temperature. As in prior studies, we found that expected HR increases with increasing body temperature across the full range of body temperatures, not only in febrile children.[13–15] Our findings support the general relationship described in the heuristics used by some clinicians to expect an increase in HR of ~10 beats per minute for each increase in body temperature of 1°C, but also allow clinicians to be much more precise regarding the degree to which the HR for their patients deviates from the expected HR for hospitalized patients with the same age and body temperature. For example, the median HR for a 6- to 12-month infant differs by 15 beats per minute at a temperature of 37° vs 38°C, whereas in a 14- to 18-year old, the median HR differs by only 8 beats per minute between 36° vs 37°C.

We restricted our analysis to observations that included a core body temperature measurement, which we defined as either oral or rectal. Our evaluation of HR in children with core and non–core temperature measurements supports our concern that using non–core temperatures would likely have resulted in a small (average 3 beats per minute) overestimation of expected HR. We recognize that in many clinical situations non–core body temperature measurements are necessary or preferred. We recommend using these percentiles without adjustment regardless of the method of body temperature measurement because the difference in expected HR for core and non–core measurements is small and the amount of error in body temperature using non–core methods is variable.

There were some consistent differences between our percentiles and 2 references for nonhospitalized patients in the primary care and ED triage settings.[13,14] At the same temperature, young nonhospitalized children, particularly those under 2 years of age, had higher HR than found in our hospitalized subjects. Older nonhospitalized children had similar or somewhat lower HRs compared with our subjects. The difference in HR for young children

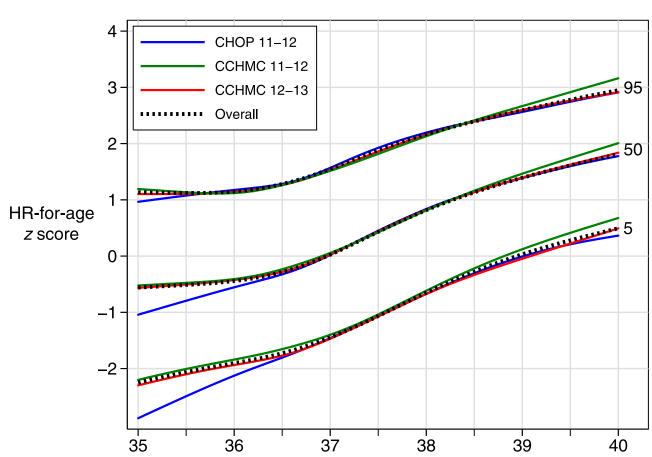

FIGURE 4
Comparison of age-nonspecific curves in primary analysis with curves created using each hospital data set separately.

TABLE 3 Comparison of Our Percentiles for Hospitalized Children With Existing Percentile Curves From Primary Care and ED Settings

	Hospital 90th	Primary Care 90th	Hospital 95th	ED 95th
7 mo	183	204	189	202
1.5 y	176	191	182	194
3.5 y	169	174	176	177
7.5 y	159	155	167	153
12 y	147	N/A	154	145
15 y	140	N/A	146	147

N/A, not available.

may reflect differences in patient characteristics between the nonhospitalized and hospitalized populations and possibly the use of non–core body temperature measurements in nonhospitalized patients compared with the core temperatures included in our percentiles. Some of the difference may reflect the emotional stress of young children who are ill and being assessed by strangers, and the effect of this stress on HR. Young inpatients may be somewhat less upset every time vital signs are obtained, and inpatient staff generally have somewhat more flexibility to obtain vital signs when patients are more calm or even asleep. Some of the difference in young children could also be related to measurement. In Thompson et al,[13] HR was measured using pulse oximetry, which may be more accurate for high HRs. Measurement is unlikely to account for all of the differences at young ages given that Davies et al[14] also used a mix of HR measurement methods.

The differences in expected HR for age and temperature will be important to consider when designing or implementing tools that include HR cut points in inpatient, ED, or primary care settings. For example, tools that can be used to screen for severe sepsis are desired for both inpatients and ED patients. A severe sepsis screening tool that uses the same temperature-adjusted HR cut points in both patient populations would likely identify a higher proportion of infants and toddlers as test-positive in the ED compared with inpatients and a higher proportion of school-age children as test-positive in inpatients compared with ED patients. Because of these differences in the HR distributions between settings, it is possible that different HR cut points are needed in different settings to achieve optimal test performance.

Of note, we found differences in the body temperature distribution between the 2 hospitals from which we obtained data. This was unexpected and seems more likely attributable to differences in temperature measurement rather than differences in body temperature regulation or clinical conditions between the patients at the 2 hospitals. This explanation is supported by our analysis of the temperature distribution at CCHMC during the year it transitioned to a different thermometer. Sensitivity analyses showed small differences by hospital in the relationship among HR, age, and body temperature.

The strengths of our analysis include the large sample size and the validation across subgroups in a separate sample. Our ability to create an initial set of age-nonspecific percentile curves improved the stability of outer percentiles. It also allows researchers to precisely determine $HRZ_{agetemp}$ regardless of age, compared with age-stratified curves that may perform less accurately at the extremes of age groups.

There are several limitations to our retrospective analysis. First, the data come from 2 similar hospitals, and the percentile curves have not yet been validated in a population of children from other hospitals. The percentiles generally fit the validation data set well across age and body temperature combinations, but in febrile infants there was some deviation from expected fit that should be evaluated further in other populations. Second, the data included relatively few observations with extremely high temperatures. Finally, our data did not include variables describing other patient-level factors associated with HR such as pain at the time of vital sign observation or medications such as inhaled bronchodilators and β-blockers that influence HR.

The proper application of our percentiles in clinical care is informed by 2 studies that have evaluated the performance of temperature-adjusted HR for the identification of children with serious illness. Cruz et al demonstrated that an age- and temperature-adjusted tachycardia alert identified most subjects with septic shock, with a sensitivity of 81% and a positive predictive value of 3.7%.[21] However, when Brent et al compared temperature-adjusted HR-for-age percentiles to HR-for-age percentiles for the identification of serious bacterial illness, they found that HR-for-age was the stronger predictor of serious bacterial illness.[22] Further evaluation of our temperature-adjusted HR percentiles will be necessary to determine the test characteristics of various percentile cut points for the early identification of children with serious illness and to determine whether they perform better than non–temperature-adjusted HR cut points. A lower percentile threshold (eg, 90th vs 95th percentile) for temperature-adjusted HR cut points may be needed when sensitivity is valued over specificity such as in a sepsis screen.

CONCLUSIONS

We created reference percentile curves for use in hospitalized children that characterize the age-dependent expected increases in HR as body temperature increases. Our sensitivity analyses indicate that these percentiles are appropriate for use regardless of the method of temperature measurement. As in studies of primary care and ED populations, we identified an increase of ~10 beats per minute in HR for each increase of 1°C. However, our percentiles for hospitalized patients differ from those developed using data from primary care and ED settings. Further research is needed to validate these curves in a distinct population of hospitalized children and to evaluate their performance in identifying children who require further evaluation or intervention for sepsis or other serious conditions.

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