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ORIGINAL ARTICLE

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The effect of an electronic health record–based tool on abnormal pediatric blood pressure recognition

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Abstract

Background: Recognition of high blood pressure (BP) in children is poor, partly due to the need to compute age-sex-height referenced percentiles. This study examined the change in abnormal BP recognition before versus after the introduction of an electronic health record (EHR) app designed to calculate BP percentiles with a training lecture.

Methods and results: Clinical data were extracted on all ambulatory, non-urgent encounters for children 3–18 years old seen in primary care, endocrinology, cardiology, or nephrology clinics at an urban, academic hospital in the year before and the year after app introduction. Outpatients with at least 1 BP above the age-gender-height referenced 90th percentile were included. Abnormal BP recognition was defined as a BP related ICD-9 code, referral to nephrology or cardiology, an echocardiogram or renal ultrasound to evaluate BP concern, or a follow-up primary care visit for BP monitoring. Multivariable adjusted logistic regression compared odds of recognition before and after app introduction. Of 78 768 clinical encounters, 3521 had abnormal BP in the pre- and 3358 in the post-app period. App use occurred in 13% of elevated BP visits. Overall, abnormal BP was recognized in 4.9% pre-app period visits and 7.1% of visits post-app ($P < .0001$). Recognition was significantly higher when the app was actually used (adjusted OR 3.17 95% CI 2.29–4.41, $P < .001$). Without app use recognition was not different.

Conclusions: BP app advent modestly increased abnormal BP recognition in the entire cohort, but actual app use was associated with significantly higher recognition. Predictors of abnormal BP recognition deserve further scrutiny.

KEYWORDS
blood pressure, electronic health record, hypertension, pediatric, quality improvement

1 | INTRODUCTION

A growing body of literature suggests associations between pediatric and adolescent hypertension and health outcomes, including increased cardiovascular disease events, increased chronic kidney disease, and increased mortality.[1–8] These associations are particularly concerning given nearly 10% of children have abnormal blood pressure.[9]

Despite increasing evidence of the adverse effects of early life hypertension, pediatric hypertension remains under-diagnosed, with one study in a large pediatric center estimating that only 10% of children with a blood pressure (BP) >90th percentile were recognized by providers as having abnormal BP.[10] Another study found that hypertension screening occurred in only 67% of preventive pediatric visits, though screening increased over the study period.[11] Even as patients move into adult practice, diagnosis of hypertension is less likely among younger adults (18–24 years of age) than in older patients.[12]

Two key barriers to recognizing elevated BP in children are the need to determine the age-sex-height referenced BP percentiles for a given measurement and the importance of tracking BP measurements over time. We evaluated a new electronic health record–based app that extracts age, sex, height and BP data from the EHR to calculate and track a patient's BP percentile longitudinally, allowing providers the voluntary option of using this app to quickly interpret casual office BP measurements. The aim of this study was to evaluate whether provider recognition of abnormal BP (>90th percentile) differed before versus after the advent of the app and hypertension education associated with app roll-out.

2 | METHODS

The Substitutable Medical Applications & Reusable Technology (SMART) BP Centiles app is a free, substitutable, open-source, open-access BP calculator and longitudinal tracking tool capable of running within any EHR that supports the SMART Health IT Platform (https://gallery.smarthealthit.org).[13,14] When activated, the app displays the blood pressure percentile associated with a particular ambulatory blood pressure measurement, as well as historic blood pressure percentiles, allowing providers to determine if an elevated blood pressure represents an isolated event or if a patient has had multiple elevated blood pressures over time. The app does not provide any further recommendations regarding next steps in management. In addition, the app only uses blood pressures taken during ambulatory visits, and excludes inpatient and emergency department measurements, when blood pressure may be elevated as a result of an acute illness. BP percentiles were calculated based on the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents.[15] The application was introduced into the EHR at a large urban pediatric health center located in New England. Rollout of the application in 2012 was accompanied by 60 minute, voluntary hypertension education sessions given by cardiology and nephrology faculty to ambulatory care clinics and house staff groups. The use of the app was completely voluntary and not mandated by any incentive program.

This study was a retrospective cohort study of all well child visits in primary care clinics, as well as all non-urgent outpatient visits in the endocrinology, cardiology, and nephrology clinics that occurred in the year before and after the BP application and associated education sessions were introduced, with a 2-month window after the application was introduced to allow for provider uptake and app percolation. The population of interest was children 3–18 years of age with at least one systolic or diastolic BP reading above the 90th age-sex-height referenced percentile seen in these clinics between August, 2011 and July, 2012 (pre-app time period) or between October, 2012 and September, 2013 (post-app time period). BP measurements with no documented height within a 6-month period 3 months before or after a visit of interest were excluded. In the population of interest, we extracted data including demographic information about age, race, gender, and weight.

The exposure of interest was the time period after the app and BP education were introduced compared with the pre-app period. The outcome of interest was provider recognition of an abnormal BP-based documented provider action, specifically defined as either ICD-9 codes associated with hypertension (796.2 elevated BP without a diagnosis of hypertension, 401.xx hypertension, 401.9 hypertension NOS, 401.1 benign hypertension, 997.91 hypertension, or 402.9 hypertension NOS); or patient referral to nephrology or cardiology after a visit with an abnormal BP measurement; or occurrence of a renal ultrasound or an echocardiogram with abnormal BP as the indication; or a follow-up visit in primary care to repeat a BP measurement. We did not include echocardiograms or renal ultrasounds that were obtained to evaluate for other potential cardiac or renal anomalies unrelated to hypertension. To ensure new recognition of elevated BP, we excluded individuals who had a documented ICD-9 code for abnormal blood pressure in the 12 months prior to the study. In order to ensure that we captured recognition events that occurred for patients seen at the end of each time period of interest, we screened the two-month period after the study interval for any follow up visits, referrals, or imaging studies.

We performed a more in-depth analysis of 5% of the charts from the primary care clinic to determine if there was documentation of hypertension in the text of the note that did not correspond with an ICD-9 code or other form of "recognition" to determine if we may have missed recognition events using our recognition criteria.

2.1 | Analysis

The unit of analysis was individual patient visits including all visits after the initial elevated BP within the observation period until a censoring event, which was defined as either a recognition event or the end of the observation period. Therefore, the proportion of visits with elevated BP is less than 100% because BPs after an index elevated BP may have gone back into the normal range. The primary analysis compared the proportion of elevated BPs recognized between the pre- versus post-app periods using chi square testing. A secondary analysis used chi square testing to compare the pre-app period proportion recognized versus the proportion recognized in post-app patient visits where the app was actually used.

Summary statistics were used to analyze patient demographic characteristics and to determine patient factors associated with app use. We assessed whether there were any differences in patient characteristics when the app was used versus not used by evaluating all outpatient clinical encounters, regardless of blood pressure percentile, in the year after the application was introduced to help identify predictors of app usage. Chi square analyses were used for categorical variables and *t* tests for continuous variables to assess whether there were differences in app use based on gender, age, height, and blood pressure percentile. Identified predictors of app use were then incorporated into analyses of app effectiveness in order to adjust for the likelihood of using the app on the likelihood of being recognized as having elevated BP.

In order to account for possible changes in recognition over time, we conducted an interrupted time series analysis on a monthly time scale to identify secular trends in recognition throughout the observation

TABLE 1 Characteristics of patient visits

	Pre (8/11 to 8/12) *N* = 3521		Intervention (10/12-10/13) *N* = 3358			Intervention: App users only *N* = 447		
	N	%	*N*	%	*P* value (pre versus intervention*	*N*	%	*P* value (intervention versus app use only)*
App Use								
Yes	–	–	447	13.3		447	100.0	
Recognized								
Yes	173	4.9	238	7.1	<.001	74	16.6	<.0001
Number of Visits to Recognition (recognized cohort only)								
One Visit	150	86.7	205	86.1		61	82.4	
More than One	23	13.3	33	13.9		13	17.6	
Gender								
Female	1711	48.6	1717	51.1	0.035	234	52.3	
Race								
White	1347	38.3	1226	36.5	<.0001	150	33.6	
Black or African American	876	24.9	666	19.8		103	23.0	
Asian	110	3.1	109	3.2		18	4.0	
Other/unknown	1188	33.8	1357	40.4		176	39.3	
Age (median, 25–75% range, in years)	9.2	5.1–13.9	9.5	5.3–14.0	0.044	9.9	6.0–14.2	0.014
BMI pctle group								
BMI < 85th pctle	1889	54.0	1913	57.2	0.002	224	50.6	
BMI 85th to < 95th pctle	544	15.5	542	16.2		67	15.1	
BMI ≥ 95th pctle	1067	30.5	891	26.6		152	34.3	
BP pctle group								
BP < 95th pctle	1713	48.7	1636	48.7		222	49.7	
BP 95th to < 99th pctle	1203	34.2	1154	34.4		149	33.3	
BP ≥ 99th pctle	605	17.2	568	16.9		76	17.0	
Clinic								
Primary care	1462	41.5	1308	39.0	<.0001	205	45.9	<.0001
Endocrine	401	11.4	277	8.2		32	7.2	
Cardiology	1339	38.0	1125	33.5		124	27.7	
Renal	319	9.1	648	19.3		86	19.2	

**P* corresponds either to comparison of pre-intervention versus post-intervention or comparison of post-intervention with app use versus post-intervention without app use.

period. As no secular trend was observed and an interaction term before versus after the app introduction was observed, subsequent analyses used logistic regression to identify correlates of recognition before and after the app was introduced. Multivariable adjusted logistic regression models were constructed using recognition (yes/no) as the binary outcome and pre-app, post-app with no app use, and post-app with app use as the independent variable of interest; other independent variables included age, race/ethnicity, gender, body mass index percentile, number of visits, and blood pressure percentile. We performed a sub analysis in the primary care clinics to ascertain app effect in primary pediatric practice. We performed the same multivariable logistic regression analysis on a patient level as opposed to on the level of individual encounters and found very similar, though more significant results. We used the more conservative per visit approach given that individuals seen earlier in the study period would accrue more follow up time for potential recognition as compared with those seen later in the study period. To quantify the additional predictive utility of using the app, we use receiver operator characteristics in the post-app population alone with a model constructed from multivariable clinical predictors of recognition versus those same predictors combined with app use.

All analyses were conducted using SAS version 9.2. An alpha <0.05 was considered significant. This study was approved by the Institutional Review Board at Boston Children's Hospital with a waiver of informed consent.

3 | RESULTS

We screened 78 768 clinical encounters representing 35 553 individual patients. Abnormal BP occurred in 3521 encounters, representing 3052 patients, during the pre-app period and 3358 encounters, representing

TABLE 2 Characteristics of overall app usage during the post-app period

Characteristics	App used ($n = 1345$ visits)	App not used ($n = 25\,294$ visits)	*P* value
Male gender (%)	51%	45%	<.0001
Age (years)	10.6 (4.4)	11.9 (4.8)	<.0001
Height (cm)	141.3 (24.5)	144.9 (24.4)	<.0001
Mean BMI	22.2	21.7	.49
SBP (mm Hg)	109.9 (14.3)	107.2 (13.4)	<.0001
SBP percentile	64%	54%	<.0001
DBP (mm Hg)	63.6 (8.6)	61.5 (8.7)	<.0001
DBP percentile	57%	49%	<.0001
BP >90th percentile	26%	17%	<.0001
BP >95th percentile	15%	9%	<.0001
BP >99th percentile	5%	3%	<.0001
SBP>120 or DBP>80	23%	16%	<.0001
SBP>140 or DBP>90	2%	1%	.0002

All data in mean (SD) or proportions as appropriate.
P values from chi square for categorical variables or *t* test for continuous variables.

2910 patients during the post-app period. Baseline characteristics are given in Table 1. Age was not significantly different in the pre- and post-app periods. There were significantly more girls seen with high BP in the pre-app period than in the post-app period, although overall there were more boys seen with high BP than girls. The mean BMI percentile was lower in the post-app period compared with the pre-app period. There was a statistically significantly different racial composition of the population in the pre- versus post-app period, with a higher proportion of white and African American individuals in the pre-app period and a higher proportion of unreported race in the post-app period. The proportion of encounters in nephrology clinic was higher and the proportion of individuals in cardiology clinic was lower in the post-app period. There was no significant difference in proportion of encounters with a BP above the 95th percentile in the pre- and post-app period.

During the post-app period, the application was used in 5% of all encounters, and in 13% of visits with a blood pressure above the 90th percentile. Across the entire outpatient population, app use was more common for males, younger patients, and in those with higher BP, while mean BMI did not differ (Table 2). The presence of BP over the 90th percentile was associated with a 1.8 (95% CI 1.6-2.0) times higher odds of using the app.

Recognition of abnormal BP in the pre-app time period occurred in 4.9% of visits, while recognition occurred in 7.1% of visits post-app ($P < .001$) (Table 1). Focusing on the post-app period, recognition when the app was used was 16.6% while when it was not used was 5.6% (Figure 1 and Table 1). Recognition was primarily documented by ICD-9 code, with only a small subset of recognition being identified by ordering echocardiogram or renal ultrasound (data not shown). Controlling for predictors of app use (age, gender, race/ethnicity, BMI, and degree of blood pressure elevation), the odds ratio of recognition with app use was 3.17 (95% CI 2.29–4.41, $P < .001$) compared with the pre-app period (Table 3). In examining multivariable adjusted covariate associations, recognition was higher among males, white patients, higher BMI percentile, BP above the 95th percentile, and in cardiology and nephrology clinics (Table 3). Post-app period recognition was most different in those patients with BP at or above the 99th percentile (Figure 2).

In a sub-analysis of only primary care clinics, the application was used in 15% of visits. Recognition occurred in 3% of primary care encounters. The odds or recognition was not significantly higher in the post-app period compared with the pre-app period (OR 1.67, 95% CI 0.82–3.4). In ROC curves, adding app use to the baseline predictors increased the C-statistic from 0.806 to 0.821.

4 | DISCUSSION

We found that use of an EHR–based application designed to aid in recognition of elevated BP by calculating age, gender, and height referenced BP percentiles and presenting longitudinal BP percentiles, combined with pediatric BP education was associated with significantly higher recognition of elevated BP across outpatient clinics at our institution. Overall app use, however, was low, as voluntary app use only occurred in 13% of clinical encounters in which the BP was elevated, and in 5% of clinical encounters overall.

Recognition of elevated blood pressure in children is challenging in part because the definition of an elevated blood pressure depends on a child's age, gender, and height.[15] Additionally, there are conflicting recommendations regarding whom to screen for hypertension, how often

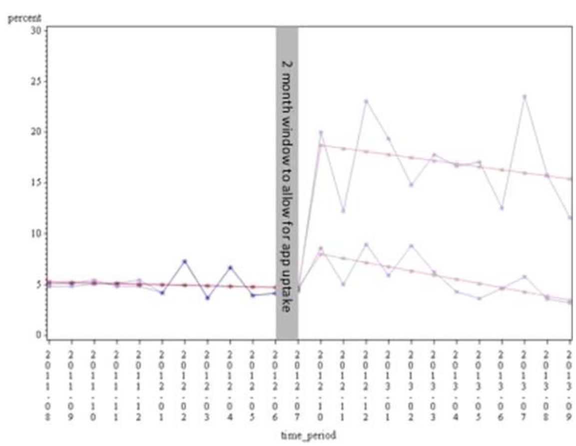

FIGURE 1 The proportion of abnormal BP readings recognized over time in the pre-app versus post-app periods. The percent abnormal BP recognized on the Y-axis is given versus calendar month in the pre- and post-app periods on the X-axis listed as year over two-digit month beginning August 2011 (2011 08). X-axis discontinuity between July and October 2012 represents the app uptake period. Blue dots represent measured recognition proportion in percent within the listed month while the red dot represents the rolling average. During the post-app period after October 2012, the upper red and blue point represents the app used group while the lower points represent app not used

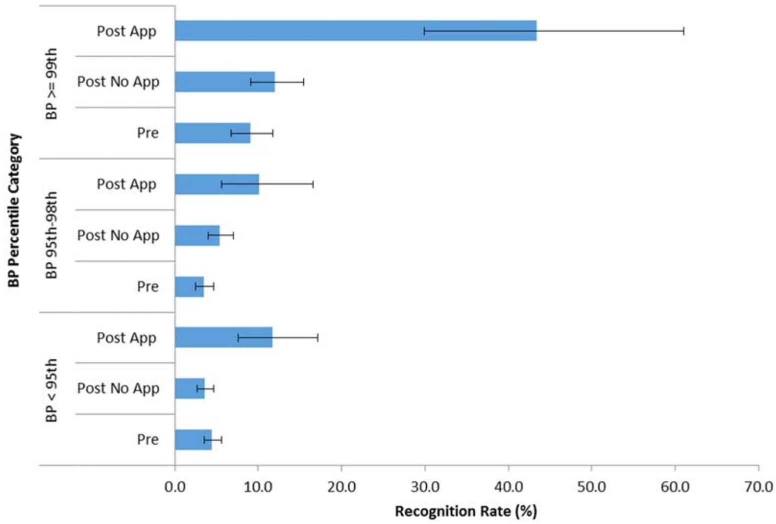

FIGURE 2 The proportion of abnormal BP recognized by height of BP elevation. Recognition rate is given along the X-axis while the BP elevation is categorized along the Y-axis as below the 95th percentile, between 95th and 98th percentiles, and over the 99th percentiles. These categories are further divided into Pre-app period, Post-app period without app used, and post-app period with app used. Error bars represent 95% confidence intervals

to screen, and at what age screening should commence.[15–17] Furthermore, many providers are unaware of existing hypertension guidelines, or are uncomfortable managing pediatric hypertension.[18] The documented under-recognition of hypertension among pediatric patients[10] is therefore potentially related to a complex combination of factors. The SMART BP app was designed specifically to address challenges related to determining if a BP is elevated based on a child's age, gender, and height, and to allow for quick evaluation of whether BP has been elevated over a number of visits.

Overall app usage and recognition of elevated BP was significantly associated with higher BPs, a finding that has been shown in other studies.[19] Recognition remained highest in patients with very elevated BPs, a difference that was more pronounced in the app usage group. Even with app usage, recognition of elevated BP based on our criteria remained low, as has been shown in other studies. This finding suggests that under recognition of elevated BPs in children is not simply the result of the challenge of identifying elevated BP in children. Other factors, including interest in BP, knowledge of BP guidelines, or comfort managing pediatric hypertension[18] may contribute to under recognition of elevated BPs. Future efforts to improve BP recognition and management in pediatric patients may require a fuller understanding of barriers to recognition to elevated BPs.

We also found that recognition was higher among male patients, white patients, and older patients in contrast to other research.[19] Uniform app availability for all outpatients did not eliminate typical healthcare disparities, although in the fully adjusted model, the effects of age and degree of blood pressure elevation were attenuated. We did not find a significant difference in recognition in the post-app period in primary care clinics, where detection of elevated BP is particularly important as this is often the first setting in which an abnormal blood pressure is identified. Further targeting of high BP recognition in the primary care setting is warranted.

Studies have shown that EHR–based tools are associated with increased recognition of elevated blood pressure in adult patients.[20–22] Similar studies in pediatrics have been limited.[23,24] An intervention performed in primary care pediatric practices using either simplified BP tables attached to the medical chart or using a PDA tool to calculate BP percentiles was not associated with significant improvement in recognition, and uptake of the intervention tool was fairly low.[23] Another smaller, EHR–based intervention study found that automated reminders did improve in abnormal BP recognition.[24] While use of the SMART BP app was associated with significant improvement in recognition of elevated blood pressures, uptake proved similarly challenging. We do not have specific data regarding barriers to app usage of the app, although higher voluntary app use in visits where BP was elevated is encouraging. We also found a significant increase in recognition when the app was used in our population. However, even when the app was used, the majority of elevated BP cases went unrecognized. Although embedded within the EHR with link out to an external viewer, our tool was provider initiated and not automated into clinic workflow nor administratively mandated, instead relying on provider interest in BP on a case-by-case basis. When utilized, tools such as the SMART BP app provide a viable alternative to current practice of finding blood pressure references in tables and also highlights the potential benefit of EHR–based tools for abnormal BP recognition since the use of raw, unreferenced BP is very difficult to interpret precisely in the ambulatory setting. These tools, however, may be most useful if regularly integrated into the clinic workflow, ensuring consistent use.

This study did have some limitations. We were dependent on the BP that was recorded in the medical record; if providers recognized an elevated blood pressure and repeated a BP but did not record the repeated value in the EHR, we would have coded that individual as a missed recognition even though the provider has addressed the BP. Our results may therefore underestimate recognition, making our

TABLE 3 Multivariable logistic regression model of recognition of elevated blood pressure

	Univariate odds ratio (95% CL)			Multivariable odds ratio (95% CL)		
			P value			*P* value
Intervention group			<.0001			<.0001
Pre	1.00			Referent		
Post-no app	1.16	(0.93, 1.44)		0.89	(0.70, 1.13)	
Post-app	3.84	(2.87, 5.14)		3.17	(2.29, 4.41)	
Gender			<.0001			<.0001
Female	1.00			Referent		
Male	1.50	(1.23, 1.84)		1.59	(1.27, 1.98)	
Race			<.0001			0.019
White	1.89	(1.55, 2.31)		1.34	(1.05, 1.70)	
Nonwhite	1.00			Referent		
Patient age (years)			<.0001			<.0001
1 unit increase	1.14	(1.11, 1.16)		1.13	(1.10, 1.16)	
BMI percentile group			0.022			0.001
BMI < 85th pctle	1.00			Referent		
BMI 85th to < 95th pctle	1.23	(0.93, 1.63)		1.29	(0.95, 1.74)	
BMI ≥ 95th pctle	1.36	(1.09, 1.71)		1.63	(1.27, 2.09)	
BP percentile group			<.0001			<.0001
BP < 95th pctle	1.00			Referent		
BP 95th to < 99th pctle	1.02	(0.79, 1.31)		0.98	(0.76, 1.28)	
BP ≥ 99th pctle	3.02	(2.38, 3.83)		2.47	(1.91, 3.20)	
Clinic			<.0001			<.0001
Primary care	1.00			Referent		
Endocrine	0.39	(0.19, 0.80)		0.24	(0.11, 0.49)	
Cardiology	1.83	(1.39, 2.43)		1.47	(1.06, 2.05)	
Renal	7.81	(5.96, 10.24)		5.26	(3.86, 7.18)	

Abbreviations: BMI, body mass index; BP, blood pressure; pctle, percentile.
Multivariable odds ratio indicates odds ratio of the subheading row relative to the referent within that heading adjusted for age, sex, race, BMI, BP percentile, and clinic.

results conservative. We conducted a more in-depth chart review of ~5% of individuals seen in primary care, however, and found that documentation only in a clinical note occurred in <5% of patients, and therefore the number of repeated blood pressures documented in notes and not in the vital signs portion of the EHR was likely low. There may have been unmeasured confounders that we did not account for in our initial design; however, we anticipate that these would have been similar in the pre- and post-app period. Much of the app use was in subspecialty clinics in which one might anticipate increased recognition of elevated BP. To maintain anonymity, clinic-level use was captured but specific provider usage was not captured. So we could not account for specific provider interest in blood pressure monitoring or facility with app usage. We did not assess specific diagnoses, such as chronic kidney disease or congenital heart disease, and therefore could not determine if specific diagnoses were associated with increased recognition of abnormal blood pressures, though we were able to assess for differences in primary care as opposed to subspecialty clinics, where children were more likely to carry additional diagnoses. Not every BP above the 90th percentile may need to be recognized. In this real-world practice analysis, it is prohibitively difficult to account for every variation in practice that denotes a worrisome blood pressure versus a transient BP elevation. We did account for reticence in making an ICD-9 diagnosis by including repeat visit with blood pressure measured as a criteria for recognition. But we did not have data regarding emotional state or details on technique which may impact decision making. This information gap may affect inferences on absolute rates of under recognition, but does not affect the inferences regarding app effect as such features should not have changed over time. While the propensity to use the app for the higher BPs may be viewed as biasing the analyses as a reflection that the provider already was internally sensitized to the BP, we infer the opposite. Namely since we define the criteria for recognition as externally documented clinical action and the criteria were the same before and after, we count improving the documented recognition of the highest BPs a strength of the app. Since we were interested in assessing utility of the application shortly after its rollout, our follow up time was relatively short, and we were limited to evaluating changes in recognition of elevated BP rather than changes in recognition of hypertension, which requires three separate measurements of elevated BP.[15] Finally, the study only examines the effect of voluntary, provider initiated used of the BP percentile calculator. The results of an EHR tool with better integration into clinical workflow and mandated use cannot be inferred from this data.

5 | CONCLUSIONS

The marked increase in high BP recognition associated with use of the BP application is encouraging, however overall app use uptake and high BP recognition remained fairly low. Further research into provider perceptions about EHR tools and provider attitudes toward pediatric blood pressure may aid in developing future programs to improve recognition of elevated BPs in pediatric patients.

CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTIONS

Drafted the article; acquired, analyzed and interpreted, data; and approved the submitted manuscript: Twichell

Contributed to the design; acquired data; critically revised the manuscript for important intellectual content, and approved of the submitted manuscript: Rea, Capraro, Mandel, Ferguson, Nigrin, Mandl

Acquired and analyzed the acquired data; critically revised the manuscript for important intellectual content, and approved of the submitted manuscript: Melvin, Graham

Conceived the BP tool; the research project; study and design; interpreted data; critically revised the manuscript for important intellectual content; and approved of the submitted manuscript: Zachariah

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