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Investigating Factors Associated with Raised Blood Pressure in New Zealand School Children

A thesis presented in partial fulfilment of the requirements for the degree of

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Abstract

Background: Childhood hypertension is associated with an increased risk of target organ damage and adulthood hypertension. Over the last few years, the prevalence of paediatric primary hypertension has been growing. A better understanding of the risk factors associated with high blood pressure could facilitate early detection and intervention. To date, no studies in New Zealand have investigated high blood pressure in the paediatric population.

Aim: The aim of this study was to investigate risk factors for raised blood pressure in year five and six primary school children, living in Auckland, New Zealand.

Methods: We examined cross-sectional data for school children participating in The Children's Bone Study. Anthropometric measures included weight, height, BMI, waist circumference and percent body fat. Blood pressure was measured on a single occasion, and the average of three readings was used for analysis. Elevated blood pressure and hypertension were defined according to the American Academy of Pediatrics' criteria. Demographic information was collected using a questionnaire. Logistic regressions were used to examine the associations between gender, ethnicity and obesity with raised blood pressure (≥ 90 th percentile).

Results: The proportion of children ($n=669$, 10.4 ± 0.62 years) with elevated and hypertensive blood pressure readings were 14.3% and 31.1%, respectively. Age and gender were not significantly associated with raised blood pressure ($p=0.485$; $p=0.109$, respectively). South Asian children had significantly greater odds of presenting with raised blood pressure compared to European (OR: 1.65, 95% CI: 1.02—2.65, $p<0.05$). The adjusted odds of screening with raised blood pressure were significantly greater for children with an obese (OR: 2.88, 95% CI: 1.65—5.01, $p<0.001$) and overweight (OR: 2.43, 95% CI: 1.54—3.84, $p<0.001$) BMI than non-overweight children. Percent body fat above the normal range (OR: 2.16, 95% CI: 1.51—3.09, $p<0.001$) and a waist-to-height ratio ≥ 0.5 (OR: 2.60, 95% CI: 1.60—4.22, $p<0.001$) were associated with increased odds of raised blood pressure readings, irrespective of age, gender and ethnicity.

Conclusion: Ethnicity, and general and central obesity appear to be key risk factors for raised blood pressure in children. Although blood pressure was only measured on a single occasion, the results suggest that paediatric hypertension may be a potential health concern for New Zealand. Further research is needed to establish a more accurate picture of the situation and allow for New Zealand specific guidelines to be formulated.

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Dedication

I would like to dedicate this thesis to my best friend, Frankie. Unfortunately, you didn't get to see me finish my studies, but the beautiful time we spent together continued to motivate me every step of the way. You will always hold the most special place in my heart.

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List of Abbreviations

AAP	American Academy of Pediatrics
ANOVA	Analysis of variance
BIA	Bioelectrical Impedance Analysis
BP	Blood pressure
BF	Body fat
BMI	Body mass index
CV	Cardiovascular
CVD	Cardiovascular disease
cIMT	Carotid intima-media thickness
DBP	Diastolic blood pressure
DASH	Dietary Approaches to Stop Hypertension
DEXA	Dual-energy X-ray absorptiometry
IOTF	International Obesity TaskForce
LVH	Left ventricular hypertrophy
MAP	Mean arterial blood pressure
NHANES	National Health and Nutrition Examination Survey
OR	Odds ratio
%BF	Percent body fat
SD	Standard deviation

SBP	Systolic blood pressure
TOD	Target organ damage
UK	United Kingdom
U.S.	United States
WC	Waist circumference
WHtR	Waist-to-height ratio

Chapter 1 Introduction and Scope

1.1 Background

Cardiovascular disease (CVD) is the second most common cause of death in New Zealand (Ministry of Health, 2018c) and primary cause of adult mortality worldwide (World Health Organization, 2018a). High blood pressure (BP) in adults is a major risk factor for CVD, alongside obesity, poor dietary habits, tobacco use and physical inactivity (Benjamin et al., 2018). Recent evidence suggests that the development of adulthood hypertension and related risk factors may begin as early as childhood (Muntner et al., 2004; Chen and Wang, 2008; Theodore et al., 2015). In this context, the early identification of those at risk is pivotal to the introduction of strategies that may reduce or prevent high BP tracking into adulthood (Theodore et al., 2015).

In children, the terms elevated BP and hypertension describe BP levels above the normal range (Flynn et al., 2017). International guidelines define elevated BP in children as systolic blood pressure (SBP) or diastolic blood pressure (DBP) $\geq 90^{\text{th}}$ to $<95^{\text{th}}$ percentile, and continue to classify hypertension as SBP or DBP $\geq 95^{\text{th}}$ percentile for sex, age and height on three or more occasions (Flynn et al., 2017; Lurbe et al., 2016).

Raised BP in childhood has been associated with several health problems, including target organ damage (TOD) and blood vessel changes which could increase the likelihood of cardiovascular (CV) complications in adulthood (Litwin et al., 2010; Urbina et al., 2011; Kollias et al., 2014). In addition, findings from tracking studies suggest that high BP in childhood is correlated with high BP in later life and may predispose to hypertension in adulthood without early detection and management (Chen and Wang, 2008; Theodore et al., 2015).

Previously, high BP in childhood was thought to be relatively uncommon and if present, was normally secondary to other conditions. However, over the last several years, essential hypertension has become increasingly recognised among youth due to better practice guidelines and a rise in poor lifestyle habits (Rosner et al., 2013; Gupta-Malhotra et al., 2015; Baracco et al., 2012).

The worldwide prevalence of high BP in children is difficult to determine as normative values

are not representative of all populations and findings are inconsistent (Karatzi et al., 2017; Lurbe et al., 2016). Studies reporting on measurements from a single screening, estimate that the observed prevalence of elevated BP ranges between 9% and 23% (Kit et al., 2015; Haas et al., 2014; Karatzi et al., 2017; Maldonado et al., 2011), whilst the rate of hypertension is around 1 to 12.8% (Kit et al., 2015; Maldonado et al., 2011). However, studies in which BP is measured on separate occasions, report that the prevalence of elevated BP in children is around 2% to 12% (Hansen et al., 2007; Lo et al., 2013) and the prevalence of hypertension ranges between 0.3% and 4.5% (Hansen et al., 2007; Lo et al., 2013; Sorof et al., 2004). The prevalence of high BP is also significantly higher among overweight and obese youth than those with a normal body mass index (BMI) (Haas et al., 2014; Genovesi et al., 2008; Rosner et al., 2013).

In New Zealand, findings from national health surveys based on single BP screenings suggest that 22% of participants over the age of 15 had high BP, with a higher prevalence among low socioeconomic groups (Ministry of Health, 2017c). To the best of our knowledge, no data exists describing the prevalence of elevated BP or hypertension in New Zealand children.

Less is known about the aetiology of high BP in children than in adults. In the absence of arterial ageing and other comorbidities common in adulthood, high BP in youth may develop due to hereditary, behavioural and environmental influences (Falkner, 2010; Kapur and Mattoo, 2018). Over the years, researchers have identified a range of modifiable and non-modifiable factors associated with childhood hypertension, including obesity (Friedemann et al., 2012; Kelishadi et al., 2015), non-ideal dietary habits (Moore et al., 2012; Leyvraz et al., 2018), family history (Juhola et al., 2012), gender (Rosner et al., 2013) and ethnicity (Rosner et al., 2013).

The association between obesity and high BP in youth has been well described. Findings from cross-sectional and longitudinal studies show that childhood hypertension risk may increase with increasing BMI (Friedemann et al., 2012), waist-to-height ratio (WHtR) and percent body fat (%BF) (Kelishadi et al., 2015). However, more research is required to confirm this association and determine the most reliable and practical measures for use in the healthcare setting.

Several studies have reported higher BP levels and hypertension rates among boys than girls

(Sorof et al., 2004; Rosner et al., 2013; Davis et al., 2005). However, findings are inconsistent (Genovesi et al., 2005; Steinthorsdottir et al., 2011; Schwandt et al., 2015; Karatzi et al., 2017) and evidence exclusive to primary school-aged children is limited as the majority of these studies include participants from a wide range of ages.

Cross-sectional data from the United States (U.S.) also suggests that elevated BP and hypertension rates may be higher among African American and Hispanic children than Caucasian (Rosner et al., 2013; Rosner et al., 2009; Cheung et al., 2017; Lo et al., 2013). Yet, others have failed to detect any ethnic differences, particularly after adjusting for potential confounding factors (Rosner et al., 2000; Sorof et al., 2004; McNiece et al., 2007b). In New Zealand, findings in adults also show higher rates of raised BP and other non-communicable diseases among ethnic minorities, in particular Maori and Pacific Island groups (Ministry of Health, 2017c; Ministry of Health, 2017a). National data in children is severely lacking, however, BP trends may be similar to that of adults since factors known to influence hypertension risk, such as obesity (Ministry of Health, 2017b), poor dietary habits (Ministry of Health, 2016a; Ministry of Health, 2003) and poverty (Duncanson et al., 2017) are identified as being consistently higher among Maori and Pacific Island children than European.

The most recent clinical guidelines state that BP should be measured annually in healthy children beginning at the age of three (Flynn et al., 2017). This recommendation is given on the basis that early lifestyle modifications and medical treatment are likely to be more effective in reducing poor health outcomes than if introduced later in life (Flynn et al., 2017). Despite this, BP examinations are rarely conducted in healthy children (Stabouli et al., 2015; Daley et al., 2013; Brady et al., 2010b). This is mainly because the incidence of hypertension in youth is often underappreciated and overshadowed by the emphasis surrounding high BP in adulthood (Muhihi et al., 2018).

Currently, raised BP in New Zealand children is under recognised (Crossen, 2017). Understanding the factors associated with raised BP may support the development of New Zealand based clinical guidelines that reinforce standardised screening and monitoring among high risk groups. Furthermore, investigating these predictors may provide direction for public health prevention efforts and risk-based interventions (Flynn et al., 2017). Overall, this has the potential to reduce the prevalence of paediatric hypertension and mitigate the tracking of

high BP to adulthood (Theodore et al., 2015). Given the benefits of early detection, discrepancies in existing research and lack of New Zealand based evidence, further research is warranted.

1.2 Purpose of the Study

The proposed study will be the first one of its kind to explore childhood risk factors associated with raised BP in a regionally representative sample of year five and six primary school children living in Auckland. These risk factors include gender, ethnicity, and general and central obesity. The study will also be the first in New Zealand to describe BP in children in terms of BP categories (normal, elevated BP and hypertensive).

Key findings extrapolated from this study may instigate further research into the field of paediatric hypertension. In turn, this may help to determine the extent of the problem and generate evidence that contributes towards better BP screening practices in healthcare settings in the future. As raised BP is a progressive condition with many serious complications if not managed, early detection could allow for timely interventions to be initiated which, if effective, could reduce the likelihood of poor health outcomes associated with childhood hypertension.

1.3 Aims and Objectives

1.3.1 Aims

To investigate risk factors associated with raised BP in year five and six primary school children living in Auckland.

1.3.2 Objectives

1. To describe the BP of a group of year five and six primary school children using the classification scheme from the Clinical Practice Guidelines for Screening and Management of High Blood Pressure in Children and Adolescents (Flynn and Alderman, 2005).
2. To investigate the relationships between raised BP and known risk factors including gender, ethnicity, and increased BMI, %BF and central obesity.

1.4 Structure of the Thesis

This thesis is structured into four chapters. Chapter one introduces the study and justifies the importance of the research. In addition, this chapter describes the study aims, objectives and researchers' contributions. Chapter two is a review of the literature covering the key concepts related to high BP in children, including background of BP, BP classification, high BP prevalence, health implications, risk factors and management. Chapter three presents a research manuscript, composed of an abstract, introduction, methods, results, discussion and conclusion of the present study. The manuscript was written according to the author guidelines for submission to The New Zealand Medical Journal. Chapter four draws conclusions based on the main findings, reflects on the limitations and strengths of the research and provides recommendations for future studies. The referencing format (Harvard) was kept consistent throughout the thesis.

1.5 Researchers' Contribution

Table 1.1 Researchers' Contribution to the Thesis

Researchers	Contribution to Thesis
Maria David MSc Nutrition and Dietetic Student	Author of this thesis. Participated in data collection and responsible for the literature review, statistical analysis and preparing the manuscript.
Dr Pamela von Hurst Academic Supervisor	Primary investigator of The Children's Bone Study. Involved with arranging the study team, developing the ethics application, study design, funding application, liaising with stakeholders, development of questionnaires and data collection. Supervised entire thesis process, provided support and feedback on thesis chapters and approved final submission.
Dr Cheryl Gammon Academic Supervisor	Co-investigator in The Children's Bone Study. Involved in the extended study design and data collection. Provided supervision throughout the research process, feedback on all thesis chapters and support with statistical analysis.
Owen Mugridge Research Manager	Coordination of resources, data collection, team training and database preparation.
Hajar Mazahery PhD Student	Provided guidance and assistance with data analyses and results chapter.
The following individuals also contributed to The Children's Bone Study; Co-investigators: Dr Cath Conlon, Dr Kathryn Beck, Professor Marlena Kruger; Assistants: Alex Tava, David Alsford, Donna Lawgun, Emma Smirk, Emma Ternouth, Jasmine Foote, Maryam Delshad, PC Tong, Sanaz Naghizadeh, Tara Lemmon.	

Chapter 2 Literature Review

2.1 Blood Pressure

The term BP describes the force exerted by circulating blood against the walls of blood vessels (Chiras, 2011). In general terms, it refers to the pressure of blood on the inner arterial walls. The pressure fluctuations occurring in the arteries are merely a reflection of the different phases of the cardiac cycle (Chiras, 2011).

During left ventricular contraction, arterial BP reaches maximum. This is known as SBP (Chiras, 2011). The term DBP describes the minimum pressure in the arteries between two consecutive heart beats (Chiras, 2011). Blood pressure is presented as a ratio of systolic pressure over diastolic pressure measured in millimetres of mercury (mmHg) (Chiras, 2011).

Arterial pressure is dependent on cardiac output and peripheral resistance (Chiras, 2011). Cardiovascular control systems maintain BP within a narrow range to support optimal tissue perfusion by regulating these two variables (Chiras, 2011). Cardiac output is affected by stroke volume and heart rate, and ultimately describes the volume of blood ejected from the left ventricle every minute (Chiras, 2011). The resistance of the arteries to blood flow is known as peripheral resistance. This is determined by blood viscosity, and the diameter and length of blood vessels (Chiras, 2011). Consequently, arterial pressure is indirectly influenced by blood volume, stroke volume, heart rate, vessel diameter and blood viscosity (Chiras, 2011).

Blood pressure homeostasis is maintained via short- and long-term regulatory mechanisms (Hoehn and Marieb, 2015). Short-term regulation by neural and hormonal controls affect BP by acting on one or more of the formerly named variables, which in turn alters cardiac output and/or peripheral resistance (Hoehn and Marieb, 2015). Long-term mechanisms act via the renal system to alter blood volume and thus influence BP (Hoehn and Marieb, 2015).

2.1.1 Measuring Blood Pressure

2.1.1.1 Oscillometric and Auscultatory Methods

Blood pressure may be measured using non-invasive techniques, including oscillometric and auscultatory methods (Flynn et al., 2017). The oscillometric technique involves using an automated device that calculates mean arterial BP (MAP) by measuring and recording oscillations from the arterial blood vessel wall when the cuff is deflated (Pickering et al., 2005). The device then determines SBP and DBP from MAP using an algorithm (Pickering et al., 2005).

Alternatively, the auscultatory method determines SBP and DBP based on the appearance and disappearance of Korotkoff sounds at the brachial artery using a mercury or aneroid sphygmomanometer and a stethoscope (Pickering et al., 2005). Normative BP data is based on this technique, which remains the gold standard for measuring arterial BP (Flynn et al., 2017).

Due to their ease of use, oscillometric devices are becoming more common in healthcare settings (Flynn et al., 2017). However, compared to auscultatory techniques, oscillometric devices are less precise and may exaggerate BP levels, which could lead to the misclassification of BP status. For this reason, high oscillometric readings need to be confirmed by auscultation to make a clinical diagnosis of hypertension (Flynn et al., 2017). That being said, the American Academy of Pediatrics' (AAP) acknowledges that oscillometry is practical in research settings and considers it suitable for screening purposes (Flynn et al., 2017).

2.1.1.2 Standard Procedure for Measuring Blood Pressure in Children

Before measuring begins, children should be briefed on the procedure and warned of the potential discomfort associated with cuff inflation (Pickering et al., 2005). The child should remain seated at a 90° angle with their legs uncrossed, feet flat against the ground and back supported for at least five minutes before measurements are taken (Pickering et al., 2005). The child should be instructed to relax and refrain from talking until repeat measurements have been completed (Pickering et al., 2005). Blood pressure should be measured on the right arm, which should be bare to the shoulder

(Pickering et al., 2005; Flynn et al., 2017). The right arm should be horizontal and resting on a flat surface at the mid-sternal level (Petrie et al., 1986). An appropriately sized cuff should be placed on the upper arm, two centimetres above the crease of the elbow, with the midline of the bladder positioned two to three centimetres above the antecubital fossa (Pickering et al., 2005). The midportion of the bladder should align with the brachial artery (Pickering et al., 2005). The cuff should fit firmly, with sufficient space to fit two fingers width underneath (Petrie et al., 1986).

In clinical settings, if a child's BP is raised (BP $\geq 90^{\text{th}}$ percentile) at the initial assessment, two additional measurements should be taken at the same visit to obtain an average (Flynn et al., 2017). During and between healthcare visits, BP can vary due to external influences such as caffeine intake, anxiety and exercise (Flynn et al., 2017). For this reason, clinicians should obtain multiple measurements over a number of different visits before diagnosing high BP (Flynn et al., 2017). Hypertension can be diagnosed by trained healthcare professionals if auscultatory BP measurements are $\geq 95^{\text{th}}$ percentile on three separate occasions (Flynn et al., 2017).

There is uncertainty in the literature regarding the optimal age to begin taking regular BP measurements in children (Sun et al., 2007; Chen and Wang, 2008). However, acknowledging the importance of prevention and benefits of early intervention, the AAP recommend that measurements should be conducted annually after the age of two (Flynn et al., 2017; Litwin et al., 2010; Śladowska-Kozłowska et al., 2011). Children with obesity, aortic arch obstruction, diabetes, renal conditions; or those taking medication known to raise BP, should have their BP measured at every healthcare visit (Flynn et al., 2017).

2.2 High Blood Pressure in Children

Hypertension in pre-adolescents is defined as consistently high SBP and/or DBP $\geq 95^{\text{th}}$ percentile for age, gender and height (Flynn et al., 2017). It can be further classified as primary or secondary, depending on the aetiology (Flynn et al., 2017). Primary hypertension, often referred to as essential hypertension, has no identifiable cause and commonly occurs in adolescents and adults (Kapur and Mattoo, 2018; McCance and Huether, 2014; Essouma et

al., 2015).

Over the last few decades, primary hypertension has become a more frequent diagnosis among children (Wirix et al., 2015; Kapur and Mattoo, 2018; Rosner et al., 2013). Common characteristics amongst children with this condition include obesity, a family history of hypertension and older age (Flynn et al., 2017; Flynn et al., 2012; Rossana et al., 2012).

Unlike primary hypertension, secondary hypertension is caused by an underlying condition that alters cardiac output or peripheral vascular resistance (McCance and Huether, 2014) such as renal disease (Flynn et al., 2017). This form of hypertension may account for up to 85% of diagnoses in those under the age of 12 (Viera and Neutze, 2010; Flynn, 2001). In those with secondary hypertension, levels may normalise if the cause is treated before long-term vascular changes occur (Gilbert and Weiner, 2017).

2.2.1 Pathogenesis of Hypertension in Children

Despite their differences, both forms of hypertension result from abnormalities in the mechanisms involved with BP regulation (McCance and Huether, 2014). In brief, hypertension is caused by an increase in peripheral resistance and/or cardiac output (McCance and Huether, 2014). Peripheral resistance is altered by conditions that raise blood viscosity or induce vasoconstriction, whereas cardiac output is elevated by states that increase stroke volume or heart rate (McCance and Huether, 2014).

Primary hypertension resulting from increased vascular resistance and stiffness is more common in adulthood, whilst in youth, it is often related to increased cardiac output (AlGhatrif et al., 2013; Franklin et al., 2009). The pathogenesis of primary hypertension is multifactorial, involving an interaction between various genetic and environmental factors (Kapur and Mattoo, 2018). Mechanisms that contribute to the development and maintenance of this condition may include the activation of the sympathetic nervous system, changes to the renin-angiotensin system, obesity, insulin resistance, disruptions in sodium homeostasis, endothelial dysfunction, fetal programming and genetic influences (Kapur and Mattoo, 2018; Flynn and Tullus, 2008; Raj and Krishnakumar, 2013). Among these, studies suggest that childhood obesity may be one of the primary drivers of hypertension among children (Kotchen, 2010; Wirix et al., 2015; Herouvi et al., 2013; Redwine et al., 2012). Obesity is

strongly associated with metabolic abnormalities such as insulin resistance and increased inflammation (Wirix et al., 2015; Raj and Krishnakumar, 2013).

Despite a growing interest in this field of research, our current understanding is limited. Some authors have suggested that the mechanisms driving adult hypertension may help us to better understand the development of high BP in children (Kapur and Mattoo, 2018; Flynn and Tullus, 2008). Research in adults has shown that deranged neurohumoral function and insulin resistance promote vasoconstriction and increased vascular resistance (McCance and Huether, 2014). Further neurohumoral dysfunction in conjunction with systemic inflammation promotes kidney dysfunction, leading to salt and water retention, and in turn, an elevated blood volume. These factors can all lead to an increase in BP (McCance and Huether, 2014).

2.2.2 Classification of Blood Pressure in Children

In 2004, the AAP published a report on the clinical diagnosis and management of high BP in children (American Academy of Pediatrics, 2004). Following publication, the report received extensive criticism for including data from overweight and obese children in the normative BP curves and failing to ensure that adolescent threshold values were consistent with adult guidelines (Samuels, 2018).

To amend these issues and incorporate more recent evidence, the AAP published new practice guidelines (Flynn et al., 2017). In comparison to the Fourth Report, these guidelines focus on simplifying the screening and diagnosis of BP abnormalities and ensure consistency between adolescent and adult values and terminology (Dionne, 2017; Samuels, 2018; Flynn et al., 2017). In these guidelines, 'elevated BP' replaced the former term 'prehypertension'. This was done to emphasize that rather than being 'pre-normal' these values are abnormal and require lifestyle intervention (Flynn et al., 2017; Dionne, 2017). Furthermore, the updated classification scheme provides a separate criteria for children aged between 1 to 13 years-old and adolescents aged 13 years-old and over (Flynn et al., 2017). This change acknowledges that while BP in young children is relative to their gender, age and height, BP in adolescents should be interpreted differently (Samuels, 2018; American Academy of Pediatrics, 2004). For this reason, BP classification for younger children is based on percentiles, whilst adolescents are now classified based on absolute values (Flynn et al., 2017; Dionne, 2017).

Recognising that the oldest and tallest children may have percentiles above adolescent thresholds, the AAP subcommittee has provided two definitions for both elevated BP and hypertension, advising health practitioners to choose the lowest value to avoid under diagnosis (Flynn et al., 2017; Dionne, 2017). Table 2.1 from Flynn et al. (2017) details the BP classification scheme for children and adolescents.

Although there are many advantages to the new guidelines, outstanding issues remain due to insufficient data in youth (Dionne, 2017; Samuels et al., 2018). At present, the classification of BP in pre-adolescents is based on normative data as opposed to outcome data sourced from clinical trials. Furthermore, BP thresholds for adolescents are now based on adult standards. It is unknown whether these definitions can be generalised to this population group and only time will enable health practitioners and researchers to evaluate the practicality and effectiveness of this modification (Dionne, 2017).

In this thesis, the terms raised, or high BP will be used interchangeably to describe any form of BP above the normal range ($BP \geq 90^{\text{th}}$). The terms elevated BP and hypertension will only be used according to their given definition (Flynn et al., 2017).

Table 2.1 Blood Pressure Classification for Children and Adolescents

Blood pressure category	Children (1—12 years-old)	Adolescents (13—17 years-old)
Normal	<90 th percentile	<120/80mmHg
Elevated BP	≥90 th percentile to <95 th percentile or 120/80mmHg to <95 th percentile	120/<80 to 129/<80mmHg
Stage 1 hypertension	≥95 th to <95 th percentile + 12mmHg or 130/80 to 139/89mmHg	130/80 to 139/89mmHg
Stage 2 hypertension	95 th percentile + 12mmHg or ≥140/90mmHg	≥140/90mmHg

Source: Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents (Flynn et al., 2017).

2.3 The Prevalence of High Blood Pressure in Children

In more recent times, elevated BP and hypertension have been increasingly recognised among children (Rosner et al., 2013; Feber and Ahmed, 2010). The exact prevalence of high BP in children is difficult to estimate as results vary between studies depending on the number of BP readings taken, definition criteria, reference values, study population and measurement techniques used (Karatzi et al., 2017; Lurbe et al., 2016; Redwine et al., 2012; Dobson et al., 2015). The poor recognition and frequent under diagnosis of paediatric hypertension in clinical practice also makes it challenging to determine rates (Hansen et al., 2007; Stabouli et al., 2015; Shapiro et al., 2012; Daley et al., 2013).

Findings from the National Health and Nutrition Examinations Surveys (NHANES) in the U.S., provides some insight into the prevalence of high BP in children (Flynn et al., 2017). Using the most recent data from NHANES, Kit et al. (2015) reported that the prevalence of elevated BP and hypertension in children aged 8 to 17, is approximately 9.4% and 1.6%, respectively. Using the same dataset, Rosner et al. (2013) found that high BP was more prevalent among adolescents than younger children, which is consistent with other studies (Diaz and Calandra, 2017).

However, given that BP variability in clinical settings is high and elevated readings normalise with repeated measurements, findings based on single screenings may not accurately reflect the true prevalence of paediatric hypertension (Dobson et al., 2015; Sorof et al., 2004; American Academy of Pediatrics, 2004). In studies where measurements have been repeated over time the prevalence of high BP is considerably lower. In a clinical setting the prevalence of elevated BP may actually range between 2% to 12% (Chiolero et al., 2007; Hansen et al., 2007; Lo et al., 2013). Similarly, the prevalence of hypertension in youth is estimated to be 0.3% to 4.5% (Hansen et al., 2007; Sorof et al., 2004; Steinhorsdottir et al., 2011; Koebnick et al., 2013b; Lo et al., 2013).

2.3.1 The Trend of High Blood Pressure Prevalence

There is conflicting evidence surrounding the trend of hypertension prevalence in children (Roulet et al., 2017). Previously, Rosner et al. (2013) compared findings between NHANES III and NHANES 1999 to 2008 surveys and found that the prevalence of elevated BP had increased from 15.8% to 19.2%, and 8.2% to 12.6% in boys and girls, respectively. The likelihood of elevated BP in children also increased by approximately 27% during this time, which the authors attributed to the rise in obesity, waist circumference (WC) and salt intake (Rosner et al., 2013).

Another study in the United states, based on the military health insurance database found a 17% increase in the incidence of hypertension in children from 2006 to 2011 (Dobson et al., 2015). Similarly, findings based on the China Health and Nutrition Survey showed that the rate of elevated BP and hypertension in children has increased by 6.4% between 1991 and 2004 (Liang et al., 2011).

Alternatively, while investigating BP and obesity trends in a sample of 7 to 17 year-old Chinese children, Dong et al., (2018) found that the prevalence of elevated BP had remained relatively stable between 1995 and 2014 despite a 14.1% increase in the prevalence of overweight during this time.

In order to gain a better understanding of worldwide trends in paediatric BP, Roulet et al. (2017) conducted a systematic review of 18 studies from 13 different high- and middle-income countries including Greece, Japan, Seychelles and Russia. The authors found that although

most of the studies described an increase in the prevalence of childhood obesity, more than half reported a decline in the prevalence of high BP from 1963 to 2012 (Roulet et al., 2017). In light of these findings, several researchers have concluded that other factors must also be contributing to the increasing prevalence of paediatric hypertension alongside obesity (Dong et al., 2018; de Moraes et al., 2014; Roulet et al., 2017).

2.3.2 The Prevalence of Primary Hypertension

As discussed, the prevalence of elevated BP in children varies across different countries and study populations (Roulet et al., 2017). Regardless of the overall trend of paediatric hypertension, authors acknowledge there has been a shift towards more of the primary form being diagnosed (Flynn and Alderman, 2005; Gupta-Malhotra et al., 2015; Baracco et al., 2012). This is due to both better clinical guidelines and poorer dietary habits, which can contribute directly to high BP, but also indirectly through increases in obesity rates (Flynn and Alderman, 2005; American Academy of Pediatrics, 2004; Feld and Springate, 1988; Arar et al., 1994; Gupta-Malhotra et al., 2015; Kapur et al., 2010; Robinson et al., 2005).

At present, there is limited evidence regarding the prevalence of primary hypertension in the general paediatric population. Findings from studies in outpatient clinics suggest that 50% of hypertensive patients under the age of 18 have primary hypertension (Baracco et al., 2012; Flynn et al., 2012; Flynn and Alderman, 2005). In a more recent study, Gupta-Malhotra et al. (2015) found that of the 275 children with confirmed hypertension, 43% had essential hypertension, and 57% had high BP related to secondary causes. More interestingly, Flynn et al. (2012) reported that of the children diagnosed with primary hypertension, 17% were under the age of six, whilst more than 60% were between 6 and 17 years-old. Similarly, Gupta-Malhotra et al. (2015) concluded that children with primary hypertension are typically older and have a family history of the condition. On the basis of these findings, it seems that secondary hypertension may be more prevalent among younger children, whilst primary hypertension is more frequent among pre-adolescents and adolescents (Flynn and Alderman, 2005; Baracco et al., 2012; Yoon et al., 2014; Gupta-Malhotra et al., 2015; Flynn et al., 2012).

2.3.3 The Prevalence of High Blood Pressure in New Zealand

At present, there is a lack of national data describing the prevalence of elevated BP and hypertension in New Zealand children. Although some studies have reported on mean BP values (shown in Table 2.2) (Stoner et al., 2017; Rush et al., 2013; Taylor et al., 2007; Rush et al., 2016), to the best of our knowledge, no studies have examined the prevalence of high BP in a New Zealand cohort.

Data from national surveys provides insight into BP rates in adults (Ministry of Health, 2016a). Since 1992, the New Zealand Health Survey has been collecting data on the BP status of adults from participant reports (Statistics New Zealand and Ministry of Health, 1993). However, as self-reported findings are likely to underestimate the prevalence of high BP, the survey also began to conduct BP measurements from 2012 onwards (Ministry of Health, 2013; Ministry of Health, 2016a). In the survey 'measured raised BP' is now defined as SBP ≥ 140 mmHg and/or a DBP ≥ 90 mmHg (Whitworth et al., 2003).

Findings from the most recent Health Survey show that 22% of participants aged 15 years and over had raised BP readings (Ministry of Health, 2017c). Subgroup comparisons showed that 25% of men and 20% of women had high BP readings after three consecutive measurements (Ministry of Health, 2017c). Although the prevalence of high BP readings was similar between Maori, Pacific and European/other ethnic groups, the findings revealed that after adjusting for age and sex, Pacific and Maori adults were more likely to have high BP readings than European and other groups (Ministry of Health, 2017c).

Table 2.2 Mean Blood Pressure Levels in New Zealand Children

Study Reference	Study Design	Mean SBP (mmHg)	Mean DBP (mmHg)
Taylor et al. (2007)	A two-year long non randomised community based intervention in 5 to 12 year-old children (n=730). Mean BP levels at two years post-baseline are reported in the following column.	Control, 107 Intervention, 104	Control, 62.0 Intervention, 60.0
Rush et al. (2013)	Cross-sectional study of 2,752 children aged between 5 and 10 years.	10 year-olds, 106.6	10 year-olds, 67.1
Rush et al. (2016)	Cross-sectional analysis of 14 year-old children (n=931) participating in the Pacific Islands Families Study.	Boys, 122 Girls, 117	Boys, 65.0 Girls, 67.0
Stoner et al. (2017)	Cross-sectional study of 392 children aged between 8 to 10 years.	101	61.7

2.4 Health Implications of High Blood Pressure in Children

Primary hypertension in children and adolescents may have serious consequences later in life (Flynn et al., 2017; Muntner et al., 2004). Blood pressure levels in adulthood can be traced back to levels in childhood (Chen and Wang, 2008; Sun et al., 2007; Juhola et al., 2012; Bao et al., 1995). In adults, high BP is a well-recognised risk factor for CVD (World Health Organization, 2009; Wilson et al., 1998; Stamler et al., 1993). Sustained hypertension in childhood can increase the likelihood of TOD which can increase the risk of CVD in later life (Sun et al., 2007; Raitakari et al., 2003; Kollias et al., 2014; Juhola et al., 2013; Litwin et al., 2010; Sorof et al., 2003a).

2.4.1 Blood Pressure Tracking

A strong body of evidence suggests that BP levels may persist throughout the lifespan (Chen and Wang, 2008; Bao et al., 1995). The Bogalusa Heart Study, the world's longest longitudinal study in children, which sought to understand the early development of CVD from childhood to adulthood, described a positive correlation between childhood and adulthood BP levels (Bao et al., 1995). The findings showed that of all the variables measured, baseline BP was the best predictor of follow-up BP status. Of the 116 adult participants with clinical hypertension, 48% and 41% had high SBP and DBP in childhood, respectively (Bao et al., 1995).

Similarly, using data from the Fels Longitudinal Study, Sun et al. (2007) found that even one high BP reading during childhood may increase the likelihood of hypertension and metabolic abnormalities in the future, with a greater risk among those with persistently high readings. More recently, Theodore et al. (2015) conducted a prospective longitudinal study in Dunedin which followed the BP trajectory of 975 participants from 7 to 38 years of age. Their findings showed that SBP levels from as early as seven years of age could predict BP status and CVD risk in early mid-life (Theodore et al., 2015). Figure 2.1 from Theodore et al. (2015), shows the estimated tracking of BP for the different BP groups from childhood to mid-adulthood.

Whilst investigating factors affecting BP tracking in a subsample of more than 700 participants, Kelly et al. (2015) found that those with high childhood BP had a 35% increased risk of having abnormal BP as adults than normotensive subjects. The researchers also concluded that achieving a healthy BMI, meeting the recommended fruit and vegetable intake and decreasing

alcohol consumption could help to normalise BP levels in both childhood and later life.

Finally, a meta-analysis of 50 cohort studies from different countries, has confirmed that childhood BP is strongly associated with adulthood BP status (Chen and Wang, 2008). Given the potential CVD risk associated with hypertension, identification and appropriate intervention in early life is critical.

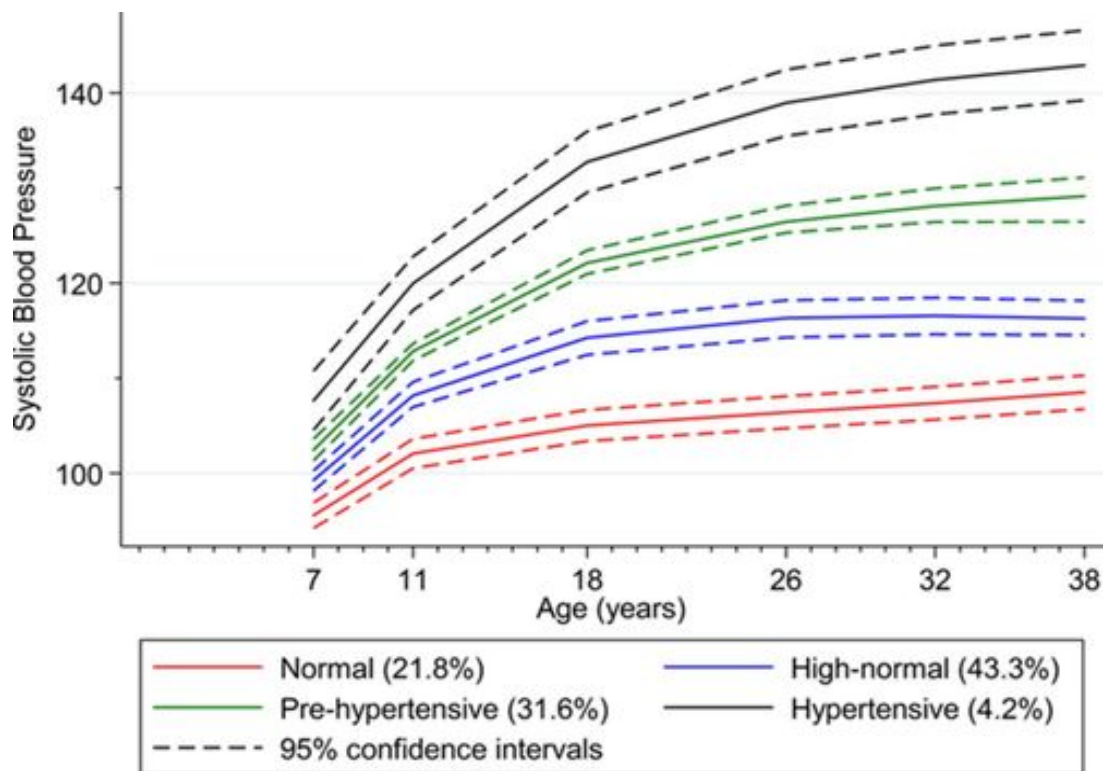


Figure 2.1 Estimated trajectory for normal, high-normal, pre-hypertensive and hypertensive BP trajectory groups from 7 to 38 years of age. Reprinted from Theodore et al. (2015), Childhood to early-midlife systolic blood pressure trajectories: early-life predictors, effect modifiers, and adult cardiovascular outcomes, Hypertension, 66, 1108-1115 © with permission from Wolters Kluwer Health, Inc.

2.4.2 Target Organ Damage

Childhood hypertension may also increase the risk of future CVD through early organ damage (Litwin et al., 2010; Urbina et al., 2011; Hartiala et al., 2012; Sorof et al., 2003b; Raitakari et al., 2003). Findings from imaging (Urbina et al., 2011) and autopsy studies (Tracy et al., 1995) reveal that children with high BP can experience TOD. This can manifest as injury to various organs, including the kidneys, eyes, blood vessels, brain and the heart. In the heart, persistent hypertension can lead to left ventricular hypertrophy (LVH) (Urbina et al., 2011; McNiece et al., 2007a; Brady et al., 2008; de Simone et al., 1995). Evidence from some population groups

suggest that LVH may be present in up to 40% of hypertensive children, making it the most common type of organ damage among children with high BP (Brady et al., 2008; Hanevold et al., 2004; Litwin et al., 2006).

In addition, childhood hypertension can promote adverse structural and functional vascular changes, such as increased carotid intima-media thickness (cIMT) (Lande et al., 2006; Urbina et al., 2011; Sorof et al., 2003b; Juhola et al., 2013) and biomarkers of arterial stiffness, including increased pulse wave velocity (Urbina et al., 2011). In adults, LVH, increased cIMT and arterial stiffness are linked with an increased likelihood of poor CV outcomes and are often used to predict morbidity and mortality (Li et al., 2008; Havranek et al., 2008; Vlachopoulos et al., 2010; Mitchell et al., 2010). Although, hypertensive children do not experience hard CV events, these early changes may mark the beginning of atherosclerosis (Raitakari et al., 2003; Juhola et al., 2013; Sorof et al., 2003b; Juonala et al., 2006; Hartiala et al., 2012; Curcio et al., 2017; Li et al., 2004).

Persistent hypertension in early life can also affect the function and structure of other organs, which in turn can lead to future complications, including retinopathy (Foster et al., 2009; Daniels et al., 1991), reduced kidney function (Seçil et al., 2015; Lubrano et al., 2008; Wuhl et al., 2009; Mitsnefes et al., 2003) and altered neurocognitive function (Lande et al., 2003; Rovio et al., 2017; Adams et al., 2010; Lande et al., 2011; Wong et al., 2011; Lande et al., 2017). Fortunately, if high BP is controlled in the initial stages, it may be possible to reverse some organ and tissue damage (Juhola et al., 2013; Assadi, 2007; Kupferman et al., 2014).

2.5 Risk Factors for High Blood Pressure in Children

Factors known to influence BP status in youth include, include obesity (Friedemann et al., 2012), dietary intake (Moore et al., 2012), family history (Juhola et al., 2012), gender (Sorof et al., 2004) and ethnicity (Rosner et al., 2013).

2.5.1 Obesity

Among the risk factors for childhood hypertension, obesity is one of the most important. In overweight and obese children, the prevalence of high BP ranges from 3.8% to 24.8% and appears to increase with increasing levels of adiposity (Sorof et al., 2004; Skinner et al., 2015;

Falkner et al., 2006; Koebnick et al., 2013a). Evidence suggests that raised BP in youth is positively associated with BMI (Friedemann et al., 2012) and measures of central adiposity (Kelishadi et al., 2015). The exact manner by which obesity promotes the development of hypertension is unknown. However, insulin resistance, endocrine abnormalities, sodium retention, systemic inflammation and endothelial dysfunction are some of the potential factors involved in the development of high BP among overweight and obese children (Wirix et al., 2015; Raj and Krishnakumar, 2013).

2.5.1.1 Body Mass Index

Body mass index is a measure of weight adjusted for height that is frequently used to assess obesity (World Health Organization, 2018b). In both adults and children, BMI can be used as a surrogate measure of excess fat mass and help to identify those at risk of weight-related health issues (Freedman and Sherry, 2009; Friedemann et al., 2012; Sardinha et al., 2016). For pre-adolescents, the index is adjusted for age and gender to acknowledge the changes in weight, height and body fat (BF) that occur with growth and maturation (Whitlock et al., 2005).

The ability of BMI to accurately identify excess adiposity is influenced by BF levels and ethnicity. In heavy children, BMI is a fine measure of excess body fatness, but a poor indicator in those with low or normal body weight (Freedman et al., 2004).

The association between BMI and excess adiposity also varies by ethnicity. Findings from the U.S. show that at the same level of BMI, Caucasian children have higher BF than African American children (Freedman et al., 2008). Similarly, a study by Rush et al. (2008) based on a subsample of 643 children from the New Zealand Child Nutrition Survey, found that at the same BMI-for-age, Pacific Island and Maori girls had significantly lower %BF and higher fat free mass than their European counterparts. There were no ethnic differences in body fatness observed among boys, which is consistent with their previous work (Rush et al., 2003). To reduce misclassification among minority groups, Rush et al. (2003) proposed that BMI cut-offs should be increased by approximately 3 to 4 units for Maori and Pacific Island girls between the ages of 5 and 14.

Conversely, Asian children have higher BF levels than European children of the same BMI (Freedman et al., 2008; Hudda et al., 2017). Findings from adults also suggest that Asian populations have higher disease risks at lower BMIs (Deurenberg-Yap et al., 2001; World Health Organization, 2004). The association of BMI and body fatness differs within the Asian population due to the variability between subgroups (World Health Organization, 2004; Liu et al., 2011). To improve the efficacy of BMI as a measure of excess adiposity and health risk, BMI cut-offs specific to the Asian population have been formulated for both adults (World Health Organization, 2004) and children (Cole and Lobstein, 2012). However, the use of multiple cut-offs in clinical settings is not always practical and further research is needed before cut-offs can be adjusted for Maori and Pacific Island children.

To date, BMI remains the most widely used screening method for overweight and obesity in both adults and children (Vanderwall et al., 2017; Ortega et al., 2016). Like all other obesity measures, it has several limitations, one being that it does not distinguish between skeletal, muscle and fat mass, such that children with different ratios of fat mass to fat free mass, may still present with the same BMI (Whitlock et al., 2005). Despite its limitations, BMI is more commonly accepted, affordable and practical in clinical and research settings than other measures of adiposity (Daniels, 2009). Given its poorer ability to detect excess adiposity among some ethnic groups, BMI values should be interpreted with caution when working with Asian, Maori and Pacific Island children (Rush et al., 2003; Rush et al., 2008; Freedman et al., 2008).

Currently, there are several BMI reference standards and cut-offs available for children to account for differences in body composition between different population groups, including the World Health Organization growth reference for 5 to 19 year-olds (de Onis et al., 2007), the British 1990 Growth Reference (Cole et al., 1998), the Centre for Disease and Control and Prevention BMI-for-age (Kuczmarski et al., 2002) and International Obesity TaskForce cut-offs (IOTF) (Cole and Lobstein, 2012).

The IOTF cut-offs are based on BMI cut-off values at 18 years and use survey data derived from six countries including: the U.S., United Kingdom (UK), Netherlands, Brazil, Singapore and Honk Kong (Cole and Lobstein, 2012). Since the original IOTF cut-

offs were proposed, adjustments have been made to allow for BMI to be interpreted in terms of percentiles and standard deviation scores. This facilitates a direct comparison with other reference standards and between studies (Cole and Lobstein, 2012). In contrast to other standards, the IOTF cut-offs are easily obtained and interpreted, and ensure consistency between child and adult definitions (Cole and Lobstein, 2012). The IOTF provides cut-offs to denote underweight, normal, overweight and obesity, which coincide with the World Health Organization adult reference values. Table 2.3 shows the different levels of classification of the IOTF childhood BMI cut-offs.

Table 2.3 The International Obesity TaskForce Childhood BMI Cut-offs for Overweight, Obesity and Thinness

Classification	Cut-off Points (kg/m²)
Underweight	<18.50 [†]
Thinness grade 3	<16.00
Thinness grade 2	<17.00
Thinness grade 1	<18.50
Normal	18.50—24.99 [†]
Overweight	25—29.99 [†]
Obesity	≥30.00 [†]
Obese	30—34.99
Morbidly Obese	≥35.00

Source: Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity (Cole and Lobstein, 2012). [†]Main cut-off points.

In New Zealand, the revised IOTF reference standards have been used to assess children's body weight. Data from the New Zealand Health Survey shows that the prevalence of overweight and obesity in children is 21.1% (Ministry of Health, 2016a) and 12.4% (Ministry of Health, 2017b), respectively. Between 2006 and 2018, the prevalence of childhood obesity increased significantly, but rates have remained relatively stable over the last seven years (Ministry of Health, 2017b). Among the ethnic groups sampled, Maori and Pacific children were 3.1 and 1.6 times more likely

to present with obesity than those from other ethnicities, irrespective of gender and age differences (Ministry of Health, 2017b). Asian children were less likely to be overweight (Ministry of Health, 2016a) and obese (Ministry of Health, 2017b) than children from other ethnic backgrounds. It is important to note, that in these surveys 'Asian' was used as an umbrella term for East, South and South East Asian ethnicities (Ministry of Health, 2016a). The higher prevalence of obesity among children from ethnic minorities looks to mirror the higher prevalence of raised BP amongst Maori and Pacific Island adults.

2.5.1.1.1 Body Mass Index and High Blood Pressure in Children

Compared to other indices of obesity, the association between BMI and BP in childhood has been the most consistently studied (Flynn et al., 2017). Findings from observational and longitudinal studies suggest that a high BMI is independently associated with an increased risk of elevated BP and hypertension (Meininger et al., 2010; Wang et al., 2015b; Angelopoulos et al., 2006).

Meininger et al. (2010) measured BP in a sample of 1,070 primary school children in the U.S. on three separate occasions. The study found that children classed as overweight were 4.8 times more likely to have high BP (BP $\geq 90^{\text{th}}$ percentile) than those of normal weight (Meininger et al., 2010). This odds ratio was similar to findings from other studies in U.S. cohorts (Sorof et al., 2004; King et al., 2006).

Comparably, a longitudinal study of 7,203 school children in China found that the incidences of hypertension were markedly higher among obese (70%) and overweight children (50%), than those within the thin BMI range, after four years follow-up (Wang et al., 2015b). The authors also noted that an overweight or obese BMI status strongly predicted hypertension risk, whilst membership into the thin BMI category was protective against hypertension risk in boys, but not girls (Wang et al., 2015b). These observations are consistent with findings from other studies in China (Zhang and Wang, 2011; Hu et al., 2016; Lu et al., 2018), Italy (Pileggi et al., 2005), Portugal (Rodrigues

et al., 2018), Greece (Moschonis et al., 2018) and Thailand (Rerksuppaphol and Rerksuppaphol, 2015). However, some discrepancies in the literature remain, particularly within demographic groups due to differences in the number of BP screenings, age groups, reference standards and threshold values used (Meininger et al., 2010).

2.5.1.1.1 Childhood Obesity and Future High Blood Pressure Risk

Recently, Perng et al. (2016) found that rapid gains in BMI during the first three years of life was linked to higher SBP in childhood, regardless of birth weight. Munthali et al. (2016) reported that children with an early onset of overweight or obesity were more likely to have elevated BP in late adolescence than those within the normal BMI trajectory. The risk of future hypertension also seems to increase with increasing BMI percentile. A retrospective cohort study by Parker et al. (2016) found that compared to normal weight children, obese subjects had a two-fold increased risk of hypertension, and those with severe obesity had a four-fold increased risk of hypertension after three years. Their findings emphasized the importance of consistent BP monitoring throughout childhood and the need for more public health initiatives that effectively target childhood obesity (Parker et al., 2016).

2.5.1.2 Percent Body Fat

Several techniques, including dual-energy X-ray absorptiometry (DEXA) and magnetic resonance imaging can be used to measure obesity (Haroun et al., 2010). However, although they provide more accurate estimates of BF than BMI and other anthropometric measures, they are complex, expensive and inconvenient to use in research and healthcare settings (Haroun et al., 2010).

Bioelectrical impedance analysis (BIA) is an alternative method for assessing BF that uses small electrical currents and electrical impedance to estimate the composition of different body tissues. This technique is simple, cost effective and convenient to use in clinical practice (Haroun et al., 2010; Łątko et al., 2016; Kyle et al., 2004). In adults,

findings show a good correlation between BIA and DEXA body composition values (Von Hurst et al., 2015). Recently, BIA was also validated against DEXA for measuring BF in a sample of primary school children in New Zealand (Delshad et al., 2018).

Several studies that have measured skinfolds or used DEXA techniques to measure BF in children have shown an association between hypertension and fat mass (Ying-Xiu and Shu-Rong, 2011; Schommer et al., 2014; Maximova et al., 2011; Brion et al., 2007). However, only a limited number of studies have investigated this association using BIA-derived %BF, and those which have, show conflicting findings (see Table 2.4).

A cross-sectional study of 8 to 16 year-old children in Germany showed that subjects over the age of 10 had an increased likelihood of hypertension with every 5% increase in %BF (Reich et al., 2003). In contrast, this study also found that %BF was a poor predictor of hypertension risk among children under the age of 10. The authors further reported that the ability of BMI to predict hypertension was superior compared to %BF and other obesity indices. Alternatively, others have demonstrated that BF is a stronger predictor of hypertension in children aged 8 to 10 years-old than both BMI and skinfold measures (Martínez Vizcaíno et al., 2007). Moreover, other findings suggest that %BF may be a good indicator of high BP and other CV risk factors among overweight and obese children (Bohn et al., 2015), but not among those of normal weight (Xu et al., 2018). Due to inconsistencies in the literature, further research is needed to determine whether BF, measured by BIA, is a suitable screening tool for hypertension risk.

Table 2.4 Summary of Studies Investigating the Link between BIA-Derived Body Fat and the Risk of High Blood Pressure in Children

Study Reference	Aims	Study Design	Relevant Findings
Reich et al. (2003)	To investigate the association of hypertension with BMI, skinfolds, waist-to-hip ratio and %BF in youth.	Cross-sectional study of 2,365 children aged 8 to 16 years-old.	For children aged 10 and above, the likelihood of hypertension (BP $\geq 95^{\text{th}}$ percentile) increased with every 5% increase in %BF. No significant association was found for children under the age of 10. In addition, the authors found that of the other BF indices, BMI was the strongest predictor of hypertension.
Martínez Vizcaíno et al. (2007)	To explore the association between different BF indices and CV risk factors in children.	Cross-sectional study of 1,280 children aged between 8 to 11 years living in Spain.	Findings from the multiple regression analysis showed that after controlling for BMI and triceps skinfold thickness, %BF was strongly associated with DBP and all other CV risk factors. Moreover, the study demonstrated that among the BF indices studied, %BF was the strongest predictor of lipid, lipoprotein and DBP levels.
Drozdz et al. (2009)	To investigate the correlation between different BF indices and BP status in children.	Cross-sectional study of 193 children in Poland aged 8 to 16 years.	Systolic BP and DBP increased with increases in %BF, regardless of BP status. Children with hypertension (SBP or DBP $\geq 95^{\text{th}}$ percentile) had significantly higher BF than their normotensive counterparts. The authors concluded that BF was a good indicator of BP status in both obese and normal weight children.

Bohn et al. (2015)	To compare the ability of BMI and BIA-acquired BF to identify CV risk factors in children and adolescents.	A total of 3,327 overweight and obese children aged 3 to 15 years were included in this cross-sectional analysis. All participant data was derived from the Adiposity Patients Registry based in Germany.	Findings from the logistic regression suggested that BF was a significant predictor of hypertension (SBP or DBP $\geq 95^{\text{th}}$ percentile), high liver enzymes and raised triglycerides, independent of age and gender. The study also found that there were no significant differences in the abilities of BMI and BF to detect CV risk factors.
Xu et al. (2018)	To investigate the association between BMI, WC and %BF, and hypertension risk in non-obese children.	Longitudinal study of 1,526 Chinese children between the ages of 6 to 14 years. Subjects were normotensive at baseline and followed from 2014 to 2016.	After adjusting for potential cofounders, %BF was not significantly associated with an elevated risk of hypertension (SBP or DBP $\geq 95^{\text{th}}$ percentile) in normal weight children.

2.5.1.3 Central Adiposity

Central BF distribution may be more strongly associated with cardiometabolic risk factors and disease than general adiposity (Kelishadi et al., 2015). Waist circumference and WHtR are some of the most common measures used to assess intra-abdominal fat (Kelishadi et al., 2015).

2.5.1.3.1 Waist Circumference and High Blood Pressure in Children

A high WC is a known risk factor for raised BP and CVD in adults (Browning et al., 2010). Studies in children show that a high WC is associated with an increased likelihood of elevated BP (Rosner et al., 2013) and hypertension (Genovesi et al., 2010; So et al., 2016). However, some findings suggest that it may be a poor predictor of high BP among children of normal weight (Kovacs et al., 2010; Pazin et al., 2017).

In adults, WC cut-offs have been established for both men (>88cm) and women (>102cm) to denote excess abdominal fat (Lean et al., 1995). In children, WC varies with age and gender, and is therefore expressed in terms of percentiles. Currently, there are a wide range of WC percentile curves available for children from different ethnic backgrounds (McCarthy et al., 2001; Eisenmann, 2005; Khadilkar et al., 2014; Matsushita et al., 2015; Fryar et al., 2016). However, there is no clear consensus regarding the optimal cut-off for central obesity among children. This is due to large variations in body composition with age, gender, pubertal stage and ethnicity, as well as conflicting findings regarding the most sensitive cut-off value for multiple health risks (Fredriksen et al., 2018). Studies specifically focusing on the association between WC and high BP in children have used different cut-offs to define central obesity, including $\geq 90^{\text{th}}$ (Kovacs et al., 2010; Flores-Huerta et al., 2009), $\geq 80^{\text{th}}$ (Yan et al., 2008), $\geq 75^{\text{th}}$ percentiles (Dong et al., 2016).

2.5.1.3.2 Waist-to-Height Ratio and High Blood Pressure in Children

Waist-to-height ratio is an alternative proxy for central obesity. Similar to WC, WHtR has been found to be a good predictor of cardiometabolic risk in the

paediatric age group (Freedman et al., 2012; Arnaiz et al., 2014; Savva et al., 2000; Brambilla et al., 2013). Table 2.5 provides a summary of findings from seven studies that investigated the association between WHtR and high BP in children. Overall, the majority of these findings suggest that BP levels and hypertension risk increase with increasing WHtR (Hu et al., 2011; Campagnolo et al., 2011; Zhang et al., 2014; Choy et al., 2012; Mishra et al., 2015). Other evidence regarding the utility of WHtR as a screening tool for multiple CV risk factors in children also confirms this relationship (Kelishadi et al., 2015).

Table 2.5 Summary of Studies Investigating the Association between Waist-to-Height Ratio and High Blood Pressure in Children

Study Reference	Aims	Study Design	WHtR cut-off	Relevant Findings
Hu et al. (2011)	To determine if using central adiposity measures alongside BMI improves the identification of children with high BP.	Cross-sectional study using a subsample of 1,145 Chinese children aged 7 to 17 years from the 2006 China Health and Nutrition Survey.	≥ 0.5	After adjusting for age and gender, children with a WHtR ≥ 0.5 were more likely to have hypertension (SBP or DBP $\geq 95^{\text{th}}$ percentile) than those with a WHtR < 0.5 . Additionally, the study found that using BMI and WC together was the strongest predictor of hypertension in this population.
Choy et al. (2012)	To investigate the association between WHtR and hypertension in school-aged children in Taiwan.	Cross-sectional study of 2,334 seven year-old children from six elementary schools in Taiwan.	WHtR quartiles.	Using the first WHtR quartile as the reference value, the likelihood of hypertension (SBP or DBP $\geq 95^{\text{th}}$ percentile) increased gradually from the second to the fourth quartile.
Moser et al. (2013)	To investigate the association between a range of anthropometric indices and high BP in	Cross-sectional study of 1,441 children aged 10 to 16 years from Public schools in Brazil.	≥ 0.5	Pearson's Partial correlation showed that most anthropometric indices, including WHtR were weakly associated with SBP and DBP after controlling for gender, age and sexual maturation. The multivariate regression found

	Brazilian children.			that WHtR was not significantly associated with high BP. In this study, high BP was defined as SBP or DBP $\geq 90^{\text{th}}$ percentile (elevated BP and hypertension combined).
Keefer et al. (2013)	To compare the ability of BMI and WHtR to predict high SBP and total cholesterol in children of different age groups.	Subsample of 2,300 children aged between 6 and 17 years from the 2003 to 2004 NHANES.	>0.5	In children aged between 12 and 17 years, a WHtR >0.5 was associated with high SBP (BP $\geq 90^{\text{th}}$ percentile). In contrast, there was no significant association found between high WHtR and high SBP in younger children. Based on these findings, the authors concluded that WHtR was a good indicator of high BP in adolescents, however it may not be appropriate for pre-pubertal children.
Mishra et al. (2015)	To assess the effectiveness of WHtR to predict high BP as compared to BMI and WC in Indian children.	A total of 1,913 children aged 6 to 16 years-old were recruited from an ongoing cohort study in Indian, Paediatric Epidemiology and	≥ 0.5	Multivariable analysis showed that after adjusting for age, gender and average sleep duration, children with a WHtR ≥ 0.5 had a 2.38 times greater likelihood of elevated SBP and 3.38 times greater likelihood of elevated DBP than normal weight children. In addition, the authors found that all three anthropometric indices

		Child Health (PEACH), for this cross- sectional analysis.		(WHtR, BMI and WC) had similar abilities to detect elevated BP in Indian school children. In this study, elevated BP was defined as SBP or DBP ≥ 90 th percentile.
Maffeis et al. (2010)	To investigate the association between anthropometric indices, insulin resistance and BP in overweight and obese children.	A total of 1,044 overweight and obese pre- adolescents were recruited from 15 clinical centres across Italy for this cross- sectional analysis.	≥ 0.5	High BP was positively associated with WHtR. The binary logistic regression analysis found that after controlling for age and pubertal stage, children with a WHtR ≥ 0.5 were 1.08 times more likely to have high BP than those below the cut- off. In this study high BP was defined as SBP or DBP ≥ 95 th percentile.
Khoury et al. (2012)	To determine if WC measures can improve the ability of BMI to identify adolescents with deranged lipid profiles and high BP.	Cross-sectional study of 3,248 adolescents aged 14 to 15 years- old in Niagara, Ontario.	WHtR was classified into three groups <0.5 , $0.5-0.6$, and ≥ 0.6	After controlling for age and gender, multivariable analysis showed that overweight and obese children in the higher WHtR categories were more likely to have hypertension than those below the WHtR cut-off across all three BMI categories (normal, overweight and obese).

A WHtR ≥ 0.5 has been suggested as a suitable cut-off for identifying central obesity in adults and found to be a good indicator of cardiometabolic risk regardless of age, gender and ethnicity (Ashwell et al., 2012). The cut-off is also considered appropriate for use in the paediatric population, where it has been linked with several risk factors (Kelishadi et al., 2015) including hypertension (Kahn et al., 2005; Savva et al., 2000; Freedman et al., 2007).

A New Zealand study by Goulding et al. (2010) previously compared WHtR values to the BMI cut-offs for overweight and obesity in children. Their findings indicated that for all ethnic groups, WHtR cut-offs and BMI reference values for overweight and obesity were similar. On the basis of this, the authors agreed that a WHtR ≥ 0.5 could be used to screen for CV risk factors in children. The study also found that compared to New Zealand European, Pacific Island children were more likely to have a WHtR > 0.5 , followed by Maori (Goulding et al., 2010).

Alternatively, other authors suggest that this cut-off may underestimate obesity in some groups and propose lower reference values for those aged 6 to 18 years (Lobor Cancelier et al., 2018). However, compared to the single 0.5 value, these cut-offs are not practical in clinical settings and lack evidence surrounding their use to screen for cardiometabolic risk factors.

Over the years, many studies have compared the ability of different measures of adiposity to predict health status. In adults, central adiposity indices have been shown to be better predictors of CV risk factors, than measures of general obesity (Huxley et al., 2009; World Health Organization, 2008). In children, results from studies comparing the ability of WHtR, WC and BMI to detect health risks, in particular high BP, are less consistent (Lu et al., 2018; Savva et al., 2000; Freedman et al., 2007; Lee et al., 2008; Ashwell et al., 2012; Kahn et al., 2005). This is likely because the correlation between obesity markers and BP varies with gender, ethnicity and maturational stage (Song, 2014; Tebar et al., 2017).

Recently, a meta-analysis by Ma et al. (2016) demonstrated that BMI, WC and

WHtR had similar predictive abilities. All three obesity indices also had low sensitivities ranging from 42% to 43%, meaning they had failed to identify over 50% of children with raised BP. These findings reinforce the importance of using both measures of obesity simultaneously to best evaluate the risk of hypertension, particularly among non-Caucasian, and thin and normal weight children (Javed et al., 2015). However, some authors have acknowledged that WHtR may be preferred in clinical and public health settings due to its ease of use (Freedman et al., 2007).

Since WHtR is not strongly correlated with age and gender, it does not have to be expressed in terms of percentiles, unlike BMI and WC measures, and can be obtained through a simple calculation (Buchan et al., 2017). Another advantage of WHtR, is that practitioners are able to use the same cut-off point to define central obesity in children and adults, and across different ethnic groups (Keefer et al., 2013).

2.5.1.3.3 Ethnicity and Central Fat Distribution

Body fat distribution differs between ethnicities. These differences are evident in early life and persist throughout adulthood (Modi et al., 2009). In general, Caucasian and Hispanic children have higher central fat deposition, visceral fat and truncal subcutaneous fat than African American children of the same fat mass (Herd et al., 2001). However, controversy in the literature remains as ethnic differences seem to vary by gender and age (He et al., 2002; Staiano and Katzmarzyk, 2012). Despite having less visceral fat, African Americans have been shown to have higher levels of insulin resistance than European (Herd et al., 2001), which can influence the development of hypertension by increasing sodium retention and sympathetic nervous system activation (Zhang et al., 2016).

Asian ethnicities, in particular South Asian, have a higher risk of cardiometabolic disease at a lower WC than Europeans (World Health Organization, 2008). This is likely due to higher levels of total BF and central adiposity at a given WC (Lear et al., 2007). Most of the evidence suggests that

Asian children (He et al., 2002) and adults (Wu et al., 2007; Raji et al., 2001; Park et al., 2001) have greater total truncal fat and visceral adipose tissue than Caucasian. Despite this, Asian children tend to have a smaller WC than Caucasian, Mexican and African American children, most likely due to their smaller body frame size (Lakshmi et al., 2012).

Findings from a cross-sectional study in New Zealand suggest that Pacific Island children may have greater truncal fat deposition than their European counterparts (Gordon et al., 2003). However, data from adults suggest that Pacific Islanders may have less visceral fat than Caucasian at a given WC (World Health Organization, 2008). Rush et al. (2009) previously conducted a cross-sectional study of more than 900 Maori, Pacific Island, Asian Indian and New Zealand European adults to determine ethnic differences in body composition. Their findings showed that after adjusting for age, height and weight, central adiposity was highest among Asian Indian adults and lowest among Pacific Islanders than other ethnic groups. Compared to New Zealand European, Maori and Pacific adults had a higher proportion of their total BF distributed around the abdomen (Rush et al., 2009). These findings suggest that using ethnic specific percentiles for central obesity indices may improve the identification of high risk groups (World Health Organization, 2008).

2.5.2 Dietary Intake

The relationship between diet and BP has been extensively studied in adults over the years, and more recently in children. Yang et al. (2012) previously showed that children with high sodium intake had a two-fold increased risk of elevated BP and hypertension, with a one-fold higher risk for those with obesity. Since then, data from observational and experimental studies has confirmed the association between excessive salt consumption and high BP in the paediatric population (Leyvraz et al., 2018).

Whilst acknowledging the potential influence of single nutrients or foods on BP is important (Flynn et al., 2017), focusing on whole dietary patterns is more meaningful as foods are not eaten in isolation. Research in both children (Lazarou et al., 2009a; Moore et al., 2005; Lazarou et al., 2009b) and adults (Saneai et al., 2014) supports the notion that dietary patterns are

better predictors of BP than the intake of individual dietary components.

Adopting healthy dietary and lifestyle habits in early life has been shown to improve BP control and reduce CVD risk in both childhood and adulthood (Saneei et al., 2014; Moore et al., 2016; Krupp et al., 2015; Laar et al., 2013). A high consumption of reduced fat dairy foods has been linked with lower SBP and DBP in primary school-aged children, regardless of their total calcium, magnesium and potassium intake (Yuan et al., 2013; Rangan et al., 2012).

Similarly, a longitudinal study following 2,185 girls from the ages of 10 to 20, found that those consuming ≥ 2 servings of dairy foods and ≥ 3 servings of fruits and vegetables each day had lower BP levels in youth and a 36% lower risk of elevated BP in early adulthood (Moore et al., 2012). Interventional data suggests that an adequate intake of low fat dairy, fruits and vegetables may improve SBP in hypertensive adolescents (Couch et al., 2008). Moreover, maintaining a low saturated fat diet from early life through to adolescence has been linked with lower BP levels (Niinikoski et al., 2009).

Currently, a Dietary Approaches to Stop Hypertension (DASH) eating pattern is advised for preventing and managing raised BP in both childhood (Flynn et al., 2017) and adulthood (Whelton et al., 2018). This diet, which is high in fruits, vegetables, wholegrains, nuts, fish, reduced fat dairy, and low in saturated fat, sodium and sugar has been associated with lower SBP and DBP (Couch et al., 2008; Saneei et al., 2014; Cohen et al., 2017; Asghari et al., 2016; Novotny et al., 2015) and a lower risk of developing high BP in childhood (Asghari et al., 2016; Moore et al., 2012).

2.5.3 Family History

Studies have shown that children with hypertensive parents have a 1.3- to 2.0-fold increased risk of developing high BP (Burke et al., 1998; Juhola et al., 2012). For this reason, family history is considered an important predictor of high BP in youth (Niiranen et al., 2017). Studies have shown that approximately 20% to 60% of variation in BP is determined by genetic factors (Kupper et al., 2005; Wang et al., 2015a; Evans et al., 2003).

There are a number of monogenetic syndromes that present as extreme BP levels in youth and follow classic mendelian inheritance patterns (Levy et al., 2009; Ehret et al., 2011). Although several genetic variants, including single nucleotide polymorphisms, responsible for

these syndromes have been identified, they only account for a small proportion of familial hypertension (Levy et al., 2009; Lurbe et al., 2016). This evidence reinforces that BP is a polygenic trait (Seidel and Scholl, 2017; Pickering, 1955; Levy and *et al*, 2009).

As primary hypertension most often results from environmental and lifestyle factors acting on genetic predisposition, further research surrounding these complex interactions is needed (Kapur and Mattoo, 2018; Khanna et al., 2011; Redwine, 2018). As children with a family history of hypertension have a greater likelihood of developing this condition (Othman et al., 2012; Alpay et al., 2009; Lurbe et al., 2005), they should be closely monitored to ensure early detection and provide timely interventions to improve long-term health outcomes (Flynn et al., 2017; Lurbe et al., 2016).

2.5.4 Gender

Sex is a non-modifiable risk factor for hypertension. Throughout the reproductive lifespan, BP levels (Wang et al., 2006) and hypertension risk (Wolf-Maier et al., 2003; Yoon et al., 2015; Theodore et al., 2015) are higher among males than females. Although the mechanisms underlying these sex differences are not yet fully understood, they may be attributable, in part, to the effect of sex hormones on BP regulatory systems (Maranon and Reckelhoff, 2013; Dasgupta et al., 2006).

In early childhood, there are no significant differences in BP between the sexes (American Academy of Pediatrics, 2004). In all children, BP rises progressively with age due to increases in body size and hormonal changes (American Academy of Pediatrics, 2004). During puberty, sex differences in BP begin to develop, as SBP levels increase faster among males than females (Jackson et al., 2007; Shankar et al., 2005; Dasgupta et al., 2006; Harshfield et al., 1994). Males seem to maintain higher BP levels than females until older age, when sex differences in BP become no longer apparent (Martins et al., 2001; Burt et al., 1995; Wiinberg et al., 1995).

The majority of studies investigating gender differences in childhood hypertension include participants from a broad range of age groups. This makes it difficult to compare results from different studies due to the high variability in chronological ages and biological maturation (Karatzi et al., 2017; Shankar et al., 2005; Barba et al., 2008). Several studies in children aged between 3 and 18 years-old, reveal that high BP is more frequent among boys than girls (Sorof

et al., 2004; Rosner et al., 2013; Davis et al., 2005), although findings remain mixed (Genovesi et al., 2005; Steinthorsdottir et al., 2011; Schwandt et al., 2015; Karatzi et al., 2017). Similarly, there are also inconsistencies in the literature surrounding sex differences among primary school children (Liu et al., 2017; Okoh et al., 2012). Emerging evidence from longitudinal studies also suggests that the progression of high BP from adolescence to early adulthood may be sex dependent (Dasgupta et al., 2006), with three to four times more risk for males than females (Tirosh et al., 2010).

Despite mixed findings regarding boy-girl differences in BP, sufficient evidence indicates that males are at higher risk of hypertension for a large proportion of the lifespan and thus, male sex is still considered an important risk factor in the assessment of primary hypertension in the paediatric age group (Flynn et al., 2017; Moyer V.A, 2013).

2.5.5 Ethnicity

Most of our current knowledge of ethnic differences in BP comes from research in adults, where levels and hypertension risk vary between ethnic groups (Ong et al., 2007). The majority of findings from the U.S. show that ethnic minorities, particularly African American adults, have higher mean BP levels, a greater prevalence of hypertension and are more likely to experience severe hypertension and end organ damage than other groups (Guo et al., 2012; Hajjar and Kotchen, 2003; Holmes et al., 2013; Havranek et al., 2015).

In children, studies investigating racial disparities in BP have produced conflicting findings. When observed, ethnic differences in BP are more common among boys than girls (Rosner et al., 2009; Hardy et al., 2017; Muntner et al., 2004). Although several cross-sectional studies report a higher prevalence of elevated BP and hypertension among African American and Hispanic children independent of obesity (Rosner et al., 2013; Rosner et al., 2009; Cheung et al., 2017; Lo et al., 2013), other studies have found that after adjusting for potential confounding factors, ethnic disparities are no longer significant (Rosner et al., 2000; Sorof et al., 2004; McNiece et al., 2007b).

There are also other studies that have shown that African American children may be more likely to experience TOD (Brady et al., 2010a) and develop elevated BP at a younger age (Hardy et al., 2017) than those from other ethnicities.

Previous longitudinal and cross-sectional studies suggest that ethnic differences in BP can be detected in late childhood and adolescence (Wang et al., 2006; Rosner et al., 2009; Harding et al., 2010; Dekkers et al., 2002), however uncertainty remains regarding the exact age of onset (Flynn et al., 2017). Although the cause of racial differences in BP and associated health outcomes have not been fully determined (Flynn et al., 2017), they are likely explained by differences in BMI, body composition, sexual maturation and environmental factors (Dekkers et al., 2002; Rosner et al., 2009; Cheung et al., 2017).

The normative BP values in the most recent guidelines are derived from a multi-ethnic sample in the U.S. (Flynn et al., 2017). As it stands, ethnicity is not accounted for in the determination of BP status in children as the strength of the evidence is insufficient to warrant ethnic specific normative values (Samuels et al., 2018).

2.5.5.1 High Blood Pressure among Ethnic Groups in New Zealand

Similar to international findings, the burden of raised BP (Ministry of Health, 2017c; Gentles et al., 2006) and CVD (Ministry of Health, 2017a) falls on ethnic minority groups in New Zealand, particularly among Pacific Island and Maori adults. Given this increased risk, Maori, Pacific and South Asian adults are recommended to begin routine CV risk assessments 15 years earlier than other population groups (Ministry of Health, 2018a). These ethnic disparities in health may be related to genetic and hereditary factors (Rosner et al., 2009; Klimentidis et al., 2011), but may also be attributable to modifiable factors known to affect hypertension risk, which are distinctly high among ethnic minority groups. In comparison to children from European and Asian backgrounds, Pacific and Maori children are known to have higher levels of obesity (Ministry of Health, 2017b), poorer dietary habits (Ministry of Health, 2016a; Ministry of Health, 2003) and experience more financial and material hardship (Duncanson et al., 2017).

Despite the lack of data in the paediatric population, ethnic differences in BP and hypertension prevalence may mimic patterns seen in adults. In this way, it is plausible that Maori, Pacific Island and South Asian children may present with higher BP levels and hypertension risk, particularly in late childhood and adolescence than other population groups. A sound understanding of these differences is important to determine the need for national screening initiatives among high risk groups.

2.6 Management of High Blood Pressure in Children

Treatment and management strategies are determined by the aetiology of high BP, diagnosis type, and the presence of TOD and other comorbidities (Flynn et al., 2017). The treatment goals for primary and secondary hypertension are to achieve and maintain BP levels that reduce the risk of TOD, and high BP and CV outcomes in later life (Flynn et al., 2017). According to evidence, the optimal BP target for children with high BP should be SBP and DBP <90th percentile (Urbina et al., 2011; Śladowska-Kozłowska et al., 2011; Stabouli et al., 2009).

For children with consistently high BP, a combination of lifestyle and pharmacologic interventions are advised (Flynn et al., 2017). Lifestyle modifications are strongly recommended for children with abnormal BP as the first line treatment. This involves adopting healthy dietary habits, particularly those that align with a DASH style of eating. In addition, several studies have shown that achieving a healthy body weight (Chiolerio et al., 2007; Falkner et al., 2006) and moderate to vigorous physical activity (Rebholz et al., 2012; Torrance et al., 2007; Chen et al., 2010; Farpour-Lambert et al., 2009; Kelley et al., 2003) are associated with lower BP. Finally, pharmacological therapy should be offered alongside lifestyle counselling to children with symptomatic hypertension, stage 2 hypertension, CKD, diabetes mellitus or continuous hypertension (Flynn et al., 2017).

2.7 Summary

In the last few decades, primary hypertension has become a serious health concern among school-aged children. In New Zealand adults, the rate of hypertension is significantly higher among ethnic minorities and low socioeconomic groups (Ministry of Health, 2017c). To date, no studies or surveys in New Zealand have investigated elevated BP or hypertension in the paediatric population. High BP in childhood has several implications for health, including TOD (Urbina et al., 2011) and high BP in the future (Sun et al., 2007; Bao et al., 1995; Kelly et al., 2015). The risk factors associated with high BP in adults are well known, however in children, further research is needed to establish a clear consensus. A better understanding of these risk factors has the potential to improve individual and population wide health outcomes by ensuring that treatment and management strategies are implemented early to reduce the risk of organ damage and deter the tracking of high BP into adulthood (Theodore et al., 2015).

Chapter 3 Research Study Manuscript

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Original Article

Investigating Risk Factors Associated with Raised Blood Pressure in New Zealand School Children

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3.1 Abstract

Aims: High BP in childhood has several health consequences. A better understanding of the factors associated with this condition can support the establishment of screening initiatives and health strategies that facilitate early detection and intervention. The aim of this study was to investigate risk factors for raised BP in 8 to 12 year-old children, living in Auckland, New Zealand.

Methods: Cross-sectional data from primary school children participating in The Children's Bone Study were analysed. Anthropometric measures included weight, height, BMI, WC and %BF (measured by BIA). Blood pressure was measured on a single occasion and the average of three readings was used for analysis. Elevated BP and hypertension were defined according to the American Academy of Pediatrics' criteria. Information regarding gender, age and ethnicity was collected by means of a questionnaire. Logistic regressions were used to examine the associations between gender, ethnicity and obesity with raised BP (BP $\geq$ 90th percentile).

Results: The proportion of children ($n=669$, 10.4 ± 0.62 years) with elevated and hypertensive BP readings were 14.3% and 31.1%, respectively. Age and gender were not significantly associated with raised BP ($p=0.485$; $p=0.109$, respectively). South Asian children had significantly greater odds of presenting with raised BP compared to European (OR: 1.65, 95% CI: 1.02—2.65, $p<0.05$). The adjusted odds of screening with raised BP were significantly greater for children with an obese (OR: 2.88, 95% CI: 1.65—5.01, $p<0.001$) and overweight (OR: 2.43, 95% CI: 1.54—3.84, $p<0.001$) BMI than non-overweight children. Moreover, %BF

above the normal range (OR: 2.16, 95% CI:1.51—3.09, $p<0.001$) and a WHtR ≥ 0.5 (OR: 2.60, 95% CI: 1.60—4.22, $p<0.001$) were associated with increased odds of raised BP readings, irrespective of age, gender and ethnicity.

Conclusions: Ethnicity, and general and central obesity are key risk factors for raised BP in children. Although BP was only measured on a single occasion, the results suggest that paediatric hypertension may be a potential health concern for New Zealand. Further research is needed to establish a more accurate picture of the situation and allow for New Zealand based guidelines to be formulated.

Key words: blood pressure; childhood; children; elevated blood pressure; hypertension; New Zealand children; paediatrics; prehypertension; obesity; risk factors.

3.2 Introduction

High blood pressure (BP) is a significant risk factor for cardiovascular disease (CVD) (Rapsomaniki et al., 2014), health loss (Lim et al., 2012) and adult mortality worldwide (Global Burden of Disease Collaborative Network, 2017 ; Ritchie and Roser, 2018). In New Zealand, raised BP was the fourth leading cause of health loss in 2013, accounting for 8.3% of disability-adjusted life years (Ministry of Health, 2016b). A growing body of evidence suggests that high BP in adulthood may have its origins in childhood (Theodore et al., 2015; Muntner et al., 2004; Chen and Wang, 2008).

Over the last several decades, the burden of primary hypertension (i.e. hypertension without an identifiable cause) has increased among children, alongside obesity and poor lifestyle habits (Rosner et al., 2013; Gupta-Malhotra et al., 2015). The prevalence of high BP in children varies between studies and depends on the definition, population group and measurement techniques used (Karatzi et al., 2017; Lurbe et al., 2016). Nonetheless, studies conducting repeated BP screenings in children report that the rate of elevated BP is between 3% and 12% (Hansen et al., 2007; Lo et al., 2013), and the rate of hypertension ranges from 0.3% to 4.5% (Sorof et al., 2004; Lo et al., 2013; Hansen et al., 2007; Moore et al., 2009). This prevalence may be higher among overweight and obese children than non-obese children (Haas et al., 2014; Genovesi et al., 2008; Rosner et al., 2013). According to New Zealand's most recent health survey, 22% of people aged 15 years and over had high BP readings at a single screening, with greater rates seen among males, Maori and Pacific Island ethnicities, and those living in the most deprived areas (Ministry of Health, 2017c). As it stands, no studies in New Zealand have investigated BP trends in the paediatric population.

Raised BP in youth has become a serious public health issue, not only due to the increased prevalence, but also because of its consequences in both childhood and later life (Flynn et al., 2017; Muntner et al., 2004). In children, high BP has been associated with left ventricular hypertrophy (Urbina et al., 2011; Brady et al., 2008), greater carotid intima-thickness (Lande et al., 2006) and reduced pulse wave velocity (Lurbe et al., 2012), which in turn may influence future CVD risk. Even more, studies following BP trajectories through the lifespan have shown that elevated BP is likely to track from childhood to adulthood (Chen and Wang, 2008; Sun et al., 2007; Theodore et al., 2015).

In children, the development of primary hypertension is unrelated to arterial ageing and other comorbidities as seen in adults, but rather driven by hereditary, behavioural and environmental influences (Falkner, 2010; Flynn et al., 2013). Several modifiable and non-modifiable factors are known to affect BP in youth.

Obesity is one of the primary risk factors for high BP in children. Cross-sectional and longitudinal studies have shown that both general and central obesity are strongly linked with an increased risk of high BP in childhood (Meininger et al., 2010; Wang et al., 2015b; Campagnolo et al., 2011) and later life (Parker et al., 2016). This is particularly concerning for New Zealand, where findings from recent health surveys show that approximately 34% of children are either overweight or obese (Ministry of Health, 2016a; Ministry of Health, 2017b).

Ethnicity may also influence high BP in youth, with reports of greater risk and adverse outcomes being identified for some ethnic groups including African American and Hispanic populations compared to Caucasian groups (Sorof et al., 2004; Brady et al., 2010a). However, further research is needed as findings in the literature are equivocal (Rosner et al., 2013) and often confounded by other factors including body mass index (BMI), body composition and socioeconomic deprivation, which are often high among ethnic minority groups (Dekkers et al., 2002; Rosner et al., 2009; Cheung et al., 2017).

Gender differences in childhood hypertension risk have also been described. During puberty, SBP begins to rise faster in boys than girls and sex differences in BP emerge (Shankar et al., 2005; Dasgupta et al., 2006). From adolescence through to midlife, males are known to be at higher risk of raised BP (Theodore et al., 2015) and show stronger high BP tracking than age matched females (Tirosh et al., 2010). Whether these boy-girl differences in hypertension risk are apparent in childhood remains undetermined. Several studies have reported higher rates of hypertension among boys than girls (Sorof et al., 2004; Rosner et al., 2013; Davis et al., 2005), whilst others have found the reverse (Genovesi et al., 2005; Karatzi et al., 2017), or no significant differences (Steinthorsdottir et al., 2011).

Other factors that may influence hypertension include family history (Niiranen et al., 2017), low socioeconomic status (Kaczmarek et al., 2015; Fallah et al., 2015), poor dietary intake (Cohen et al., 2017; Yang et al., 2012), sedentary lifestyle (Janssen and LeBlanc, 2010) and birthweight (Mhanna et al., 2015; Tan et al., 2018; Belfort et al., 2007; Bowers et al., 2011).

Given New Zealand's rates of childhood obesity and ethnic disparities in health, it is important to investigate factors associated with raised BP in children. Investigating these factors may outline the need for routine BP screenings during clinical examinations, particularly among vulnerable groups, so that interventions can be initiated early to minimize the risk of future complications and disease progression. Subsequently, this has the potential to reduce the health and economic burden of hypertension. Therefore, the aim of this study is to explore potential risk factors for raised BP in year five and six primary school children living in Auckland using a multi-ethnic sample.

3.3 Methods

3.3.1 Study Design and Participants

This cross-sectional observational analysis was performed using a subset of participants (collected between August 2016 and August 2017) from 'The Children's Bone Study'. Primary schools in the Auckland region with different decile ratings and a range of ethnicities were approached to take part in the wider study. All year five and six students attending participating schools were eligible to participate in the broader study. Written information detailing the purpose of the study and measurement procedures was provided to all children, parents and staff from participating schools. Informed written consent was obtained from parents and children prior to data collection. Ethical approval for 'The Children's Bone Study' was provided by the Massey University Human Ethics Committee, Application SOA 16/42.

3.3.2 Questionnaires

Participants' demographic information and medical history (including, the presence of a chronic illness and medication use) was collected with a demographics questionnaire completed by parents or legal guardians. Children's age was calculated based on their date of birth and the date of the school visit. The ethnic classification system developed by Statistics New Zealand was used to determine the ethnicity reported for each participant (Statistics New Zealand, 2017). The system, which is based on hierarchical classification, allows for individuals that identify with more than one ethnicity to be classified into a specific ethnic group (Statistics New Zealand, 2017). This standardised approach ensures that ethnic minority groups are well represented in research studies and national surveys.

3.3.3 Study Measures

Anthropometric data was collected at participating schools during school hours. All staff involved in the study received standardised training prior to collection. The same measurement procedures and equipment were used across all schools and participants. Children's height was measured, without shoes, relaxed shoulders, and head in the Frankfort plane, to the nearest 0.1cm using a portable stadiometer (Seca 2013, Hamburg, Germany), with two measurements taken and averaged. Weight was measured to the nearest 0.1kg using Bioelectrical Impedance Analyser (BIA), without shoes or heavy clothing (Biospace InBody 230, Seoul, Korea). Waist circumference (WC) was measured in the standing position, over light clothing, to the nearest 0.1cm using a measuring tape (Lufkin pocket tape, W606PM 6mm x 2m, Maryland, USA).

Body mass index was calculated as weight (in kilograms) divided height squared (in meters). Children were classified as thin (<16 to $<18.5\text{kg/m}^2$), normal (18.5 to 24.99kg/m^2), overweight (25 to 29.99kg/m^2) or obese ($\geq 30\text{kg/m}^2$) according to the International Obesity TaskForce (IOTF) BMI age and gender specific cut-offs (Cole and Lobstein, 2012; Cole et al., 2000).

Bioelectric Impedance Analyser provided percent body fat (%BF) estimates and classified children into below normal, normal and above normal %BF categories using an algorithm to apply children's standards (BioSpace InBody, 2017). BIA has been recently validated against dual-energy X-ray absorptiometry (DEXA) for predicting %BF in a sample of New Zealand children (Delshad et al., 2018).

Waist-to-height ratio (WHtR) was calculated as WC divided by height (cm). Central obesity was defined as a WHtR ≥ 0.5 (Goulding et al., 2010; Kromeyer-Hauschild et al., 2013; Mishra et al., 2015; Ministry of Health, 2015).

3.3.4 Blood Pressure Measurements and Definitions

Systolic and diastolic blood pressure (SBP and DBP) measurements were measured in accordance with the recommendations from the American Academy of Pediatrics (2004). Briefly, subjects were seated at a 90° angle, with their legs uncrossed and back supported, resting quietly for at least five minutes before the first measurement. Blood pressure was measured on the right arm, which was resting on a flat surface in a semi-flexed position, using

a digital automatic BP monitor (Omron HEM-907, Japan). Depending on the size of the upper arm, a small (17 to 22cm) or large (32 to 42cm) sized cuff was chosen and placed at the mid-sternal level.

A total of three consecutive measurements were performed for each student, with a one minute interval in between each measurement. The means of the three SBP and DBP readings were used for the analysis. If one reading was abnormally high or low this reading was excluded, and the average was taken from the other readings.

The criteria of the 2017 practice guidelines was used to classify BP based on sex, height and age (Flynn et al., 2017). Elevated BP was defined as the average SBP and/or DBP $\geq 90^{\text{th}}$ percentile to $<95^{\text{th}}$ percentile or 120/80mmHg to $<95^{\text{th}}$ percentile (the lowest value was chosen). Hypertension was defined as the average SBP and/or DBP $\geq 95^{\text{th}}$ percentile or 130/80 to 139/89mmHg (the lowest value was chosen).

3.3.5 Inclusion Criteria

Inclusion criteria for the BP analyses were: two or more BP readings; available information regarding gender, height and age to determine BP percentile; available information regarding at least one or more of the risk factors of interest; no chronic health conditions associated with secondary hypertension and no use of BP lowering medications.

3.3.6 Statistical Analyses

All statistical analyses were performed using the IBM SPSS statistic software, version 24.0 (IBM Corporation, New York, USA). The central limit theorem was applied and normality was assumed for all parametric data (Kwak and Kim, 2017). Categorical variables were displayed as proportions and continuous variables as mean and standard deviation (SD) in the descriptive analysis. The three BP groups (normal BP, elevated BP and hypertensive) were compared by analysis of variance (one-way) (ANOVA), followed by Tukey's post hoc test for continuous variables. Differences between European with other ethnicities were also tested using one-way ANOVA (followed by Tukey's post hoc test for multiple comparisons) for continuous variables. Chi-square tests were used for categorical variables, followed by post hoc tests using adjusted residuals and applying the Bonferroni correction for multiple comparisons.

For the regression analyses, the term 'raised BP' was used to denote BP $\geq 90^{\text{th}}$ percentile (includes elevated BP and hypertensive). Participants with BP $\geq 90^{\text{th}}$ percentile were compared to the normal BP group (BP $< 90^{\text{th}}$ percentile). Univariate logistic regression analyses were used to investigate the relationship between gender, ethnicity, BMI, %BF, WHtR and raised BP. Multicollinearity diagnostics revealed potential collinearity between body index measures (BMI/%BF; BMI/WHtR), indicating they should not be used in the same model. Logistic regressions were used to examine the association of the aforementioned variables with raised BP separately, after adjusting for age, gender and ethnicity. Odds ratios (OR) and 95% confidence intervals were obtained for each variable assessed. Statistical significance was set at $p < 0.05$.

3.4 Results

Of the 805 children that were invited to take part in the wider study, 714 provided consent (88.7%). Complete BP measurements were obtained from 676 children. Seven participants were excluded from the BP analyses. Six of these children were identified as having extremely abnormal BP readings for any child aged 3 to 18 years in accordance to the paediatric BP percentile charts (Flynn et al., 2017), and one child lacked the data necessary to determine their BP percentile. No participants reported having a medical condition associated with secondary hypertension. No participants reported taking BP lowering medications. A total of 669 children were included in the final study group. Figure 3.1 describes the number of participants from recruitment to the final study population.

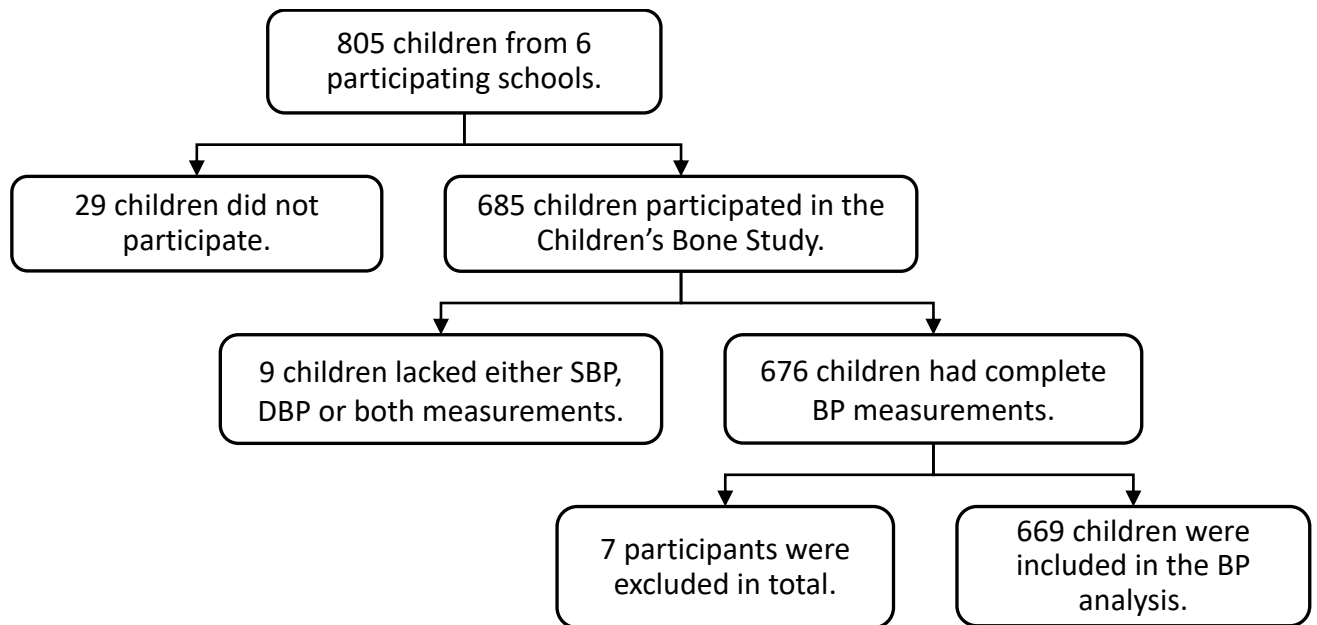


Figure 3.1 Flow diagram showing participant numbers from recruitment to final study sample

3.4.1 Characteristics of Total Population and by Blood Pressure Group

Descriptive characteristics of the study population by BP group are summarised in Table 3.1. The total study sample was comprised of 306 males (45.7%) and 363 females (54.3%). Participants' age ranged from 8.39 to 12.1 years with a mean of 10.4 ± 0.62 years. Most children in the study identified as European (37.4%), followed by Pacific Island (14.3%), Maori (14.2%), South Asian (14.2%), Asian (13.9%) and other (6.0%). Mean SBP was 110 ± 10.5 mmHg and mean DBP was 68.0 ± 9.21 mmHg for the total study sample. Given the ethnic diversity of the other ethnic group, it was excluded from all other analyses and regression models.

The proportion of children with normal, elevated and hypertensive BP readings in the total study sample were 54.6%, 14.3% and 31.1%, respectively. There were no significant differences in age between the three BP groups ($p=0.534$). There was a significant association between gender and BP group ($p<0.05$). The proportion of girls classified into the elevated BP and hypertensive groups (47.9%) was greater compared to the proportion of boys classified into the elevated BP and hypertensive group (42.8%).

Subjects in the elevated BP group had significantly higher mean BMI ($p<0.05$), %BF ($p<0.05$) and WHtR values ($p<0.05$) than those within the normal BP group. Similarly, participants in the hypertensive group had significantly higher mean weight ($p<0.001$), BMI ($p<0.001$), %BF ($p<0.001$) and WHtR values ($p<0.001$) than those classified into the normal BP group. There were no significant differences in any of the anthropometric measures between participants in the elevated BP and hypertensive groups. There was a significant association between BMI group and BP group ($p<0.001$), with a greater proportion of overweight and obese subjects classified into the hypertensive group, compared to the normal BP group. Percent body fat and WHtR cut-off groups were also significantly associated with BP screening status ($p<0.001$), with a greater proportion of participants with excess body fat (as indicated by %BF and WHtR group membership) being classified into the hypertensive group, compared to the normal BP group.

Table 3.1 Demographic and Anthropometric Characteristics of Primary School Children for the Total Sample and According to Blood Pressure Category

	Total group, n=669	Normal BP, n=365	Elevated BP, n=96	Hypertensive, n=208	p-value*
Age (years)	10.4 ± 0.62	10.4 ± 0.64	10.3 ± 0.60	10.3 ± 0.59	
Gender, n (%)					<0.05
Male	306 (45.7)	175 (57.2)	51 (16.7)	80 (26.1)	
Female	363 (54.3)	190 (52.3)	45 (12.4)	128 (35.3)	
Ethnicity, n (%)					<0.05
European	250 (37.4)	154 (61.6)	30 (12.0)	66 (26.4)	
Maori	95 (14.2)	48 (50.5)	18 (18.9)	29 (30.6)	
Pacific Island [†]	96 (14.3)	50 (52.1)	12 (12.5)	34 (35.4)	
South Asian [‡]	95 (14.2)	47 (49.5)	14 (14.7)	34 (35.8)	
Asian [§]	93 (13.9)	54 (58.0)	13 (14.0)	26 (28.0)	
Other [¶]	40 (6.0)	12 (30.0)	9 (22.5)	19 (47.5)	
Anthropometric Measures					
Weight (kg)	38.9 ± 11.2	36.9 ± 10.2	39.8 ± 11.8	41.9 ± 11.9 ^b	
BMI (kg/m ²)	18.7 ± 3.93	17.8 ± 3.52	19.1 ± 4.20 ^a	19.9 ± 4.15 ^b	
BMI groups, n (%) ⁺⁺					<0.001
Thin & normal (16— 24.99kg/m ²)	481 (72.0)	294 (61.1)	68 (14.2)	119 (24.7)	
Overweight BMI (25— 29.99kg/m ²)	110 (16.5)	42 (38.2)	14 (12.7)	54 (49.1)	

Obese ($\geq 30\text{kg/m}^2$)	77 (11.5)	29 (37.7)	14 (18.2)	34 (44.1)	
Body fat (%)	22.7 ± 9.05	20.8 ± 7.94	23.7 ± 9.30^a	25.8 ± 9.87^b	
Percent body fat groups, n (%) ^{††}					<0.001
Under & normal	363 (60.5)	222 (61.2)	47 (12.9)	94 (25.9)	
Above normal	237 (39.5)	97 (40.9)	40 (16.9)	100 (42.2)	
WHtR	0.43 ± 0.07	0.42 ± 0.06	0.44 ± 0.07^a	0.45 ± 0.07^b	
WHtR groups, n (%) ^{§§}					<0.001
<0.5	567 (85.5)	328 (57.8)	79 (13.9)	160 (28.3)	
≥ 0.5	96 (14.5)	32 (33.3)	17 (17.7)	47 (49.0)	
Blood Pressure					
SBP (mmHg)	110 ± 10.5	103 ± 6.68	113 ± 3.96^a	121 ± 7.96^b	
DBP (mmHg)	68.0 ± 9.21	62.9 ± 6.35	68.5 ± 6.34^a	76.7 ± 7.90^b	

IOTF: International Obesity TaskForce; BMI: body mass index; %BF: percent body fat; WHtR: waist-to-height ratio. Data is presented as mean $\pm$ SD unless otherwise stated. Blood pressure is classified as per the 2017 American Academy of Paediatrics guidelines (Flynn et al., 2017). ^aSignificant difference between normal BP and elevated BP groups ($p < 0.05$) from one-way ANOVA, followed by Tukey's post hoc test. ^bSignificant difference between normal BP and hypertensive groups ($p < 0.05$) from one-way ANOVA, followed by Tukey's post hoc test. *Significant differences in categorical variables between BP groups using Pearson's Chi-square. [†]Samoan, Tongan, Cook Islander, Fijian, Kiribati, Niuean; [‡]Indian, Fijian Indian, Pakistani, Sri Lankan, Bangladeshi; [§]Chinese, Korean, Japanese, Taiwanese, Cambodian, Thai, Lao, Filipino, Malaysian, Singaporean, Vietnamese, Burmese; [¶]Middle Eastern, Latin American, South African, African. ^{††}IOTF body mass index cut-offs (Cole and Lobstein, 2012). ^{††}Cut-offs for %BF (BioSpace InBody, 2017) and ^{§§}Central obesity (Goulding et al., 2010; Kromeyer-Hauschild et al., 2013; Mishra et al., 2015) were applied.

3.4.2 Body Index and Blood Pressure Measures by Ethnic Group

Anthropometric and BP characteristics by ethnic group are shown in Supplementary Table 3.1. Mean BMI was significantly higher among Maori and Pacific Island children than European ($p<0.001$). Maori, Pacific Island and South Asian children had significantly higher %BF, WC and WHtR than European subjects. Regarding BP, there were no significant differences in SBP between European and any of the other ethnicities. In contrast, Maori, Pacific Island and South Asian ethnicities had significantly higher DBP than European children ($p<0.05$).

3.4.3 Relationship between Demographic and Anthropometric Factors with Raised Blood Pressure

Unadjusted and adjusted odds ratios and 95% confidence intervals for the associations between risk factors and raised BP readings are shown in Table 3.2. There was no significant relationship between age ($p=0.485$) and gender ($p=0.109$) with raised BP. Ethnicity and anthropometric indices were associated with raised BP in the univariate analysis and remained statistically significant after controlling for potential confounding factors. There were no significant differences in the odds of having raised BP for Maori, Pacific Island and Asian children compared to European. In contrast, South Asian children had significantly higher odds ($p<0.05$) of presenting with raised BP than their European counterparts (OR: 1.65, 95% CI: 1.02—2.65). The odds of having raised BP readings were significantly greater for obese children (OR: 2.88, 95% CI: 1.65—5.01) and overweight children (OR: 2.43, 95% CI: 1.54—3.84) than those within the thin and normal BMI ranges ($p<0.001$). Similarly, children with a WHtR (OR: 2.60, 95% CI: 1.60—4.22) and %BF (OR: 2.16, 95% CI: 1.51—3.09) above the normal range had greater odds of screening with raised BP than those below the acceptable cut-offs ($p<0.001$).

Table 3.2 Logistic Regression Analysis Investigating the Association between Factors and Raised Blood Pressure among Primary School Children

Variable	Unadjusted OR (95% CI)		Adjusted OR (95% CI) [†]	
	Raised Blood pressure	p-value*	Raised Blood pressure	p-value*
Age (years)				
	0.92 (0.72—1.20)	—	0.93 (0.72—1.21)	—
Gender				
Male	1.00		1.00	
Female	1.29 (0.94—1.77)	—	1.30 (0.94—1.79)	—
Ethnicity				
European	1.00		1.00	
Maori	1.57 (0.98—2.53)	—	1.59 (0.99—2.56)	—
Pacific Island [‡]	1.48 (0.92—2.37)	—	1.50 (0.93—2.41)	—
South Asian [§]	1.64 (1.02—2.64)	<0.05	1.65 (1.02—2.65)	<0.05
Asian [¶]	1.16 (0.71—1.88)	—	1.14 (0.70—1.86)	—
IOTF BMI Cut Off ^{††}				
Thin and normal (16—24.99kg/m ²)	1.00		1.00	
Overweight (25—29.99kg/m ²)	2.53 (1.63—3.93)	<0.001	2.43 (1.54—3.84)	<0.001
Obese (≥30kg/m ²)	2.86 (1.72—4.73)	<0.001	2.88 (1.65—5.01)	<0.001
Percent Body Fat Cut Off ^{‡‡}				
Under and normal	1.00		1.00	

Above normal	2.24 (1.59—3.17)	<0.001	2.16 (1.51—3.09)	<0.001
WHtR Cut Off ^{§§}				
<0.5	1.00		1.00	
≥0.5	2.76 (1.74—4.38)	<0.001	2.60 (1.60—4.22)	<0.001

OR: Odds Ratio; CI: confidence interval; IOTF: International Obesity TaskForce; BMI: body mass index; WHtR: waist-to-height ratio. [†]Adjusted for age, gender and ethnicity. Raised blood pressure includes elevated blood pressure and hypertension (BP ≥90th percentile). [‡]Samoan, Tongan, Cook Islander, Fijian, Kiribati, Niuean; [§]Indian, Fijian Indian, Pakistani, Sri Lankan, Bangladeshi; [¶]Chinese, Korean, Japanese, Taiwanese, Cambodian, Thai, Lao, Filipino, Malaysian, Singaporean, Vietnamese, Burmese. ^{††}IOTF body mass index cut-offs (Cole and Lobstein, 2012). ^{‡‡}Cut-offs for percent body fat (BioSpace InBody, 2017) and ^{§§}central obesity (Goulding et al., 2010; Kromeyer-Hauschild et al., 2013; Mishra et al., 2015) were applied. *Statistical significance at p<0.05 level. —, not statistically significant.

3.5 Discussion

The present study examined BP and its associated risk factors in a sample of New Zealand schoolchildren. The results demonstrated that elevated BP and hypertensive group membership was less common among non-obese children and those of European ethnicity. The multivariable analysis revealed that BP screening status was associated with ethnicity and obesity, but not gender. The odds of raised BP were increased in South Asian children, those with an overweight or obese BMI status, and among children with excess body fat as indicated by a high %BF and WHtR.

In this cohort, 14.3% of children presented with elevated BP readings, and 31.1% had BP readings within the hypertensive range. Findings regarding the prevalence of high BP from other cross-sectional studies in the paediatric age group vary significantly. The rate of elevated BP readings in our study is similar to that previously described by Haas et al. (2014), Önsüz and Demir (2015) and Karatzi et al. (2017), but higher compared to other reports (Kit et al., 2015; Cao et al., 2012; Larkins et al., 2018). Furthermore, the proportion of children with hypertensive BP readings in our sample was considerably higher than the prevalence reported for children in Australia, 5.8% (Larkins et al., 2018), the United States (U.S.), 1.6% (Kit et al., 2015), Africa, 10.8% (Muhihi et al., 2018) and Turkey, 4% (Önsüz and Demir, 2015). Differences between our findings and those of other cross-sectional studies may be attributable to differences in participant characteristics and measurement methods used (Martin-Espinosa et al., 2017; Katona et al., 2011).

In New Zealand no studies have assessed the prevalence of high BP in children (Flynn et al., 2017). Among studies that have described mean BP levels in children (Rush et al., 2013; Rush et al., 2016; Stoner et al., 2017; Taylor et al., 2007), only two have included participants from a similar age group as our study (Stoner et al., 2017; Rush et al., 2013). While BP levels in our sample were relatively consistent with other reports in 10 year-old children (Rush et al., 2013), mean SBP and DBP were around 8mmHg higher than previous findings from Stoner et al. (2017). As BP in children depends on sex, age and height, this variability may be explained by differences in the gender ratios, age range and height between studies.

Since high BP readings are common at the first assessment and normalise with repeated

measurements (Sorof et al., 2004; Chiolero et al., 2007), studies conducting multiple screenings over time provide a more accurate estimate of the prevalence of high BP (Hansen et al., 2007; Sorof et al., 2004; Moore et al., 2009; Steinhorsdottir et al., 2011). Given the cross-sectional nature of this study, our findings likely overestimate the rate of paediatric hypertension in New Zealand.

In this study, the proportion of girls with BP readings above the normal range was slightly higher than that of boys. Findings from our regression analysis concur with previous reports from Rosaneli et al. (2014), Muhihi et al. (2018) and Urrutia-Rojas et al. (2006), showing a lack of association between high BP (BP $\geq 90^{\text{th}}$ percentile) and gender, even after controlling for age and ethnicity. However, other studies have identified gender differences in childhood hypertension risk. A study conducted by Rosner et al. (2013) using data from the National Health and Nutrition Examination Survey (NHANES), found that the odds of raised BP (BP $\geq 90^{\text{th}}$ percentile) were significantly higher for boys than girls. Interestingly, Dasgupta et al. (2006) showed that boys were also more likely than girls to develop high SBP from adolescence to adulthood. Conversely, others have reported that high BP is more common among girls (Karatzi et al., 2017; Genovesi et al., 2005). In these studies, the authors have attributed these gender differences to differences in BMI, body fat distribution (Gupta et al., 2018), sedentary behaviour (Durrani and Fatima, 2015), stages of biological maturation (Karatzi et al., 2017) and sex hormones (Ojeda et al., 2014).

There is uncertainty in the literature regarding ethnic differences in the prevalence of paediatric hypertension. Some studies have shown that the rate (Rosner et al., 2009; Cheung et al., 2017; Lo et al., 2013) and risk (Rosner et al., 2013) of high BP is greater among ethnic minority groups, such as African American, Hispanic and Asian children, compared to those of European descent. Yet, others have found that racial differences are no longer apparent after controlling for potential confounders (Sorof et al., 2004; McNiece et al., 2007b).

In our sample, elevated BP and hypertensive readings were more common among South Asian, Pacific Island and Maori children compared to European. The greater proportion of ethnic minority children with raised BP levels, may be in part attributable to higher BMI, WHtR and %BF values in these groups compared to European. In addition, socioeconomic deprivation (Duncanson et al., 2017; Fallah et al., 2015), poor dietary habits (Ministry of

Health, 2016a; Ministry of Health, 2003; Cohen et al., 2017) and other factors associated with high BP not examined in this study (Janssen and LeBlanc, 2010; Mhanna et al., 2015), are known to be more prevalent among Pacific Island and Maori children than New Zealand European children.

Furthermore, our findings showed that South Asian children had increased odds of presenting with raised BP (BP $\geq 90^{\text{th}}$ percentile) compared with those of European ethnicity. To the best of our knowledge, no studies have compared the risk of high BP between South Asian and Caucasian children. Those that have investigated BP in these groups have reported higher levels among South Asian children (Jafar et al., 2005), although findings are inconsistent (Thomas et al., 2012; Henderson et al., 2011; Whincup et al., 2002) and often vary between South Asian subgroups (Harding et al., 2006). South Asian populations are known to be highly susceptible to cardiometabolic risk factors (Whincup et al., 2002; Whincup et al., 2005; Ehtisham et al., 2004), which may be due, in part, to higher %BF and central fat distribution in this group compared to Caucasian (World Health Organization, 2008; Lear et al., 2007; He et al., 2002).

In our study, we were unable to adjust for obesity indices in the regression analysis due to multicollinearity. This makes it difficult to determine whether the higher odds observed among South Asian children is related to the amount and distribution of excess fat. We noted that Maori and Pacific Island children also had significantly greater %BF and WHtR compared to European, yet, interestingly, neither ethnic group was considered a significant predictor of raised BP. Although our finding is likely attributable to a combination of genetic, environmental and lifestyle factors, some studies have shown that the relationship between obesity and cardiometabolic markers may be stronger among South Asian populations than among Caucasian groups (World Health Organization, 2008; Whincup et al., 2002; Vikram et al., 2003). In this way, it is plausible that South Asian children in our study were more likely to present with raised BP levels at a lower %BF and WHtR than children from other ethnicities. However, as we did not examine the associations between all three variables, further research is needed to draw any valuable conclusions.

Our findings support the well known association between obesity and raised BP. In regards to BMI, overweight and obese children had higher odds of screening with raised BP than thin or

normal weight children, even after adjusting for age, gender and ethnicity. Comparably, Meininger et al. (2010) found that among 8 to 10 year-old children, those that classified as overweight were 4.8 times more likely to have elevated BP or hypertension than those within their healthy weight percentile. In a longitudinal study of six to eight year-old children in China, Wang et al. (2015b) reported that overweight and obese students had an increased risk of developing hypertension compared to those of normal weight. The authors also found that thinness was protective against hypertension risk among boys, but not girls (Wang et al., 2015b). The association between a high BMI and raised BP has also been reported by other studies in the U.S. (Sorof et al., 2004; Urrutia-Rojas et al., 2006), Canada (Salvadori et al., 2008), Italy (Pileggi et al., 2005), Thailand (Rerksuppaphol and Rerksuppaphol, 2015) and Turkey (Önsuz and Demir, 2015). Although BMI is only a surrogate measure of excess body fat, these studies, along with our findings, suggest that it could be a useful tool to help prioritise children for screening. The advantage of the BMI is that it is simple, affordable and practical to use during healthcare visits, particularly if based on the IOTF cut-offs which provide a smooth transition from child to adult definitions.

Alternatively, %BF is a more accurate estimate of excess adiposity and therefore could potentially provide a better indication of hypertension risk, especially among Maori, Pacific Island (Rush et al., 2008) and Asian populations (Freedman et al., 2008; Hudda et al., 2017) where BMI may potentially over or under estimate excess fat. Although the majority of methods used to assess %BF are often complex, expensive and time consuming, BIA is simple, cost-effective and practical to use in clinical settings.

In this study, we found that children with a %BF above the normal cut-offs had greater odds of presenting with raised BP than those whose %BF was within or below the normal range. Other studies investigating the association between BIA-derived BF and high BP in children are scarce and show conflicting findings, making comparisons with our results rather difficult. Bohn et al. (2015) previously showed that %BF, as measured by BIA, was a good predictor of hypertension and other cardiovascular risk factors among overweight and obese children. In contrast, a longitudinal study of normal weight children found a lack of association between %BF and hypertension risk (Xu et al., 2018). A possible explanation for this could be that there is a non-linear relationship between %BF and high BP risk, and this measure may only be able to predict this outcome in overweight and obese states (Parker et al., 2016; Sardinha et al.,

2016). Moreover, Reich et al. (2003) observed that the likelihood of hypertension in children over the age of 10 increased with every 5% increase in %BF. However, their findings also showed that %BF was a poor indicator of hypertension risk among children under the age of 10. These discrepancies in the literature may be due to inter-study differences in confounder adjustments, age ranges, ethnicity and maturational stage.

Body fat distribution is known to be a better indicator of disease risk than total adiposity (Kelishadi et al., 2015). In children, a high central fat deposition has been associated with the presence of cardiometabolic risk factors, including deranged lipid profiles, high fasting glucose and high BP (Kelishadi et al., 2015; Campagnolo et al., 2011). Despite some controversy (Lobor Cancelier et al., 2018), research suggests that a WHtR ≥ 0.5 is a good proxy for abdominal obesity (Ashwell et al., 2012; Freedman et al., 2007) and most likely a suitable indicator of cardiometabolic risk in New Zealand children (Goulding et al., 2010).

In our analysis, the odds of presenting with raised BP were higher among children whose WHtR was ≥ 0.5 , compared to those below the cut-off. This finding is inconsistent with reports from Moser et al. (2013) and Keefer et al. (2013) who found no significant association between a WHtR ≥ 0.5 and high BP. Our results, however, align with the findings of Mishra et al. (2015), who observed that among 6 to 16 year-old children in India, those with a WHtR ≥ 0.5 had a 2.38 times greater risk of elevated SBP and 3.38 times greater risk of elevated DBP than their non-obese counterparts. Similarly, a cross-sectional analysis of overweight and obese children in Italy showed that even after adjusting for age and pubertal stage, those with a WHtR ≥ 0.5 were 1.08 times more likely to have hypertension than those below the cut-off (Maffeis et al., 2010). Interestingly, another cross-sectional study in older children found that a WHtR ≥ 0.5 was a good predictor of hypertension risk across all three BMI categories (Khoury et al., 2012).

The advantage of using a WHtR ≥ 0.5 to define central obesity is that it is universal, and translates to the simple public health message of “keeping your WC to less than half your height” (Ashwell and Gibson, 2014). Additionally, because WHtR is not expressed in terms of percentiles, unlike BMI and WC in children, and can be obtained from a simple calculation, it may also be preferred in clinical and community settings over other indices. However, to best evaluate the risk of high BP, general and central obesity measures should be assessed simultaneously during healthcare visits, as some population groups such as Asian ethnicities

could potentially screen with a normal BMI or %BF, and yet present with abdominal obesity. Although obesity indices can help prioritise individuals for screening, BP should also be monitored in normal weight children as the ability of these measures to detect hypertension is still considered relatively low (Ma et al., 2016).

The present study has several limitations and strengths. First, due to its cross-sectional design, causality cannot be inferred. Secondly, our findings cannot be generalised to the wider population as our sample was only representative of children in the Auckland region. As previously discussed, BP measurements were only performed on one occasion, which may have led to the overestimation of raised BP and thus affected the validity of our findings. To obtain a more accurate estimate of the prevalence of high BP in New Zealand children, future surveys and studies should consider ambulatory BP monitoring or ensure measurements are conducted on three or more separate occasions. The lack of normative reference values specific to New Zealand children and reliance on the reference data and BP definitions from the U.S., may also contribute to misclassification in our cohort.

Another limitation of this study was that we did not include other factors known to influence BP in our analysis, such as family history, dietary habits and physical activity, and were therefore unable to adjust for their effects. Additionally, given the high proportion of subjects in the raised BP groups, some readings may have been falsely elevated due to anxiety or excitement during measurement. To minimize this error, all measurements were taken according to protocol (Flynn et al., 2017) and outliers were excluded from the analysis. A strength of this study was that our cohort was representative of the main ethnic groups in New Zealand (Statistics New Zealand, 2014). Our study is also the first in New Zealand to explore high BP and its associated risk factors in the paediatric population.

In conclusion, our results suggest that paediatric hypertension may be a potential health concern for New Zealand and emphasize the importance of further BP surveillance in this age group. Identifying factors associated with high BP may support the development of clinical guidelines that reinforce routine BP examinations during healthcare visits. Subsequently, this may enable early detection so that timely interventions can be initiated to reduce the risk of target organ damage and mitigate the tracking of high BP into adulthood. In this study, we found that South Asian children were more likely to present with raised BP than those of

European ethnicity. We also found that both general and central obesity were associated with increased odds of high BP readings. This finding suggests that BMI, BIA-derived BF and WHtR may be suitable tools to help prioritise children for BP screening in clinical settings. However, future studies are needed to confirm and compare the ability of these measures to detect high BP pressure in children of normal weight, overweight and obesity. Finally, further prospective studies are warranted to (a) gain insight into the prevalence of high BP in New Zealand and (b) explore other known determinants of BP.

3.6 Acknowledgements

The study gratefully acknowledges the contribution of all of the schools, children and parents who participated. We would also like to thank Massey University for providing funding for the study.

3.7 Competing Interests

The authors declare no competing interests.

3.8 Supplementary Tables

Supplementary Table 3.1 Anthropometric and Blood Pressure Characteristics of Primary School Children Stratified by Ethnic Group

	European, n=250	Maori, n=95	Pacific Island, n=96 [†]	South Asian, n=95 [‡]	Asian, n=93 [§]
Body index measures					
Height (m)	1.43 ± 0.07	1.47 ± 0.09 ^a	1.48 ± 0.08 ^a	1.42 ± 0.07	1.40 ± 0.08
Weight (kg)	35.6 ± 7.28	46.1 ± 14.6 ^a	47.1 ± 13.8 ^a	37.3 ± 9.71	34.1 ± 7.43
BMI (kg/m ²)	17.4 ± 2.55	21.1 ± 5.02 ^a	21.3 ± 4.92 ^a	18.4 ± 3.81	17.2 ± 2.45
Body Fat (%)	19.6 ± 7.13	25.9 ± 10.1 ^a	26.9 ± 10.3 ^a	25.3 ± 10.4 ^a	20.3 ± 6.57
WC (cm)	58.5 ± 7.99	68.2 ± 13.7 ^a	69.1 ± 11.0 ^a	63.0 ± 10.3 ^b	57.0 ± 8.20
WHtR	0.41 ± 0.05	0.46 ± 0.08 ^a	0.47 ± 0.07 ^a	0.44 ± 0.07 ^a	0.41 ± 0.05
Blood pressure measures					
SBP (mmHg)	109 ± 10.5	112 ± 10.8	111 ± 10.1	112 ± 11.2	109 ± 9.44
DBP (mmHg)	66.1 ± 9.35	69.6 ± 8.69 ^b	69.4 ± 8.95 ^b	70.2 ± 9.60 ^b	66.5 ± 9.03

BMI: body mass index; %BF: percent body fat; WHtR: waist-to-height ratio; SBP: systolic blood pressure; DBP: diastolic blood pressure. Data is presented as mean ± SD. Each ethnicity was compared to the European group using one-way ANOVA, followed by Tukey's post hoc test. [†]Samoan, Tongan, Cook Islander, Fijian, Kiribati, Niuean; [‡]Indian, Fijian Indian, Pakistani, Sri Lankan, Bangladeshi; [§]Chinese, Korean, Japanese, Taiwanese, Cambodian, Thai, Lao, Filipino, Malaysian, Singaporean, Vietnamese, Burmese. ^aMean value significantly different to European (p<0.05). ^bMean value significantly different to European (p<0.001).

Chapter 4 Conclusion and Recommendations

4.1 Research Problem and Study Aims

High BP in childhood can have several short- and long-term consequences (Muntner et al., 2004). Sustained hypertension in children has been linked with TOD, including LVH and other vascular changes, that if left unmanaged could increase the risk of future CV complications (Litwin et al., 2010; Urbina et al., 2011). Studies have also shown that high BP levels in childhood can track into later life (Chen and Wang, 2008; Theodore et al., 2015).

As healthcare practitioners have regular contact with patients, they play a pivotal role in the prevention and detection of childhood conditions such as high BP. Routine BP monitoring facilitates early diagnosis, and thus helps to reduce the likelihood of long-term complications. Understanding the factors implicated in the development of high BP can help in the early identification of those at risk.

The aim of this study was to investigate the relationship between gender, ethnicity and obesity indices with raised BP in primary school-aged children.

4.2 The Main Findings of the Study

In this study, the proportion of children with elevated and hypertensive BP readings were 14.3% and 31.1%, respectively. The rates for elevated BP are comparable to those from other cross-sectional studies in children (Haas et al., 2014; Karatzi et al., 2017; Önsüz and Demir, 2015), while our level of hypertensive readings was considerably higher than other reports (Larkins et al., 2018; Kit et al., 2015; Urrutia-Rojas et al., 2006; Muhihi et al., 2018; Önsüz and Demir, 2015). This may be attributable to differences in the study populations and measurement techniques used.

One of the challenges of measuring BP is that readings can be falsely elevated by different factors, including anxiety (Flynn et al., 2017). In children, the prevalence of high BP has been shown to decrease by more than half from the first to the third screening (Sorof et al., 2004). For this reason, the most reliable estimates come from studies conducting repeated

measurements over several visits. Since we only assessed BP on a single occasion, the present findings are unlikely to reflect the true prevalence of elevated BP and hypertension in our sample.

Similar to previous studies (Rosaneli et al., 2014; Muhihi et al., 2018; Urrutia-Rojas et al., 2006), we found no significant differences in the odds of raised BP between boys and girls after adjusting for age and ethnicity. However, gender differences in childhood hypertension risk have been described elsewhere (Rosner et al., 2013; Dasgupta et al., 2006; Karatzi et al., 2017) and are usually attributed to differences in body composition (Gupta et al., 2018), activity levels (Durrani and Fatima, 2015), sex hormones (Ojeda et al., 2014) and pubertal stage (Karatzi et al., 2017).

We found that compared to European children, those of South Asian ethnicity had increased odds of presenting with raised BP. It has been shown that the risk of high BP may be greater among ethnic minority groups (Rosner et al., 2013). However, some investigators have found that after adjusting for potential confounders, ethnic differences in hypertension risk were no longer significant (Sorof et al., 2004; McNiece et al., 2007b). Of the common ethnicities, South Asians have the greatest risk of CV and metabolic diseases (Shai et al., 2006; Lee et al., 2001), which could be related to higher %BF and abdominal adiposity in this group compared to European (Lear et al., 2007; He et al., 2002). In our study, South Asian children had higher BMI, %BF and WHtR values than those of European ethnicity. As we could not adjust for these indices in our analysis, we were unable to determine whether the higher odds observed among South Asian children were independent of obesity. In order to reduce the disproportionate burden of disease among minority groups, further research is needed to examine ethnic disparities in paediatric hypertension risk.

Our findings showed that overweight and obesity, as indicated by BMI status, %BF and WHtR, were associated with increased odds of raised BP readings regardless of age, gender and ethnicity. These results are in agreement with several studies assessing the relationship between high BP and BMI (Meininger et al., 2010; Wang et al., 2015b), %BF (Bohn et al., 2015; Reich et al., 2003) and a WHtR ≥ 0.5 (Mishra et al., 2015; Maffei et al., 2010) in the paediatric age group. However, inconsistencies in the literature remain, with other studies suggesting

that the strength of this association may vary depending on BMI (Xu et al., 2018; Bohn et al., 2015), gender (Wang et al., 2015b) and age (Reich et al., 2003). Using a combination of general and central obesity indices may provide a better indication of high BP risk, particularly among Pacific Island (Rush et al., 2003) and Asian ethnic groups (Freedman et al., 2008; Hudda et al., 2017) where BMI may over or under estimate obesity. However, as obesity indices have been shown to have a low sensitivity for high BP (Ma et al., 2016), routine BP monitoring is also recommended among non-obese children.

In summary, the present findings suggest that South Asian ethnicity, an overweight or obese BMI status, high %BF and a WHtR ≥ 0.5 are possible risk factors for high BP in New Zealand children. By drawing attention to the potential magnitude of this issue and exposing gaps in the literature, this study may encourage further research in this field. This may provide the evidence required to guide public health initiatives in vulnerable communities and reinforce routine BP screenings during healthcare visits for those at risk. In turn, this will facilitate the identification of children with high BP, and thus ensure that lifestyle and medical interventions are introduced early to reverse or prevent further complications. In the long-term, this could contribute to reducing the prevalence and economic burden of high BP in both children and adults.

4.3 Strengths and Limitations of the Study

4.3.1 Strengths

The present study has a number of key strengths. Firstly, as this analysis was part of a wider study, we were able to access a large sample of children from different school deciles in Auckland, which increases statistical power. As a result of this, our cohort was representative of a range of body types and included children from different socioeconomic backgrounds. Our sample was also representative of the main ethnic groups in New Zealand (Statistics New Zealand, 2014), and there were relatively even numbers of Maori, Pacific Island, Asian and South Asian participants.

Moreover, the inclusion of several anthropometric measures in our analysis facilitates risk

assessments in healthcare settings by providing a range of options, and also helped to strengthen our findings surrounding the positive association between obesity and high BP.

Another strength of this study was the use of the BIA which provides a more accurate measure of %BF than other surrogate techniques (Kettaneh et al., 2005), and has also been validated against DEXA for estimating BF in New Zealand children (Delshad et al., 2018). More importantly, by being the first to discuss the rate of high BP and associated risk factors in New Zealand children, our study has paved the way for further research in this field.

4.3.2 Limitations

This study has some limitations that could potentially influence the validity of the findings. Due to the cross-sectional study design, our findings only provide a snapshot of the population and thus, causality cannot be inferred. Moreover, we only collected data from children attending schools in the Auckland region, and therefore our findings cannot be generalised to the wider population of New Zealand. The accuracy of the data collected via the demographics questionnaire was also dependent on caregivers' and children's literacy skills and willingness to share information. Other methods, such as conducting interviews, may have provided more accurate data, however, these are often more costly and time consuming.

A further limitation of this study was measuring BP on a single occasion, as opposed to taking measurements over three or more separate visits. Although other studies and surveys have followed a similar approach (Flynn et al., 2017; Rosner et al., 2013; Lazarou et al., 2009b; Martin et al., 2014), this practice is known to over-estimate the number of participants with high BP due to white coat hypertension.

Another factor that may have contributed to misclassification was the absence of normative BP data from New Zealand and use of reference values and definitions based on normative data from U.S. children. Furthermore, we only assessed a limited number of risk factors for high BP, with a strong focus on obesity indices. Due to multicollinearity between these measures, we were unable to adjust for obesity in our analysis, and therefore could not determine whether some of the variance in high BP was explained by ethnicity, gender or %BF alone.

Finally, we did not assess Tanner stage, or study other factors associated with BP such as family history, diet, exercise and socioeconomic status, which may have confounded our analysis.

4.4 Recommendations for Future Research

In order to gather the evidence required to inform clinical practice and health initiatives, further research in New Zealand is needed. The following are recommendations for future studies investigating risk factors for high BP in children:

- To accurately determine the presence of elevated BP or hypertension, BP should be measured three or more times, on three or more separate occasions. This will provide a more accurate indication of the prevalence of elevated BP and hypertension in New Zealand children. In order to do this, future studies may need to sample from several healthcare centres or employ a longitudinal study design.
- Investigate other factors that may be implicated in the development of high BP in children, including family history, dietary habits, socioeconomic status and physical activity. This may allow investigators to adjust for potential confounders to gain a better understanding of these associations.
- Evidence suggests that universal BMI cut-offs do not account for ethnic differences in body composition (World Health Organization, 2004). To improve the efficacy of BMI as a measure of excess adiposity and reduce misclassification, future studies should consider the use of ethnic specific threshold values (Cole and Lobstein, 2012). This will need to be balanced with the practicality of using multiple cut-off values in clinical settings.
- Ideally, future studies should ensure that their sample is representative of the main ethnic groups in New Zealand and include participants of different body weights and compositions.

Given the lack of evidence surrounding paediatric hypertension in New Zealand, further research is needed to understand the magnitude of the problem. The following are recommendations for future research:

- Since 2013, the New Zealand Health Survey has measured BP in adults and reported on the prevalence of raised BP and mean BP levels in the population (Ministry of Health, 2017c). This annual survey also collects data from children under the age of 14, and reports on a range of health-related topics, including nutrition, physical activity, body size, primary healthcare use and oral health (Ministry of Health, 2018b). If feasible, this survey should consider conducting BP measurements among pre-pubertal children.
- Investigate current BP screening practices in healthcare clinics and identify potential enablers and barriers to conducting routine measurements in children. It may also be important to assess the frequency of undiagnosed elevated BP and hypertension in New Zealand children.
- To investigate and compare the ability of different obesity indices to identify high BP in New Zealand children.

Appendices

Appendix A: Study Information Form

The Children's Bone Study

INFORMATION SHEET FOR PARENTS

Thank you for your interest in the children's bone study. This sheet gives information on the conduct and organisation of this study, including confidentiality and data protection. It is important that you read this and are happy with the information given before agreeing to take part in the study.

Why is this research important?

Anecdotal evidence suggests that a greater number of primary school children are having more broken bones than their grandparents did. We want to find out the relationships between history of broken bones, bone mineral density, dietary intake of nutrients related to bone health, beverage choices and preferences, physical activity, sun exposure behaviours and body composition of children living in Auckland.

Who are we looking for?

We are inviting around 600+ children who are enrolled in Year 5 or 6 in Auckland primary schools and who do not have any gastrointestinal disorders or bone disease to take part in this study. Each child and at least one of the child's parents/guardians need to be able to read and comprehend English to a sufficient level that they can understand the information provided about the study and make an informed decision about whether or not they wish to participate.

What is going to happen?

Initially, the children will have a science lesson, facilitated by our specialist science teacher, on the topic of bone health. Classroom sessions will be arranged at times to suit teachers and teaching schedules, and will be designed to link with curriculum. All data collection from the children will take place in school. They will also bring home a short questionnaire about different types of drinks which

the child must complete themselves. Further information will be sought from you, parents or caregivers, through two questionnaires, which your child will also bring home, along with a consent form.

One questionnaire will have questions about your child such as: Gender, date of birth, ethnicity, and information about any broken bones your child has had. Also history of sun exposure/sun protection practices, physical activity and type of sports your child plays. The second questionnaire is a food frequency questionnaire to find out about your child's milk/dairy product consumption, other beverage choices, and other dietary sources of calcium. These questionnaires will take approximately twenty (20) minutes to complete. You will only need to complete these questionnaires once.

All data collection from the children will take place in school. The children will have measurements made to determine their body composition (level of muscle and fat), and a finger prick blood spot to measure vitamin D levels. We will also measure the bone density of their heel bone using the quantitative ultra sound (QUS), and their blood pressure.

All the children in the class will be shown a short video which will explain all the things that will happen during the study. Your child will have the opportunity to ask both his/her teacher and the specialist teacher who is part of the study team, any questions about the study.

If you and your child decide against participating in the study, your child will still be involved in all the classroom activities associated with the study. There is no obligation to be part of the study, but we do ask that your child returns the envelope with the form in it.

Height and waist measurement

We will ask your child to remove his/her shoes due to measuring his/her height. Standing height using a stadiometer, and waist circumference using a measuring tape will be measured for each child.

Blood pressure

We will measure your child blood pressure with automated blood pressure monitor.



BIA (above left)

BIA is a method for measuring body composition. This machine is used to tell us how much fat and muscle mass your child has on his/her body. This test will take only a few minutes and won't hurt at all. We will ask your child to remove her/his shoes and socks, Stand on the machine's scale. Then hold the two handles for a few seconds (as in the picture). A very tiny electrical current passes through the body, but you cannot feel anything.

Quantitative Ultra Sound (QUS- above right)

Quantitative ultrasound is a radiation-free technique for providing a proxy for bone mineral density by determining how rapidly sound travels through the bone. We will ask your child to bare one of his/her legs (no shoes or socks) and then put his/her heel into the machine for less than one minute.

Who will see the information about your child?

All information about your child will be stored in a locked filing cabinet accessed by the research team only. No names or any other information that could be used to identify your child will be used in any publication.

We are required to keep any data that may be medically relevant for your child in the future for ten years. All electronic data will be stored password-protected on the University's secure

server. For the first 5 years we will store any paper copies of data in a locked filing cabinet within a locked office. For the remainder of the time, data will be stored in a secure archive in boxes labelled by barcode only. This data will be accessible by nominated staff only. After the mandatory storage time has passed, all data filed on paper will be shredded and electronic data will be deleted from our computer records and databases.

Would you like your child to take part?

If “YES”

If your child would like to take part in this study and you are happy for them to do so, please sign the attached consent form and ask your child to return it to their teacher.

If “NO”

If you do not want your child to participate or your child does not want to take part in this study then you do not need to complete or sign anything, just send the envelope full of forms back to class with your child. Your child will still take part in the special science lesson, but we will not collect any data from, or about, your child.

What are the benefits and risks of taking part in this study?

You will receive a brief report summarising the main findings of the project via mail or email.

The principal benefit of taking part in this study is that you will contribute to a study and our understanding of bone mineral density, dietary intake of nutrients related to bone health, beverage choices and preferences, physical activity, sun exposure behaviours and body composition of children.

It is not envisaged that there will be any discomforts or risks to the participants as a result of participation, other than the minor discomfort of the finger prick blood test.

If you have any specific requirements including cultural requirements or concerns about the project, or about being a participant, please contact a member of the research team to discuss.

Who is funding the research?

This is funded by a grant from the Massey University Research Fund.

What are my rights and the rights of my child?

We respect your rights and your child's rights to:

- Refuse to answer any particular question or take part in any testing (finger prick blood spot, QUS or BIA).
- Withdraw from the study at any time.
- Ask further questions about the study that occur to you during your participation.
- Provide information on the understanding that it is completely confidential to the researchers. All information is collected confidentially, and it will not be possible to identify you or your child in any reports that are prepared from the study.
- Be given access to a summary of the findings from the study when it is concluded.

Compensation for injury

In the unlikely event that physical injury results from your child's participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim from Massey University.

If you have any questions please contact Dr Pamela von Hurst who will be happy to discuss the project in more detail.

Contact details:

Dr Pamela von Hurst

School of Food and Nutrition, College of Health

Massey University

Email P.R.vonHurst@massey.ac.nz

Phone (09) 213 6657

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 16/42. If you have any concerns about the conduct of this research, please contact Mr Jeremy Hubbard, Chairperson, Massey University Human Ethics Committee: Southern A, telephone 64 9 414 0800 x 63487.

Appendix B: Parent and Child Consent Forms

Parent to complete this section:

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

- ☐ I agree for my child to participate in this study including the finger prick blood spot under the conditions set out in the Information Sheet.
- ☐ I agree for my child to participate in this study but not the finger prick blood spot under the conditions set out in the Information Sheet.

Signature:

Date:

Full Name (printed)

Child's Full Name

Child's date of birth

Any allergies and/or medication

Child to complete this section:

- ☐ I agree to participate in this study including the finger prick blood spot under the conditions set out in the Information Sheet.
- ☐ I agree to participate in this study but not the finger prick blood spot under the conditions set out in the Information Sheet.

Signature:

Date:

The Children's Bone Study

This questionnaire asks about your child's demographic details, fracture history, sun exposure, and physical activity levels

To be completed by parent or guardian

Thank you for participating in this study, if you have any questions please feel free to discuss them with the researcher.

Principal Investigator:

Dr Pamela von Hurst, School of Food and Nutrition, Massey University

Email: p.r.vonhurst@massey.ac.nz

All information you provide will remain strictly confidential

Participant Demographics

First Name of your child

.....

Family Name of your child

.....

Date of birth of your child

.....

Address

.....

.....

Phone (home)

.....

Phone (mobile)

.....

Email

.....

Which ethnic group or groups does your child belong to? (Please ✓ all that apply)

- New Zealand European ☐
- Maori ☐
- Pacific ☐ Please specify _____
- South Asian ☐
- Chinese ☐
- Korean ☐
- Southeast Asian ☐ Please specify _____
- Other ethnicity ☐ Please specify _____

How would you describe your child skin colour? (Please ✓ one)

- ☐ Fair Easily burns in the sun, doesn't tan
- ☐ Medium Can burn, but tans after some sun exposure
- ☐ Olive Rarely gets sunburnt, becomes quite tanned in summer
- ☐ Brown Light to medium brown, very rarely gets sunburnt
- ☐ Dark Very dark brown, never gets sunburnt

Is your child taking any medication or supplements? Please list

.....

.....

.....

Does your child have any chronic illness (for example, asthma) or food allergy? Please list

.....

.....

.....

Participant fracture history

Has your child ever been diagnosed with any bone fracture (broken bone)?

☐ Yes (Please put the details in the table)

☐ No (go to next page)

Which bone For instance: upper right arm, lower left leg	Age when it happened	How did it happen For instance: Fell out of a tree, fell off skateboard, was doing a cartwheel
1.		
2.		
3.		
4.		
5.		
6.		

Does your child have brothers and/or sisters who have also had a bone fracture?

☐ Yes ☐ No or ☐ No siblings

If yes, please note the details below:

Gender of sibling: Age when fractured:

Location of fracture

A large part of how strong our bones are is determined by our genes. Therefore, family history provides important information about the health of your child's bones.

Do any other family members have a history of broken bones or osteoporosis?

If so, please provide details over the page of relationship to child, the type of problem and approximate age when it occurred/emerged.

Sun light exposure

How many hours each day does your child usually spend outside in summer?

During school time

During weekends and holidays

Which part of his/her body is usually exposed to the sunlight?

- ☐ Only face
- ☐ Only arms
- ☐ Face and arms
- ☐ Only legs
- ☐ Arms and legs
- ☐ Face, arms, and legs

Does he/she use sunscreen cream?

- ☐ Yes - all year round ☐ Yes - only in summer
- ☐ No (go to next page)

If "Yes" how often does he/she use it?

- ☐ Always
- ☐ Some times
- ☐ Rarely
- ☐ Never

To which part of his/her body does he/she apply sunscreen?

- ☐ Only face
- ☐ Only arms
- ☐ Face and arms
- ☐ Only legs
- ☐ Arms and legs
- ☐ Face, arms, and legs

Physical activity levels

Does your child walk to school?

☐ Yes - approximately how far, or how long does the walk take?

☐ No

Does your child play sport or some other kind of physical activity like dance?

☐ Yes

☐ No

What kind of activity?

.....
.....

How many times each week does he/she do this activity?

.....
.....

How many hours is he/she active for each time?

.....
.....

Anything else you would like to tell us about your child?

.....
.....
.....
.....

Appendix D: Anthropometric Data Form

StudyID:			
School:			
Date:			
Name			
Date of Birth			
Age			
Gender (circle)	Male	Female	
Last drank (mins ago)			
Complete above this line only			
Height (cm)			
Weight (kg)			
Waist circumference (cm)			
BIA Body Fat %		Remove watches, rings, bracelets and necklaces	
QUS T-Score			
QUS Stiffness			
QUS BMD			
Blood Pressure			
Ave Heart Rate (bpm)			
Blood Spot complete			
HbA1c			
Notes			

References

- Adams HR, Szilagyi PG, Gebhardt L, et al. (2010) Learning and attention problems among children with pediatric primary hypertension. *The Journal of Pediatrics* 126: 1425-1429.
- AlGhatrif M, Strait JB, Morrell CH, et al. (2013) Longitudinal trajectories of arterial stiffness and the role of blood pressure. *Hypertension* 62: 934-941.
- Alpay H, Ozdemir N, Wuhl E, et al. (2009) Ambulatory blood pressure monitoring in healthy children with parental hypertension. *Pediatric Nephrology* 24: 155-161.
- American Academy of Pediatrics. (2004) The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents. *Journal of Pediatrics* 114: 555-576.
- Angelopoulos PD, Millionis HJ, Moschonis G, et al. (2006) Relations between obesity and hypertension: preliminary data from a cross-sectional study in primary schoolchildren: The children study. *European Journal of Clinical Nutrition* 60: 1226-1234.
- Arar MY, Hogg RJ, Arant BSJ, et al. (1994) Etiology of sustained hypertension in children in the southwestern United States. *Pediatric Nephrology* 8: 186-189.
- Arnaiz P, Grob F, Cavada G, et al. (2014) Waist-to-height ratio does not change with gender, age and pubertal stage in elementary school children. *Revista Médica de Chile* 142: 574-578.
- Asghari G, Yuzbashian E, Mirmiran P, et al. (2016) Dietary Approaches to Stop Hypertension (DASH) dietary pattern is associated with reduced incidence of metabolic syndrome in children and adolescents. *The Journal of Pediatrics* 174: 178-184.
- Ashwell M and Gibson S. (2014) A proposal for a primary screening tool: 'Keep your waist circumference to less than half your height'. *BMC Medicine* 12: 207-207.
- Ashwell M, Gunn P and Gibson S. (2012) Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obesity Reviews* 13: 275-286.
- Assadi F. (2007) Effect of microalbuminuria lowering on regression of left ventricular hypertrophy in children and adolescents with essential hypertension. *Pediatric Cardiology* 28: 27-33.
- Bao W, Threefoot SA, Srinivasan SR, et al. (1995) Essential hypertension predicted by tracking of elevated blood pressure from childhood to adulthood: The Bogalusa Heart Study. *American Journal of Hypertension* 8: 657-665.
- Baracco R, Kapur G, Mattoo T, et al. (2012) Prediction of primary vs secondary hypertension in children. *The Journal of Clinical Hypertension* 14: 316-321.
- Barba G, Casullo C, Dello Russo M, et al. (2008) Gender-related differences in the relationships between blood pressure, age, and body size in prepubertal children. *American Journal of Hypertension* 21: 1007-1010.
- Belfort MB, Rifas-Shiman SL, Rich-Edwards J, et al. (2007) Size at birth, infant growth, and blood pressure at three years of age. *The Journal of Pediatrics* 151: 670-674.
- Benjamin EJ, Virani SS, Callaway CW, et al. (2018) Heart Disease and Stroke Statistics-2018 Update: A Report From the American Heart Association. *Circulation* 137: 67-492.
- BioSpace InBody. (2017) *InBody 720 Results interpretation and Application*. Available at:

https://www.bodyanalyse.no/gammel/images/stories/inbody/dokumenter/Inbody_7_20_Results_Interpretation.pdf.

- Bohn B, Müller MJ, Simic-Schleicher G, et al. (2015) BMI or BIA: Is body mass index or body fat mass a better predictor of cardiovascular risk in overweight or obese children and adolescents? *The European Journal of Obesity* 8: 156-165.
- Bowers K, Liu G, Wang P, et al. (2011) Birth weight, postnatal weight change, and risk for high blood pressure among chinese children. *The Journal of Pediatrics* 127: 1272-1279.
- Brady TM, Fivush B, Flynn JT, et al. (2008) Ability of blood pressure to predict left ventricular hypertrophy in children with primary hypertension. *The Journal of Pediatrics* 152: 73-78.
- Brady TM, Fivush B, Parekh RS, et al. (2010a) Racial differences among children with primary hypertension. *The Journal of Pediatrics* 126: 931-937.
- Brady TM, Solomon BS, Neu AM, et al. (2010b) Patient-, provider-, and clinic-level predictors of unrecognized elevated blood pressure in children. *The Journal of Pediatrics* 125: 1286-1293.
- Brambilla P, Bedogni G, Heo M, et al. (2013) Waist circumference-to-height ratio predicts adiposity better than body mass index in children and adolescents. *International Journal Of Obesity* 37: 943-946.
- Brion MA, Ness AR, Davey Smith G, et al. (2007) Association between body composition and blood pressure in a contemporary cohort of 9-year-old children. *Journal of Human Hypertension* 21: 283-290.
- Browning LM, Hsieh SD and Ashwell M. (2010) A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0.5 could be a suitable global boundary value. *Nutrition Research Reviews* 23: 247-269.
- Buchan DS, Boddy LM, Grace FM, et al. (2017) Utility of three anthropometric indices in assessing the cardiometabolic risk profile in children. *American Journal of Human Biology* 29: e22934.
- Burke V, Gracey MP, Beilin LJ, et al. (1998) Family history as a predictor of blood pressure in a longitudinal study of Australian children. *Hypertension* 16: 269-276.
- Burt VL, Whelton P, Roccella EJ, et al. (1995) Prevalence of hypertension in the US adult population. Results from the Third National Health and Nutrition Examination Survey, 1988-1991. *Hypertension* 25: 305-313.
- Campagnolo PD, Hoffman DJ and Vitolo MR. (2011) Waist-to-height ratio as a screening tool for children with risk factors for cardiovascular disease. *Annals of Human Biology* 38: 265-270.
- Cao ZQ, Zhu L, Zhang T, et al. (2012) Blood pressure and obesity among adolescents: A school-based population study in China. *American Journal of Hypertension* 25: 576-582.
- Chen HH, Chen YL, Huang CY, et al. (2010) Effects of one-year swimming training on blood pressure and insulin sensitivity in mild hypertensive young patients. *Chinese Journal Physiology* 53: 185-189.
- Chen X and Wang Y. (2008) Tracking of blood pressure from childhood to adulthood: A systematic review and meta-regression analysis. *Circulation* 117: 3171-3180.
- Cheung EL, Bell CS, Samuel JP, et al. (2017) Race and obesity in adolescent hypertension. *The Journal of Pediatrics* 139: e20161433.
- Chiolero A, Cachat F, Burnier M, et al. (2007) Prevalence of hypertension in schoolchildren

- based on repeated measurements and association with overweight. *Hypertension* 25: 2209-2217.
- Chiras DD. (2011) *Human Biology*, Sudbury, Massachusetts: Jones & Bartlett Learning, LLC.
- Choy C-S, Chan W-Y, Chen C-H, et al. (2012) Waist-to-height ratio and elevated blood pressure among children in Taiwan. *Indian Pediatrics* 49: 463-466.
- Cohen JFW, Lehnerd ME, Houser RF, et al. (2017) Dietary Approaches to Stop Hypertension Diet, weight status, and blood pressure among children and adolescents: National Health and Nutrition Examination Surveys 2003-2012. *Journal of the Academy of Nutrition and Dietetics* 117: 1437-1444.
- Cole TJ, Bellizzi MC, Flegal KM, et al. (2000) Establishing a standard definition for child overweight and obesity worldwide: International survey. *The BMJ* 320: 1240-1240.
- Cole TJ, Freeman JV and Preece MA. (1998) British 1990 growth reference centiles for weight, height, body mass index and head circumference fitted by maximum penalized likelihood. *Statistics in Medicine* 17: 407-429.
- Cole TJ and Lobstein T. (2012) Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatric Obesity* 7: 284-294.
- Couch SC, Saelens BE, Levin L, et al. (2008) The efficacy of a clinic-based behavioral nutrition intervention emphasizing a DASH-type diet for adolescents with elevated blood pressure. *The Journal of Pediatrics* 152: 494-501.
- Crossen K. (2017) Hypertension: under recorded and under recognised in general paediatric outpatient clinics. *Journal of Comprehensive Pediatrics* 8: 553-563.
- Curcio S, García-Espinosa V, Castro JM, et al. (2017) High blood pressure states in children, adolescents, and young adults associate accelerated vascular aging, with a higher impact in females' arterial properties. *Pediatric Cardiology* 38: 840-852.
- Daley MF, Sinaiko AR, Reifler LM, et al. (2013) Patterns of care and persistence after incident elevated blood pressure. *The Journal of Pediatrics* 132: e349-e355.
- Daniels SR. (2009) The use of BMI in the clinical setting. *The Journal of Pediatrics* 124: 35-41.
- Daniels SR, Lipman MJ, Burke MJ, et al. (1991) The prevalence of retinal vascular abnormalities in children and adolescents with essential hypertension. *American Journal Ophthalmology* 111: 205-208.
- Dasgupta K, O'Loughlin J, Chen S, et al. (2006) Emergence of sex differences in prevalence of high systolic blood pressure: Analysis of a longitudinal adolescent cohort. *Circulation* 114: 2663-2670.
- Davis CL, Flickinger B, Moore D, et al. (2005) Prevalence of cardiovascular risk factors in schoolchildren in a rural Georgia community. *The American Journal of the Medical Sciences* 330: 53-59.
- de Moraes ACF, Lacerda MB, Moreno LA, et al. (2014) Prevalence of high blood pressure in 122,053 adolescents: A systematic review and meta-regression. *Medicine* 93: e232.
- de Onis M, Onyango AW, Borghi E, et al. (2007) Development of a WHO growth reference for school-aged children and adolescents. Geneva: World Health Organization, 660-667.
- de Simone G, Devereux RB, Daniels SR, et al. (1995) Effect of growth on variability of left ventricular mass: Assessment of allometric signals in adults and children and their capacity to predict cardiovascular risk. *Journal of the American College of Cardiology* 25: 1056-1062.
- Dekkers JC, Snieder H, van den Oord EJCG, et al. (2002) Moderators of blood pressure

- development from childhood to adulthood: A 10-year longitudinal study. *The Journal of Pediatrics* 141: 770-779.
- Delshad M, Beck KL, Conlon CA, et al. (2018) Validity of quantitative ultrasound and bioelectrical impedance analysis against dual X-ray absorptiometry for measuring bone quality and body composition in children. *Proceedings of the Nutrition Society of New Zealand Annual Meeting*. Auckland
- Deurenberg-Yap M, Chew SK, Lin VF, et al. (2001) Relationships between indices of obesity and its co-morbidities in multi-ethnic Singapore. *International Journal of Obesity Related Metabolic Disorders* 25: 1554-1562.
- Diaz A and Calandra L. (2017) High blood pressure in school children and adolescents in Argentina over the past 25 years: A systematic review of observational studies. *Archivos Argentinos De Pediatría* 115: 5-11.
- Dionne JM. (2017) Updated guideline may improve the recognition and diagnosis of hypertension in children and adolescents; Review of the 2017 AAP Blood Pressure Clinical Practice Guideline. *Current Hypertension Reports* 19.
- Dobson CP, Eide M and Nylund CM. (2015) Hypertension prevalence, cardiac complications, and antihypertensive medication use in children. *The Journal of Pediatrics* 167: 92-97.
- Dong B, Wang Z, Yang Y, et al. (2016) Intensified association between waist circumference and hypertension in abdominally overweight children. *Obesity research & clinical practice* 10: 24-32.
- Dong Y, Ma J, Song Y, et al. (2018) Secular trends in blood pressure and overweight and obesity in Chinese boys and girls aged 7 to 17 years from 1995 to 2014. *Hypertension* 71.
- Drozdz D, Kwinta P, Korohoda P, et al. (2009) Correlation between fat mass and blood pressure in healthy children. *Pediatric Nephrology* 24: 1735-1740.
- Duncanson M, Oben G, Wicken A, et al. (2017) Child Poverty Monitor: Technical Report. Dunedin: New Zealand Child and Youth Epidemiology Service, University of Otago.
- Durrani AM and Fatima W. (2015) Effect of physical activity on blood pressure distribution among school children. *Advances in Public Health* 2015: 1-4.
- Ehret GB, Munroe PB, Rice KM, et al. (2011) Genetic variants in novel pathways influence blood pressure and cardiovascular disease risk. *Nature* 478: 103-109.
- Ehtisham S, Hattersley AT, Dunger DB, et al. (2004) First UK survey of paediatric type 2 diabetes and MODY. *Archives of Disease in Childhood* 89: 526-529.
- Eisenmann JC. (2005) Waist circumference percentiles for 7- to 15-year-old Australian children. *Acta Paediatrica* 94: 1182-1185.
- Essouma M, Noubiap JJN, Bigna JJR, et al. (2015) Hypertension prevalence, incidence and risk factors among children and adolescents in Africa: a systematic review and meta-analysis protocol. *The BMJ* 5.
- Evans A, Van Baal GC, McCarron P, et al. (2003) The genetics of coronary heart disease: the contribution of twin studies. *Twin Research* 6: 432-441.
- Falkner B. (2010) Hypertension in children and adolescents: Epidemiology and natural history. *Pediatric Nephrology* 25: 1219-1224.
- Falkner B, Gidding SS, Ramirez-Garnica G, et al. (2006) The relationship of body mass index and blood pressure in primary care pediatric patients. *The Journal of Pediatrics* 148: 195-200.
- Fallah Z, Kelishadi R, Heshmat R, et al. (2015) A nationwide report on blood pressure of

- children and adolescents according to socioeconomic status: The CASPIAN-IV study. *Journal of Research in Medical Sciences* 20: 646-655.
- Farpour-Lambert NJ, Aggoun Y, Marchand LM, et al. (2009) Physical activity reduces systemic blood pressure and improves early markers of atherosclerosis in pre-pubertal obese children. *Journal of the American College of Cardiology* 54: 2396-2406.
- Feber J and Ahmed M. (2010) Hypertension in children: new trends and challenges. *Clinical Science* 119: 151-161.
- Feld LG and Springate JE. (1988) Hypertension in children. *Current Problems in Pediatric and Adolescent Health Care* 18: 317-373.
- Flores-Huerta S, Klünder-Klünder M, Reyes de la Cruz L, et al. (2009) Increase in body mass index and waist circumference is associated with high blood pressure in children and adolescents in Mexico City. *Archives of Medical Research* 40: 208-215.
- Flynn J and Alderman M. (2005) Characteristics of children with primary hypertension seen at a referral center. *Pediatric Nephrology* 20: 961-966.
- Flynn J, Ingelfinger JR and Portman RJ. (2013) *Pediatric Hypertension*, Cham, Switzerland: Springer Science & Business Media.
- Flynn J, Zhang Y, Solar-Yohay S, et al. (2012) Clinical and demographic characteristics of children with hypertension. *Hypertension* 60: 1047-1054.
- Flynn JT. (2001) Evaluation and management of hypertension in childhood. *Progress in Pediatric Cardiology* 12: 177-188.
- Flynn JT, Kaelber DC, Baker-Smith CM, et al. (2017) Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents. *The Journal of Pediatrics* 140.
- Flynn JT and Tullus K. (2008) Severe hypertension in children and adolescents: Pathophysiology and treatment. *Pediatric Nephrology* 24: 1101-1112.
- Foster BJ, Ali H, Mamber S, et al. (2009) Prevalence and severity of hypertensive retinopathy in children. *Clinical Pediatrics* 48: 926-930.
- Franklin SS, Lopez VA, Wong ND, et al. (2009) Single versus combined blood pressure components and risk for cardiovascular disease: The Framingham Heart Study. *Circulation* 119: 243-250.
- Fredriksen PM, Skår A and Mamen A. (2018) Waist circumference in 6–12-year-old children: The Health Oriented Pedagogical Project (HOPP). *Scandinavian Journal of Public Health* 46: 12-20.
- Freedman DS, Goodman A, Contreras OA, et al. (2012) Secular trends in BMI and blood pressure among children and adolescents: The Bogalusa Heart Study. *The Journal of Pediatrics* 130: 159-166.
- Freedman DS, Kahn HS, Mei Z, et al. (2007) Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: The Bogalusa Heart Study. *The American Journal of Clinical Nutrition* 86: 33-40.
- Freedman DS and Sherry B. (2009) The validity of BMI as an indicator of body fatness and risk among children. *The Journal of Pediatrics* 124: 23-34.
- Freedman DS, Wang J, Maynard LM, et al. (2004) Relation of BMI to fat and fat-free mass among children and adolescents. *International Journal Of Obesity* 29: 1.
- Freedman DS, Wang J, Thornton JC, et al. (2008) Racial/ethnic differences in body fatness among children and adolescents. *Obesity* 16: 1105-1111.

- Friedemann C, Heneghan C, Mahtani K, et al. (2012) Cardiovascular disease risk in healthy children and its association with body mass index: Systematic review and meta-analysis. *The BMJ* 345: e4759.
- Fryar C, Gu Q, Ogden C, et al. (2016) Anthropometric reference data for children and adults: United States, 2011–2014. *National Center for Health Statistics* 3.
- Genovesi S, Antolini L, Giussani M, et al. (2010) Hypertension, prehypertension, and transient elevated blood pressure in children: Association with weight excess and waist circumference. *American Journal of Hypertension* 23: 756-761.
- Genovesi S, Antolini L, Giussani M, et al. (2008) Usefulness of waist circumference for the identification of childhood hypertension. *Hypertension* 26: 1563-1570.
- Genovesi S, Giussani M, Pieruzzi F, et al. (2005) Results of blood pressure screening in a population of school-aged children in the province of Milan: Role of overweight. *Hypertension* 23: 493-497.
- Gentles D, Metcalf P, Dyal L, et al. (2006) Blood pressure prevalences and levels for a multicultural population in Auckland, New Zealand: Results from the Diabetes, Heart and Health Survey 2002/2003. *The New Zealand Medical Journal* 119.
- Gilbert S and Weiner DE. (2017) *National Kidney Foundation Primer on Kidney Diseases*: Elsevier Health Sciences.
- Global Burden of Disease Collaborative Network. (2017) Global Burden of Disease Study 2016 (GBD 2016) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME).
- Gordon FK, Ferguson EL, Toafa V, et al. (2003) High levels of childhood obesity observed among 3- to 7-year-old New Zealand Pacific children is a public health concern. *The Journal of Nutrition* 133: 3456-3460.
- Goulding A, Taylor RW, Grant AM, et al. (2010) Waist-to-height ratios in relation to BMI z-scores in three ethnic groups from a representative sample of New Zealand children aged 5–14 years. *International Journal Of Obesity* 34: 1188.
- Guo F, He D, Zhang W, et al. (2012) Trends in prevalence, awareness, management, and control of hypertension among United States adults, 1999 to 2010. *Journal of the American College of Cardiology* 60: 599-606.
- Gupta A, Sachdeva A, Mahajan N, et al. (2018) Prevalence of pediatric metabolic syndrome and associated risk factors among school-age children of 10-16 Years living in District Shimla, Himachal Pradesh, India. *Indian Journal of Endocrinology and Metabolism* 22: 373-378.
- Gupta-Malhotra M, Banker A, Shete S, et al. (2015) Essential hypertension vs. secondary hypertension among children. *American Journal of Hypertension* 28: 73-80.
- Haas GM, Bertsch T and Schwandt P. (2014) Prehypertension and cardiovascular risk factors in children and adolescents participating in the community-based prevention education program family heart study. *International Journal of Preventive Medicine* 5: 50-56.
- Hajjar I and Kotchen TA. (2003) Trends in prevalence, awareness, treatment, and control of hypertension in the United States, 1988-2000. *The Journal of the American Medical Association* 290: 199-206.
- Hanevold C, Waller J, Daniels S, et al. (2004) The effects of obesity, gender, and ethnic group on left ventricular hypertrophy and geometry in hypertensive children: A collaborative

- study of the International Pediatric Hypertension Association. *The Journal of Pediatrics* 113: 328-333.
- Hansen ML, Gunn PW and Kaelber DC. (2007) Underdiagnosis of hypertension in children and adolescents. *The Journal of the American Medical Association* 298: 874-879.
- Harding S, Maynard M, Cruickshank JK, et al. (2006) Anthropometry and blood pressure differences in black Caribbean, African, South Asian and white adolescents: The MRC DASH study. *Hypertension* 24: 1507-1514.
- Harding S, Whitrow M, Lenguerrand E, et al. (2010) Emergence of ethnic differences in blood pressure in adolescence: The determinants of adolescent social well-being and health study. *Hypertension* 55: 1063-1069.
- Hardy ST, Holliday KM, Chakladar S, et al. (2017) Heterogeneity in blood pressure transitions over the life course: Age-specific emergence of racial/ethnic and sex disparities in the United States. *The Journal of the American Medical Association* 2: 653-661.
- Haroun D, Taylor SJC, Viner RM, et al. (2010) Validation of bioelectrical impedance analysis in adolescents across different ethnic groups. *Obesity* 18: 1252-1259.
- Harshfield GA, Alpert BS, Pulliam DA, et al. (1994) Ambulatory blood pressure recordings in children and adolescents. *The Journal of Pediatrics* 94: 180-184.
- Hartiala O, Magnussen CG, Kajander S, et al. (2012) Adolescence risk factors are predictive of coronary artery calcification at middle age: The Cardiovascular Risk in Young Finns Study. *Journal of the American College of Cardiology* 60: 1364-1370.
- Havranek EP, Froshaug DB, Emserman CDB, et al. (2008) Left ventricular hypertrophy and cardiovascular mortality by race and ethnicity. *The American Journal of Medicine* 121: 870-875.
- Havranek EP, Mujahid MS, Barr DA, et al. (2015) Social Determinants of Risk and Outcomes for Cardiovascular Disease: A Scientific Statement From the American Heart Association. *Circulation* 132: 873-898.
- He Q, Horlick M, Thornton J, et al. (2002) Sex and race differences in fat distribution among Asian, African-American, and Caucasian prepubertal children. *The Journal of Clinical Endocrinology & Metabolism* 87: 2164-2170.
- Henderson EJ, Jones CH, Hornby-Turner YC, et al. (2011) Adiposity and blood pressure in 7- to 11-year-old children: comparison of British Pakistani and white British children, and of British Pakistani children of migrant and British-born mothers. *The American Journal of Human Biology* 23: 710-716.
- Herd SL, Gower BA, Dashti N, et al. (2001) Body fat, fat distribution and serum lipids, lipoproteins and apolipoproteins in African-American and Caucasian-American prepubertal children. *International Journal Of Obesity* 25: 198-204.
- Herouvi D, Karanasios E, Karayianni C, et al. (2013) Cardiovascular disease in childhood: The role of obesity. *European Journal of Pediatrics* 172: 721-732.
- Hoehn K and Marieb E. (2015) *Human Anatomy and Physiology*, Harlow, United Kingdom: Pearson Education Limited.
- Holmes L, Hossain J, Ward D, et al. (2013) Racial/ethnic variability in hypertension prevalence and risk factors in national health interview survey. *ISRN Hypertension* 8: 8.
- Hu J, Chu G-p, Huang F-f, et al. (2016) Relation of body mass index (BMI) to the prevalence of hypertension in children: A 3 years' school-based prospective study in Suzhou, China. *International Journal of Cardiology* 222: 270-274.

- Hu Y-H, Reilly K, Liang Y-J, et al. (2011) Increase in body mass index, waist circumference and waist-to-height ratio is associated with high blood pressure in children and adolescents in China. *Journal of International Medical Research* 39: 23-92.
- Hudda MT, Nightingale CM, Donin AS, et al. (2017) Body mass index adjustments to increase the validity of body fatness assessment in UK Black African and South Asian children. *International Journal Of Obesity* 41: 1048-1055.
- Huxley R, Mendis S, Zheleznyakov E, et al. (2009) Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk: A review of the literature. *European Journal of Clinical Nutrition* 64: 16-22.
- Jackson LV, Thalange NK and Cole TJ. (2007) Blood pressure centiles for Great Britain. *Archives of Disease in Childhood* 92: 298-303.
- Jafar TH, Islam M, Poulter N, et al. (2005) Children in South Asia have higher body mass-adjusted blood pressure levels than white children in the United States. *Circulation* 111: 1291-1297.
- Janssen I and LeBlanc AG. (2010) Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity* 7: 40.
- Javed A, Jumean M, Murad MH, et al. (2015) Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: A systematic review and meta-analysis. *Pediatric Obesity* 10: 234-244.
- Juhola J, Magnussen CG, Berenson GS, et al. (2013) Combined effects of child and adult elevated blood pressure on subclinical atherosclerosis: The International Childhood Cardiovascular Cohort Consortium. *Circulation* 128: 217-224.
- Juhola J, Oikonen M, Magnussen CG, et al. (2012) Childhood physical, environmental, and genetic predictors of adult hypertension. *Circulation* 126: 402-409.
- Juonala M, Viikari JSA, Rönnemaa T, et al. (2006) Elevated blood pressure in adolescent boys predicts endothelial dysfunction. *Hypertension* 48: 424-430.
- Kaczmarek M, Stawińska-Witoszyńska B, Krzyżaniak A, et al. (2015) Who is at higher risk of hypertension? Socioeconomic status differences in blood pressure among Polish adolescents: A population-based ADOPOLNOR study. *European Journal of Pediatrics* 174: 1461-1473.
- Kahn HS, Imperatore G and Cheng YJ. (2005) A population-based comparison of BMI percentiles and waist-to-height ratio for identifying cardiovascular risk in youth. *The Journal of Pediatrics* 146: 482-488.
- Kapur G, Ahmed M, Pan C, et al. (2010) Secondary hypertension in overweight and stage 1 hypertensive children: A midwest pediatric nephrology consortium report. *The Journal of Clinical Hypertension* 12: 34-39.
- Kapur G and Mattoo TK. (2018) Primary Hypertension in Children. In: Flynn JT, Ingelfinger JR and Redwine KM (eds) *Pediatric Hypertension*. Cham: Springer International Publishing, 405-429.
- Karatzis K, Protogerou AD, Moschonis G, et al. (2017) Prevalence of hypertension and hypertension phenotypes by age and gender among schoolchildren in Greece: The Healthy Growth Study. *Atherosclerosis* 259: 128-133.
- Katona É, Zrínyi M, Lengyel S, et al. (2011) The prevalence of adolescent hypertension in Hungary: The Debrecen Hypertension Study. *Blood Pressure* 20: 134-139.

- Keefer DJ, Caputo JL and Tseh W. (2013) Waist-to-height ratio and body mass index as indicators of cardiovascular risk in youth. *Journal of School Health* 83: 805-809.
- Kelishadi R, Mirmoghtadaee P, Najafi H, et al. (2015) Systematic review on the association of abdominal obesity in children and adolescents with cardio-metabolic risk factors. *Journal of Research in Medical Sciences* 20: 294-307.
- Kelley GA, Kelley KS and Tran ZV. (2003) The effects of exercise on resting blood pressure in children and adolescents: A meta-analysis of randomized controlled trials. *Preventive Cardiology* 6: 8-16.
- Kelly RK, Thomson R, Smith KJ, et al. (2015) Factors affecting tracking of blood pressure from childhood to adulthood: The Childhood Determinants of Adult Health Study. *The Journal of Pediatrics* 167: 1422-1428.e1422.
- Kettaneh A, Heude B, Lommez A, et al. (2005) Reliability of bioimpedance analysis compared with other adiposity measurements in children: The FLVS II Study. *Diabetes & Metabolism* 31: 534-541.
- Khadilkar A, Ekbote V, Chiplonkar S, et al. (2014) Waist circumference percentiles in 2-18 year old Indian children. *The Journal of Pediatrics* 164: 1358-1362.
- Khanna N, Sharma RS and Sidhu RS. (2011) A study of the basic and derived anthropometric indices among the healthy adults (20-30 years of age) of amritsar city (punjab) having family history of hypertension. *International Journal of Biological & Medical Research* 2: 743-746.
- Khoury M, Manlhiot C, Dobbin S, et al. (2012) Role of waist measures in characterizing the lipid and blood pressure assessment of adolescents classified by body mass index. *The Archives of Pediatrics & Adolescent Medicine* 166: 719-724.
- King CA, Meadows BB, Engelke MK, et al. (2006) Prevalence of elevated body mass index and blood pressure in a rural school-aged population: Implications for school nurses. *Journal of School Health* 76: 145-149.
- Kit BK, Kuklina E, Carroll MD, et al. (2015) Prevalence of and trends in dyslipidemia and blood pressure among US children and adolescents, 1999-2012. *Journal of the American Medical Association Pediatrics* 169: 272-279.
- Klimentidis YC, Dulin-Keita A, Casazza K, et al. (2011) Genetic admixture, social-behavioural factors and body composition are associated with blood pressure differently by racial-ethnic group among children. *Journal of Human Hypertension* 26: 98.
- Koebnick C, Black MH, Wu J, et al. (2013a) High blood pressure in overweight and obese youth: Implications for screening. *The Journal of Clinical Hypertension* 15: 793-805.
- Koebnick C, Black MH, Wu J, et al. (2013b) The prevalence of primary pediatric prehypertension and hypertension in a real-world managed care system. *The Journal of Clinical Hypertension* 15: 784-792.
- Kollias A, Dafni M, Poulidakis E, et al. (2014) Out-of-office blood pressure and target organ damage in children and adolescents: A systematic review and meta-analysis. *Hypertension* 32: 2315-2331.
- Kotchen TA. (2010) Obesity-related hypertension: Epidemiology, pathophysiology, and clinical management. *American Journal of Hypertension* 23: 1170-1178.
- Kovacs VA, Gabor A, Fajcsak Z, et al. (2010) Role of waist circumference in predicting the risk of high blood pressure in children. *International Journal of Pediatric Obesity* 5: 143-150.

- Kromeyer-Hauschild K, Neuhauser H, Schaffrath Rosario A, et al. (2013) Abdominal obesity in German adolescents defined by waist-to-height ratio and its association to elevated blood pressure: The KiGGS Study. *Obesity Facts* 6: 165-175.
- Krupp D, Shi L, Egert S, et al. (2015) Prospective relevance of fruit and vegetable consumption and salt intake during adolescence for blood pressure in young adulthood. *European Journal of Nutrition* 54: 1269-1279.
- Kuczmarski RJ, Ogden CL and Guo SS. (2002) 2000 CDC growth charts for the United States: Methods and development. National Center for Health Statistics.
- Kupferman JC, Aronson Friedman L, Cox C, et al. (2014) Blood pressure control and left ventricular hypertrophy regression in children with CKD. *Journal of the American Society of Nephrology* 25: 167-174.
- Kupper N, Willemsen G, Riese H, et al. (2005) Heritability of daytime ambulatory blood Pressure in an extended twin design. *Hypertension* 45: 80-85.
- Kwak SG and Kim JH. (2017) Central limit theorem: The cornerstone of modern statistics. *Korean Journal of Anesthesiology* 70: 144-156.
- Kyle UG, Bosaeus I, De Lorenzo AD, et al. (2004) Bioelectrical impedance analysis part II: Utilization in clinical practice. *Clinical Nutrition* 23: 1430-1453.
- Laar RJJ, Stehouwer CDA, Bussel BCT, et al. (2013) Adherence to a Mediterranean dietary pattern in early life is associated with lower arterial stiffness in adulthood: The Amsterdam Growth and Health Longitudinal Study. *Journal of Internal Medicine* 273: 79-93.
- Lakshmi S, Metcalf B, Joglekar C, et al. (2012) Differences in body composition and metabolic status between white U.K. and Asian Indian children (EarlyBird 24 and the Pune Maternal Nutrition Study). *Pediatric Obesity* 7: 347-354.
- Lande MB, Batisky DL, Kupferman JC, et al. (2017) Neurocognitive function in children with primary hypertension. *The Journal of Pediatrics* 180: 148-155.
- Lande MB, Carson NL, Roy J, et al. (2006) Effects of childhood primary hypertension on carotid intima media thickness: A matched controlled study. *Hypertension* 48: 40-44.
- Lande MB, Gerson AC, Hooper SR, et al. (2011) Casual blood pressure and neurocognitive function in children with chronic kidney disease: A report of the children with chronic Kidney disease cohort study. *Clinical Journal of the American Society of Nephrology* 6: 1831-1837.
- Lande MB, Kaczorowski JM, Auinger P, et al. (2003) Elevated blood pressure and decreased cognitive function among school-age children and adolescents in the United States. *The Journal of Pediatrics* 143: 720-724.
- Larkins NG, Teixeira-Pinto A and Craig JC. (2018) The prevalence and predictors of hypertension in a National Survey of Australian Children *Blood Pressure* 27: 41-47.
- Łątka M, Wójtowicz K, Drożdż T, et al. (2016) Relationship between water compartments, body composition assessed by bioelectrical impedance analysis and blood pressure in school children. *Przegląd Lekarski* 73: 1-5.
- Lazarou C, Panagiotakos DB and Matalas A-L. (2009a) Foods E-KINDEX: A dietary index associated with reduced blood pressure levels among young children: The CYKIDS Study. *Journal of the American Dietetic Association* 109: 1070-1075.
- Lazarou C, Panagiotakos DB and Matalas AL. (2009b) Lifestyle factors are determinants of children's blood pressure levels: The CYKIDS study. *Journal of Human Hypertension* 23:

456-463.

- Lean MEJ, Han TS and Morrison CE. (1995) Waist circumference as a measure for indicating need for weight management. *The BMJ* 311: 158-161.
- Lear SA, Humphries KH, Kohli S, et al. (2007) The use of BMI and waist circumference as surrogates of body fat differs by ethnicity. *Obesity* 15: 2817-2824.
- Lee CMY, Huxley RR, Wildman RP, et al. (2008) Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: A meta-analysis. *Journal of Clinical Epidemiology* 61: 646-653.
- Lee J, Heng D, Chia KS, et al. (2001) Risk factors and incident coronary heart disease in Chinese, Malay and Asian Indian males: The Singapore Cardiovascular Cohort Study. *International Journal of Epidemiology* 30: 983-988.
- Levy D, Ehret GB, Rice K, et al. (2009) Genome-wide association study of blood pressure and hypertension. *Nature Genetics* 41: 677-687.
- Levy D and et al. (2009) Genome-wide association study of blood pressure and hypertension. *Nature Reviews Nephrology* 41: 677-687.
- Leyvraz M, Chatelan A, da Costa BR, et al. (2018) Sodium intake and blood pressure in children and adolescents: A systematic review and meta-analysis of experimental and observational studies. *International Journal of Epidemiology* 47: 1796-1810.
- Li S, Chen W, Srinivasan SR, et al. (2004) Childhood blood pressure as a predictor of arterial stiffness in young adults: The Bogalusa Heart Study. *Hypertension* 43: 541-546.
- Li Z, Dahlof B, Okin PM, et al. (2008) Left bundle branch block and cardiovascular morbidity and mortality in hypertensive patients with left ventricular hypertrophy: The Losartan Intervention For Endpoint Reduction in Hypertension Study. *Hypertension* 26: 1244-1249.
- Liang Y-J, Xi B, Hu Y-H, et al. (2011) Trends in blood pressure and hypertension among Chinese children and adolescents: China Health and Nutrition Surveys 1991–2004. *Blood Pressure* 20: 45-53.
- Lim SS, Vos T, Flaxman AD, et al. (2012) A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet* 380: 2224-2260.
- Litwin M, Niemirska A, Sladowska J, et al. (2006) Left ventricular hypertrophy and arterial wall thickening in children with essential hypertension. *Pediatric Nephrology* 21: 811-819.
- Litwin M, Niemirska A, Śladowska-Kozłowska J, et al. (2010) Regression of target organ damage in children and adolescents with primary hypertension. *Pediatric Nephrology* 25: 2489-2499.
- Liu A, Byrne NM, Kagawa M, et al. (2011) Ethnic differences in the relationship between body mass index and percentage body fat among Asian children from different backgrounds. *British Journal of Nutrition* 106: 1390-1397.
- Liu WJ, Xiong LH, Guo CS, et al. (2017) Weight status, cardiorespiratory fitness and high blood pressure relationship among 5–12-year-old Chinese primary school children. *Journal of Human Hypertension* 31: 808-814.
- Lo JC, Sinaiko A, Chandra M, et al. (2013) Prehypertension and hypertension in community-based pediatric practice. *The Journal of Pediatrics* 131: 415-424.
- Lobor Cancelier A, Trevisol D and Schuelter-Trevisol F. (2018) Waist-to-height ratio as a

- screening tool for childhood obesity: A systematic literature review. *Annals of Pediatrics & Child Health* 6: 1141-1147.
- Lu Y, Luo B, Xie J, et al. (2018) Prevalence of hypertension and prehypertension and its association with anthropometrics among children: A cross-sectional survey in Tianjin, China. *Journal of Human Hypertension* 32: 789-798.
- Lubrano R, Travasso E, Raggi C, et al. (2008) Blood pressure load, proteinuria and renal function in pre-hypertensive children. *Pediatric Nephrology* 24: 823-831.
- Lurbe E, Agabiti-Rosei E, Cruickshank JK, et al. (2016) 2016 European Society of Hypertension guidelines for the management of high blood pressure in children and adolescents. *Hypertension* 34: 1887-1920.
- Lurbe E, Torro I, Alvarez V, et al. (2005) Prevalence, persistence, and clinical significance of masked hypertension in youth. *Hypertension* 45: 493-498.
- Lurbe E, Torro I, Garcia-Vicent C, et al. (2012) Blood pressure and obesity exert independent influences on pulse wave velocity in youth. *Hypertension* 60: 550-555.
- Ma C, Wang R, Liu Y, et al. (2016) Performance of obesity indices for screening elevated blood pressure in pediatric population: Systematic review and meta-analysis. *Medicine* 95: e4811.
- Maffeis C, Banzato C, Brambilla P, et al. (2010) Insulin resistance is a risk factor for high blood pressure regardless of body size and fat distribution in obese children. *Nutrition, Metabolism and Cardiovascular Diseases* 20: 266-273.
- Maldonado J, Pereira T, Fernandes R, et al. (2011) An approach of hypertension prevalence in a sample of 5381 Portuguese children and adolescents. The AVELEIRA registry. "Hypertension in Children". *Blood Pressure* 20: 153-157.
- Maranon R and Reckelhoff JF. (2013) Sex and gender differences in control of blood pressure. *Clinical Science* 125: 311-318.
- Martin L, Oepen J, Reinehr T, et al. (2014) Ethnicity and cardiovascular risk factors: Evaluation of 40 921 normal-weight, overweight or obese children and adolescents living in Central Europe. *International Journal Of Obesity* 39: 45-51.
- Martin-Espinosa N, Diez-Fernandez A, Sanchez-Lopez M, et al. (2017) Prevalence of high blood pressure and association with obesity in Spanish schoolchildren aged 4-6 years old. *PLOS One* 12: e0170926.
- Martínez Vizcaíno V, Salcedo Aguilar F, Solera Martínez M, et al. (2007) Association of adiposity measures with blood lipids and blood pressure in children aged 8–11 years. *Acta Paediatrica* 96: 1338-1342.
- Martins D, Nelson K, Pan D, et al. (2001) The effect of gender on age-related blood pressure changes and the prevalence of isolated systolic hypertension among older adults: Data from NHANES III. *The Journal of Gender-Specific Medicine* 4: 10-13.
- Matsushita R, Isojima T, Takaya R, et al. (2015) Development of waist circumference percentiles for Japanese children and an examination of their screening utility for childhood metabolic syndrome: A population-based cross-sectional study. *BMC Public Health* 15: 1121.
- Maximova K, Chiolerio A, O'Loughlin J, et al. (2011) Ability of different adiposity indicators to identify children with elevated blood pressure. *Hypertension* 29: 2075-2083.
- McCance K and Huether S. (2014) *Pathophysiology: The Biologic Basis for Disease in Adults and Children*, Saint Louis, Missouri: Elsevier.

- McCarthy HD, Jarrett KV and Crawley HF. (2001) The development of waist circumference percentiles in British children aged 5.0–16.9 years. *European Journal of Clinical Nutrition* 55: 902-907.
- McNiece KL, Gupta-Malhotra M, Samuels J, et al. (2007a) Left ventricular hypertrophy in hypertensive adolescents. *Hypertension* 50: 392-395.
- McNiece KL, Poffenbarger TS, Turner JL, et al. (2007b) Prevalence of hypertension and pre-hypertension among adolescents. *The Journal of Pediatrics* 150: 640-644.
- Meininger JC, Brosnan CA, Eissa MA, et al. (2010) Overweight and central adiposity in school-age children and links with hypertension. *The Journal of Pediatric Nursing* 25: 119-125.
- Mhanna MJ, Iqbal AM and Kaelber DC. (2015) Weight gain and hypertension at three years of age and older in extremely low birth weight infants. *Journal of Neonatal-Perinatal Medicine* 8 363-369.
- Ministry of Health. (2003) NZ Food NZ Children: Key results of the 2002 National Children's Nutrition Survey. Wellington: Ministry of Health.
- Ministry of Health. (2013) New Zealand Health Survey: Annual Update of Key Findings 2012/13. Wellington Ministry of Health.
- Ministry of Health. (2015) Understanding Excess Body Weight: New Zealand Health Survey. Wellington: Ministry of Health.
- Ministry of Health. (2016a) Annual Update of Key Results 2015/16: New Zealand Health Survey. Wellington Ministry of Health.
- Ministry of Health. (2016b) Health Loss in New Zealand 1990–2013: A report from the New Zealand Burden of Diseases, Injuries and Risk Factors Study. Wellington: Ministry of Health, 25-30.
- Ministry of Health. (2017a) Indicator: Ischaemic Heart Disease. *New Zealand Health Survey*. Wellington: Ministry of Health.
- Ministry of Health. (2017b) Indicator: Obese: Based on IOTF cut-offs (children aged 2-14 years). *New Zealand Health Survey*. Wellington: Ministry of Health.
- Ministry of Health. (2017c) Indicator: Raised Blood Pressure (measured). *New Zealand Health Survey*. Wellington: Ministry of Health
- Ministry of Health. (2018a) Cardiovascular Disease Risk Assessment and Management for Primary Care. Wellington: Ministry of Health.
- Ministry of Health. (2018b) Content Guide 2017/18: New Zealand Health Survey. Wellington: Ministry of Health.
- Ministry of Health. (2018c) *Mortality 2015 Data Tables*. Available at: <https://www.health.govt.nz/publication/mortality-2015-data-tables>.
- Mishra PE, Shastri L, Thomas T, et al. (2015) Waist-to-height ratio as an indicator of high blood pressure in urban Indian school children. *Indian Pediatrics* 52: 773-778.
- Mitchell GF, Hwang S-J, Vasan RS, et al. (2010) Arterial stiffness and cardiovascular events: The Framingham Heart Study. *Circulation* 121: 505-511.
- Mitsnefes M, Ho PL and McEnery PT. (2003) Hypertension and progression of chronic renal insufficiency in children: A report of the North American Pediatric Renal Transplant Cooperative Study (NAPRTCS). *Journal of the American Society of Nephrology* 14: 2618-2622.
- Modi N, Thomas EL, Uthaya SN, et al. (2009) Whole body magnetic resonance imaging of healthy newborn infants demonstrates increased central adiposity in Asian Indians.

- Pediatric Research* 65: 584-587.
- Moore LL, Bradlee ML, Singer MR, et al. (2012) Dietary Approaches to Stop Hypertension (DASH) eating pattern and risk of elevated blood pressure in adolescent girls. *The British Journal of Nutrition* 108: 1678-1685.
- Moore LL, Singer MR, Bradlee ML, et al. (2016) Adolescent dietary intakes predict cardiometabolic risk clustering. *European Journal of Nutrition* 55: 461-468.
- Moore LL, Singer MR, Bradlee ML, et al. (2005) Intake of fruits, vegetables, and dairy products in early childhood and subsequent blood pressure change. *Epidemiology* 16: 4-11.
- Moore WE, Eichner JE, Cohn EM, et al. (2009) Blood pressure screening of school children in a multiracial school district: The Healthy Kids Project. *American Journal of Hypertension* 22: 351-356.
- Moschonis G, Karatzi K, Androutsos O, et al. (2018) Anthropometric cut-off values identifying Greek children at risk of hypertension: The Healthy Growth Study. *Journal of Human Hypertension* 32: 190-196.
- Moser DC, Giuliano IdCB, Titski ACK, et al. (2013) Anthropometric measures and blood pressure in school children. *Jornal de Pediatria* 89: 243-249.
- Moyer V.A. (2013) Screening for primary hypertension in children and adolescents: U.S. Preventive Services Task Force recommendation statement. *Annals of Internal Medicine* 159: 613-619.
- Muhihi AJ, Njelekela MA, Mpembeni RNM, et al. (2018) Elevated blood pressure among primary school children in Dar es salaam, Tanzania: Prevalence and risk factors. *BMC Pediatrics* 18: 54.
- Munthali RJ, Kagura J, Lombard Z, et al. (2016) Childhood adiposity trajectories are associated with late adolescent blood pressure: Birth to twenty cohort. *BMC Public Health* 16: 665.
- Muntner P, He J, Cutler JA, et al. (2004) Trends in blood pressure among children and adolescents. *The Journal of the American Medical Association* 291: 2107-2113.
- Niinikoski H, Jula A, Viikari J, et al. (2009) Blood pressure is lower in children and adolescents with a low-saturated-fat diet since infancy. *Hypertension* 53: 918-924.
- Niiranen TJ, McCabe EL, Larson MG, et al. (2017) Heritability and risks associated with early onset hypertension: Multigenerational, prospective analysis in the Framingham Heart Study. *The BMJ* 357.
- Novotny R, Nigg CR, Li F, et al. (2015) Pacific kids DASH for health (PacDASH) randomized, controlled trial with DASH eating plan plus physical activity improves fruit and vegetable intake and diastolic blood pressure in children. *Journal of Childhood Obesity* 11: 177-186.
- Ojeda NB, Intapad S and Alexander BT. (2014) Sex differences in the developmental programming of hypertension. *Acta Physiologica* 210: 307-316.
- Okoh BA, Alikor EA and Akani N. (2012) Prevalence of hypertension in primary school-children in Port Harcourt, Nigeria. *Paediatrics & International Child Health* 32: 208-212.
- Ong KL, Cheung BM, Man YB, et al. (2007) Prevalence, awareness, treatment, and control of hypertension among United States adults 1999-2004. *Hypertension* 49: 69-75.
- Önsüz FM and Demir F. (2015) Prevalence of hypertension and its association with obesity among school children aged 6–15 living in Sakarya Province in Turkey. *Turkish Journal of Medical Sciences* 45: 907-912.

- Ortega FB, Sui X, Lavie CJ, et al. (2016) Body mass index, the most widely used but also widely criticized index: Would a criterion standard measure of total body fat be a better predictor of cardiovascular disease mortality? *Mayo Clinic Proceedings* 91: 443-455.
- Othman AS, Othman NI, Rosman A, et al. (2012) Central and peripheral blood pressure profile of young offspring with hypertensive and normotensive parents. *Hypertension* 30: 1552-1555.
- Park Y-W, Allison DB, Heymsfield SB, et al. (2001) Larger amounts of visceral adipose tissue in Asian Americans. *Obesity Research* 9: 381-387.
- Parker ED, Sinaiko AR, Kharbanda EO, et al. (2016) Change in weight status and development of hypertension. *Journal of Pediatrics* 137: e20151662.
- Pazin DC, Rosaneli CF, Olandoski M, et al. (2017) Waist circumference is associated with blood pressure in children with normal body mass index: A cross-sectional analysis of 3,417 school children. *Arquivos Brasileiros de Cardiologia* 109: 509-515.
- Perng W, Rifas-Shiman SL, Kramer MS, et al. (2016) Early weight gain, linear growth, and mid-childhood blood pressure: A prospective study in project Viva. *Hypertension* 67: 301-308.
- Petrie JC, O'Brien ET, Littler WA, et al. (1986) Recommendations on blood pressure measurement. *The BMJ* 293: 611-615.
- Pickering GW. (1955) The concept of essential hypertension. *Annals of Internal Medicine* 43: 1153-1160.
- Pickering TG, Hall JE, Appel LJ, et al. (2005) Recommendations for blood pressure measurement in humans and experimental animals. *Circulation* 111: 697-716.
- Pileggi C, Carbone V, Nobile CG, et al. (2005) Blood pressure and related cardiovascular disease risk factors in 6–18 year-old students in Italy. *Journal of Paediatrics and Child Health* 41: 347-352.
- Raitakari OT, Juonala M, Kahonen M, et al. (2003) Cardiovascular risk factors in childhood and carotid artery intima-media thickness in adulthood: The Cardiovascular Risk in Young Finns Study. *Journal of the American Medical Association Pediatrics* 290: 2277-2283.
- Raj M and Krishnakumar R. (2013) Hypertension in children and adolescents: Epidemiology and pathogenesis. *The Indian Journal of Pediatrics* 80: 71-76.
- Raji A, Seely EW, Arky RA, et al. (2001) Body fat distribution and insulin resistance in healthy Asian Indians and Caucasians. *The Journal of Clinical Endocrinology & Metabolism* 86: 5366-5371.
- Rangan AM, Flood VL, Denyer G, et al. (2012) The effect of dairy consumption on blood pressure in mid-childhood: CAPS cohort study. *European Journal of Clinical Nutrition* 66: 652-657.
- Rapsomaniki E, Timmis A, George J, et al. (2014) Blood pressure and incidence of twelve cardiovascular diseases: Lifetime risks, healthy life-years lost, and age-specific associations in 1.25 million people. *The Lancet* 383: 1899-1911.
- Rebholz CM, Gu D, Chen J, et al. (2012) Physical activity reduces salt sensitivity of blood pressure: The Genetic Epidemiology Network of Salt Sensitivity Study. *American Journal of Epidemiology* 176: 106-113.
- Redwine KM. (2018) Epidemiology of Primary Hypertension in Children. In: Flynn JT, Ingelfinger JR and Redwine KM (eds) *Pediatric Hypertension*. Cham, Switzerland: Springer International Publishing, 323-333.

- Redwine KM, Acosta AA, Poffenbarger T, et al. (2012) Development of hypertension in adolescents with pre-hypertension. *The Journal of Pediatrics* 160: 98-103.
- Reich A, Müller G, Gelbrich G, et al. (2003) Obesity and blood pressure: Results from the examination of 2365 schoolchildren in Germany. *International Journal Of Obesity* 27: 1459-1464.
- Rerksuppaphol S and Rerksuppaphol L. (2015) Association of obesity with the prevalence of hypertension in school children from central Thailand. *Journal of Research in Health Sciences* 15: 17-21.
- Ritchie H and Roser M. (2018) *Causes of Death* Available at: <https://ourworldindata.org/causes-of-death>.
- Robinson RF, Batisky DL, Hayes JR, et al. (2005) Significance of heritability in primary and secondary pediatric hypertension. *American Journal of Hypertension* 18: 917-921.
- Rodrigues PRM, Pereira RA, Gama A, et al. (2018) Body adiposity is associated with risk of high blood pressure in Portuguese schoolchildren. *Revista Portuguesa de Cardiologia* 37: 285-292.
- Rosaneli CF, Baena CP, Auler F, et al. (2014) Elevated blood pressure and obesity in childhood: A cross-sectional evaluation of 4,609 schoolchildren. *Arquivos Brasileiros de Cardiologia* 103: 238-244.
- Rosner B, Cook N, Portman R, et al. (2009) Blood pressure differences by ethnic group among U.S. children and adolescents. *Hypertension* 54: 502-508.
- Rosner B, Cook NR, Daniels S, et al. (2013) Childhood blood pressure trends and risk factors for high blood pressure: The NHANES Experience 1988–2008. *Hypertension* 62: 247-254.
- Rosner B, Prineas R, Daniels SR, et al. (2000) Blood pressure differences between blacks and whites in relation to body size among US children and adolescents. *American Journal of Epidemiology* 151: 1007-1019.
- Rossana B, Gaurav K, Tej M, et al. (2012) Prediction of primary vs secondary hypertension in children. *The Journal of Clinical Hypertension* 14: 316-321.
- Roulet C, Bovet P, Brauchli T, et al. (2017) Secular trends in blood pressure in children: A systematic review. *The Journal of Clinical Hypertension* 19: 488-497.
- Rovio SP, Pakkala K, Nevalainen J, et al. (2017) Cardiovascular risk factors from childhood and midlife cognitive performance: The Young Finns Study. *Journal of the American College of Cardiology* 69: 2279-2289.
- Rush E, Oliver M, Plank LD, et al. (2016) Cohort profile: Pacific Islands Families (PIF) growth study, Auckland, New Zealand. *The BMJ* 6: e013407.
- Rush E, Reed PW, Simmons D, et al. (2013) Baseline measures for a school-based obesity control programme: Project Energize: Differences by ethnicity, rurality, age and school socio-economic status. *Journal of Paediatrics and Child Health* 49: 324-331.
- Rush EC, Freitas I and Plank LD. (2009) Body size, body composition and fat distribution: Comparative analysis of European, Maori, Pacific Island and Asian Indian adults. *British Journal of Nutrition* 102: 632-641.
- Rush EC, Puniani K, Valencia ME, et al. (2003) Estimation of body fatness from body mass index and bioelectrical impedance: Comparison of New Zealand European, Maori and Pacific Island children. *European Journal of Clinical Nutrition* 57: 1394-1401.
- Rush EC, Scragg R, Schaaf D, et al. (2008) Indices of fatness and relationships with age,

- ethnicity and lipids in New Zealand European, Māori and Pacific children. *European Journal of Clinical Nutrition* 63: 627-633.
- Salvadori M, Sontrop JM, Garg AX, et al. (2008) Elevated blood pressure in relation to overweight and obesity among children in a rural Canadian community. *The Journal of Pediatrics* 122: 821-827.
- Samuels J. (2018) New guidelines for hypertension in children and adolescents. *The Journal of Clinical Hypertension* 20: 1-3.
- Samuels J, Negroni-Balasquide X and Bell C. (2018) Ethnic differences in childhood blood pressure. In: Flynn JT, Ingelfinger JR and Redwine KM (eds) *Pediatric Hypertension*. Cham, Switzerland: Springer International Publishing, 351-364.
- Saneei P, Salehi-Abargouei A, Esmailzadeh A, et al. (2014) Influence of Dietary Approaches to Stop Hypertension (DASH) diet on blood pressure: A systematic review and meta-analysis on randomized controlled trials. *Nutrition, Metabolism and Cardiovascular Diseases* 24: 1253-1261.
- Sardinha LB, Santos DA, Silva AM, et al. (2016) A comparison between BMI, waist circumference, and waist-to-height ratio for identifying cardio-metabolic risk in children and adolescents. *PLOS One* 11: e0149351.
- Savva SC, Tornaritis M, Savva ME, et al. (2000) Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. *International Journal Of Obesity* 24: 1453-1458.
- Schommer VA, Barbiero SM, Cesa CC, et al. (2014) Excess weight, anthropometric variables and blood pressure in schoolchildren aged 10 to 18 years. *Arquivos Brasileiros de Cardiologia* 102: 312-318.
- Schwandt P, Scholze JE, Bertsch T, et al. (2015) Blood pressure percentiles in 22,051 German children and adolescents: The PEP Family Heart Study. *American Journal of Hypertension* 28: 672-679.
- Seçil C, Ebru Y, Şükriye H, et al. (2015) Is daytime systolic load an important risk factor for target organ damage in pediatric hypertension? *The Journal of Clinical Hypertension* 17: 760-766.
- Seidel E and Scholl UI. (2017) Genetic mechanisms of human hypertension and their implications for blood pressure physiology. *Physiological Genomics* 49: 630-652.
- Shai I, Jiang R, Manson JE, et al. (2006) Ethnicity, obesity, and risk of type 2 diabetes in women: A 20-year follow-up study. *Diabetes Care* 29: 1585-1590.
- Shankar RR, Eckert GJ, Saha C, et al. (2005) The change in blood pressure during pubertal growth. *The Journal of Clinical Endocrinology & Metabolism* 90: 163-167.
- Shapiro DJ, Hersh AL, Cabana MD, et al. (2012) Hypertension screening during ambulatory pediatric visits in the United States, 2000–2009. *The Journal of Pediatrics* 130: 604-610.
- Skinner AC, Perrin EM, Moss LA, et al. (2015) Cardiometabolic risks and severity of obesity in children and young adults. *New England Journal of Medicine* 373: 1307-1317.
- Śladowska-Kozłowska J, Litwin M, Niemirska A, et al. (2011) Change in left ventricular geometry during antihypertensive treatment in children with primary hypertension. *Pediatric Nephrology* 26: 2201-2209.
- So H-K, Yip GW-K, Choi K-C, et al. (2016) Association between waist circumference and childhood-masked hypertension: A community-based study. *Journal of Paediatrics and Child Health* 52: 385-390.

- Song Y-H. (2014) The association of blood pressure with body mass index and waist circumference in normal weight and overweight adolescents. *Korean Journal of Pediatrics* 57: 79-84.
- Sorof JM, Alexandrov AV, Cardwell G, et al. (2003a) Carotid artery intimal-medial thickness and left ventricular hypertrophy in children with elevated blood pressure. *The Journal of Pediatrics* 111: 61-66.
- Sorof JM, Alexandrov AV, Garami Z, et al. (2003b) Carotid ultrasonography for detection of vascular abnormalities in hypertensive children. *Pediatric Nephrology* 18: 1020-1024.
- Sorof JM, Lai D, Turner J, et al. (2004) Overweight, ethnicity, and the prevalence of hypertension in school-aged children. *Journal of Pediatrics* 113: 475-482.
- Stabouli S, Kotsis V, Rizos Z, et al. (2009) Left ventricular mass in normotensive, prehypertensive and hypertensive children and adolescents. *Pediatric Nephrology* 24: 1545-1551.
- Stabouli S, Sideras L, Vareta G, et al. (2015) Hypertension screening during healthcare pediatric visits. *Hypertension* 33: 1064-1068.
- Staiano AE and Katzmarzyk PT. (2012) Ethnic and sex differences in body fat and visceral and subcutaneous adiposity in children and adolescents. *International Journal Of Obesity* 36: 1261-1269.
- Stamler J, Stamler R and Neaton JD. (1993) Blood-pressure, systolic and diastolic, and cardiovascular risks: United-States population-data. *Archives of Internal Medicine* 153: 598-615.
- Statistics New Zealand. (2014) 2013 Census QuickStats about culture and identity. Wellington: Statistics New Zealand
- Statistics New Zealand. (2017) *Ethnicity* Available at: <http://archive.stats.govt.nz/methods/classifications-and-standards/classification-related-stats-standards/ethnicity.aspx>.
- Statistics New Zealand and Ministry of Health. (1993) A Picture of Health Wellington: Ministry of Health
- Steinthorsdottir SD, Eliasdottir SB, Indridason OS, et al. (2011) Prevalence of hypertension in 9- to 10-year-old Icelandic school children. *The Journal of Clinical Hypertension* 13: 774-779.
- Stoner L, Weatherall M, Skidmore P, et al. (2017) Cardiometabolic risk variables in preadolescent children: A factor analysis. *Journal of the American Heart Association* 6: e007071.
- Sun SS, Grave GD, Siervogel RM, et al. (2007) Systolic blood pressure in childhood predicts hypertension and metabolic syndrome later in life. *The Journal of Pediatrics* 119: 237-246.
- Tan M, Cai L, Ma J, et al. (2018) The association of gestational age and birth weight with blood pressure among children: A Chinese national study. *Journal of Human Hypertension*.
- Taylor RW, McAuley KA, Barbezat W, et al. (2007) APPLE Project: 2-year findings of a community-based obesity prevention program in primary school age children. *The American Journal of Clinical Nutrition* 86: 735-742.
- Tebar WR, Ritti-Dias RM, Farah BQ, et al. (2017) High blood pressure and its relationship to adiposity in a school-aged population: Body mass index vs waist circumference. *Hypertension Research* 41: 135-140.

- Theodore RF, Broadbent J, Nagin D, et al. (2015) Childhood to early-midlife systolic blood pressure trajectories: Early-life predictors, effect modifiers, and adult cardiovascular outcomes. *Hypertension* 66: 1108-1115.
- Thomas C, Nightingale CM, Donin AS, et al. (2012) Ethnic and socioeconomic influences on childhood blood pressure: The Child Heart and Health Study in England. *Hypertension* 30: 2090-2097.
- Tirosh A, Afek A, Rudich A, et al. (2010) Progression of normotensive adolescents to hypertensive adults: A study of 26,980 teenagers. *Hypertension* 56: 203-209.
- Torrance B, McGuire KA, Lewanczuk R, et al. (2007) Overweight, physical activity and high blood pressure in children: A review of the literature. *Vascular Health and Risk Management* 3: 139-149.
- Tracy RE, Newman WP, 3rd, Wattigney WA, et al. (1995) Histologic features of atherosclerosis and hypertension from autopsies of young individuals in a defined geographic population: The Bogalusa Heart Study. *Atherosclerosis* 116: 163-179.
- Urbina EM, Khoury PR, McCoy C, et al. (2011) Cardiac and vascular consequences of pre-hypertension in youth. *The Journal of Clinical Hypertension* 13: 332-342.
- Urrutia-Rojas X, Egbuchunam CU, Bae S, et al. (2006) High blood pressure in school children: Prevalence and risk factors. *BMC Pediatrics* 6: 32-39.
- Vanderwall C, Randall Clark R, Eickhoff J, et al. (2017) BMI is a poor predictor of adiposity in young overweight and obese children. *BMC Pediatrics* 17: 135-135.
- Viera AJ and Neutze DM. (2010) Diagnosis of secondary hypertension: An age-based approach. *American Family Physician* 82: 1471-1478.
- Vikram NK, Pandey RM, Misra A, et al. (2003) Non-obese Asian Indians with normal waist circumference have high cardiovascular risk. *Nutrition* 19: 503-509.
- Vlachopoulos C, Aznaouridis K and Stefanadis C. (2010) Prediction of cardiovascular events and all-cause mortality with arterial stiffness: A systematic review and meta-Analysis. *Journal of the American College of Cardiology* 55: 1318-1327.
- Von Hurst PR, Walsh DCI, Conlon CA, et al. (2015) Validity and reliability of bioelectrical impedance analysis to estimate body fat percentage against air displacement plethysmography and dual-energy X-ray absorptiometry. *Nutrition & Dietetics* 73: 197-204.
- Wang B, Liao C, Zhou B, et al. (2015a) Genetic contribution to the variance of blood pressure and heart rate: A systematic review and meta-regression of twin studies. *Twin Research and Human Genetics* 18: 158-170.
- Wang J, Zhu Y, Jing J, et al. (2015b) Relationship of BMI to the incidence of hypertension: A 4 years' cohort study among children in Guangzhou, 2007-2011. *BMC Public Health* 15: 782-789.
- Wang X, Poole JC, Treiber FA, et al. (2006) Ethnic and gender differences in ambulatory blood pressure trajectories: Results from a 15-year longitudinal study in youth and young adults. *Circulation* 114: 2780-2787.
- Whelton PK, Carey RM, Aronow WS, et al. (2018) 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults. *Journal of the American College of Cardiology* 71: 127-248.
- Whincup PH, Gilg JA, Owen CG, et al. (2005) British South Asians aged 13–16 years have higher

- fasting glucose and insulin levels than Europeans. *Diabetic Medicine* 22: 1275-1277.
- Whincup PH, Gilg JA, Papacosta O, et al. (2002) Early evidence of ethnic differences in cardiovascular risk: Cross sectional comparison of British South Asian and white children. *The BMJ* 324: 635.
- Whitlock EP, Williams SB, Gold R, et al. (2005) Screening and interventions for childhood overweight: A summary of evidence for the US preventive services Task Force. *The Journal of Pediatrics* 116: 125-144.
- Whitworth JA, World Health Organization and International Society of Hypertension Writing Group. (2003) 2003 World Health Organization (WHO)/International Society of Hypertension (ISH) statement on management of hypertension. *Hypertension* 21: 1983-1992.
- Wiinberg N, Hoegholm A, Christensen HR, et al. (1995) 24-hour ambulatory blood pressure in 352 normal Danish subjects, related to age and gender. *American Journal of Hypertension* 8: 978-986.
- Wilson PWF, D'Agostino RB, Levy D, et al. (1998) Prediction of coronary heart disease using risk factor categories. *Circulation* 97: 1837-1847.
- Wirix AJ, Kaspers PJ, Nauta J, et al. (2015) Pathophysiology of hypertension in obese children: A systematic review. *Obesity Reviews* 16: 831-842.
- Wolf-Maier K, Cooper RS, Banegas JR, et al. (2003) Hypertension prevalence and blood pressure levels in 6 European countries, Canada, and the United States. *The Journal of the American Medical Association* 289: 2363-2369.
- Wong LJ, Kupferman JC, Prohovnik I, et al. (2011) Hypertension impairs vascular reactivity in the pediatric brain. *Stroke* 42: 1834-1838.
- World Health Organization. (2004) Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Geneva: The Lancet 157-163.
- World Health Organization. (2008) Waist Circumference and Waist-Hip Ratio: Report of a WHO Expert Consultation. Geneva: World Health Organization.
- World Health Organization. (2009) Global Health Risks: Mortality and burden of diseases attributable to selected major risks. Geneva, v-37.
- World Health Organization. (2018a) Global Health Estimates 2016: Deaths by Cause, Age, Sex, by Country and by Region, 2000-2016. Geneva: World Health Organization.
- World Health Organization. (2018b) *Obesity and Overweight*. Available at: <https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight>.
- Wu CH, Heshka S, Wang J, et al. (2007) Truncal fat in relation to total body fat: Influences of age, sex, ethnicity and fitness. *International Journal Of Obesity* 31: 1384-1391.
- Wuhl E, Trivelli A, Picca S, et al. (2009) Strict blood-pressure control and progression of renal failure in children. *The New England Journal of Medicine* 361: 1639-1650.
- Xu RY, Zhou YQ, Zhang XM, et al. (2018) Body mass index, waist circumference, body fat mass, and risk of developing hypertension in normal-weight children and adolescents. *Nutrition, Metabolism and Cardiovascular Diseases* 28: 1061-1066.
- Yan W, Yao H, Dai J, et al. (2008) Waist Circumference cutoff points in school-aged Chinese Han and Uygur children. *Obesity* 16: 1687-1692.
- Yang Q, Zhang Z, Kuklina EV, et al. (2012) Sodium intake and blood pressure among US children and adolescents. *Journal of Pediatrics* 130: 611-619.
- Ying-Xiu Z and Shu-Rong W. (2011) Distribution of skinfold thickness and blood pressure

- among children and adolescents in Shandong, China. *Journal of Tropical Pediatrics* 57: 258-262.
- Yoon EY, Cohn L, Freed G, et al. (2014) Use of antihypertensive medications and diagnostic tests among privately insured adolescents and young adults with primary versus secondary hypertension. *Journal of Adolescent Health* 55: 73-78.
- Yoon SS, Gu Q, Nwankwo T, et al. (2015) Trends in blood pressure among adults with hypertension: United States, 2003 to 2012. *Hypertension* 65: 54-61.
- Yuan WL, Kakinami L, Gray-Donald K, et al. (2013) Influence of dairy product consumption on children's blood pressure: Results from the QUALITY cohort. *Journal of the Academy of Nutrition and Dietetics* 113: 936-941.
- Zhang T, Zhang H, Li S, et al. (2016) Impact of adiposity on incident hypertension Is modified by insulin resistance in adults: Longitudinal observation from the Bogalusa Heart Study. *Hypertension* 67: 56-62.
- Zhang Y-X and Wang S-R. (2011) The relationship of body mass index distribution to relatively high blood pressure among children and adolescents in Shandong, China. *Annals of Human Biology* 38: 630-634.
- Zhang YX, Zhang ZC and Xie L. (2014) Distribution curve of waist-to-height ratio and its association with blood pressure among children and adolescents: study in a large population in an eastern coastal province, China. *European Journal of Pediatrics* 173: 879-885.