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ORIGINAL ARTICLE

Comparison of percentile tables and algorithm-based calculators for classification of blood pressures in children and adolescents with obesity: A secondary analysis of a clinical trial

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Aim: Obesity as a major risk factor for childhood hypertension necessitates careful blood pressure (BP) monitoring of those affected. This study aimed to compare BP classification in a cohort of children affected by obesity using tables versus digital calculations in two sets of guidelines.

Methods: This study was a secondary analysis of data collected from a randomised clinical trial of a multidisciplinary life-style assessment and intervention program. Baseline data from 237 children with a body mass index >99th percentile or >91st percentile with weight-related comorbidities and available BP measurements were analysed. We assessed agreement between tables and algorithms in classification of elevated BP/pre-hypertension and hypertension based on the American Academy of Paediatrics (AAP) clinical practice guidelines (CPG) and the older Fourth Report using Cohen's weighted kappa. The prevalence of hypertensive diagnoses was also compared between the two guidelines.

Results: Agreement between BP tables and algorithmic calculation of percentiles was discordant, though improved in the AAP CPG compared to the Fourth Report (Cohen's kappa = 0.70 vs. 0.57, respectively). None (0%) were missed diagnoses, and 59 (24.9%) were false positives for the Fourth Report, and 0 (0%) were missed diagnoses, and 49 (20.9%) were false positives for the AAP CPG. Under the recent guidelines, there was an increase in prevalence of 6.0% (95% confidence interval (CI) 2.5–9.4%; $P = 0.0001$) for BP ≥90th percentile, and of 3.0% (95% CI 0.4–5.6%; $p = 0.016$) for hypertension (BP ≥ 95th percentile) in the cohort (18.0% and 6.8%, respectively, increased from 12.0% and 3.8%).

Conclusions: Digital calculators over tables in clinical practice are recommended where possible to improve the accuracy of paediatric BP classification. Substantial rates of elevated BP/Hypertension were found in this cohort of children and adolescents with overweight and obesity.

Key words: adolescent; blood pressure; hypertension; normative blood pressure tables; obesity; paediatric.

What is already known on this topic

1 New guidelines for paediatric blood pressure categorisation include an algorithm as well as the widely used percentile tables
2 Percentiletables may overestimate hypertension compared to algorithms

What this paper adds

1 Agreement between tables and algorithms is improved with contemporary paediatric hypertension guidelines
2 Use of tables compared to algorithms to categorise hypertension in children with obesity results in false positives and algorithm-based calculators should be used where clinically feasible

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Characterisation of blood pressure (BP) in children is an important part of a visit to a healthcare provider, as increasing numbers of children and adolescents experience hypertension and other weight-related comorbidities.[1,2] Childhood cardiovascular risk factors (including systolic BP) are linked to adult cardiovascular events.[3] Early detection and treatment of hypertension can reduce and even reverse end-organ damage, and lowers the risk for cardiovascular disease in adulthood.[2,4] As well as potential effects on an individual's long-term health, misclassification of hypertensive status has implications for resource allocation for further diagnostic testing, review and treatment.

In 2004, the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents (Fourth Report) updated guidelines for screening and management of hypertension using revised normative data.[4] The report provided tables for categorising BP percentiles in clinical practice.

In 2017, the American Academy of Paediatrics released the Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents (AAP CPG),[2] an update of the Fourth Report aiming to resolve issues with its predecessor. Importantly, the AAP CPG excluded individuals with body mass index (BMI) ≥85th percentile from normative data to avoid potential bias due to the association of overweight and obesity with elevated BP/hypertension. The result is a lower threshold for elevated BP than in the Fourth Report tables.

Simplified tables for establishing BP percentile were reported to overestimate hypertension in a large cohort of Greek children,[5] but these tables are widely used in clinical practice. As well as percentile tables, the AAP CPG also released links to an application for percentile calculation, modelling the normative data.[2] Similarly, an algorithm-based calculator from the Baylor College of Medicine's USDA/ARS Children's Nutrition Research Center was developed using coefficients supplied in the Fourth Report (Baylor algorithm).[6] These algorithms may be of greater clinical value when compared to simplified tables.

The detection of elevated BP and hypertension is critical when screening for weight-related comorbidities in children and youth.[2] Whānau Pakari is an assessment and intervention program for children and adolescents with obesity with a randomised controlled trial (RCT) embedded in a clinical service in Taranaki, Aotearoa/New Zealand (henceforth referred to as NZ). Health assessments for participants included manual measurement of BP.[7] Hypertension was initially characterised using reference tables adapted from the Fourth Report to determine BP percentiles (which was best practice at the time of the RCT); however, concerns about rounding errors led to use of the Baylor algorithm based on the Fourth Report instead.

With lack of agreement between traditional percentile charts and algorithm-based calculators, alongside increased availability and acceptance of digital technology in clinical medicine, it is important to understand how these tools may affect hypertensive diagnoses in children affected by obesity. Therefore, the objectives of this study were to compare the algorithms based on Fourth Report and AAP CPG with one another and with their respective percentile charts for describing pre-hypertension/elevated BP and hypertension prevalence in the Whānau Pakari cohort.

Methods

The Whānau Pakari trial has been described in prior publications.[7,8] In brief, it was an unblinded RCT comparing a low-intensity 'control' group (comprehensive medical, dietary, physical and psychological assessment in the home with advice) with a high-intensity intervention group (same assessment/advice model and weekly multidisciplinary group sessions).[7] This secondary analysis focuses on the results of the baseline assessment relating to BP.

Ethics approval for the overall trial was granted by the NZ Health and Disability Ethics Committee (CEN/11/09/054). Written and verbal informed consents were obtained from all participants or their guardians. The trial was registered with the Australian NZ Clinical Trials Registry (ANZCTR: 12611000862943).

Participants

Eligible participants were between 5 and 16 years old and had a BMI >98th percentile or >91st percentile with weight-related comorbidities and available BP measurements. Recruitment was from January 2012 to August 2014. Participants were residents of Taranaki, a mixed urban/rural region of NZ.[7,8]

For analysis involving the AAP CPG Statistical Analysis Software (SAS) file, participants with height >99.9th or <0.01th percentile for gender and age did not have their BP percentile calculated and were excluded.

Data

Assessments were undertaken by a Healthy Lifestyles Coordinator (HLC) at home visits, who was trained in BP measurement by the paediatrician overseeing the study.

Relevant demographic data collected during the baseline visit included participant age at assessment, gender, ethnicity, and household deprivation index.[9] Weight, height and BPs of participants were obtained from trial data.[7]

Measures

BMI standard deviation score (SDS) was calculated using UK Cole normative data and KIGS auxology software (Pfizer Endocrine Care).[10] BPs were measured using a Welch Allyn DS66 Aneroid Sphygmomanometer, repeated two times, with the lowest value recorded.[11]

BP percentiles were calculated from raw data in four ways: using adapted Fourth Report charts by Starship Children's Hospital (Fourth Report charts),[4,12] using an algorithmic calculator based on the Fourth Report data (Baylor algorithm),[6] using charts supplied from the AAP CPG (AAP CPG charts)[2] and using an algorithm from the AAP CPG (AAP CPG SAS file). BP <90th percentile was categorised as 'normotensive', BP 90th–94th percentile as 'pre-hypertension' (Fourth Report) or 'elevated BP' (AAP CPG), and BP ≥ 95th percentile as 'hypertension'. For adolescents, pre-hypertension was defined as BP ≥ 120/80 mmHg to <95th percentile, or ≥90th and <95th percentile, whichever was lower, and hypertension as systolic BP and/or diastolic BP ≥ 95th percentile (Fourth Report), and ≥13 years elevated BP 120/<80 to 129/<80, and hypertension ≥130/80 in line with both sets of guidelines respectively.[2,4]

Outcome measures

The primary outcome was agreement between chart-based and algorithmic-based methods of calculating BP percentiles and definition categories, both for the Fourth report guidelines and the AAP CPG 2017 guidelines. The secondary outcome was agreement between the two sets of guidelines.

Data analyses

Agreement and discordance of BP classifications between chart- and algorithm-based methods were calculated using Cohen's weighted kappa statistic and 95% confidence interval (CI).[13] Cohen's kappa can take values between 0 (no agreement between the two methods) and 1 (perfect agreement).

To assess whether there were differences in characterisation of BP between the two guidelines, we compared the proportion of children classified as having BP outside the normotensive range (i.e., 'elevated BP/pre-hypertension' or 'hypertension') under the two guidelines using McNemar's paired exact test. We then similarly compared the proportion classified as 'hypertensive' between the two guidelines.

A one-sample chi-squared goodness of fit test was used to compare the observed and expected numbers (under chance, i.e., equal numbers) of children in each of the deprivation quintiles. All analyses were undertaken in Stata v15.[14]

Results

Of the 239 children who were referred and assessed, a total of 237 children and adolescents had available BP data and were included in analyses. Using AAP CPG SAS files, individuals considered to be height outliers (according to their age and sex) were excluded ($n = 3$), resulting in an $n = 234$ for comparison of the SAS file with AAP CPG charts, and any other use of SAS file data. Participants had a mean BMI SDS of 3.08 (Table 1).

Table 1 Characteristics of participants at baseline†

Characteristic	Total ($n = 237$)
Female, *n* (%)	125 (52.7)
Age in years, mean (s.d.)	10.7 (3.2)
BMI SDS, mean (s.d.)	3.08 (0.59)
Ethnicity,‡ *n* (%)	
Māori	108 (45.6)
Pacific	6 (2.5)
European	114 (48.1)
Asian	9 (3.7)
Deprivation quintiles,§ *n* (%)	
1 (least)	23 (9.7)
2	38 (16.0)
3	47 (19.8)
4	60 (25.3)
5 (most)	69 (29.1)

† Data collection for baseline from January 2012 to August 2014.
‡ Prioritised ethnic group. § Quintiles of level of household deprivation based on the New Zealand Deprivation Index 2006.[9] BMI, body mass index; SDS, standard deviation score.

Demographics

Table 1 outlines the demographic characteristics of participants. The cohort had strong representation in terms of those participants identifying as Māori, and those residing in areas of high socioeconomic disadvantage.[8] The one-sample chi-squared goodness of fit test evidenced that frequencies were not equally distributed across the deprivation quintiles ($\chi2(4) = 27.6$, $P < 0.001$). This indicates a downward skew of representation from the most deprived quintiles.

Table 2 demonstrates the variation in the prevalence of hypertension classifications when comparing the use of percentile charts and algorithms for the Fourth Report and the AAP CPG 2017 guidelines. Systolic pre-/hypertension accounted for 59% ($n = 46$) and diastolic pre-/hypertension for 76% ($n = 59$) using the Fourth Report charts, and systolic and diastolic early/hypertension 55% ($n = 4$) and 75% ($n = 63$) for the AAP CPG 2017 charts, respectively.

Systolic pre-/hypertension accounted for 62% ($n = 18$) and diastolic hypertension for 55% ($n = 16$) using the Fourth Report algorithms, and systolic and diastolic early/hypertension 57% ($n = 24$) and 55% ($n = 23$) for the AAP CPG 2017 algorithms, respectively. $N = 3$ children would have missed results without applying the ≥13 years adjustment in the AAP CPG charts.

Original classification of BP

Under the Fourth Report classification of pre-hypertension and hypertension comparing adapted Fourth Report charts and the Baylor algorithm, there were 24.9% ($n = 59$) discordant classifications and 75.1% ($n = 178$) classifications in agreement. Cohen's weighted kappa of 0.57 (95% CI 0.46–0.68, $P < 0.0001$) indicated fair agreement between the Fourth Report charts and Baylor algorithm based on the same guidelines.

AAP clinical practice guideline classification of BP

Using the AAP CPG classification of elevated BP and hypertension comparing report charts and algorithm, there were 20.9% ($n = 49$) discordant classifications, and 79.1% ($n = 185$) classifications in agreement. Cohen's weighted kappa of 0.70 (95% CI 0.61–0.79, $p < 0.0001$) indicated moderate – substantial agreement between the AAP CPG charts and the AAP CPG SAS file.

Comparing the two sets of guidelines, there was an increase of 6.0% (95% CI 2.5–9.4%; $P = 0.0001$) in the prevalence of pre-hypertension/elevated BP or hypertension, when the AAP CPG SAS file (18.0%) was used instead of the Baylor algorithm (12.0%). There was an increase of 3.0% (95% CI 0.4–5.6%; $P = 0.016$) in the prevalence of hypertension when applying the AAP CPG SAS file (6.8%) instead of the Baylor algorithm (3.8%).

Discussion

This study found that when assessing BP classification methods in a cohort of children/adolescents with obesity, there was better agreement between AAP CPG charts and accompanying

Table 2 Prevalence of pre-hypertension/elevated BP and hypertension in the Whānau Pakari cohort; a comparison of definitions using percentile charts and algorithms

	Baylor algorithm			
Fourth report charts	Normotensive (%)	Pre-hypertension (%)	Hypertension (%)	*Total*
Normotensive	159 (10.00)	0 (0.00)	0 (0.00)	*159*
Pre-hypertension	49 (83.05)	10 (16.95)	0 (0.00)	*59*
Hypertension	0 (0.00)	10 (52.63)	9 (47.37)	*19*
Total	*208 (87.76)*	*20 (8.44)*	*9 (3.80)*	*237*
	AAP CPG SAS file			
AAP CPG charts	Normotensive (%)	Elevated BP (%)	Hypertension (%)	*Total*
Normotensive	150 (100.00)	0 (0.00)	0 (0.00)	*150*
Elevated BP	42 (68.85)	19 (31.15)	0 (0.00)	*61*
Hypertension	0 (0.00)	7 (30.43)	16 (69.57)	*23*
Total	*192 (82.05)*	*26 (11.11)*	*16 (6.84)*	*234*

AAP, American Academy of Pediatrics; BP, blood pressure; CPG, clinical practice guidelines.

algorithms than between the adapted Fourth Report charts and a Baylor calculator algorithm. This was expected due to the use of a polynomial regression model with the Fourth Report, but a more sophisticated model in the AAP CPG, utilising polynomial regression, restricted cubic spline and quantile regression.[2,4]

Despite Cohen's kappa statistic representing the substantial agreement between the AAP CPG chart and algorithm based on Cohen's original interpretation, it has been noted that this interpretation is arbitrary[15] and likely too lenient to be applied in health settings.[16] Indeed, one in five Whānau Pakari participants had discordant classifications between the two methods. Alternative interpretations suggest that any value below 0.60 represents inadequate agreement between two raters or measurements, and that only values above 0.80 should be considered strong agreement.[16] Based on this interpretation, the tables used in the AAP CPG have 'moderate' agreement with the algorithm (Cohen's kappa = 0.70), and it is therefore recommended that algorithm calculations in digital applications are the preferred method of calculating BP in clinical practice where possible. Given improvements in technology, incorporation of updated algorithms into medical records software and/or standalone devices is becoming more realistic and obviates the use of simple tables in many more clinical settings. Simplified tables based on the Forth Report used in this study have 'weak' agreement with the Baylor algorithm and thus are less optimal for classification of BP in children and youth (Cohen's kappa = 0.57).

In this study, one in three children classified as having elevated BP or hypertension using the newer AAP CPG guidelines were 'normotensive' according to Fourth Report guidelines (18.0% vs. 12.0%, $P = 0.0001$). Especially in the context of our cohort with obesity or obesity with weight-related comorbidities, this increase in diagnosis creates an opportunity to monitor BP over time and reiterate the importance of healthy lifestyle change. Similarly to our findings, a large study of the NHANES data set found an increase in the prevalence of elevated BP from 11.8% to 14.2% using the AAP CPG guidelines, with 5.8% of participants now classed in a more at-risk group compared to Fourth Report classification.[17] This change was likely due to the exclusion of children/adolescents with a BMI ≥ 85th percentile in the AAP CPG charts, resulting in an overall increase in hypertension prevalence. That study noted that children who shifted risk groups had 'clustering' of cardiovascular risk factors, meaning their risk may have been underestimated under old guidelines.[17,18]

A strength of this study was that BPs were measured in the home, therefore white coat hypertension due to the office or clinical environment was minimised, though not necessarily eliminated.[2] This study used adapted Fourth Report charts that had fewer height percentile columns and removed even-age values after 6 years, which may have increased disagreement between the Fourth Report chart and algorithm. However, these charts were in clinical use at the time so they reflect real-world use of the guidelines. In this study, it was not possible to establish the presence or absence of end-organ damage, with only health indicators available. This was due to the 'real-world' nature of the clinical service; investigations such as echocardiography and plasma urate were not undertaken on all participants. Therefore, it remains unclear how much medical management will be necessary from the prevalence of elevated BP or hypertension in this cohort over time. Whether our findings are generalisable to those identified as having a healthy weight is unclear. One may hypothesise that there would be fewer cases of hypertension and therefore lower borderline cases, that is, the number of Type 1 and Type 2 errors would most likely be different. However, for a specific missed diagnosis, the relevant numbers are BP, height and age. Whilst obesity drives growth and makes a child taller for any given age compared to genetic height potential, it is unclear how this contributes to hypertensive risk.

Casual BP measurement and interpretation can be more difficult in a child, due to acceptance of the investigation, and dependence on accompanying age and height information.[2] Which children should be screened for hypertension remains controversial, with many advocating for a targeted approach.[19] However, the AAP CPG recommends that all children from the age of 3 have their BP measured opportunistically and at regular check-ups.[2] The high

prevalence of elevated BP or hypertension in this cohort indicates that regular BP measurement is warranted in children and youth with BMI above the overweight or obesity cutoffs. Tables designed to interpret this information provide a moderate fit to actual cutoffs, with a reasonably high chance of discordant classifications. Along with the increasing availability of integration of BP classification into electronic health records, our findings support a shift away from table usage. A recent study also showed significant improvements in hypertension recognition and better guideline adherence when algorithms within a clinical decision support tool are used.[2,20] Since guideline release, two online calculators are available for determining the significance of BP readings; an updated Baylor algorithm and one reported within the AAP CPG.[21,22]

In conclusion, this study supports consideration of the use of digital assessment for classifying BPs where clinically possible, due to their improved accuracy over tables. Options are the use of the AAP CPG calculator, or other clinical decision support tools. This study also confirms the improved agreement in BP classification using the AAP CPG. Multidisciplinary assessment and intervention healthy lifestyle programmes that can screen for and address weight-related comorbidities in children and adolescents are urgently required to try to reduce long-term morbidity, and specifically the potential health burden of weight-related hypertension.

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