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Research article

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Synergy of Technology and Healthcare: The Development of a Smartphone Application to Detect Hypertension in Children and Adolescents

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Abstract

The prevalence of hypertension and pre-hypertension in the pediatric population is increasing. The development of primary hypertension earlier in life increases the chances of cardiovascular morbidity and mortality later in life. Studies have shown that 34 to 38% of children and adolescents with mild untreated hypertension already show signs of left ventricular hypertrophy. Evidence shows that childhood and adolescent hypertension and pre-hypertension are under-recognized due to a number of factors including lack of provider knowledge regarding the National High Blood Pressure Educational Program (NHBPEP) guidelines for diagnosing, evaluation, and treatment of high blood pressure in children and adolescents. Another issue is the complexity of diagnosing HTN in this population that requires utilizing 1,904 variables based on gender, age, and height percentile delineated from the CDC development charts. To more easily detect hypertension in children and adolescents, a Smartphone application, Pedia BP, was designed and developed. The existing tables from The Fourth Report on the Diagnosis, Evaluation and Treatment of High Blood Pressure in Children and Adolescents (NHBPEP, 2005), which contain hundreds of normal and abnormal blood pressure values based on gender, age, and height percentile, were analyzed and streamlined into a much simplified, single user interface Smartphone application. Pedia BP makes it easy to identify abnormal blood pressure values in an accurate and timely manner and resides on the mobile device so Internet access is not required and can be used in any setting. The time saving Pedia BP application, allows the practitioner to quickly follow best practice protocols regarding management of identified issues.

Keywords: Hypertension; Pre-hypertension; Children; Adolescents; Blood pressure measurement; Guidelines; Primary care; Screening; Smartphone application

Introduction

Pediatric hypertension is under-diagnosed. Due to the cumbersome process of using the BP tables, the diagnosis of hypertension may be missed in some children. Recent data show the 2005 Working Group blood pressure standards for children and adolescents have not been adopted into actual practice [ ]. In a review of electronic medical records to determine whether children with elevated blood pressure measurements were correctly identified, a comparison was made between the office blood pressure readings and the blood pressure diagnosis classification based on the NHBPEP Working Group criteria for normal blood pressure, pre-hypertension or hypertension. The results showed a significant discrepancy between subjects classification by blood pressure readings compared to their clinical diagnoses. Hypertension was present in 3.6% of the entire sample but had been diagnosed in just 0.9%. There was a similar rate of under diagnosis of pre-hypertension. The odds of having a correct diagnosis of hypertension or pre-hypertension were increased for older, taller children who were either obese or who had >3 abnormal blood pressure readings [2].

These findings suggest pediatricians may be unfamiliar with diagnostic blood pressure measurement standards for hypertension in younger children. Providers may pay more attention to obese children and lack confidence and inappropriate equipment to take blood pressure measurements [2]. A survey of general pediatricians affiliated with an urban academic center revealed that 40% were uncomfortable with diagnosing and evaluating hypertensive children. Of these, 54% who were unfamiliar with the report were uncomfortable, compared to 33% who were familiar with the report, yet still uncomfortable [3]. The implication is that no matter how well guidelines are designed, they either fail to reach their intended audiences or that significant barriers to their implementation prevent their universal adoption in their clinical practice [1].

One of the complexities of identifying abnormal blood pressure values in children and adolescents is that hundreds of normal and abnormal values exist, and differentiation of abnormal values depends on the child's gender, age, and height percentile. Provider's ability to remember and recall the variety of normal and abnormal blood pressure ranges may limit the provider's ability to perform an accurate blood pressure [4]. To simplify the complexity of the 1904 variables of the NHBPEP and to better recognize childhood and adolescent HTN, a Smartphone application called Pedia BP, was designed and developed to aid healthcare professionals in diagnosing child and adolescent HTN. The purpose of the article is to evaluate the effectiveness and efficiency of Pedia BP in assessing blood pressure measurement in the management of pediatric pre-hypertension and hypertension.

Hypertension is the most common diagnosis in primary care settings in the United States, affecting nearly one in three adults [5]. Unfortunately, this is increasingly becoming a problem for children (3-11 years of age) and adolescents (12-17 years of age). From 1993 to 2004, the prevalence of hypertension in the pediatric population increased from 1.0% to 4.5% [6]. This increase in prevalence is due to the increasing rate of childhood obesity, and heightened awareness of pediatric hypertension among health care providers [7].

The National Health and Nutrition Examination Surveys

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(NHANES) reported a significant increase in both children's and adolescent's systolic and diastolic blood pressure from 2.7% in the 1988-1994 survey to 3.7% in the 1999-2002 survey. This increase was mostly associated with obesity in children [8]. This direct relationship is observed as early as age five, and becomes more evident in the adolescent development stage [9]. Based on child and adolescent blood pressure guidelines, the combined prevalence of hypertension and pre-hypertension in high school students is over 30% in obese boys and 23-30% in obese girls [10]. Additionally, from 2002 to 2004, in a school-based blood pressure screening of a cohort of 5,000 children (12-15 years of age), the prevalence of hypertension and pre-hypertension increased 19.4% [11].

There is also evidence that childhood hypertension can lead to adult hypertension. Among all known childhood predictors of adult blood pressure measurement, the level of blood pressure in childhood is by far the strongest. Therefore, more information is needed about the relationship of childhood and adult hypertension and knowledge of its alterable determinants, such as obesity and sodium intake [12]. One preventive strategy that is potentially beneficial in preventing long-term complications resulting from hypertension is early detection and intervention with children who are hypertensive.

Hypertension is a known risk factor for Coronary Artery Disease (CAD) in adults, and the presence of childhood hypertension may contribute to the early development of CAD [7]. Additionally, the younger the child and the more severe the blood pressure abnormalities, the more likely secondary causes of hypertension are present [13]. Due to the epidemic of obesity in youth, the prevalence of primary pre-hypertension and hypertension is increasing [13]. This is primarily related to obesity metabolic syndrome, which accelerates atherosclerosis and increases the likelihood of target-organ damage, such as Left Ventricular Hypertrophy (LVH). LVH is the most prominent clinical evidence of end-organ damage in childhood hypertension. Studies show that 34 to 38% of children and adolescents with mild untreated hypertension already show signs of LVH and that LVH can be seen in as many as 41 % of adult patients with childhood hypertension [13,14]. LVH has been correlated with increased carotid intima-media thickness, an early marker for atherosclerosis and increasing adiposity in children and adolescents with hypertension [15]. Additionally, children and adolescents with severe hypertension are also at increased risk of developing hypertensive encephalopathy, seizures, cerebrovascular accidents, and congestive heart failure [7].

In the adult population, hypertension is based on the correlation with adverse outcomes, such as, myocardial infarction and stroke. For example, each 5mmHg increase in the diastolic blood pressure increases the risk of coronary artery disease by 20% and the risk of stroke by 35% [14]. Since these unfortunate outcomes are extremely rare in children and adolescents, the definition of elevated blood pressure in the young population is based on statistical data that delineate percentiles in a way similar to the CDC weight and height charts and the National High Blood Pressure Education Program (NHBPEP, 2005) blood pressure tables. Using the blood pressure tables requires multiple steps: first, measure and record the child's Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP). Second, use the correct gender table for the SBP and DBP. Third, find the child's age on the left side of the table and follow the age row horizontally across the table to the intersection of the line for the height percentile (vertical column). Fourth, find the 50th, 90th, 95th, and 99th percentiles for the SBP in the left columns and for the DBP in the right columns. This final step allows the clinician to establish a goal for antihypertensive treatment in the child in question. Blood pressure should be reduced to <95th percentile unless there are concurrent conditions such as, chronic renal disease and / or diabetes, in which case blood pressure should be reduced to <90th percentile [16].

Background of the Problem

Errors in measuring blood pressure can directly contribute to inaccurate diagnosis and treatment of childhood and adolescent hypertension. Clinical studies show that 35-60% of healthcare professionals in the United States measure blood pressure incorrectly [ ]. A study conducted by Grim and Grim showed that out of 373 medical staff, 66% reported lack of knowledge of the existence of the relevant AHA blood pressure guidelines and 92% had never read the guidelines [17,18]. In addition, 60% were unfamiliar with how to avoid errors of auscultatory gap; 62% did not use the bell of their stethoscope; 35% used Korotkoff Phase 4, rather than Phase 5, for their diastolic reading; and 48% measured blood pressures of their patients seated on the examination table, a practice known to raise diastolic blood pressure by as much as 10 mmHg [ ]. Furthermore, studies show average errors in blood pressure measurement ranging between 5-15 mmHg [14], important since a reduction of 5-6 mmHg would reduce risk of CHD by 20% and of stroke by 40%. [17,19] (Table 1) presents common factors that can affect - and produce errors in- blood pressure measurement [ ].

Accurate blood pressure measurement may impact estimates of cardiovascular disease prevalence and life expectancy. In a cohort study of 14,187 children and adolescents aged 3 to 18 years who received 3 well-child checks from 1999 to 2006, researchers found that hypertension and pre-hypertension frequently went undiagnosed. Out of the 507 children and adolescents who had hypertension, only 131 had a diagnosis of hypertension or elevated blood pressure documented in the medical record [2]. The consequences of untreated pediatric hypertension are startling; this chronic disorder is associated with increased risk of premature death. Additionally, overestimating blood pressure could lead to nearly 30 million Americans receiving inappropriate antihypertensive treatment each year [20].

Alternately, a study showed blood pressure measurement technique errors (e.g., when a patient's arm is placed too high or the cuff is too wide) that produce scores 5 mmHg too low in the range of 90-95 mmHg can overlook as many as 21 million people with hypertension in the United States each year of whom about 125,000 are likely to die over a six-year period [21]. However, if hypertension is adequately diagnosed and treated, an estimate of one death could be avoided for every 80 patients treated, and thus an equal number of fatal strokes also could be prevented [22].

Addressing the Problem

Providers' lack of knowledge regarding the NHBPEP guidelines and the complexity of variables contained in the guidelines contribute to inaccurate evaluation of pediatric blood pressure. Accurate blood

Equipment	Cuff Bladder Size Stethoscope Bell Versus Diaphragm Standard Mercury Sphygmomanometer Versus Automated Oscillometric Devices
Subject Factors	Activities Before and During Measurement Sex, Age and Height
Environmental Factors	Time of Day Surroundings Season and Temperature
Observer and / or Technique Factors	Standardization and Training Observer Biased Measurement of Diastolic Pressure
How Many Measurements to Take	Blood Pressure Variability Optimal Number of Measurements

Table 1: Factors Affecting Blood Pressure Measurement

pressure measurement is an exact process that requires careful attention and periodic retraining. The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC-7) and the American Heart Association (AHA) recommend that those responsible for measuring blood pressure should be trained and regularly retrained, and that all types of appropriate equipment should be regularly inspected and validated [23].

More specifically, the AHA recommends retraining and evaluation on blood pressure measurement technique every six months, including assessment of blood pressure measurement competency in the following areas: (a) knowledge of proper technique and different types of observer bias; (b) awareness of the need for properly maintained and calibrated equipment; (c) interpretation of measurements including an understanding of the variability of blood pressure depending on time of day, exercise, and timing of medications; and (d) demonstration of accurate technique of patient positioning, selection of cuff size, obtaining a valid blood pressure measurement, recording it accurately, and reporting abnormal results [24]. Because normal and abnormal blood pressure levels vary with gender, age, and height, the diagnosis of pediatric hypertension is complex. According to the National Heart, Lung, and Blood Institute (NHLBI) and the NHBPEP Working Group (2005) hypertension is defined as an average SBP and /or DBP that is greater than or equal to the 95th percentile for gender, age, and height on three or more occasions [16].

In 2005, the Working Group on High Blood Pressure in Children and Adolescents revised the standards for measurement of blood pressure in children and adolescents. The definition of hypertension cited above remained unchanged; however, blood pressure levels that are ≥ 90th percentile but < 95th percentile are now defined as “pre-hypertension.” The adult definition of pre-hypertension is used for adolescents because the 90th percentile for systolic blood pressure is >120 mmHg by age 12 years. Adolescents with blood pressure ≥ 120/80 mmHg, but < 95th percentile, have pre-hypertension. Additionally, the NHBPEP Fourth Report (2005) added a method for staging the severity of hypertension by providing the range of blood pressure elevation for both stage 1 and 2 hypertension. Stage 2 hypertension is generally ~ 12 mmHg or more above the 95th percentile and represents a level of blood pressure that should result in further evaluation within 1 week or immediately if the patient is symptomatic [16]. The NHBPEP Working Group made a number of additional recommendations:

- The onset of measurement of blood pressure is recommended at 3 years of age.
- The recommended method of blood pressure measurement is auscultation. Although oscillometric devices are convenient and frequently used as replacements for mercury manometers, these instruments do not provide measurements that are identical to auscultation. Blood pressure measurement should be with a standard clinical sphygmomanometer, using a stethoscope over the brachial artery pulse, proximal and medial to the cubital fossa, and below the bottom edge of the cuff. To better hear Korotkoff sounds, the bell of the stethoscope is recommended [2].
- Preparation of blood pressure measurement in children and adolescents can affect the blood pressure level just as much as technique. Prior to the measurement of blood pressure, children and adolescents should avoid stimulants, including certain food and drugs. They should be encouraged to sit quietly for 5 minutes, with their back supported, feet on the floor, right arm supported, and cubital fossa at heart level [26]. Due to the increased possibility of coarctation of the aorta, which may lead to false readings in the left arm, the right arm is preferred [27].
- Equipment of appropriate size should be used. Blood pressure measurements taken with a cuff that is too small may overestimate and measurements taken with a cuff that is too large may underestimate. To determine the appropriate cuff size, the cuff bladder should cover 80-100% of the circumference of the arm [28]. This requires the ratio for bladder width-to-length ratio be 1:2. Commercially available cuffs do not meet this standard and cuffs designed for certain age populations are constructed with widely disparate dimensions, thus the Working Group (2005) recommends that standard cuff dimensions for children be adopted. As a general rule, if a cuff size is too small, the next largest cuff size should be used, even if it appears too large [29].
- Adherence to clinical blood pressure standards is critical to accurately diagnose and treat hypertension. Due to the tendency of blood pressure measurements at high levels to decrease as a result of an accommodation effect (e.g., reduction of anxiety, and regression of the mean), it is important to confirm a diagnosis of hypertension by taking an average of multiple blood pressure measurements over weeks to months.

Conceptual Framework

In today’s rapidly changing healthcare system, ensuring patient safety and needs are at the forefront of the healthcare profession. Understanding the fundamentals of quality improvement is paramount to the implementation of evidence-based research. The aim of this project was to design and develop a Smartphone application with regard to Advanced Practice Registered Nurse (APRN) clinical services based on Donabedian’s structure-process-outcomes model for improving the quality of performing blood pressure measurement in children and adolescents [30].

The Donabedian conceptual model focuses on how quality and safety are inextricably linked to healthcare outcomes. According to Donabedian the definition of quality depends on whether one assesses only the performance of practitioners or also the contributions of patients and of the health care system. The Donabedian conceptual model suggests that quality of care can be divided by types of measurement into structure, process, and outcome (Figure 1); structure is defined as the environment in which healthcare is provided, process as the method by which healthcare is provided, and outcome as the consequence of the healthcare provided [30]. For example, structure

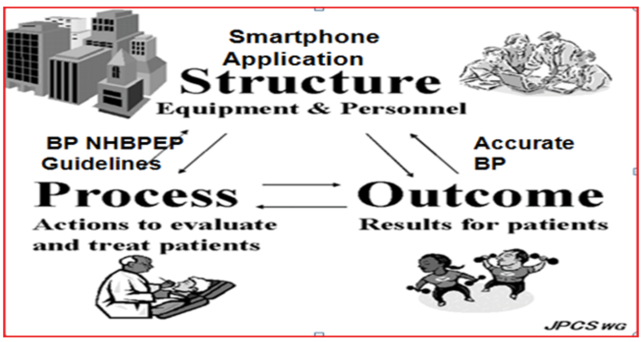

Figure 1: Donabedian’s model of quality assessment (1988). (Used with permission)

refers to whether a particular characteristic (e.g., an electronic health record) is present. Process refers to the way care is delivered, such as whether an aspirin was administered to a patient with a suspected myocardial infarction. Outcome refers to what actually happens, such as the mortality rate in myocardial infarctions. This approach suggests organizations should evaluate the care they deliver on an on-going basis, thus making small changes to improve their individual processes over time [6,31].

To improve quality of care and assist in simplifying the complexity of BP guidelines, the quality concepts of the Donabedian's model were adopted into the design of the Smartphone application. Any setting where blood pressures are taken and healthcare providers have access to Smartphones; healthcare providers should be equipped with the Smartphone application. The diligent utilization of the Smartphone application by healthcare providers can improve the detection and the outcome of an accurate blood pressure measurement in children and adolescents.

Method Setting, Design, and Instrument

In general, healthcare providers find the integration of Health Informatics Technology (HIT) into clinical practice critical period [32] with the complexity management required in healthcare, the role of technology is intuitively apparent. Unfortunately, to date, most information technology applications have centered on administrative and financial transactions rather than on the delivery of clinical care [33]. For this reason, easy to use Pedia BP was tested in a clinical usage study to measure the effectiveness and efficiency of the technology and delivery of patient care. Using Donabedian's model, the structure, process, and outcome of performing an accurate blood pressure measurement in children and adolescents was evaluated. A pilot study was conducted at the Farm Worker Family Health summer school program in Moultrie, Georgia in June of 2012. Prior to departure for the program, sixteen BSN students were oriented to the NHBPEP Guidelines, including the traditional blood pressure tables and navigation of the Pedia BP Smartphone application. The BSN students were randomly assigned in two groups; Group 1 was assigned to the traditional BP cards and Group 2 was assigned to easy-to-use Pedia BP. The BSN students assigned to the traditional blood pressure tables were given traditional blood pressure pocket cards and the students assigned to Pedia BP simply downloaded Pedia BP.com on their mobile devices (Figure 2). Pedia BP Smartphone application resides on the mobile device; therefore, Internet access is not needed and Pedia

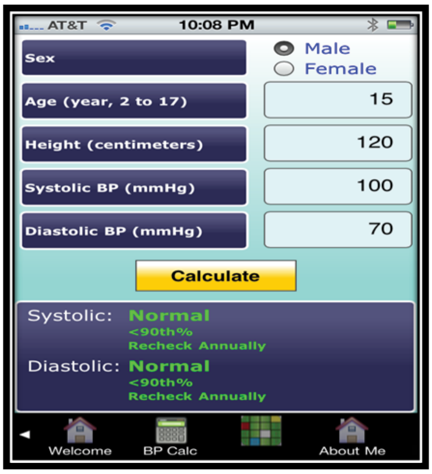

Figure 2: Pedia BP Smartphone Application

BP can be utilized in any setting. Examples of pediatric patients' vital signs were distributed for the BSN students to review and practice with both the blood pressure tables and Pedia BP. The blood pressure measurement percentiles results and the appropriate management recommendations were discussed. In addition, the importance of the order of the health screening clinical stations was reviewed; prior to the participant sitting for five minutes and the BSN students collecting the remaining variables needed; e.g., age, gender, and systolic and diastolic blood pressure measurement, the BSN students would first need to obtain the height percentile in centimeters. Group 1 would measure the participant height and use the standard CDC height charts to determine the height percentile. Group 2 would measure the participant height in centimeters and submit in Pedia BP. Pedia BP would then auto-convert the height in centimeters to height percentile. After the percentile was determined, the students in Group 1 would need to refer to the NHBPEP Guidelines for diagnosis and appropriate management. For Group 2, Pedia BP students would press calculate and the blood pressure percentile, the diagnosis and appropriate practice guidelines would auto-populate.

During the two-week summer immersion course, from the 2012 Farm Worker Family Health summer school program blood pressures were measured on two hundred and thirty students, ages 3 to 17 whose parents had given written permission for their children to have a health screen. Prior to each blood pressure measurement, the child's age, gender, and vital signs (excluding B/P), were collected and the pediatric blood pressure measurement recommendations were reviewed. To evaluate the efficiency of Pedia BP, a stop clock was used to assess how long it took to calculate a blood pressure measurement with Pedia BP and the traditional blood pressure tables. To test the traditional blood pressure tables each group performed the following steps:

Group 1: Traditional Blood Pressure Charts

1. The stop clock was started when the age, gender, height percentile, and systolic/diastolic BP were being plotted on the traditional B/P tables.

2. The blood pressure measurement percentile was identified.

3. The stop clock was stopped.

4. The time was recorded.

Group 2: Pedia BP

1. The stop clock was started when age, gender, height, and systolic/diastolic BP were being entered into the Pedia BP application period

2. Blood pressure measurement percentile and practice guideline recommendations auto-populated period

3. The stop clock was stopped when the blood pressure measurement percentile was identified period

4. The time was recorded.

For quality improvement, the BSN students were asked to submit suggestions to improve the Pedia BP application. The suggestion to add an auto-clear button was offered and this option was added to Pedia BP.

Data collection

Data collection took place during the two-week immersion course. The time calculation for Pedia BP was compared to the time calculation for the traditional B/P tables. The student suggestions were collected and listed. We used a general linear model to examine the relationship

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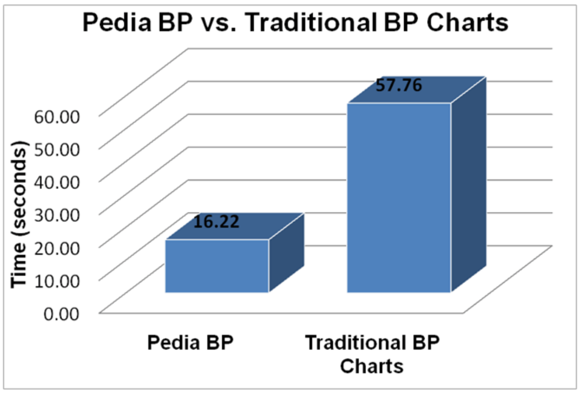

Figure 3: Differences in time between Pedia BP and Traditional BP Charts in taking an accurate BP measurement in children and adolescents

between the type of assessment protocol (phone application versus chart) used and the amount of time required for classification. Patient gender was also included as an independent variable. The age and body mass index of the patient as covariates were also included.

Results and Discussion

Due to the incomplete collection of the independent variables, a total of 203 of the 230 Hispanic children, ages 3 to 14, were included in the study. An independent samples t-test was conducted to compare the time to perform an accurate B/P measurement on children and adolescents. The mean amount of time observed for classification was significantly less for the Pedia BP intervention group ($\overline{x}=16.0$)) than the control group ($\overline{x}=58.0$) ($P \leq .05$). Covariates appearing in the model were evaluated at the following values: Age = 7.0, BMI = 19.2. Approximately, 9% (R^2=. 087) of the total variance in classification time was explained by the protocol used.

The mean amount of time was significantly less with Pedia BP compared to the traditional B/P tables, taking about a third of the time to take an accurate blood pressure measurement saving thousands of dollars in staff salary (Figure 3). These results suggest the implementation of health informatics technology in the delivery of patient care significantly affects the quality of care, health care safety, and provides cost effective health services.

Conclusion

The concept of technology and direct patient care, Smartphone applications in clinical practice, is promising in terms of assisting health care providers to improve time, accuracy, and task management. It allows them to remotely monitor, diagnose and treat a greater number of patients effectively, while giving healthcare providers the ability to quickly shift their attention from one case to another. For consistent patient-centered healthcare, Pedia BP offers healthcare providers an avenue for increased mobility, saving time and money, thus improving the pediatric patient quality of care in delivering an accurate BP measurement in a timely manner. As a result, pediatric hypertension will be accurately diagnosed and long-term complications related to untreated pediatric hypertension will decrease.

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