OBESITY AND ITS DETERMINANTS IN GIRLS FROM FIVE ETHNIC GROUPS

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BTech (Hons)

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Elizabeth Karndu Duncan

25/7/2008

Co-authored Works

Chapters 2-6 of this thesis are comprised of scientific papers that are either published or under review. The percentage contribution of each author is presented below.

Chapter 2: BIA in Chinese and Indian Ethnicities

Elizabeth Duncan... 80%

Elaine Rush 5%

Scott Duncan 5%

Grant Schofield.. 5%

Ismael Freitas 5%

Chapter 3: Diagnostic Accuracy of BMI

Elizabeth Duncan... 85%

Scott Duncan 10%

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Chapter 4: Ethnic-Specific BMI Cut-Off Points

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Chapter 5: Weight Control Perceptions and Practices

Elizabeth Duncan... 85%

Grant Schofield.. 10%

Scott Duncan 5%

Chapter 6: Physical Activity and Active Transport

Elizabeth Duncan... 80%

Scott Duncan 10%

Grant Schofield.. 10%

Research Outputs

Listed below are the peer-reviewed publications and conference presentations that have resulted from this thesis, in addition to the publications currently under review. The original published versions of all papers are presented in Appendix A.

Peer-reviewed Publications

Duncan, E. K., Duncan, J. S., and Schofield, G. (2008) Pedometer-determined physical activity and active transport in girls. *International Journal of Behavioral Nutrition and Physical Activity*, 2008. 5(2): doi:10.1186/1479-5868-5-2.

Duncan, E. K., Rush, E. C., Duncan, J. S., Schofield, G. & Freitas Jr, I. F. (2007). Validity of bioelectrical impedance for predicting fat-free mass in Chinese and Indian children. *International Journal of Body Composition Research*, 5(1): (17-25).

Duncan, E. K., Schofield, G. & Duncan, J. S. (2006). Physical activity and dietary patterns in Asian adolescent girls and their associations with body fatness. In S. Tse, M. E. Hoque, K. Rasanathan, M. Chatterj, R. Wee, S. Garg, & Y. Ratnasabapathy (Eds.). Prevention, protection, and promotion. Proceedings of the Second International Asian Health and Wellbeing Conference, November 11, 13-14, (188-195). Auckland, New Zealand: University of Auckland.

Duncan, E. K., Schofield, G., Duncan, J. S., Kolt, G. & Rush, E. C. (2004). Ethnicity and body fatness in New Zealanders. *New Zealand Medical Journal* 117(1195): 1-9.

Conference Presentations

Duncan, E. K., Schofield, G. & Duncan, J. S. (2006). *Pedometer-determined physical activity in adolescent girls: Comparisons between five ethnic groups.* Paper presented at the Ninth International Congress of Behavioural Medicine, Bangkok, Thailand.

Duncan, E. K., Schofield, G., & Duncan, J. S. & Rush, E. (2006). *Ethnic-specific body mass index cut-off points for classifying obesity in girls.* Paper presented at the Tenth International Congress on Obesity, Sydney, Australia.

Duncan, E. K., Schofield, G. & Duncan, J. S. (2006). *Correlates of obesity in New Zealand adolescent girls.* Paper presented at the Physical Activity and Obesity International Congress, Brisbane, Australia.

Duncan, E. K. (2006). *Physical activity and dietary patterns in Asian adolescent girls and their associations with body fatness.* Paper presented at the Second International Asian Health and Wellbeing Conference, Auckland, New Zealand.

Duncan, E. K. (2005). *Physical activity and body composition in New Zealand Asian adolescent girls.* Paper presented at the Asian Women's Health Symposium, Auckland, New Zealand.

Duncan, E. K., Schofield, G. & Duncan, J. S. (2005*). Using seven-day-memory pedometers to assess physical activity in NZ adolescents: results from the Girls ABC Study.* Paper presented at the Australian Conference of Science and Medicine in Sport, Melbourne, Australia.

Duncan, E. K., Rush, E. C., Duncan, J. S., Schofield, G. & Freitas, I. F. (2005*). Estimation of body fatness from bioelectrical impedance in Chinese and Indian children.* Paper presented at the Seventh International Symposium In Vivo Body Composition Studies, Southampton, UK.

Duncan, E. K., Schofield, G. & Duncan, J. S. (2005*). Using seven-day-memory pedometers to assess physical activity in NZ adolescents: Preliminary results from the Girls ABC Study.* Paper presented at the Agencies for Nutrition Action Conference, Christchurch, New Zealand.

Sherpa, E. K., Schofield, G., Kolt, G. & Rush, E. C. (2003). *Ethnicity and body fatness in New Zealanders.* Paper presented at the New Zealand Sports Medicine and Science Conference, Nelson, New Zealand.

Publications in Review

Duncan, E. K., Schofield, G. & Duncan, J. S. (2008). Associations between weight perceptions, weight control, and body fatness in a multiethnic sample of adolescent girls. *Journal of Adolescent Health* (in review).

Duncan, E. K., Duncan, J. S. & Schofield, G. (2008). Accuracy of universal body mass index definitions of childhood overweight for predicting excess body fat in girls from five ethnic groups. *Obesity* (in review).

Duncan, E. K., Duncan, J. S. & Schofield, G. (2008). Ethnic-specific Body Mass Index cut-off points for overweight and obesity in girls. *Asia Pacific Journal of Clinical Nutrition* (in review).

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Abbreviations

%BF ....Percentage Body Fat

^{2}H ....Deuterium

ANOVA...Analysis of Variance

ANCOVA ....Analysis of Covariance

AT .... Active Transport

BIA .... Bioelectrical Impedance Analysis

BMC... Bone Mineral Content

BMI ....Body Mass Index

CVD ....Cardiovascular Disease

CI.. Confidence Interval

CV .... Coefficient of Variation

DEXA .... Dual-energy X-ray Absorptiometry

FFM...Fat-free Mass

FM ....Fat Mass

HR ....Heart Rate

H .... Height

HEHA ....Healthy Eating – Healthy Action

H_s ....Sitting Height

IOTF .... International Obesity Taskforce

LINZ... Life in New Zealand

MDM ....Multiday Memory

NHANES.. National Health and Nutrition Survey

PAC-Q ....Physical Activity Questionnaire for Older Children

PRESS...Predicted Residual Error Sum of Squares

R..Resistance

SAS.. Statistical Analysis Systems

SBC... Schwarz Bayesian Criterion

SD ....Standard Deviation

SEE .... Standard Error of the Estimate

SES ....Socioeconomic Status

SPARC ....Sport and Recreation New Zealand

SPSS .... Statistical Package for the Social Sciences

TBW ....Total Body Water

VIF...Variance Inflation factor

WC .... Waist Circumference

WHR .... Waist-to-hip Ratio

WHO ....World Health Organisation

X.. Reactance

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Abstract

In light of alarming rises in the prevalence of obesity worldwide, tackling the obesity 'epidemic' is now a national health priority in many countries. Increasingly, population measures that provide accurate estimates of body fatness in children are required. Body mass index (BMI), or weight standardised for height, remains the most cost-effective and practical tool in this regard. However, there is evidence that the association between BMI and body fatness is variable in children from different ethnic backgrounds. The primary aim of this thesis was to investigate the appropriateness of BMI thresholds for defining overweight and obesity in female children and adolescents from five diverse ethnic groups. Secondary objectives were to examine the associations between weight control practices and perceptions, and to compare objectively-measured physical activity levels with participation in active transport (AT).

In order to achieve the primary aim stated above, it was necessary to obtain valid and reliable measures of body fat percentage (%BF) in a large sample of children. Bioelectrical impedance analysis (BIA) is well suited for this purpose, providing a portable and cost-effective means to estimate fat-free mass (and subsequently %BF). While equations exist for European, Maori, and Pacific Island children, findings from the preliminary study described in Chapter 2 demonstrate that there are no BIA equations appropriate for Chinese and Indian children. Given that these two groups are two of the fastest growing ethnicities in New Zealand, a new equation was developed that enables Asian girls to be included in future BIA research.

The main study of this thesis involved a large-scale investigation of body composition in New Zealand's five major ethnic groups (European, Maori, Pacific Island, East Asian, and South Asian). A total of 1,081 adolescent girls aged 11-16 years participated in the Girls' Activity and Body Composition (ABC) Study. To extend the age range, data were combined with another study of 5-11-year-old New Zealand children (595 girls), coined the Body-Size and Steps in Children (BASIC) Study. Both studies measured BMI from height and weight, %BF from bioimpedance measurements, and physical activity using sealed multiday memory pedometers over five consecutive days. A questionnaire was

also administered to the adolescent-aged girls to gather data related to weight perceptions and practices.

Initial analyses of the main dataset demonstrated that existing BMI definitions of overweight were relatively insensitive for predicting excess %BF in South and East Asian girls. Conversely, low specificity was observed for Pacific Island and Maori children. These findings provided the rationale for the second set of analyses: the development of BMI cut-off points that correspond to an equivalent level of %BF across all ethnicities. The adjusted BMI curves for overweight and obesity ranged from an average of 3.3 and 3.8 $kg.m^{-2}$ (respectively) lower than international standards in South Asian girls to 1.5 and 1.9 $kg.m^{-2}$ higher in Pacific Island girls. Clearly, the proposed changes will have significant effect on our estimates of overweight and obesity in this population group.

Subsequent investigation revealed that many adolescent girls misclassify their weight status. However, the number of girls trying to lose weight exceeded those who perceived themselves as being overweight, with the magnitude of the difference dependent on ethnicity. It was concluded that interventions and educational campaigns that assist girls in recognising a state of excess body fat are a priority for all ethnic groups to ensure that behavioural changes necessary to combat widespread overweight and obesity are adopted.

Finally, it was observed that the physical activity levels of the participants were significantly lower on weekends ($9,528 \pm 4,407$) than on weekdays ($12,597 \pm 3,630$). Furthermore, a consistent decline in daily step counts was observed with age: after adjustment for ethnicity and socioeconomic status (SES), girls in school years 9-10 achieved 2,469 (weekday) and 4,011 (weekend) fewer steps than girls in years 1-2. Daily step counts also varied by ethnicity, with Maori girls the most active and South Asian girls the least active. Overall, girls who used AT to and from school averaged 1,052 more weekday steps than those who did not use AT. These data suggest that adolescent-aged girls and girls of Asian descent are priority groups for future physical activity interventions, and that the promotion of AT in girls appears to be worthwhile.

Chapter 1: Introduction

Overview

The purpose of this chapter is to demonstrate the theoretical pathway that contributed to the design of this thesis. The review begins with a summary of our current knowledge of overweight and obesity in young New Zealanders, discusses the key issues related to the measurement of obesity in different ethnic groups, and finishes with a description of the thesis rationale and organisation. The preparation of this chapter enabled research gaps to be identified and prioritised, resulting in the development of the study design and synthesis of the research questions. The following areas will be discussed:

- Prevalence and trends in obesity
  - Provides a background on the magnitude of this condition both locally and internationally.
- Burden of obesity in young people
  - Provides a background on the consequences of this condition among young people and into adulthood.
- Assessment of obesity in young people
  - Covers clinical and population measures of body composition and current definitions of overweight and obesity in young people.
- Ethnic Variability in Obesity
  - The main focus of this thesis. Explains the key differences in body composition between particular ethnic groups and examines the merit of ethnic-specific definitions of obesity.
- Thesis rationale
  - Synthesises key points from the preceding sections in a general overview, providing the motivation behind this thesis and how it contributes to the existing body of knowledge.
- Thesis organisation
  - Description and diagram of the overall layout of the thesis.

Prevalence and Trends in Obesity

Obesity is defined as a condition of excessive fat accumulation to the extent that health and wellbeing may be impaired [240]. Within the last two decades, the prevalence of this condition has progressed to epidemic proportions in both developed and developing countries around the world. In 2003, the World Health Organisation (WHO) estimated that there were at least 300 million obese people worldwide, representing an increase of 100 million since 1995 [243]. Furthermore, in the next two decades predicted rates of obesity have been forecast to reach 45–50% in the USA, and 30–40% in Australia and England [94].

Figure 1-1. Temporal trends in the prevalence of obesity in New Zealand adults.
1989: Life in New Zealand Survey [181]; 1997: National Nutrition Survey [140]; 2003: 02/03 New Zealand Health Survey [144]; 2007: 06/07 New Zealand Health Survey [147].

New Zealand is no exception to the rising obesity trends observed overseas. National survey results indicate a 2.4-fold increase in the number of obese adults since 1989, to the stage where one in four adults are obese (Figure 1-1), although the rate of increase does appear to be slowing. In addition, a further 36.2% of the adult population were classified as overweight (but not obese), leaving only 37.4% with a body size not associated with an elevated risk of health conditions [147]. Considerable variation in

prevalence values is evident across different subgroups of the population. For example, Maori and Pacific Island adults appear particularly susceptible, with obesity rates 1.7 and 2.5 times (respectively) higher than that of the total population. Obesity was also more common in the most deprived areas, especially for women, and tended to increase with age.

Among children and young people, levels of overweight and obesity are also a concern, reaching epidemic proportions in some areas and continuing to rise in others. Table 1-1 presents the prevalence figures from nationally representative surveys of young people in a number of major countries. While these figures are useful for gauging the general direction of trends within populations, the different age ranges and methodologies used to define overweight and obesity preclude direct comparisons among countries. Furthermore, the prevalence values presented reflect a mix of overweight and/or obesity levels. The potential implications of inaccuracies in obesity measurement are fundamental to this thesis and will be discussed in more detail in the following section. Temporarily putting these issues aside, it is reasonable to conclude that:

- The prevalence of overweight and obesity is unequally distributed across global regions and counties;
- Childhood overweight and obesity have been rising steeply in many countries, with Canada, Australia, and the UK experiencing the greatest rate of increase at approximately 1% per year over the last two decades;
- In developed countries, levels of childhood overweight and obesity are higher among those from low socioeconomic groups;
- The prevalence of overweight and obesity is higher among older children and adolescents than young children.

Table 1-1. International trends in childhood overweight and obesity.

Country	Year	% Overweight/Obese
Australia [8]	1969	11%
	1985	12%
	1997	21%
Brazil [232]	1974	4%
	1997	14%
Canada [217]	1984	12%
	1996	32%
China [232]	1991	6%
	1997	8%
Finland [99]	1977	6%
	1999	13%
France [173, 227]	1980	5%
	1996	13%
	2000	19%
Germany [107]	1975	11%
	1985	12%
	1995	19%
Japan [130]	1978	9%
	1988	13%
	1998	15%
Netherlands [68]	1980	10%
	1997	18%
Spain [148]	1985	15%
	1995	22%
Switzerland [247]	1965	10%
	1999	32%
UK [20, 33, 34]	1974	7%
	1984	8%
	1994	12%
	2002	25%
	2006	30%
USA [159, 160]	1965	4%
	1980	7%
	1994	11%
	2004	17%

The prevalence of overweight and obesity among young New Zealanders is similar to that reported overseas. Results from the recently released 06/07 New Zealand Health Survey indicated that 20.9% (95% CI: 19.2-22.6%) of New Zealand children aged 2-14

years were overweight, and a further 8.3% (7.4-9.3%) were obese [147]. Unlike most international trends, these figures indicate an apparent stabilisation of childhood overweight and obesity: the 2002 National Children's Nutrition Survey found that 21.3% and 9.8% of young New Zealanders aged 5-14 years were overweight and obese, respectively [143]. It should be noted, however, that the 06/07 survey sampled children from two years of age. The national surveys follow findings from an earlier study of 11-12 year old children living in Hawke's Bay in 1989 and 2000, where the prevalence of overweight increased from 11.0% to 20.9%, and from 2.4% to 9.1% for obesity [221]. Thus, the relative risk of being overweight was 2.2 times higher in 2000 than in 1989, and 3.8 times higher for obesity. Taken together, these results suggest that the prevalence of overweight and obesity in New Zealand children has increased in recent years, but may now be starting to plateau.

Ethnic inequalities in childhood overweight and obesity prevalence have also remained relatively unchanged between national surveys. In both 2002 and 2007, the prevalence of obesity was greatest among Pacific Island and Maori groups. These observations align with results from an earlier Auckland study in 2001 that reported obesity rates of 24.1% and 15.8% in Pacific Island and Maori children (respectively) compared with 8.6% in European children [223]. One noticeable feature of the 06/07 New Zealand Health Survey was the separation of Asian groups from the 'European and Other' category, providing the first national prevalence estimates of body size for Asian populations. Among Asian children, the prevalence of obesity was 5.9% (3.5-8.3%), suggesting that they make up a relatively low risk sub group of the population. Given the percentage increase of Asian peoples in New Zealand from 2001 (6.6%) to 2006 (9.6%) [203], it would be interesting to assess the extent to which the comparatively low prevalence of obesity in this ethnic grouping was responsible for the apparent stabilisation of childhood overweight and obesity across the whole population.

A key trend reported in 2002 was that younger children were less likely to be overweight or obese than older children; the proportion of overweight males increased with age, as did the proportion of obese females [143]. Interestingly, the association between age and obesity was not evident in the 2007 dataset [147]. Given

that the overall prevalence of childhood obesity remained stable, this would suggest an increase in the age at which the prevalence of obesity begins the rise to adult levels. In line with overseas research [232], an unequal distribution of overweight and obesity was observed among young New Zealanders from different socio-economic backgrounds was observed in the 2002 Children's Nutrition Survey [143] and the 06/07 NZ Health Survey [147].

Burden of Obesity in Young People

Escalating levels of overweight and obesity in virtually all age, ethnic, and socioeconomic groups have generated widespread increases in the incidence of related health complications, imposing a major economic burden on society and lowering the quality of life for those affected. Indeed, obesity is now considered to be one of the key contributors to the global burden of chronic disease and disability.

Health Consequences of Obesity in Young People

During the younger years, associations between excessive body fat and health risks are less clear than in adults. Until recently, it was unlikely that complications would be clinically apparent until years after the development of obesity. As both the prevalence and severity (i.e. degree of excess body fat) of this condition have increased, so too have the immediate health risks for young people. Clinical studies with obese children and adolescents have identified a number of immediate health complications [126, 152]. Major conditions include:

- Sleep disordered breathing and asthma [19, 196];
- Fatty liver disease [189];
- Early menarche [1] and lowered fertility [245];
- Type 2 diabetes and associated risk factors, including glucose intolerance, and insulin resistance [17, 75];
- Cardiovascular risk factors, such as hypertension and dyslipidemia [15, 69].

Perhaps even more detrimental are the social challenges faced by overweight and obese youth and the subsequent impact on psychological development. The

stigmatisation of obese children and adolescents by their peers has been well documented in Western societies. In a study of children's perception of body shape stereotypes, the silhouettes of overweight children were commonly associated with negative personality characteristics, such as laziness, dirtiness, and stupidity [86]. Furthermore, findings that overweight adolescents receive fewer 'friendship nominations' than their peers, [207] and obese adolescents are less likely to 'hang out' with friends in an average week [61] suggests exclusion from social networks. Not surprisingly, obese adolescents are more likely to report experiencing serious emotional problems [61], and to both receive and adopt bullying behaviour as a result of social stigmatisation [98].

Research into the effects of childhood obesity on self-efficacy has produced variable results. It appears that obese children do not differ in self-efficacy from their peers, and yet this is not the case in adolescents. At age 9-10 years, overweight and normal weight youth showed similar levels of self-efficacy, but four years later, their self-efficacy was more likely to have declined [206]. Indeed, of all the young years, adolescence is a critical time for the development of body image perceptions and self-efficacy, given the onset of puberty and peers assuming greater importance than parents. Overweight and obesity during adolescence is also associated with lower academic achievement, [78] increased body dissatisfaction, and unhealthy eating behaviours such as binge eating and chronic dieting [156].

An increased awareness of social norms is also characteristic of the transition from childhood to adolescence. External pressures to be slim can lead to unrealistic expectations and distorted body image, especially in adolescent girls. While only a small proportion of girls are at risk of developing eating disorders, the effects of weight dissatisfaction on self-efficacy may be much more profound, resulting in a substantial proportion of girls that regularly diet or exercise for weight control [64, 136]. However, there is evidence that many girls are unable or unwilling to accurately classify their weight status [10, 74, 119, 154, 197]. This is concerning given that girls with excess body fat who do not diagnose their condition are unlikely to adopt the lifestyle changes required to reach a healthy weight.

Unfortunately, the complications associated with overweight and obesity during the younger years do not end here. Many of the immediate physical conditions carry life-long consequences, and psychological problems tend to persist. An association between fatness in adolescence and undesirable socio-economic consequences has been observed. Longitudinal data on 10,039 adolescents and young adults indicate that as adults, women who were obese as adolescents had lower academic achievement, earned less money, and were less likely to be married than women who had not been overweight, regardless of their base-line socioeconomic status and aptitude-test scores [78]. In addition, there is strong evidence that levels of body fatness track into adulthood [15, 18, 22, 59, 80, 238]. The likelihood of tracking will be dependent on the severity of obesity, as well as the age at which it developed and the age of follow-up. Obesity in adulthood brings with it much more severe medical complications. These include a myriad of life threatening non-communicable diseases, debilitating conditions, and psychosocial problems (Table 1-2).

Table 1-2. Long-term consequences of obesity in youth.

Category	Condition
Metabolic	Impaired glucose tolerance & type 2 diabetes Dyslipidaemia Metabolic syndrome
Cardiovascular	Hypertension Coronary Heart Disease
Mechanical	Osteoarthritis Spinal problems Obstructive sleep disorder
Cancer	Breast cancer Colorectal caner
Psychosocial	Low self-efficacy Discrimination and stigmatisation Depression

Economic Burden of Obesity in Young People

Although excessive body fatness among young people is associated with numerous short-term health complications, the greatest health problems will manifest during adulthood. Thus, the extent of the burden upon health services (direct costs of obesity) will not be known until the current generation of young people passes into adulthood. At present, the WHO estimates that obesity accounts for 2–7% of the annual health budget in developed countries [242]. This figure is based on the proportion of health spending attributable to obesity co-morbidities, although experts consider it to be a conservative estimate [109]. For New Zealand, this amounted to NZ$303 million in 2003 [142].

The actual economic burden on countries will be far greater as obesity affects many other facets of society and an individual's life. These costs are commonly referred to as the indirect and intangible costs of obesity. Indirect costs represent the value of lost output due to a reduction in productivity following illness or death. In America, which has a population of around 280 million, the indirect cost of adult obesity was estimated to be US$23 billion per year [242]. Corresponding costs associated with childhood obesity are more difficult to calculate because of the highly variable contribution that young people make to a country's economy. Obviously, the methodology used would need to consider other factors such as lost productivity of parents who must take time off work to care for children experiencing complications related to obesity. Intangible or opportunity costs to the individual represent the social and personal loss associated with obesity. Although there is no standard approach to measuring these costs, in a report to the IOTF, the intangible costs of adult obesity in Australia were estimated to be in the order of ten times the direct costs [123].

Assessment of Obesity in Young People

There are a wide range of measures available for estimating body composition and fatness in young people. Selection of an appropriate tool is dependent on the purpose of the study, methodological considerations, and the project budget. In a clinical setting, reference techniques such as air displacement plethysmography (ADP), hydrostatic weighing, dual-energy x-ray absorptiometry (DEXA), magnetic resonance

imaging (MRI), isotope dilution, or a combination of these are employed on small numbers of participants, and give the most accurate estimates of body composition and fatness. Nevertheless, these methods are expensive and often confined to a laboratory, and are therefore impractical for use in population research. Indirect measures that provide an estimate of body fat with a degree of accuracy while requiring minimal expenditure or researcher training are critical in this regard. This section begins with a brief overview of the clinical measures of body fatness before reviewing the common techniques used by field researchers in more detail. Emphasis is placed on the three techniques used in this thesis: isotope dilution, body mass index, and bioelectrical impedance analysis. The potential effects of ethnicity on the measurement of body composition – the primary focus of this thesis – are also discussed.

Clinical Measures of Body Composition

Clinical measures of body composition have three main applications for health professionals. First, they can be used by physicians to diagnose anatomical abnormalities in patients. Second, many clinical measures enable the body to be visualised as three or four 'compartments' (i.e., fat mass, fat-free mass, bone mineral content, total body water) at a high level of precision, enabling specific research questions to be answered with relatively small samples. Third, clinical techniques can be used as a 'gold standard' to validate the more indirect measures implemented by field researchers.

Table 1-3 outlines the clinical measures of body composition commonly used in young people. The preliminary study in the proposed research used isotopic dilution of deuterium oxide in 79 Chinese and Indian children in order to validate an equation for predicting fat-free mass (FFM) from bioimpedance measurements. Isotope dilution provides a direct measure of total body water, which, based on the theory that water is distributed in all parts of the body except fat, is a useful estimate of FFM. Fat mass (FM) is then simply calculated as the difference between body weight and FFM. Total body water measurements obtained using isotope dilution are based on the dilution principal, (that the volume of a compartment is equal to the amount of tracer added to

the compartment, divided by its concentration in that compartment). The dilution principle relies on four basic assumptions:

1. The tracer is distributed only in body water;
2. The tracer is evenly distributed in all body water compartments;
3. Equilibration of the tracer occurs rapidly;
4. The tracer and body water are not metabolised during the time of tracer equilibration.

In practice, the isotope tracers do deviate from these assumptions during in vivo dilution. Optimal accuracy and precision of total body water measurement can be achieved through the right choice of tracer, and the use of correction factors, and protocols that minimise deviations. However, isotopes are classically assayed by isotopic ratio mass spectrometry (IRMS), an expensive and time-consuming technique requiring a highly skilled staff. More practical measures are required to observe the prevalence and trends associated with excess fatness across a large sample.

Table 1-3. Clinical measures of body composition in young people.

Technique	Description
Air displacement plethysmography (ADP)	• Relatively new laboratory-based technique that indirectly measures body volume by determining the volume of air displaced inside an enclosed chamber (plethysmograph). • Body density = body mass/body volume; %BF determined from body density using estimation formula. • Valid and reliable technique for measuring %BF in people of all ages and body sizes [65]. • Only one commercially available system: BOD-POD. • Quick, comfortable, automated, non-invasive, and safe process.
Hydrostatic weighing	• The most widely used measure of body density. • Subject sits in a specialised seat, expels all air from their lungs, and is lowered into a hydrostatic weighing tank filled with water until fully submerged. • Body volume = body weight/underwater body weight. • %BF determined from same equation as ADP. • Valid and reliable technique for measuring %BF in adults [12]. • Requires a high degree of water confidence: excludes most children and one-third of middle-aged women [12].
Dual energy x-ray absorptiometry (DEXA)	• Three compartment technique that uses a whole-body scanner and two different low dose x-rays to measure bone mass, fat mass, and lean body mass. • Can be used to isolate body fat in specific body regions (e.g., central adiposity) • Valid and reliable technique for measuring %BF in people of all ages and body sizes [14, 168, 182]. • Comfortable, non-invasive, and safe process.
Magnetic resonance imaging (MRI)	• Provides high-resolution cross-sectional images through selected anatomic regions. • Excellent method to visualise internal fat stores. • Valid and reliable technique for measuring %BF in people of all ages and body sizes [216]. • Contiguous slices covering entirety of body provides most accurate estimate but requires considerable scanning and analysis time. • A smaller number of slices can be used to extrapolate total fat content, but results in reduced accuracy. • Comfortable, non-invasive, and safe process.
Isotope dilution	• Only criterion measure where it is not necessary for the subject to visit a laboratory. • Isotopes of hydrogen or oxygen are ingested into the body as labelled water. After an equilibration period, a sample of urine or saliva is taken from the subject. The extent to which the isotope concentration dilutes provides an estimate of total body water (TBW). • FFM (and subsequently %BF) is derived from TBW using common hydration factors. • Valid and reliable technique for measuring %BF in people of all ages and body sizes [191]. • Comfortable, non-invasive, and safe process.

Table 1-4. Population measures of body composition in young people.

Technique	Description
Body Mass Index (BMI)	• A simple anthropometric measurement of weight (kg) divided by squared height (m^2). • Easy to measure with low cost equipment, making it the most commonly used method to classify overweight and obesity in population studies. • Does not distinguish between fat and fat-free mass, so may not represent the same level of body fat in populations with different body builds. • Highly age dependent in young people. • Correlates reasonably well with body fatness in young people [115], although this association appears stronger in children than adolescents [186]. • Sex- and age-specific thresholds available for classifying body size in young people.
Waist Circumference	• Can provide a valid estimate of central adiposity in children and adolescents [76]. • No established thresholds for classifying body size in young people. • Easy to measure with low cost equipment.
Skinfold Thickness	• Can provide a direct measure of subcutaneous fat. • Can be measured at numerous sites. • Low cost equipment, but requires trained personnel for accurate and reliable measurements. • Relatively time consuming especially if multiple sites are measured. • Relatively invasive for use with young people, restricting the number of sites that can be measured. • Varies with age, sex, and ethnicity. • Requires population-specific prediction equations for estimating total body fatness. • Poor inter-rater reliability in large-scale studies involving numerous researchers. • Validity in obese people questionable as relatively more fat is stored internally [39].
Bioelectrical Impedance Analysis (BIA)	• Measures resistance to a small alternating electrical current passed through the body. • Segmental and whole body types. Segmental BIA considers upper or lower body only, which may be inappropriate given individual variation in body fat distribution. • Assumes that fat mass is anhydrous, and that conductivity reflects fat-free mass (i.e. the more fat mass an individual has, the less body water, and the greater resistance measured). • Requires population-specific equations to estimate total body fatness based on resistance measurements. • Correlates well with more direct measures of body fatness in young people [4, 149, 180]. • Non- invasive and painless. • Quick and relatively inexpensive.

Population Measures of Body Composition

Although more accurate, the reference techniques described in the preceding text are too costly and laborious for use with large numbers of participants in a field setting. Table 1-4 summarises the commonly used methods for estimating paediatric body composition in population research. In large-scale epidemiological studies, body fatness is most commonly estimated using body mass index (BMI), a simple anthropometric measurement of weight (kg) divided by squared height (m^2), which tends to correlate well with both body fat percentage (%BF) and health-risk [46, 71, 121, 158, 195]. In 1998, the WHO provided international BMI standards for classifying overweight and obesity in adults based on the risk of obesity-related disease for Europeans at each BMI category (Table 1-5) [240]. Overweight was defined as BMI ≥ 25 kg.m^{-2} and obesity as BMI ≥ 30 kg.m^{-2}, with the latter corresponding to approximately 25% and 35% BF in young European men and women, respectively [239].

Table 1-5. Classification of weight status by BMI in adult Europeans.

BMI (kg.m^{-2})	Classification
< 18.5	Underweight
18.5-24.9	Normal
25.0-29.9	Pre-obese
30-34.9	Obese I
35.0-39.9	Obese II
≥ 40	Obese III

Relationships between BMI, %BF, and health risk and are not as well established for young people. Nonetheless, BMI is generally accepted as a valid indirect measure of body fatness in children and adolescents, although the typical increases in BMI as children develop necessitate the use of age-adjusted BMI reference charts. The two most widely used are the US Centers for Disease Control and Prevention (CDC) BMI growth curves [108] and the International Obesity TaskForce (IOTF) BMI cut-off points [23]. The CDC reference charts were the first age- and sex-specific BMI charts for defining overweight and obesity in young people, and were based on the 85th and 95th

percentile of an American reference population. In 2001, the IOTF proposed alternative thresholds based on the mean of the BMI-for-age curves from six major countries (Figure 1-2). For a given age, individuals are classified as overweight or obese if they have a BMI greater than the curve that passes through 25 kg.m^{-2} or 30 kg.m^{-2} (respectively) at age 18 years. The intention of the IOTF cut-off points was to establish a higher degree of international applicability, although the averaging of the six diverse datasets could be considered arbitrary. Similar to overseas research, New Zealand surveys have adopted the IOTF standards as the preferred definition of childhood overweight and obesity.

Figure 1-2. International age- and sex-specific BMI cut-off points for defining overweight and obesity in children [23].

More recently, waist circumference (WC) has been suggested as a better alternative to BMI. As an estimate of central adiposity (accumulation of fat around the trunk), WC appears to provide a closer correlation to the health risks associated with excess body fat than weight-based indices in both adults [106, 112, 113, 118, 187, 194, 237] and young people [3, 32, 82, 91, 150, 215]. The Ministry of Health considers a WC greater than 94 cm in men and 80 cm in women to be a sign of a central fat pattern [146]. The

only WC thresholds available for New Zealand children show an age-related increase in magnitude, ranging from 53.1 cm and 50.3 cm in three-year-old boys and girls (respectively) to 88.4 cm and 80.1 cm in male and female youth aged 19 years [212]. While these thresholds are essential for the diagnosis of central adiposity in children, further work needs to be done to test their accuracy in other populations. Given that WC is not standardised for overall body size, it is possible that adjustments need to be made for children in population groups with markedly different physical characteristics. Waist-to-hip ratio is frequently used measure that is standardised to the individual (i.e., dimensionless); however, there is evidence that WC provides a better indication of central fat deposition in children [67, 76] and adults [117, 214].

An obvious limitation of BMI and waist/hip measurements is that they do not distinguish between FM and FFM, and therefore do not provide an estimate of %BF. Skinfold testing, on the other hand, is able to derive an estimate of total and regional body fat, and is consequently one of the most common field measures of body composition. It involves a researcher raising a double layer of skin (including the underlying adipose tissue) at a given site on the body and applying callipers 1 cm below and at 90° to the skinfold. While the sum of multiple skinfold thicknesses (tricep, bicep, subscapular, supraspinale, abdominal, thigh, calf) is often used to compare body fatness between subjects, prediction equations are available to generate %BF or body density values for population researchers interested in comparing results from different methods [95, 96, 188, 234]. However, the potentially embarrassing nature of the procedure restricts the number of sites that can be tested in a paediatric sample. Realistically, the triceps skinfold is the only site that can be used without risking excessive embarrassment or anxiety in children and adolescents. In this instance, inflated error through inter-individual variability in fat distribution reduces its accuracy for paediatric populations. Another potential shortcoming is the inability of skinfold callipers to accurately record subcutaneous fat in obese individuals, as relatively more fat is stored internally [39]. Moreover, the precision of skinfold measurements is highly dependent on the skill and techniques of the individual researcher. Poor inter-rater reliability is particularly relevant in large-scale studies involving a number of researchers.

Bioelectrical impedance analysis (BIA) is a much less invasive technique for assessing %BF that has been developed for use in the field. BIA estimates the FFM within an individual by recording the impedance or resistance to a small (< 1 mA) alternating electrical current that is passed through the body. Put simply, the more muscle a person has, the more water they store and the easier the current will pass through their body (greater resistance corresponds to a lower FFM and consequently a higher %BF). However, the relationship between resistance and FFM is affected by differences in body size and shape. Calculating FFM in this manner requires the use of prediction equations that account for differences in height, weight, age, and gender.

A common criticism of BIA (also applicable to skinfold testing on limited sites) is the potential error associated with the use of prediction equations to indirectly calculate %BF. As mentioned previously, more direct estimates of body fat, such as DEXA, hydrostatic weighing, and isotope dilution, cannot be implemented in large-scale research. However, these reference measures can be used to assess the validity of BIA prediction equations for describing %BF in paediatric populations. Table 1-6 summarises the major publications in this area prior to this thesis, including two from New Zealand children and adolescents [180, 222]. The results indicate that BIA can provide valid estimates of body fatness in child and adolescent populations. Furthermore, several studies have reported a high level of reliability when using BIA in young people [4, 90, 222]. BIA has also been implemented in several large-scale studies, including the third National Health and Nutrition Survey (NHANES III) of more than 16,000 American adults and children [21], and the Pathways Study, an obesity prevention programme for Native American children established in 41 elementary-level schools [125].

The main limitation of using BIA to assess FFM is that the study sample must be comparable to the reference population from which the prediction equation was derived. Rush et al [180] implemented whole-body BIA to assess the body fatness of Auckland children and adolescents from three New Zealand ethnic groups (European, Maori, and Pacific Island). A prediction equation for the estimation of FFM was developed that correlated closely with FFM obtained from deuterium dilution

measurements of total body water (r^2 = 0.96). This equation was used (in conjunction with another developed in Chapter 2) to investigate %BF in New Zealand girls in this thesis. A similar equation was developed for Auckland children by Tyrell et al [222], however fundamental differences in the testing protocol (foot-to-foot rather than whole-body BIA) reduces its relevance to the present research.

Although BIA enables FM and FFM to be distinguished, and thus determination of %BF, there is debate as to the appropriate %BF definition of childhood overweight and obesity. Several studies have proposed %BF thresholds for classifying obesity in young people based on an elevated level of cardiovascular disease risk factors. In a sample of children and adolescents aged 5-18 years, Williams et al [236] proposed body fat cut-points of 25% for boys and 30% for girls. Similarly, Dwyer and Blizzard [55] suggested 20% for boys and 30% for girls aged 9 or 15 years. Higgins et al [85] found no gender differences in the relationship between %BF and risk in prepubertal children aged 4 to 11 years, and as such recommended the same thresholds for young girls and boys. These were an upper value of 33% and a lower value of 20% for defining health-related obesity. To date, the only age-adjusted %BF cut-off points were developed by Taylor et al [213] to correspond with the IOTF BMI cut-off points for childhood overweight and obesity. These %BF-for-age curves appear more practical than single cut-off points given the natural changes in %BF as children develop. However, the relation of the %BF curves to increased metabolic risk in children remains uncertain. Further research is required to establish %BF cut-off points that correspond to elevated risk profiles in children of all ages and phenotypes.

Table 1-6. Validation of bioelectrical impedance analysis in young people.

Author and Reference	Sample	Criterion Measure	Predictive Ability (r^2)	Cross-validation Measure
Bandini [4]	Non-obese females aged 8-12 years (n = 132).	Deuterium dilution	0.93	Deuterium dilution
Deurenberg [45]	Males and females aged 7-83 years (n = 827).	Hydrostatic weighing	0.97 (7-15 y.o.)	Hydrostatic weighing
Gillis [73]	Males and females ages 6-16 years (n = 67).	Hydrostatic weighing	0.92	-
Houtkooper [89]	Males and females aged 10-19 years (n = 94).	Deuterium dilution	0.95	Hydrostatic weighing Deuterium dilution
Morrison [149]	White (n = 65) and black (n = 61) females aged 6-17 years.	DEXA	0.99 (W) 0.99 (B)	DEXA
Pietrobelli [165]	Males and females aged 7-14 years (n = 75).	DEXA	0.90	-
Phillips [164]	Non-obese females aged 8-12 years (n = 196).	Deuterium dilution	0.95	Deuterium dilution
Rush [180]	Males and females aged 5-14 years (n = 172).	Deuterium dilution	0.96	Deuterium dilution
Tyrrell [222]	NZ European, NZ Maori, and Pacific Island males and females aged 5-11 years (n = 82).	DEXA	0.96	-

Ethnic Variability in Obesity

International Evidence

Despite the benefits of measuring excess body fatness over excess weight, BMI remains the most practical and thus the most commonly used estimate of obesity. The WHO BMI thresholds for overweight and obesity in adults have been widely used in field research; however, concerns have been raised in regard to their relevance to all populations. It is generally accepted that associations between BMI and %BF are dependent on age and gender. More recently, these associations have been shown to vary with ethnicity. For example, Pacific Islanders tend to have lower levels of %BF than Europeans at a given BMI [179, 210, 211]. Conversely, Asian ethnic groups tend to have higher levels of BF than Europeans at specific BMI, elevating risk of obesity-related disease at relatively low BMI scores [41, 47, 244].

Even at the same level of %BF, risk profiles may differ between ethnic groups [132]. This may be reflective of ethnic-specific variation in the patterns of fat distribution. Indeed, central fat accumulation (i.e., an android fat pattern) appears to be a greater predictor of obesity-related health risks than overall fatness [32, 112]. Research indicates that, in general, Asian adults are more prone to visceral and central obesity than Europeans [134, 163]. In particular, Hughes et al [92] found that Asian Indians had a greater predisposition for central obesity than Malay and Chinese Asians. Likewise, there is evidence that Asian children [83] and adolescents [127] have a greater central fat mass when compared with Europeans and other ethnic groups. In accordance with a higher %BF at a given body size, and a more centralised pattern of fat distribution, elevated disease risks have been observed in Asian populations at BMI scores well below the WHO thresholds defining overweight and obesity [226].

In response, the WHO released provisional recommendations for overweight and obese BMI cut-off points for Asian populations in the Asia-Pacific region of ≥ 23 and ≥ 25 kg.m^{-2}, respectively [241]. More recently, a WHO expert consultation on BMI in Asian populations concluded that there is no single cut-off point appropriate for defining overweight or obesity in all Asian groups [244]. Recommendations from the

consultation include: (1) retaining current WHO BMI cut-off points for international classification; (2) adding 'action points' of ≥ 23 and $\geq 27.5 \, kg.m^{-2}$ (representing 'increased' and 'high' risk) as a trigger for public health action; (3) developing ethnic- and country-specific BMI action points; and (4) refining BMI action points with waist circumference in populations predisposed to central obesity.

Compared with adults, less is known about the body composition of children and adolescents. There is, however, mounting evidence that BMI does not provide an equivalent measure of %BF among young people from different ethnic groups. Research has shown that at a given BMI, Chinese [40] and Hispanic [56, 57] youth had a higher level of %BF than Europeans, who in turn had more %BF than African-Americans [31], and Maori and Pacific Islanders [180]. Such relationships may be further complicated by sexual maturation processes that occur during puberty and can alter associations between BMI and fat mass [7, 31, 79, 131]. For example, Ellis et al [58] observed that ethnic differences in body composition between Hispanics, African-Americans, and Europeans were much less pronounced in children younger than eight years of age (pre-puberty). Thus, differences in body composition observed during childhood and adolescence may also reflect ethnic-specific growth and development patterns [60]. In a 6-year follow-up study of Chinese children, Wang et al [231] noted that overweight prevalence (defined according to IOTF age- and sex-specific BMI cut-off points) decreased as children became adolescents. This apparent reduction in overweight may be due to different BMI-age relationships between the study and the IOTF reference populations. Although the authors did not determine pubertal stage, they suggested that Chinese adolescents tend to mature later than the IOTF reference populations, thereby causing them to be misclassified. Consequently, the IOTF cut-offs may not be appropriate for these populations.

To our knowledge, only one study has attempted to adjust existing international BMI thresholds for defining obesity in young people. Kim et al [102] proposed a series of BMI percentiles for Korean girls aged 8 to 18 years that passed through the WHO thresholds for overweight and obesity in Asian adults at age 18 years (23 and $25 \, kg.m^{-2}$, respectively). The adjusted BMI-for-age curves for Korean girls were

substantially lower than the corresponding IOTF cut-off points; however, it is not known whether or not these ethnic-specific BMI values indicate excessive adiposity in Korean individuals. The development of BMI-for-age curves that correspond to an equivalent level of body fatness in a variety of ethnic groups would be preferable. However, ideally, the dose-response relationship between BMI and metabolic risk for each ethnic group would be explored. While this may be more difficult to gauge in young people than in adults due to the delayed onset of many obesity-related complications, there are clear advantages of using a system that diagnoses health risk rather than excess weight in children from diverse ethnic backgrounds.

Several factors have been proposed to help explain the dependency of the BMI/%BF relation on ethnicity. First, body build/frame size (commonly measured by wrist and knee girths) tends to vary among different ethnic groups. A number of studies have noted that ethnic populations with relatively high levels of %BF at a given BMI also have a more slender build [43, 81]. Furthermore, Deurenberg et al [42] found that correcting for body build eliminated most of the ethnic-specific differences associated with %BF prediction equations for BIA in Chinese, Malay, and Indian Singaporeans. In contrast, earlier research concluded that the prediction of %BF from BMI was only slightly improved by the inclusion of body build parameters [2, 174]. It is possible that the effects of body build were not observed in these studies due to low inter-group and/or high intra-group variability [43].

A second factor that may contribute to ethnic-specific relationships between BMI and %BF is variation in sitting height relative to total height. Individuals with long legs (low sitting height) generally have a lower BMI and, as such, %BF may be underestimated from BMI [157]. Relative sitting height tends to be higher in Asian ethnic groups, although the effects on BMI are inconclusive – most likely due to the large intra-group variation in this parameter [43, 81]. However, even if differences in body proportions did explain a substantial proportion of the ethnic variation in relationships between BMI and %BF, collecting data on such variables will be impractical in population studies.

Finally, there may be differences in physical activity levels among ethnic groups. More active individuals tend to have a higher proportion of muscle mass, and therefore the potential for overestimation of %BF from BMI [43]. However, this would likely only exert substantial effects in those participating in relatively intensive weight training. Nonetheless, physical activity is an important behaviour to investigate when looking at body composition. To date, most large-scale studies comparing physical activity among different ethnic groups have relied on subjective questionnaires that suffer from recall bias in young people [24, 105, 183]. Objective measures, such as direct observation, accelerometers, and pedometers, provide valid and reliable estimates of children's physical activity that can be easily compared between population groups [199]. McKenzie et al [135] and Baranowski et al [5] observed the physical activity of multiethnic samples of American preschoolers: the former reported greater activity levels in European children than in Mexican American children, whereas the latter author found no significant differences in activity among European, Mexican American, and African American children. In primary-aged children, two studies using pedometry have shown ethnic variation in physical activity levels; the first among American, Australian, and Swedish children [225], the second among New Zealand European, Polynesian, and Asian children [53]. A recent study indicated that differences in accelerometer-determined activity exist between Hispanic and non-Hispanic adolescents [16]. In summary, no studies have used objective measures to examine ethnic differences in physical activity across a range of developmental stages. We also have a limited understanding of the cultural beliefs and social norms that contribute to behavioural differences. Clearly, further research is required to enable the link between ethnicity and physical activity to be elucidated.

Ethnicity and Obesity in New Zealand

New Zealand has an ethnically diverse population comprising mainly of Europeans (67.6%), Maori (14.6%), Asians (9.2%), and Pacific Islanders (6.5%) [203]. Despite this diversity, ethnic variation in body composition has yet to be investigated in all major ethnicities. Researchers have compared ethnic differences in BMI and %BF among Maori, Pacific Island, and European populations; several studies have found that Maori and Pacific Island adults tend to be leaner (i.e., have a lower %BF, and higher fat-free

mass) than New Zealand Europeans of the same body size [179, 210, 211]. Similar results have been observed in children: Rush et al [180] noted that Maori and Pacific Island girls have (on average) 3.7% less %BF than New Zealand European girls of the same body size. Furthermore, a similar study by Tyrell et al [223] found a small but statistically significant difference in the relationship between BMI and %BF in New Zealand European, Maori, and Pacific Island school children aged 5–10 years (although they concluded that the effects of ethnicity were not clinically relevant).

These studies concluded with suggestions that BMI thresholds for overweight and obesity should be raised for Maori and Pacific Island groups. In response, the 1997 National Nutrition Survey and the 2002/03 New Zealand Health Survey defined overweight and obesity as a BMI greater than 26 $kg.m^{-2}$ and 32 $kg.m^{-2}$ (respectively) for Maori and Pacific Island peoples (compared with 25 $kg.m^{-2}$ and 30 $kg.m^{-2}$ in all other ethnic groups) [140, 144]. The modified cut-off points were abandoned in the most recent New Zealand Health Survey (2006/07) [147]. Although the reasons for the change were not provided; Mann et al [128] has suggested that our understanding of ethnic variation in the comorbidities associated with excess adiposity is currently insufficient to ensure ethnic-specific BMI thresholds standardised for %BF are related to actual metabolic risk. Thus, from a public health perspective, it may be premature to raise cut-off points until more is understood about their specific health risk profile. Nonetheless, it remains likely that BMI cut-off points adjusted to an equivalent level of %BF would be a better indication of health risk than BMI reference values based on data from predominantly European populations.

Even though Maori and Pacific Islanders tend to have a higher proportion of lean mass to fat mass than New Zealand Europeans at a given BMI, as a population they maintain a greater absolute fat mass. For example, even when higher BMI thresholds are applied to Maori and Pacific Island peoples to counteract the high lean-to-fat mass ratio, these two groups remain twice as likely to be obese than the 'European and Other' group [140]. Not surprisingly, Maori and Pacific Island populations also have a much higher prevalence of type 2 diabetes when compared with Europeans [198]. These results have established these two ethnic groups as key priorities in the Ministry

of Health's Healthy Eating – Healthy Action (HEHA) public health strategy [142]. However, it is noteworthy that the prevalence of type 2 diabetes among New Zealand Indians exceeds that seen in Maori and Pacific Islanders. The high prevalence of diabetes (and cardiovascular disease [145]) among Indians is in line with the elevated levels of %BF at a given body size seen among Asian populations overseas. This is an issue of increasing importance to New Zealand given that Asian people make up the fastest growing ethnic group, with a population increase of 50% between 2001 and 2006 [203]. Indeed, Asian ethnicities are projected to account for 16% of New Zealand's population by 2026.

In spite of their population growth, Asian ethnic groups have traditionally been neglected by New Zealand health and research policies. For example, only Maori and Pacific Island children were over-sampled in the 2002 National Children's Nutrition Survey [143]. In addition, Maori and Pacific Island children were analysed separately, whereas children of Asian descent were grouped with Europeans. Until recently, this was a common theme in national surveys by government organisations. However, calls for the independent assessment of Asian populations has resulted in the identification of this ethnicity as a target group in contemporary surveys [147]. This paradigm shift is essential to understand the public health needs of Asian populations in New Zealand and to tailor preventative health strategies that will reverse the negative health statistics observed in Asian communities.

At present, standard BMI thresholds for 'overweight' and 'obesity' are applied to Asian populations, as there are no robust New Zealand data available on the relationship between BMI and body composition variables in this ethnic group. Consequently, Asian groups at risk for health complications (accompanying their overweight and obesity conditions) may not be targeted in interventions to prevent/treat obesity. One study of 19 Indian men living in New Zealand found that they carried 7-8% more body fat at a given BMI than their European counterparts [176]. The only evidence in young people is from a study by Tyrell et al [223] that included two small groups of Asian children in their investigation of the relationship between BMI and body composition in Maori, Pacific Islanders, and Europeans. Although results were not presented, the authors

commented that Asian Indian children tended to have a higher %BF at a given BMI compared with New Zealand Europeans. However, caution must be taken when interpreting this statement given the small sample size and the fact that %BF was estimated from BIA using a prediction equation that was not specifically developed for Asian Indian children.

The recommendations put forward by the WHO expert consultation [244] offer promise for the classification of overweight and obesity in New Zealand's multiethnic society. For clinicians assessing the health status of individuals, BMI thresholds should be refined by consideration of ethnicity and other risk factors such as waist circumference. At a population level, implementation of additional BMI action points will better reflect the continuum of %BF and associated health risk. However, very little is understood about the ethnic diversity in body composition among young New Zealanders. Ultimately, national BMI action points should be developed for people of all ages and major ethnic groups based on large-scale population studies of BMI, %BF, and health risk, and used in conjunction with standard international thresholds to enable comparisons with other surveys.

Thesis Rationale

The prevalence of obesity has increased dramatically in recent years, reaching epidemic proportions in many countries including New Zealand. National survey results show a 2.4-fold increase in the number of obese adults over the last 18 years, to a stage where over 60% of all adults are overweight or obese. Perhaps of even greater concern are the figures for young New Zealanders. The 2006/07 National Health Survey found that around 20% of children and adolescents were overweight and a further 8% are obese [147]. As a consequence, accurate assessment of overweight and obesity is vital to assist public health organisations in identifying at-risk groups and to facilitate development of appropriate preventative strategies. At a population level, %BF is most commonly assessed using BMI. Although the IOTF have established universal BMI standards for defining childhood overweight and obesity, international studies have shown that these BMI thresholds do not provide an equivalent measure of %BF and associated health risk across different ethnic groups.

In New Zealand, there are currently no population data comparing body composition across all major ethnicities. Our knowledge of the ethnic variation in %BF and other body composition variables is restricted to New Zealand European, Maori, and Pacific Island ethnic groups. New Zealand Asians are of particular interest because of their rapid population growth, and the lack of published data on their BMI/%BF relationships. Furthermore, compared with Europeans, Asians from other countries show elevated levels of %BF and greater morbidity and mortality at a given BMI [36]. This raises the prospect of the underestimation of excess body fatness in Asian groups when using BMI as the proxy measure. This situation is undesirable, as it would prevent health services accessing those most at need of intervention. However, a more appropriate solution is not possible until more is known about ethnic differences in relationship between BMI and body fat in young New Zealanders.

It is clear that large-scale studies are needed to determine the relations between BMI and %BF in young people from all major ethnic groups in New Zealand. Resulting data will enable development of ethnic-specific BMI thresholds for overweight and obesity, ensuring that our population estimates of obesity in this age group are not biased by systematic misclassification. There is also a clear lack of knowledge concerning ethnic variation in other areas, such as physical activity and weight perceptions/practices. An understanding of these issues is imperative for tailoring preventative interventions that will counteract the burgeoning epidemic of obesity in New Zealand. The primary aim of this thesis was to examine the appropriateness of current BMI definitions of overweight and obesity in female children and adolescents from five diverse ethnic groups. Secondary objectives were to investigate the weight control practices and perceptions and to compare objectively-measured physical activity levels in the multiethnic sample. Young adolescents were specifically targeted as this period is a critical time for the development of obesity and lifelong health behaviours.

Thesis Organisation

This thesis consists of seven interrelated chapters as depicted in the organisation diagram presented in Figure 1-3. Chapter 1 gives an overview of the relevant literature and a rationale for the thesis. Chapter 2 presents the findings from the BIA validation

study in Chinese and Indian children. The BIA equation developed from this preliminary study was applied to the main study in this thesis: a cross-sectional survey of body composition, weight perceptions and practices, and physical activity in 1,081 adolescent girls aged 11-16 years (Girls Activity and Body Composition [ABC] Study). Body composition and physical activity data were also incorporated from the Body-size and Steps in Children (BASIC) Study, an earlier investigation conducted in 5-11-year-old children (including 595 girls). The combination of the datasets enabled the appropriateness of current BMI definitions of childhood overweight to be assessed in a wide range of ages, as described in Chapters 3 and 4. These two chapters represent the primary focus of this thesis, culminating in a series of ethnic-specific BMI cut-off points for defining overweight and obesity in girls from New Zealand's five major ethnic groups. Chapters 5 and 6 present the analyses of the weight perceptions/practices and physical activity data, adding to our knowledge of the correlates of obesity in this age group. As Chapters 2-6 are comprised of five scientific papers, there may be some duplication in the introduction and methods sections. Each chapter should be thought of as essentially independent, with its own focused literature review and discussion. To this end, the general discussion in Chapter 7 provides a summary of the main points in each chapter while noting the limitations of the research.

CHAPTER 1
Introduction

CHAPTER 2
Validity of BIA in
Chinese and Indian

VALIDATION

MEASUREMENT/ASSESSMENT

CHAPTER 3
Diagnostic Accuracy of
BMI

CHAPTER 4
Ethnic-Specific BMI
Cut-offs

CORRELATES

CHAPTER 5
Weight Control
Perceptions and
Practices

CHAPTER 6
Physical Activity and
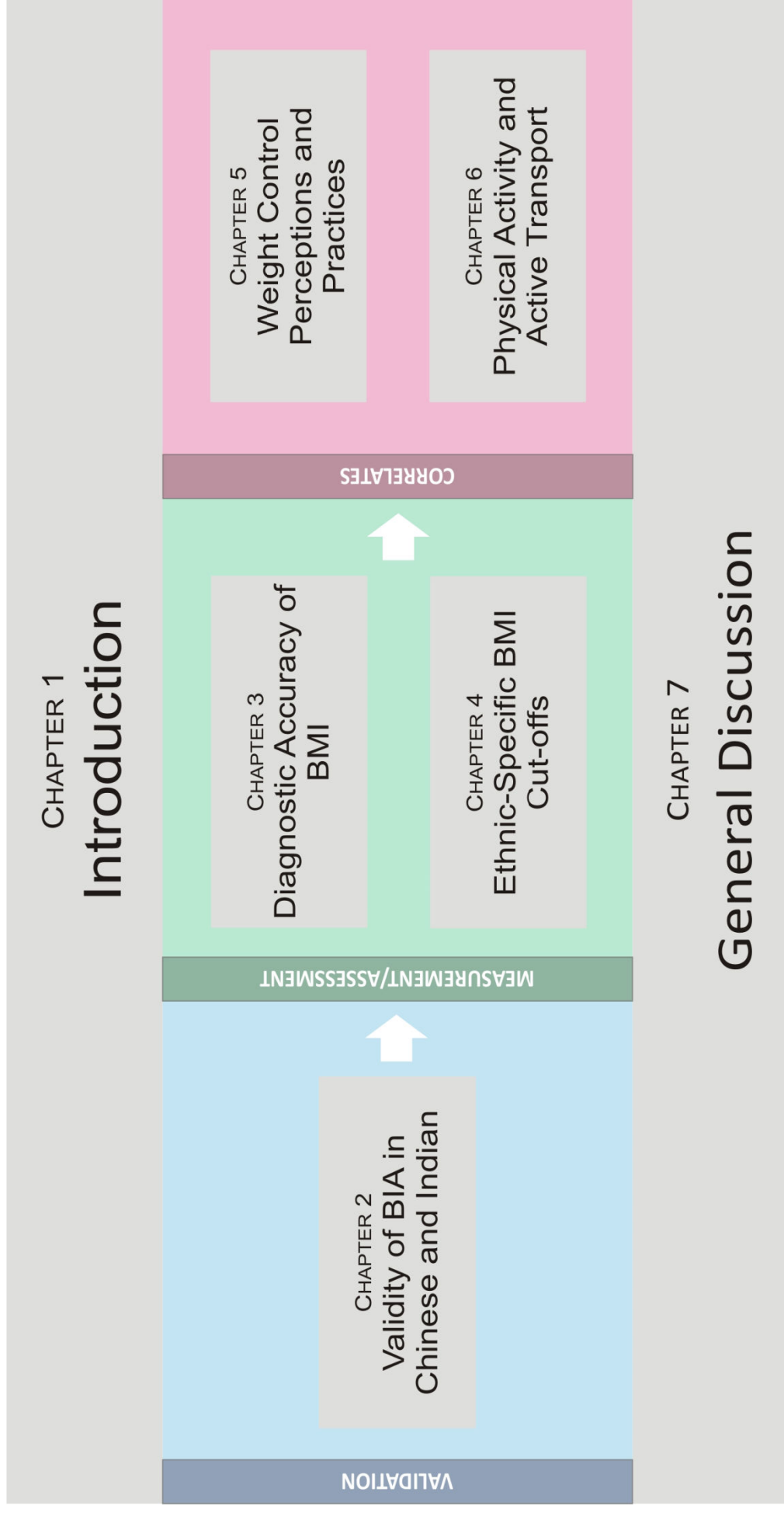Active Transport

CHAPTER 7
General Discussion

Figure 1-3. Overview of thesis organisation.

Chapter 2: BIA in Chinese and Indian Ethnicities

Preface

The main study in this thesis utilised bioelectrical impedance to assess body composition in a large multiethnic sample of New Zealand girls. BIA was the preferred option given the non-invasive nature of this technique (in comparison to equivalent field measures such as multisite skinfolds) for use in a paediatric population. The ability to distinguish between fat and lean mass is an important consideration when assessing body composition in children and adolescents given the variable relationships between fat and fat-free mass during growth and pubertal development. Moreover, evidence suggests that the level of body fat at a given BMI can differ substantially across different ethnic groups. Prior to this thesis, the accuracy of BIA for predicting FFM had not been determined in Chinese and Indian children and adolescents. The preliminary study described in this chapter was designed to validate bioimpedance measurements of FFM in Chinese and Indian children, with the intention of facilitating the main descriptive study in this thesis. The paper resulting from this chapter was published in 2007 in the *International Journal of Body Composition Research*.

Abstract

Background: Despite the increasing popularity of bioelectrical impedance analysis (BIA) as a field measure of body composition, the accuracy of BIA has yet to be investigated in Chinese and Indian children. The objectives of this study were to develop an equation for predicting fat-free mass (FFM) from bioimpedance measurements in New Zealand Chinese and Indian children, and to compare its performance with existing equations developed in other ethnic groups.

Methods: FFM derived from total body water by deuterium dilution was used as the reference standard for developing a BIA-based prediction equation in 79 healthy Chinese and Indian children (39 M, 40 F) aged 5-14 years. Nineteen published equations for predicting FFM or total body water from BIA were cross-validated in this sample.

Results: Using all possible subsets regression a single equation was developed that included height^2/resistance and body weight as independent variables ($R^2 = 0.98$; SEE = 1.49 kg; CV = 5.4%). Predicted residual error sum of squares (PRESS) analysis indicated that the equation had good potential for cross-validation in independent samples of Chinese and Indian children, with excellent predictive ability and negligible bias in each ethnic group. None of the published equations examined produced bias in FFM prediction that was statistically equivalent to zero and uncorrelated with FFM in our sample. The equation developed in this study showed excellent accuracy and precision for predicting the FFM of New Zealand Chinese and Indian children.

Conclusion: Prediction equations that have been generated specifically for children of Chinese and Indian descent are recommended when using BIA to estimate the body composition of these ethnic groups.

Introduction

The assessment of body composition has become increasingly important in epidemiological research as many countries reach a crisis point in the prevalence of overweight and obesity. Accurate estimates of body fatness are vital for public health organisations to identify at-risk groups and to facilitate the development of preventative strategies. In field settings, inexpensive techniques such as body mass index (BMI), skinfold thickness, and bioelectrical impedance analysis (BIA) are routinely used to assess nutritional status and screen for overweight and obesity. BIA is particularly useful in paediatric populations as it provides rapid and non-invasive estimates of fat-free mass (FFM). Over the last two decades, numerous studies have used criterion measures of body composition, such as isotope dilution, dual-energy-x ray absorptiometry, and hydrodensitometry, to validate BIA equations for predicting FFM (and hence body fatness) in young people.

In order to provide valid and reliable estimates of body composition in young people, it is essential that models for assessing body composition from bioimpedance measurements are population-specific. Indeed, individual FFM prediction models may not provide consistent results when applied to groups with significantly different body compositions [42, 177]. Given that the body build of different ethnic populations can

vary substantially [47, 211, 228, 230], it is important that equations for predicting FFM are validated before use in multiple ethnic groups. The majority of published BIA equations for young people were developed in predominantly Caucasian populations [27, 30, 44, 45, 89, 110, 165, 190, 209], though models also exist for Japanese [103, 129], African [120], and African American [122, 149] children. Several other equations were derived from samples with a significant proportion of Polynesian [180, 222] and African American [9, 208] children. In addition, Horlick et al [87] developed equations in a sample that was comprised of four ethnic groups (African American, Hispanic, Asian, and Caucasian children).

To date, the accuracy of existing BIA equations for assessing the body composition of Chinese and Indian children has not been investigated. Previous research indicates that the body composition of Asian children and adolescents differs substantially from the typical Caucasian phenotype, with more slender body builds and a higher ratio of fat-to-FFM at a given BMI observed in those of Asian descent [38, 40, 83, 137, 201]. Indeed, a recent study by Rush et al [177] found that BIA equations developed in Caucasian populations did not accurately predict the FFM of Indian adults, and that ethnic-specific equations were preferable. This suggests that BIA models developed in Caucasian children may not be valid in Chinese and Indian subjects. Thus, the purpose of the present study was to develop a valid equation for predicting FFM from bioimpedance measurements in Chinese and Indian children and compare its performance with existing equations developed in other ethnic groups.

Methods

Participants

Participants were 80 healthy Chinese and Indian children recruited through schools in Auckland, New Zealand. Children were only considered for selection if all four grandparents were of Chinese or Indian descent (as determined by a parent questionnaire). Two children from each sex and ethnicity were selected for each year of age from 5-15 years. Subjects with a wide range of body weights (14.1-78.3 kg) and heights (101.8-182.2 cm) were chosen to ensure that the resulting equation was applicable to children with variable body sizes. Overall, 79 of the 80 participants

provided suitable samples for deuterium (^{2}H) dilution analysis (39 Chinese [19 M, 20 F] and 40 Indian [20 M, 20 F]). All participants and their legal guardians provided written informed consent. Ethical approval was obtained from the Auckland University of Technology Ethics Committee.

Body Composition Measurements

Height (H) and sitting height (H$_s$) were measured to the nearest 0.1 cm with a portable stadiometer (Design No. 1013522, Surgical and Medical products, Seven Hills, Australia) using standard anthropometric technique. Weight (± 0.1 kg) was measured in light clothing on a digital scale (Seca 770, Seca, Hamburg, Germany). Each body composition measure was recorded by the same researcher a minimum of two times per participant to reduce artificial variation within each technique. Total body water (TBW) was measured using ^{2}H dilution following methods described previously [180]. Briefly, a baseline urine sample was collected, and 0.05 g ^{2}H$_2$O per kg of body weight was given orally. A second urine sample was collected five hours post-dose following emptying of the bladder at least one hour beforehand. Samples were prepared for analysis using the chromium reduction method in an elemental analyser furnace (Eurovector EuroEA3000, Milan, Italy) [100]. The ^{2}H isotopic enrichment of samples was measured using isotope ratio mass spectrometry (GV Instruments IsoPrime, Manchester, UK). FFM was determined from the ^{2}H dilution space by assuming that this volume is 4% larger than TBW [93], and by using the appropriate age- and sex-specific hydration factor for FFM [66, 124]. Resistance (R) and reactance (X) were measured using single frequency (50 kHz) hand-to-foot bioimpedance analyser (BIM4, Impedimed, Capalaba, Australia) according to procedures outlined in Rush et al [180].

Statistical Analyses

Data were analysed using SAS version 9.1.3 for Windows (SAS Institute Inc., Cary, NC). Descriptive statistics were calculated for age, H, H$_s$, weight, BMI, FFM, FM, percentage body fat (%BF), R, and height^2/resistance (H^2/R). Differences in participant characteristics between sex and ethnic groups were assessed using two-tailed independent samples t-tests. FFM derived from measurements of TBW by ^{2}H dilution was used as the criterion reference for the development of prediction equations based

on BIA measurements. These equations were developed for predicting FFM, as opposed to FM, because of the functional relationship between BIA and hydrated lean body tissues. FM and %BF were calculated as weight-FFM and (weight-FFM)/weight, respectively. Preliminary regression analysis in Chinese and Indian children indicated no differences in the predictor variables entering the models for each ethnic group. Therefore, Chinese and Indian ethnicities were combined in subsequent analyses.

The study population was randomly divided into validation (2/3 of the total sample) and cross-validation (1/3 of the total sample) groups. Using all possible subsets regression analysis in the validation group, a set of prospective prediction equations for FFM was formulated from the following independent variables: weight, age, H, H_s, R, reactance (X), H^2/R, H_s^2/R, sex (F = 0, M = 1), and ethnicity (Indian = 0, Chinese = 1). As a prerequisite, potential predictor variables were first screened for a linear relationship with FFM. Selection of the appropriate number of variables was based on Mallows' Cp statistic and the Schwarz Bayesian criterion (SBC). A high adjusted R^2 value, low standard error of estimate (SEE), Cp similar to the number of regressors in the model, and low SBC indicate an optimal model. A variance inflation factor (VIF) for each independent variable was calculated to assess multicollinearity. The performance of the resulting FFM equation in the cross-validation group was determined by calculating the pure error. The final equation was developed in the total sample using the independent variables determined from the initial equation, and then validated statistically using the PRESS (predicted residual error sum of squares) procedure in both ethnic groups (separately and combined). All R^2 values presented were adjusted by degrees of freedom.

Published BIA equations for predicting FFM or TBW in healthy participants that fell within the 5-14 year age range were tested in the study sample. Predictive equations were selected if they were widely used, were generated in large samples, or were developed in Asian or New Zealand samples. Models that included anthropometric variables other than height and weight were excluded. Equations that predicted TBW [9, 30, 110, 120, 129] were converted to FFM after dividing by age-specific hydration factors for FFM [66, 124]. Bias (predicted – observed FFM) was calculated to assess the

relative under- or overestimation of each equation. Power analyses using a bias SD averaged from the 19 published equations revealed that the sample size of 79 was sufficient to enable the detection of absolute bias greater than 0.67 kg (α = 0.05, 1 – β = 0.80, SD = 2.09 kg). The pure error and the 95% limits of agreement (mean bias $\pm$ 1.96 $\times$ bias SD) were also calculated to provide an indication of the overall precision of measurement. Consistency of bias at the extremes of the FFM distribution was investigated by correlation analysis, and, where necessary, Bland-Altman plots.

Results

Table 2-1. Participant characteristics grouped by sex and ethnicity.

Data are presented as mean $\pm$ SD (minimum-maximum); H, height; H_s, sitting height; BMI, body mass index; FFM, fat-free mass; FM, fat mass; %BF, percentage body fat.

	All children (n = 79)	Chinese Boys (n = 19)	Indian Boys (n = 20)	Chinese Girls (n = 20)	Indian Girls (n = 20)
Age (y)	9.9 $\pm$ 2.9 (5.9-15.6)	9.1 $\pm$ 2.3 (5.9-13.4)	10.5 $\pm$ 3.2 (5.9-15.6)	9.7 $\pm$ 3.1 (5.5-14.8)	10.1 $\pm$ 2.9 (5.5-13.4)
H (cm)	136.4 $\pm$ 18.2 (101.8-182.2)	133.3 $\pm$ 15.2 (110.9-165.1)	141.4 $\pm$ 20.4 (115.6-182.2)	133.3 $\pm$ 19.6 (101.8-163.9)	137.5 $\pm$ 17.1 (105.7-166.3)
H_s (cm)	71.8 $\pm$ 9.0 (50.5-92.5)	69.6 $\pm$ 8.8 (42.0-85.1)	72.1 $\pm$ 9.9 (50.5-92.5)	72.6 $\pm$ 9.0 (58.0-86.1)	72.8 $\pm$ 8.5 (60.2-88.8)
Weight (kg)	34.1 $\pm$ 13.9 (14.1-78.3)	31.8 $\pm$ 10.2 (17.9-59.8)	39.1 $\pm$ 19.8 (18.6-78.3)	32.4 $\pm$ 12.2 (14.1-52.6)	33.2 $\pm$ 11.0 (16.8-60.2)
BMI (kg/m^2)	17.6 $\pm$ 3.1 (13.6-27.5)	17.4 $\pm$ 2.2 (13.7-21.9)	18.3 $\pm$ 4.5 (13.9-27.5)	17.4 $\pm$ 2.5 (13.6-21.2)	17.1 $\pm$ 2.6 (14.4-23.8)
FFM (kg)	29.4 $\pm$ 13.7 (11.4-57.5)	25.0 $\pm$ 8.4 (15.2-47.0)	29.4 $\pm$ 13.7 (15.4-57.5)	23.7 $\pm$ 8.2 (11.4-36.8)	23.3 $\pm$ 7.6 (12.8-39.9)
FM (kg)	8.8 $\pm$ 4.9 (2.2-24.9)	6.8 $\pm$ 2.8 (2.2-12.8)	9.7 $\pm$ 7.0 (2.5-24.9)	8.7 $\pm$ 4.3 (2.7-15.8)	9.9 $\pm$ 4.1 (4.0-20.3)
%BF	24.9 $\pm$ 6.4 (9.3-40.3)	21.2 $\pm$ 6.1 (9.3-31.1)	23.1 $\pm$ 6.9 (12.1-39.9)	25.9 $\pm$ 4.3 (18.9-35.2)	29.3 $\pm$ 5.5 (20.8-40.3)

Table 2-1 shows the participant characteristics grouped by sex and ethnicity. There were no significant differences in age, H, H_s, weight, BMI, FFM, or FM between sexes or ethnic groups. Chinese girls averaged 4.6% more body fat (p = 0.009) than Chinese boys, and Indian girls averaged 6.2% more body fat than Indian boys (p = 0.003). There were no significant differences between Chinese and Indian boys for any of the independent variables, however Indian girls averaged 3.4% more body fat than

Chinese girls (p = 0.034). Covariance analysis revealed no significant differences in FFM at a fixed BMI and age between Chinese and Indian boys or girls.

The study population was randomly split into validation and cross-validation groups in order to develop equations for predicting FFM. The validation group consisted of 26 Chinese (13 M, 13 F) and 27 Indian (13 M, 14 F) children, and the cross-validation group consisted of 13 Chinese (6 M, 7 F) and 13 Indian (7 M, 6 F) children. These groups did not differ significantly for any of the variables listed in Table 2-1. An equation was developed in the validation group using all possible subsets regression that included H^2/R and weight for predicting FFM (R^2 = 0.97, SEE = 1.6 kg, CV = 6.2%; Table 2-2). The VIF for these two predictor variables was less than 10, indicating that collinearity was not a concern. Models that included age, sex, ethnicity, H, H_s, BMI, R, X, or H_s^2/R variables were not selected due to high Cp and SBC values. When the validation equation was applied to the cross-validation group, the predicted FFM (26.67 ± 11.66 kg) was not significantly different from the observed FFM (26.65 ± 12.00 kg). In addition, the pure error was lower than the SEE in the original validation group, indicating that the equation performed better in the independent sample. Given these results, a single equation was developed in the total sample (n = 79) using the variables determined from the initial equation (R^2 = 0.98, SEE = 1.49 kg, CV = 5.4%; Table 2). The H^2/R term accounted for 62.1% of the variability of the equation while weight alone accounted for 54.1% of the variability. The bias of the final equation was 0.00 ± 1.47 kg, with 95% limits of agreement of ± 2.88 kg. The PRESS statistic for the total sample (1.54 kg) was comparable to the SEE, which implied good potential for cross-validation in independent samples. Individual PRESS statistics for Chinese and Indian children revealed a similar level of performance in each ethnic group (1.52 kg and 1.75 kg, respectively). Furthermore, the PRESS residuals for each ethnic group (Chinese, -0.03 kg; Indian, 0.02 kg) and the total sample (0.00 kg) were close to zero, with no noticeable trends at the upper and lower ends of the FFM distribution. This suggests that prediction bias will not be a factor if the final equation is applied to independent populations of Chinese and Indian children.

Table 2-2. Development of a BIA prediction equation for FFM.

FFM, fat-free mass (kg); H, height (cm); R, resistance (Ω); SEE, standard error of estimate; CV, coefficient of variation.

Validation Sub-Sample (n = 53)	
Observed FFM	24.74 ± 8.80 kg
FFM prediction equation	FFM = (0.545 × H^2/R) + (0.311 × weight) + 0.077 R^2 = 0.969, SEE = 1.57 kg, CV = 6.2%
Predicted FFM	25.43 ± 8.67 kg
Cross-Validation Sub-Sample (n = 26)	
Observed FFM	26.65 ± 12.00 kg
Predicted FFM	pure error = 1.39 kg, CV = 5.2% 26.67 ± 11.66 kg
Total Sample (n = 79)	
Observed FFM	25.37 ± 9.93 kg
FFM prediction equation	FFM = (0.533 × H^2/R) + (0.329 × weight) - 0.004 R^2 = 0.978, SEE = 1.49 kg, CV= 5.4%
Predicted FFM	25.37 ± 9.82 kg

Nineteen published BIA-based equations for predicting FFM were evaluated in the present population of Chinese and Indian children. Most of the equations showed acceptable correlation between observed and predicted FFM in their samples, with the SEE statistics ranging from 0.93 to 5.12 kg (Table 2-3). When applied to our sample of Chinese and Indian children, the predicted FFM from each equation was highly correlated with the observed FFM. FFM was underestimated by 12 equations [30, 45, 103, 110, 120, 122, 129, 149, 165, 190, 208, 222] and overestimated by five [27, 44, 87, 89, 209]. Only predictive models by Bray et al [9] and Rush et al [180] produced bias that was not significantly different from zero. The pure error of these equations was 2.21 kg [9] and 1.59 kg [180]. For both equations, there was a significant negative correlation between the bias and observed FFM, indicating that FFM was underestimated at high values of FFM and overestimated at low values of FFM in our sample.

Table 2-3. Description of published BIA equations for the prediction of FFM in young people.

C, Caucasian; A, Asian; P, Polynesian, SA, South American; AA, African American, Af, African; J, Japanese; SEE, standard error of estimate; H, height (cm); W, weight (kg), R, resistance (Ω); Z, impedance (Ω); X, reactance (Ω); ID, isotope dilution, TBK, total body potassium, UWW, underwater weighing; HF, hydration factor; BIA-101, RJL Systems, Inc., Clinton Township, MI; Xitron, Xitron Technologies, San Diego, CA; BIM-4, Impedimed, Capalaba, Australia; Holtain, Holtain Ltd, Crymych, UK; Human Im, DS Medigroup, Milan, Italy; TBF-105, Tanita Corp, Tokyo, Japan; TP-95K, Toyo Physical, Fukuoka, Japan; SIF-891, Selco, Yokohama, Japan.

Reference	BIA Instrument	Study Characteristics	Criterion Method	Equation for FFM (kg)	R^2	SEE (kg)
Bray et al [9]	Xitron	10-12 y (C, AA) n = 129 M/F	ID	[(0.4 × H²/R) + (0.148 × W) + 3.32]/HF	—ᵃ	—ᵃ
Cordain et al [27]	BIA-101	9-14 y (C) n = 14 M, 16 F	UWW	(0.81 × H²/R) + 6.86	0.69	4.08
Danford et al [30]	BIA-101	5-9 y (C) n = 11 M, 15 F	ID	[(0.45 × H²/R) + (0.11 × W) + 1.84]/HF	—ᵃ	—ᵃ
Deurenberg et al [44]	BIA-101	7-25 y (C) n = 130 M, 116 F	UWW	(0.438 × H²/R) + (0.308 × W) + (1.6 × sex) + (0.070 × H) − 8.5 (sex: M = 1, F = 0)	0.99	2.39
Deurenberg et al [45]	BIA-101	7-15 y (C) n = 166 M/F	UWW	(0.406 × H²/R) + (0.360 × W) + (0.056 × H) + (0.56 × sex) − 6.48 (sex: M = 1, F =0)	0.97	1.68
Horlick et al [87]	BIA-101	4-18 y (C, AA, H, A) n = 640 M, 597 F	DEXA	[(0.459 × H²/R) + (0.064 × W) + 3.474]/[(0.769 − (0.009 × age) − (0.016 × sex)] (sex: M = 1, F = 0)	0.997	0.93
Houtkooper et al [89]	BIA-101	10-19 y (C) n = 225 M/F	ID, UWW	(0.61 × H²/R) + (0.25 × W) + 1.31	0.95	2.1
Kim et al [103]	SIF-891	9-14 y (J) n = 141 M	UWW	(0.56 × H²/Z) + (0.20 × W) + 1.66	0.971	1.59
Kushner et al [110]	BIA-101	0-66 y (C, SA)	ID	[(0.59 × H²/R) + (0.065 × W) + 0.04]/HF	—ᵃ	—ᵃ

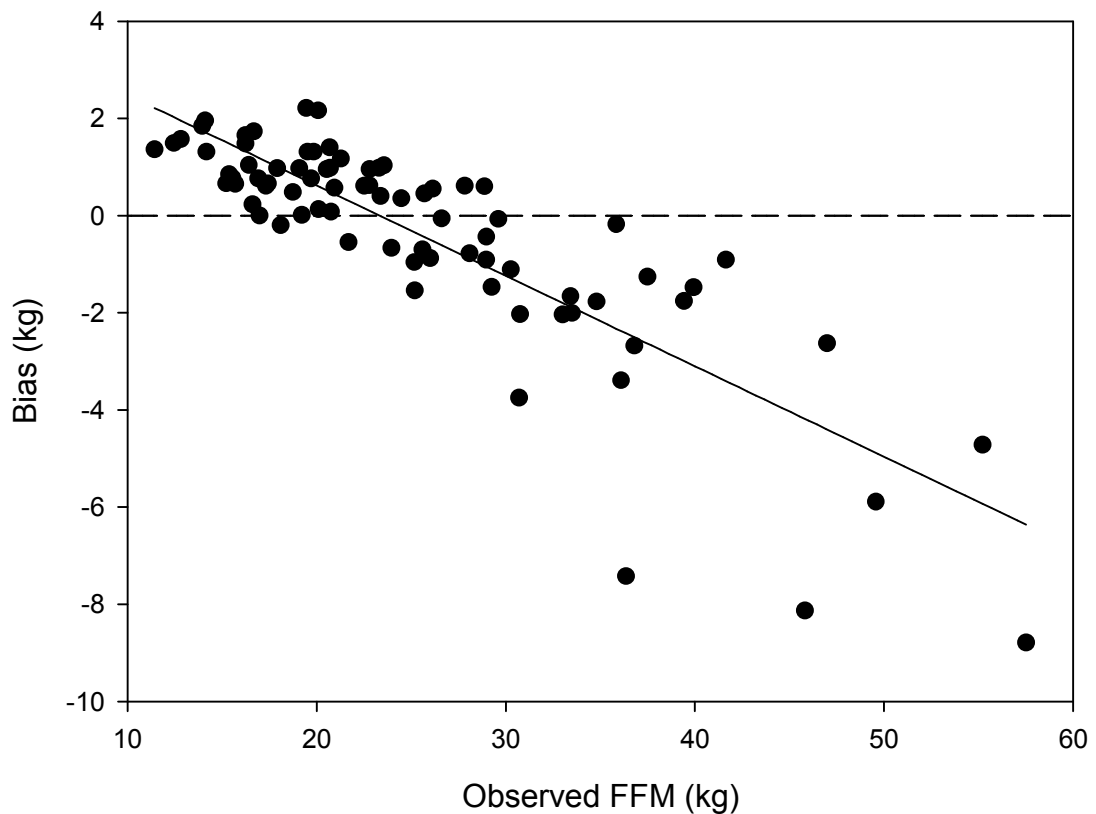| Reference	Device	Population	Method	Equation		
		$n = 175$ M/F				
Leman et al [120]	BIA-101	5-8 y (Af) $n = 17$ M, 22 F	ID	$[(0.35 \times H^2/R) + (0.24 \times W) - (0.74 \times sex) +1.67]/HF$ (sex: M = 0, F = 1)	—[a]	—[a]
Lewy et al [122]	BIA-101	M 11.4 ± 1.4 y F 10.2 ± 0.4 y $n = 19$ M, 17 F (AA)	DEXA	$(0.84 \times H^2/R) + 1.10$	0.97	1.47
Masuda & Komiya [129]	TP-95K	3-6 y (J) $n = 39$ M, 31 F	ID	$[(0.149 \times H^2/R) + (0.244 \times W) + (0.460 \times age) + (0.501 \times sex) + 1.628]/HF$ (sex: M = 1, F = 0)	—[a]	—[a]
Morrison et al [149]	BIA-101	11.2 ± 2.7 y (AA) $n = 61$ F	DEXA	$(0.78 \times H^2/R) + (0.10 \times X) + (0.18 \times W) - 8.78$	0.99	1.95
Pietrobelli et al [165]	Human-Im	7-14 y (C) $n = 50$ M, 25 F	DEXA	$(0.694 \times H^2/Z) - (1.097 \times sex) + 5.344$ (sex: M = 0, F = 1)	0.90	5.12
Rush et al [180]	BIM-4	5-14 y (C, P) $n = 83$ M, 89 F	ID	$(0.622 \times H^2/R) + (0.234 \times W) + 1.166$	0.96	2.45
Schaefer et al [190]	Holtain	3.9-19.3 y (C) $n = 59$ M, 61 F	TBK	$(0.65 \times H^2/R) + (0.68 \times age) + 0.15$	0.975	1.98
Sun et al [208]	BIA-101	12-94 y (C, AA) $n = 669$ M, 944 F	ID, UWW, DEXA	$(0.65 \times H^2/R) + (0.26 \times W) + (0.02 \times R) - 10.68$ (sex: M) $(0.69 \times H2/R) + (0.17 \times W) + (0.02 \times R) - 9.53$ (sex: F)	0.90 0.83	3.9 2.9
Suprasongsin et al [209]	BIA-101	10-22 y (C) $n = 21$ M, 21 F	ID	$(0.524 \times H^2/R) + (0.415 \times W) - 0.32$	0.96	2.8
Tyrell et al [222]	TBF-105	5-10.9 y (C, P) $n = 82$ M/F	DEXA	$(0.31 \times H^2/Z) + (0.17 \times H) + (0.11 \times W) + (0.942 \times sex) - 14.96$ (sex: M = 2, F = 1)	0.97	-

[a]Statistics based on TBW prediction equations are not presented.

Table 2-4. Cross-validation of published BIA equations for the prediction of FFM in Chinese and Indian children.

FFM, fat-free mass; $r_{y,y'}$, correlation coefficient between criterion FFM and predicted FFM; $r_{y-y',y}$, correlation coefficient between the bias and the criterion FFM.

Equation	Predicted FFM (kg)	$r_{y,y'}$	Bias (kg)[a]	p[b]	Pure Error (kg)[c]	Limits of Agreement (kg)	$r_{y-y',y}$
Bray et al [9]	24.99 ± 8.17	0.989	-0.38	0.132	2.21	-4.67, 3.92	-0.842 (p = 0.000)
Cordain et al [27]	28.33 ± 8.20	0.976	2.96	0.000	3.95	-2.19, 8.11	-0.733 (p = 0.000)
Danford et al [30]	23.08 ± 8.15	0.988	-2.28	0.000	3.22	-6.75, 2.19	-0.828 (p = 0.000)
Deurenberg et al [44]	26.47 ± 10.89	0.990	1.10	0.000	2.08	-2.37, 4.57	0.478 (p = 0.000)
Deurenberg et al [45]	24.45 ± 9.96	0.989	-0.91	0.000	1.70	-3.75, 1.93	-0.057 (p = 0.619)
Horlick et al [87]	26.83 ± 9.35	0.987	1.47	0.000	2.19	-1.76, 4.69	-0.429 (p = 0.000)
Houtkooper et al [89]	26.01 ± 9.51	0.988	0.64	0.000	1.65	-2.37, 3.65	-0.572 (p = 0.000)
Kim et al [103]	23.27 ± 8.30	0.988	-2.10	0.000	3.00	-6.32, 2.13	-0.803 (p = 0.000)
Kushner et al [110]	23.58 ± 9.23	0.983	-1.78	0.000	2.58	-5.46, 1.90	-0.456 (p = 0.000)
Leman et al [120]	24.76 ± 9.25	0.991	-0.64	0.000	1.60	-3.54, 2.26	-0.518 (p = 0.000)
Lewy et al [122]	23.36 ± 8.51	0.976	-2.01	0.000	3.17	-6.84, 2.83	-0.660 (p = 0.000)
Masuda & Komiya [129]	24.62 ± 8.18	0.987	-0.75	0.004	2.38	-5.20, 3.71	-0.819 (p = 0.000)
Morrison et al [149]	24.09 ± 10.12	0.988	-1.27	0.000	2.03	-4.39, 1.85	0.038 (p = 0.738)
Pietrobelli et al [165]	23.61 ± 7.00	0.976	-1.76	0.000	3.86	-8.54, 5.02	-0.897 (p = 0.000)
Rush et al [180]	25.63 ± 9.42	0.988	0.27	0.133	1.59	-2.82, 3.36	-0.397 (p = 0.000)
Schaefer et al [190]	24.08 ± 8.29	0.977	-1.29	0.000	2.84	-6.29, 3.71	-0.720 (p = 0.000)
Sun et al [208]	29.90 ± 8.41	0.984	-4.53	0.000	3.17	-8.94, -0.12	0.737 (p = 0.000)
Suprasongsin et al [209]	27.72 ± 10.90	0.989	2.36	0.000	2.99	-1.24, 5.96	0.462 (p = 0.000)
Tyrell et al [222]	21.57 ± 7.60	0.979	-3.79	0.000	4.79	-9.55, 1.97	-0.849 (p = 0.000)

[a]Bias = predicted – observed FFM; [b]P value for a one sample t-test that bias = 0; [c]Pure error = $\sqrt{\Sigma}$(predicted – observed)^2/n, where n is the number of subjects in the sample.

The modified Bland-Altman plots presented in Figure 2-1 and Figure 2-2 show the magnitude of the slope between the bias and observed FFM for the Bray et al [9] (slope = -0.19) and Rush et al [180] (slope = -0.02) equations, respectively. For example, at one and two SDs above the mean, we would expect the equation by Bray et al [9] to underpredict FFM by 2.2 and 4.0 kg, and by 0.4 and 1.0 kg for the equation by Rush et al [180]. At one and two SDs below the mean, we would expect the equation by Bray et al [9] to overpredict FFM by 1.5 and 3.3 kg, and by 0.9 and 1.5 kg for the equation by Rush et al [180].

Figure 2-1. Observed bias when using the Bray et al [9] equation to predict FFM in Chinese and Indian children.

Bias = (-0.186 × FFM) + 4.339; dashed line = zero reference line.

Figure 2-2. Observed bias when using the Rush et al [180] equation to predict FFM in Chinese and Indian children.

Bias = (-0.022 × FFM) + 0.533; dashed line = zero reference line.

Discussion

The continuing development of BIA as a field measure of body composition offers researchers a practical means to monitor the prevalence of excess adiposity in large samples. However, there is a lack of information regarding the accuracy of assessing FFM from bioimpedance measurements in Chinese and Indian children. To our knowledge, the BIA equation developed in the present study is the first to be validated in these population groups. Using H^2/R and weight as the predictor variables, we obtained accurate and precise estimates of FFM in the sample of 79 children. Further analyses using the PRESS procedure indicated that the equation was also likely to perform well in independent samples of Chinese and Indian children, with no evidence of prediction bias across the FFM distribution for each ethnic group, or for the combined sample. The limits of agreement of ± 2.88 kg indicate that between-subject differences in FFM less than 5.76 kg could not be confidently interpreted as true differences. This finding is consistent with the view that BIA is better suited for

population research than for the evaluation of FFM in individuals [27, 45, 87, 110, 190]. However, it is likely that the limits of agreement would narrow with a larger sample.

While Indian girls in our study were significantly fatter than Chinese girls, preliminary regression analysis revealed that the same independent variables entered the models for predicting FFM in both groups. Neither ethnicity nor its interaction with sex featured in the final prediction model, indicating that ethnicity did not explain a significant amount of the variation in FFM regardless of sex. In this study, a single model was developed that produced valid results in Chinese and Indian children, suggesting that ethnic variation in %BF does not necessarily affect the relationship between FFM and bioimpedance parameters. Age and sex also had limited effects on model performance and were consequently excluded from the final equation. Although body water (and therefore bioimpedance) does vary by age and sex, the ^{2}H-derived FFM used as the criterion measure was adjusted by age- and sex-specific hydration factors [66, 124].

The development of a model that performs well in Chinese and Indian children would be of limited significance if existing equations were capable of providing acceptable estimates of FFM in these ethnic groups. Comparing the predictive ability of a series of equations developed in subjects from diverse ethnic groups also provides insight into the adaptability of BIA as a measure of body composition. Nineteen equations previously validated in paediatric subjects were tested, all of which featured either H^2/R or H^2/Z as the major predictor variable. This was expected given that these terms provide an index of the conductive volume of the body, which (in theory) is linearly related to TBW and FFM. Surprisingly, the two equations developed specifically for Japanese children [103, 129] did not perform well in our Asian sample. Only models by Bray et al [9] and Rush et al [180] predicted the FFM of Chinese and Indian children without significant bias. Although these equations had the same predictor variables as our equation for Chinese and Indian children, neither was developed in Asian subjects. Bray et al [9] used a sample of Caucasian and African-American children aged 10-12 years to generate their equation, while Rush et al [180] used Caucasian and Polynesian

children aged 5-15 years. The pure error values of 2.21 and 1.59 kg produced by the Bray et al [9] and Rush et al [180] equations (respectively) were comparable to the SEE of the equation developed in our final sample (1.49 kg). However, the degree of bias increased significantly at the extremes of the FFM distribution for both models. This is arguably more important than the precision of measurement with regard to the applicability of equations to population research, and suggests that these equations are not ideally suited for use in Chinese and Indian children.

It should be noted that the FFM prediction equation proposed in the present study was generated in Chinese and Indian children living in New Zealand. Thus, the applicability of this equation to indigenous Chinese and Indian populations is uncertain. While there are no data comparing the body composition of New Zealand Chinese and Indian children with their native populations, the body composition of Asian populations may vary with their country of residence. For example, Lauderdale and Rathouz [114] reported that the mean BMI of Asian men and women born in America was significantly higher than that of 'foreign' Asians, and Deurenberg et al [40] has shown that the body composition of Chinese children residing in different countries varied significantly. In the present study, all four grandparents of each child were required to be Chinese or Indian to ensure that participants were as equivalent to their native populations as possible. Nonetheless, cross-validation of the FFM equation from the present study in independent samples of indigenous Chinese and Indian children from urban and rural areas is recommended.

Given the age range of the participants in this study (5-14 years), it is also relevant to consider the potential effects of maturation on bioimpedance. The rapid changes in body composition that accompany pubertal development can have a marked effect on bioimpedance parameters. Indeed, there is evidence that puberty is more important than age with regard to bioimpedance in 10-15-year-old girls, even after correction for maturational increases in BMI [13]. Changes to the bioelectrical properties of tissue during sexual maturation are associated with a reduction in the hydration of FFM [84, 172]. While maturational stage was not assessed in this study, the age-specific hydration factors used to estimate FFM from ^{2}H were developed from reference

populations that included both pre- and post-pubertal children, thereby adjusting for pubertal changes in hydration [66]. Nonetheless, differences in the mean age of maturation and/or the effect of puberty on tissue hydration between the present sample and the reference populations could result in systematic bias. Until the associations between age, maturation, and tissue hydration in Chinese and Indian children are elucidated, the implications of hydration error for BIA prediction equations in these ethnic groups remain unclear.

In summary, we propose a new model for the prediction of FFM from bioimpedance measurements in Chinese and Indian children living in Western countries. To our knowledge, this is the first BIA-based equation for the estimation of FFM in children from these ethnic groups. Our equation is applicable over a wide range of body sizes and ages, and is more suitable than BMI for assessing body fatness in field research. The use of predictive models developed in other populations is not recommended for Chinese and Indian children given their performance in the present sample. Data from this study suggest that with the use of appropriate equations, BIA can provide a practical, valid measure of body composition in young Chinese and Indian subjects.

Chapter 3: Diagnostic Accuracy of BMI

Preface

Given the development of an equation for Chinese and Indian children in the preceding chapter, it was possible to use BIA to obtain valid estimates of %BF in a large descriptive study of New Zealand girls. A multiethnic sample of more than 1,600 European, Maori, Pacific Island, East Asian, and South Asian girls were selected from 39 primary, intermediate, and secondary schools in the Auckland region. This is the first time BMI and %BF have been compared in multiple ethnic groups, and represents a unique opportunity to compare the performance of current definitions of obesity in a diverse selection of phenotypes. Indeed, few countries have major ethnic groups with such disparate physical characteristics. Pacific Island individuals are known for their relatively large frame size and high proportion of lean muscle mass, whereas Asian peoples sit at the opposite end of the body composition spectrum. The paper resulting from this chapter is currently under consideration for publication in *Obesity*.

Abstract

Background: The association between body mass index (BMI) and body fat in young people differs among ethnic groups. Consequently, BMI thresholds for defining childhood overweight may not represent an equivalent level of adiposity in multiethnic populations. The objectives of this study were to characterise the relationships between BMI and percentage body fat (%BF) in girls from five ethnic groups, and to determine the appropriateness of universal BMI standards for predicting excess fatness in each ethnicity.

Methods: The relationship between BMI and %BF in 1,676 girls (40.6% European, 12.9% Maori, 21.2% Pacific Island, 14.5% East Asian, and 10.9% South Asian) aged 5-16 y was compared using analysis of covariance. Receiver operating characteristic (ROC) curves were prepared to assess the sensitivity and specificity of the International Obesity Taskforce (IOTF) and Centres for Disease Control and Prevention (CDC) BMI thresholds for detecting %BF > 85th percentile.

Results: Compared with European girls, South and East Asians averaged 4.2% and 1.3% more %BF at a fixed BMI and age, whereas Pacific Islanders averaged 1.8% less %BF. Areas under the ROC curves ranged from 89.9% to 92.4% across the five ethnic groups, suggesting that BMI can be an acceptable screening tool for identifying excess adiposity. However, both the IOTF and CDC thresholds for overweight showed relatively low sensitivity for predicting excess %BF in South and East Asian girls. Conversely, low specificity was observed for Pacific Island and Maori girls. The development of an ethnic-specific definition of overweight resulted in significant improvements to diagnostic performance.

Conclusions: Despite substantial variation in the associations between BMI and body fatness, BMI is an acceptable proxy measure of excess body fat in girls from diverse ethnic backgrounds. However, ethnic-specific BMI reference points are recommended over universal BMI standards for defining overweight in multiethnic populations.

Introduction

Body mass index (BMI), a simple anthropometric measure of weight divided by squared height, is the most widely used screening tool for overweight and obesity. While evidence suggests that BMI can provide an acceptable proxy measure of body fatness in young people [138, 166], the natural increases in BMI that occur with age necessitate the use of age-specific thresholds. The US Centres for Disease Control and Prevention (CDC) growth charts are routinely applied to identify children and adolescents with a BMI greater than the 85th or 95th percentile [108]. However, the appropriateness of an American dataset for defining overweight in young people from other populations is questionable. As an alternative, the International Obesity Task Force (IOTF) developed age-specific BMI curves that pass through the adult standards for overweight and obesity at age 18 y (25 kg.m^{-2} and 30 kg.m^{-2}, respectively) [23]. The latter thresholds are now the most frequently used classification for childhood overweight and obesity in public health research.

Key to the international applicability of the IOTF reference values was their development from a multi-country dataset. However, averaging values from different countries does not ensure the suitability of a single set of BMI standards in all

populations. Much like the age and sex-specific variation observed in the association between BMI and body fat, differences also exist across ethnic groups. For example, young people of East Asian [40], South Asian [137], and Hispanic [56, 57] descent tend to have more body fat than Europeans at an equivalent BMI. Conversely, Polynesian [180] and African-American [31] children and adolescents average less body fat than their European counterparts for the same BMI. These findings suggest that a universal BMI classification system for childhood overweight may not correspond to a comparable level of body fatness in all populations.

To date, research assessing the diagnostic accuracy of the IOTF BMI standards has been limited to individual ethnic groups with relatively small age ranges [70, 153, 169, 246]. All studies reported less than optimal sensitivity, with values ranging from 22% in Swedish girls aged 17 y to 72% in UK girls aged 7 y [170], and from 46% in UK boys aged 7 y [170] to 83% in Chinese boys aged 6-11 y [70]. Low sensitivity in these populations reflects an inability to accurately detect individuals with high body fat, resulting in excessive misclassification of overweight young people as normal weight. The only study to compare the IOTF and CDC criteria concluded that the CDC reference values were superior for detecting overweight in Swiss children [246]. However, there is a clear need to investigate the performance of both methods in a multiethnic sample. The objectives of the present study were to (1) compare body fatness at a given BMI in girls from five diverse ethnic groups (European, Maori, Pacific Island, East Asian, and South Asian), (2) investigate the sensitivity and specificity of the CDC and IOTF reference values for detecting excess body fat in a multiethnic sample, and (3) examine the appropriateness of ethnic-specific BMI cut-off points for predicting body fatness in girls.

Methods

Participants

A total of 1,676 participants aged 5-16 y (school years 1-10) were randomly selected from 39 primary, intermediate, and secondary schools in Auckland, New Zealand. Schools were selected to replicate the geographical and socioeconomic distribution of schools in the wider Auckland region. Participants' age and ethnicity were determined

by questionnaire. The ethnic composition of this sample was 680 European (40.6%), 355 Pacific Island (21.2%), 216 Maori (12.9%), 243 East Asian (14.5%), and 182 South Asian (10.9%). The East Asian ethnic grouping was composed of Chinese (53.5%), Korean (25.5%), Filipino (10.7%), Thai (4.5%), and 'other' East Asian (5.8%) girls; and the South Asian grouping was composed of Indian (93.4%), Sri Lankan (5.5%), and 'other' South Asian (1.1%) girls. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee. Written informed consent was provided by each participant and her legal guardian. We certify that all applicable institutional and governmental regulations concerning the ethnical use of human volunteers were followed during this research.

Body Composition Measurements

The height of each participant was measured to the nearest mm with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia). Weight in light clothing without shoes was measured to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was then calculated as weight (kg) divided by squared height (m^2). Body fat measurements were obtained using hand-to-foot bioelectrical impedance analysis (BIA). Resistance (R) was measured at 50 kHz using a bioimpedance analyser (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). After swabbing the skin on the right hand and foot with alcohol, source electrodes were placed on the dorsal surface of the foot over the distal portion of the second metatarsal, and on the hand on the distal portion of the second metacarpal. Sensing electrodes were placed at the anterior ankle between the tibial and the fibular malleoli, and at the posterior wrist between the styloid processes of the radius and ulna. Testing was initiated after the participants emptied their bladder, and had been lying supine with their arms and legs abducted for at least 5 min. Testing was completed when repeated measurements of R were within $1\,\Omega$ of each other. Fat-free mass (FFM) was calculated from R, height, and weight using two separate ethnic-specific equations previously validated in New Zealand children: one specifically for Maori, Pacific Island, and European children [180] and another for Chinese and Indian children [50]. The procedures used in this study, including the BIA

instrument, were identical to those used to develop the aforementioned FFM prediction equations. Fat mass (FM) was derived as the difference between FFM and body weight, and percentage body fat (%BF) was calculated as $100 \times$ FM/weight.

The BMI status of each participant was determined using the reference values for overweight proposed by the CDC [108] and the IOTF [23]. However, the ideal criterion for the identification of excess %BF has yet to be established. While some researchers have recommended the use of a single %BF value that is directly related to increased health risk in children [55, 85, 233, 236], subsequent research suggests that %BF in children is strongly age-dependent, and that a series of age-specific cut-offs are required to avoid an underestimate of excess adiposity in younger children [213]. Adjustment for ethnicity is also necessary in multiethnic populations to allow for potential variation in body fat profiles. In the present sample, the 85th age- and ethnic-specific percentiles of %BF were used to define overweight. This statistical definition, although arbitrary, is consistent with current practice in pediatric research [133].

Statistical Analyses

Data were analysed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL). Differences in physical characteristics (age, height, weight, BMI, %BF) among ethnicities were compared using analyses of covariance with Bonferroni *post hoc* tests where applicable. Sensitivity of the IOTF and CDC reference values was defined as the percentage of overweight children (%BF ≥ 85th percentile) correctly classified, while specificity was defined as the percentage of non-overweight children (%BF < 85th percentile) correctly classified. Differences in sensitivity and specificity among ethnic groups were assessed using Bonferroni-adjusted chi-squared tests. Receiver operating characteristic (ROC) curves were used to evaluate the ability of BMI to accurately predict overweight. The age-dependency of the BMI distribution was negated by using BMI z-scores adjusted for age. As there are currently no BMI reference values that account for all five ethnic groups in this study, BMI z-scores were generated with data from the present sample. The ROC curves for each ethnic group were constructed by calculating the sensitivity and specificity of a series of ethnic-specific BMI z-score

percentiles (1-100) for predicting overweight (%BF ≥ 85th percentile). The area under the curve (AUC) was then calculated as an indicator of the overall predictive ability of BMI in each ethnic group.
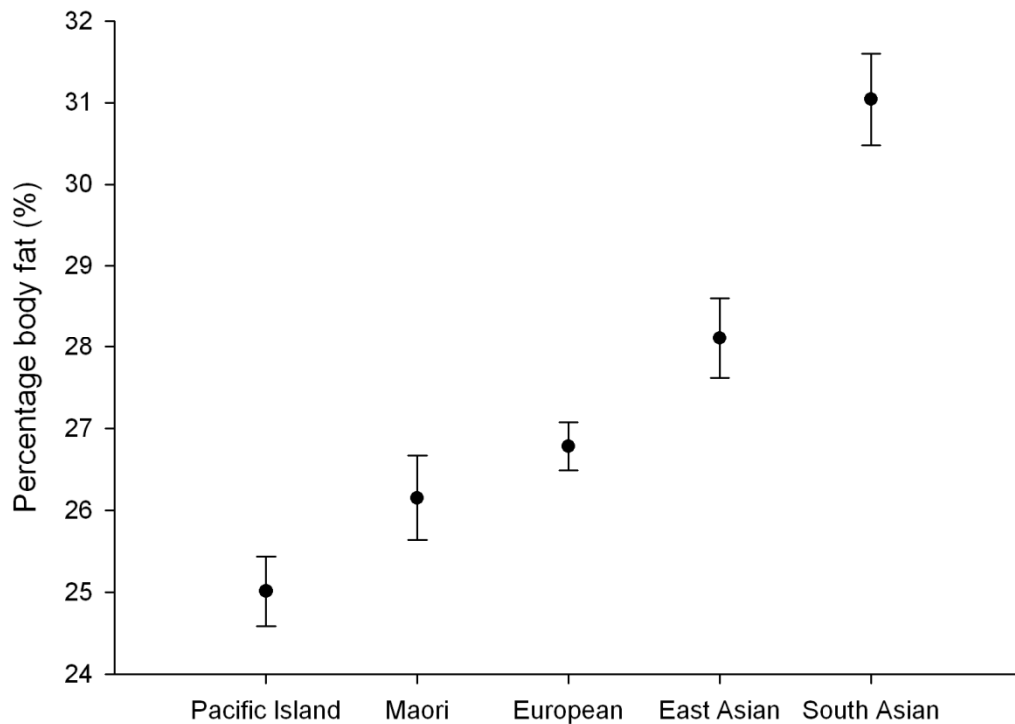
Results

Table 3-1. Participant characteristics grouped by ethnicity.

Data are presented as mean ± SD.

	European (*n* = 680)	Maori (*n* = 216)	Pacific Island (*n* = 355)	East Asian (*n* = 243)	South Asian (*n* = 182)
Age (y)	11.4 ± 2.9	11.5 ± 2.6	11.9 ± 2.9	12.1 ± 2.6	11.3 ± 2.5
Height (m)	1.47 ± 0.17	1.50 ± 0.16	1.52 ± 0.17	1.47 ± 0.15	1.45 ± 0.15
Weight (kg)	44.1 ± 16.0	51.5 ± 20.1	58.6 ± 22.2	42.9 ± 13.2	41.2 ± 14.6
BMI (kg/m^2)	19.6 ± 4.0	22.1 ± 5.5	24.2 ± 6.0	19.2 ± 3.4	19.0 ± 4.2
Body fat (%)	25.5 ± 6.6	27.6 ± 7.2	28.8 ± 6.9	26.4 ± 4.4	29.0 ± 5.2

Table 3-1 shows the characteristics of the study population according to ethnicity. The only significant difference in age was between East Asian girls who were older than European and South Asian girls ($P < 0.001$). Pacific Island girls were heavier than all other groups ($P < 0.001$), and taller than all groups except Maori ($P < 0.005$). In addition, Maori girls averaged higher body weights than the remaining three ethnicities ($P < 0.001$). BMI varied significantly across ethnicity ($P < 0.001$): Pacific Islanders were larger than all other groups ($P < 0.001$); followed by Maori, who were larger than European, East Asian, and South Asian girls ($P < 0.001$). Significant differences in %BF were also observed: Pacific Island and South Asian girls had more body fat than European and East Asian girls ($P < 0.001$), and Maori girls had more body fat than European girls ($P < 0.001$).

Figure 3-1. Percentage body fat corrected for differences in age and BMI.

Data are presented as mean ± 95% CI.

Figure 3-1 compares the mean (± 95% CI) %BF of European, Maori, Pacific Island, East Asian, and South Asian girls after adjustment for differences in age and BMI (ANCOVA). Significant differences in %BF were observed across the five ethnic groups (P < 0.001). In particular, Asian and Pacific Island girls showed contrasting %BF characteristics. South Asian girls had the highest %BF at a given BMI and age (31.0 ± 0.6%), which was significantly greater than the four remaining ethnicities ($P < 0.001$). East Asian girls had the next highest %BF (28.1 ± 0.5%), which was significantly greater than that of European, Maori, and Pacific Island girls ($P < 0.001$). At the other extreme, Pacific Island girls had the lowest %BF at a given age and BMI (25.0 ± 0.4%), which was significantly different than all other ethnic groups ($P < 0.01$). The level of %BF at a given BMI and age was similar between Maori (26.2 ± 0.5%) and European (26.8 ± 0.3%) girls ($P = 0.392$).

Figure 3-2. Receiver operating characteristic (ROC) curves of BMI z-score percentiles 100-1 (left to right) for the prediction of overweight (%BF > 85th percentile) in European, Maori, Pacific Island, East Asian, and South Asian girls

The sensitivity and specificity of the CDC (□) and IOTF (Δ) BMI reference standards for overweight are given for each ethnic group.

Figure 3-2 shows the ROC curves of BMI z-score percentiles for prediction of overweight in each ethnicity in addition to the CDC and IOTF positions for overweight. Values for sensitivity and specificity of the CDC/IOTF cut-off points are presented in Table 3-2. The sensitivity of both thresholds was lowest among East and South Asian girls, whereas the corresponding values for specificity were high among these groups. Conversely, sensitivity was high and specificity relatively low in Maori and Pacific Island girls. In European girls, sensitivity and specificity values were similar. Chi-squared analyses revealed significant differences in the sensitivity and specificity ($P < 0.001$ for both) of the CDC/IOTF thresholds for overweight across the different ethnic groups.

Table 3-2. Sensitivity and specificity of the IOTF and CDC reference standards for overweight.

Ethnicity	IOTF		CDC	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
European	83.0	86.4	83.0	86.6
Maori	96.8	62.7	96.8	62.7
Pacific Island	98.1	42.6	98.1	42.6
East Asian	65.7	90.9	65.7	91.3
South Asian	76.9	85.9	76.9	85.9

Table 3-3 gives the area under the ROC curves for the different ethnic groups and the optimum BMI z-score percentiles (first percentile where sensitivity ≥ 90) for predicting the 85th percentile of %BF. Naturally, the sensitivity of these thresholds was similar among ethnicities ($\chi^2 = 5.619$, $P = 0.229$), however, specificity showed significant ethnic variation ($\chi^2 = 20.815$, $P < 0.001$). The use of alternative criteria for defining the optimum percentile for predicting high body fat (maximum sum of sensitivity and specificity; the left-most point in the ROC curve) produced equivalent results. When compared to the CDC/IOTF cut-off points, the use of ethnic-specific percentiles offered significant improvements in sensitivity for East Asian girls ($\chi^2 = 6.873$, $P = 0.009$), but not for European ($\chi^2 = 2.098$, $P = 0.147$), Maori ($\chi^2 = 5.439$, $P = 0.076$), Pacific Island ($\chi^2 = 2.830$, $P = 0.093$), or South Asian ($\chi^2 = 2.364$, $P = 0.124$) girls. While significant improvements in specificity were observed for Maori ($\chi^2 = 11.768$, $P = 0.001$) and Pacific Island ($\chi^2 = 85.378$, $P < 0.001$) girls, specificity decreased in European

(χ^2 = 8.580, P = 0.003), East Asian (χ^2 = 13.292, P < 0.001), and South Asian (χ^2 = 15.944, P < 0.001) girls.

Table 3-3. Area under the ROC curves (AUC) of BMI z-score percentiles (1-100).
Sensitivity and specificity of the optimum BMI z-score percentiles for predicting the 85th percentile of body fat for each age and ethnic group are also given.

Ethnicity	AUC ± SE	Optimum BMI z-score Percentile[a]	Sensitivity (%)	Specificity (%)
European	0.907 ± 0.020	70th	90	80.3
Maori	0.922 ± 0.034	69th	90.3	78.9
Pacific Island	0.924 ± 0.026	69th	90.4	79.2
East Asian	0.899 ± 0.036	68th	91.4	77.9
South Asian	0.899 ± 0.041	58th	92.3	66.7

[a]First percentile where the sensitivity is ≥ 90.

Figure 3-3. Prevalence of overweight in the present sample according to CDC, IOTF, and ethnic-specific thresholds.

The prevalence of overweight in the study sample for the ethnic-specific BMI thresholds and the CDC/IOTF criteria is presented in Figure 3-3. Compared with CDC/IOTF estimates, ethnic-specific percentiles resulted in a significant increase in the prevalence of overweight in East Asian ($\chi^2 = 14.341$, $P = 0.006$) and South Asian ($\chi^2 = 14.496$, $P = 0.006$) girls, and a significant decrease in Maori ($\chi^2 = 10.630$, $P = 0.031$) and Pacific Island ($\chi^2 = 74.744$, $P < 0.001$) girls. The minor increase observed in European girls was not statistically significant ($\chi^2 = 6.594$, $P = 0.159$).

Discussion

Despite the widespread use of BMI as a screening tool for overweight and obesity in children, there is evidence that it is not a consistent predictor of %BF across all ethnicities [31, 40, 56, 57, 137, 180]. This ethnic variation has the potential to confound the identification of those at risk of negative health outcomes related to excess adiposity. Our results suggest that South Asian girls, in particular, have significantly higher body fat levels at a fixed BMI and age than other ethnic groups. The tendency for South Asians to accumulate high levels of body fat despite their relatively small body size has been demonstrated formerly in both adolescents [137] and adults [37], and is a concern for the future health status of this ethnic group. Although less pronounced, the %BF/BMI ratio in East Asian girls was also greater than European, Maori, and Pacific Island girls. These trends are consistent with previous investigations in Asian populations [38, 40, 137], and correspond to a body composition profile characterised by a slender frame and low muscularity [41]. In contrast, Pacific Island peoples tend to have greater muscle mass and bone mineral density than other ethnic groups [28, 211], evident in the present study as the lowest %BF for a given BMI of all five ethnicities.

It is clear from the preceding findings that a universal BMI-based classification scale for overweight will correspond to markedly different %BF levels in girls from diverse ethnic backgrounds. Not surprisingly, the sensitivity and specificity of both the CDC and IOTF criteria were dependent on ethnic group, with East Asian girls showing the lowest sensitivity (65.7%) and Pacific Island girls the lowest specificity (42.6%). Overall, around a third of East Asian girls with excess body fatness were not identified as overweight,

and over half of Pacific Island girls with normal levels of body fat were incorrectly categorized as overweight. These dramatic results highlight the potential inconsistencies when applying reference norms that are independent of ethnicity to a multiethnic population.

We also noted that the predictive abilities of the CDC and IOTF BMI thresholds were almost identical in all ethnic groups. This differs from previous research in Swiss children where the 85th percentile of the CDC data was preferable to the IOTF cut-off points for overweight when predicting excess adiposity (%BF ≥ 85th percentile) from multisite skinfold thicknesses [246]. Overweight classification criteria from the IOTF, the WHO, and a Swedish national survey also varied in performance when estimating the %BF status of Swedish adolescents using air-displacement plethysmography [153]. While the reasons for the discrepancies among studies are unclear, our data indicate that the ethnic variation in sensitivity and specificity associated with any universal BMI classification system is of greater importance than the differences between specific criteria.

Despite the disadvantages of using universal (non-specific) BMI reference values for predicting fat status in multiethnic populations, the high AUC values obtained in the present study indicate that BMI can provide an acceptable proxy measure of %BF if cut-off points are tailored to each ethnic group. The optimum BMI z-scores for predicting the 85th percentile of %BF ranged from the 70th percentile in European girls to the 58th percentile in South Asian girls. Application of these ethnic-specific BMI thresholds corrected both the low sensitivity in European, South Asian, and East Asian girls (although only the latter was statistically significant) and the low specificity in Maori and Pacific Island girls. However, as with any threshold adjustment to an imperfect screening instrument, an increase in sensitivity is accompanied by a subsequent decrease in specificity (and vice versa). For instance, raising the sensitivity in East Asian girls from 65.7% (IOTF) to 91.4% (ethnic-specific) resulted in a decrease in specificity from 90.9% to 77.9%. This raises the question of which parameter is considered the most important. If minimising incorrect classifications of overweight is the top priority to avoid unnecessary psychological distress, then a high specificity is

desirable. Alternatively, if it is essential that those with excess adiposity are not overlooked for lifestyle interventions, greater emphasis should be placed on achieving high sensitivity. Naturally, these preferences will vary depending on the purpose of the study, and will require resolution before the most appropriate BMI criteria can be established.

To better understand the implications of the ethnic-specific adjustments described in this study, the effects on the prevalence of overweight in the study sample were estimated. Compared with the CDC/IOTF criteria, the use of the ethnic-specific thresholds resulted in significant increases in the number of East and South Asian girls classified as overweight, and considerably fewer Maori and Pacific Island girls classified as overweight. Thus, applying ethnic-specific classification systems for young people in national and international surveys will likely initiate major changes to the monitoring and surveillance of 'high risk' groups. For example, Maori and Pacific Island children in New Zealand are viewed as the priority groups for obesity prevention in government strategies, while Asian children are often overlooked [52]. Our findings suggest that South and East Asian girls should also be included within this priority grouping.

Another point for discussion is the practicality of applying ethnic-specific cut-offs in real world settings. Introducing multiple cut-off points may make classification too complex for users thereby limiting their acceptance. The publication of thresholds for only the major ethnic groupings would limit complexity but would also reduce diagnostic accuracy. Alternatively, one reference dataset (such as the CDC growth charts) could be used as the template with different ethnic cut-off points corresponding to different BMI percentiles from the same dataset. However, it is uncertain whether growth charts generated overseas accurately reflect the change in BMI within other populations. We suggest that it would be preferable to use data from the existing population to develop BMI thresholds for overweight.

An obvious limitation of the present study is that only female participants were assessed. It is possible that the relationship between BMI and %BF in boys does not follow the same ethnic variation observed in girls. For example, Rush et al [180] found

that %BF at a fixed BMI varied among European, Maori, and Pacific Island girls but not among their male counterparts. In contrast, researchers have reported significant differences in relative %BF levels between European and Asian boys, supporting the use of ethnic-specific thresholds for these populations [40, 137]. Although gender differences in the performance of universal BMI criteria have been reported in individual ethnic groups [70, 153, 169, 246], further research is required to elucidate the role of gender on diagnostic accuracy in a multiethnic sample.

In addition, subsuming a number of distinct Asian ethnicities into the wider groupings of 'East Asian' and 'South Asian' may have masked differences between individual Asian groups (e.g., between Chinese and Korean girls). While there is evidence of variation in body composition between certain Asian populations [40], the number of Asian participants in the present study permitted only two ethnic groupings (East Asian and South Asian) to be assessed with sufficient statistical power. It may be beneficial to develop a more detailed understanding of ethnic disparity by targeting specific Asian populations in future studies. However, it is unlikely that the differences within the East Asian or South Asian groupings would surpass the observed variation between these wider ethnic groups.

The definition of overweight used in this study was based on the 85th percentile of %BF after adjustment for age and ethnicity. Previous research in European children has shown that this threshold yields a similar proportion of overweight individuals as the IOTF BMI cut-off points [133]. However, we know little about the ethnic variation in health risk across a range of %BF values. It is possible that girls from diverse ethnic groups experience health complications at markedly different levels of adiposity. This brings into question the selection of a generic %BF threshold to represent an equivalent degree of health risk in a multiethnic population. Clearly, there is an immediate need for information describing the dose-response relationship between %BF and health risk in young people. The delayed onset of many health complications related to overweight during childhood makes this a difficult undertaking.

In summary, this study represents the first investigation of the predictive ability of universal BMI criteria for childhood overweight in a multiethnic sample. Our results show that the CDC and IOTF reference values provide an equivalent degree of sensitivity and specificity that varies substantially among girls from different ethnic groups. The relatively high %BF for a given BMI in South and East Asian girls corresponded to a low sensitivity and a high specificity, whereas girls of Pacific Island descent experienced the opposite trend. Adjusting the BMI threshold parameters to the optimum diagnostic profile in each ethnic group resulted in significant improvements to sensitivity and specificity in East Asian and Pacific Island girls (respectively), with positive but non-significant effects on sensitivity in South Asian girls. These findings indicate that ethnic-specific BMI cut-off points can provide an acceptable screening tool for overweight in girls from ethnically diverse populations.

Chapter 4: Ethnic-Specific BMI Cut-Off Points

Preface

The previous chapter highlighted the potential inaccuracies associated with universal definitions of overweight in a multiethnic population, concluding that an ethnic-specific BMI classification system optimises instrument sensitivity and specificity. This chapter, written in the form of a short communication, builds upon these results by generating BMI-for-age curves for each ethnic group. Multiple linear regression was used to formulate a equation for predicting %BF from BMI, age, and ethnicity. Rearranging this equation gave the BMI values associated with a predefined level of %BF for each ethnicity. By standardising the criterion on which each BMI curve was based, the relative difference in BMI between each ethnic group was determined. It is envisaged that application of ethnic-specific BMI cut-off points developed in this chapter will enable a better understanding of excess body fat in New Zealand girls from multiple ethnic groups.

Abstract

Background: The purpose of this study was to develop ethnic-specific body mass index (BMI) cut-off points for overweight and obesity in girls from New Zealand's five major ethnic groups.

Methods: A total of 1,676 girls (41% European, 21% Pacific Island, 15% East Asian, 13% Maori, and 11% South Asian) aged 5-16 years participated in this study. BMI was determined from height and weight, and body fat percentage (%BF) was obtained from hand-to-foot bioelectrical impedance measurements.

Results: Using stepwise multiple regression, a series of ethnic-specific BMI cut-off points were developed that corresponded to a %BF equivalent to that of European girls at the BMI reference values provided by the International Obesity TaskForce (IOTF). The adjusted cut-off points for overweight and obesity ranged from an average of 3.3 and 3.9 kg.m^{-2} (respectively) lower than the IOTF standards in South Asian girls to 1.5 and 1.8 kg.m^{-2} higher in Pacific Island girls.

Conclusion: We conclude that the ethnic-specific BMI cut-off points developed in this study are more appropriate than universal definitions of overweight and obesity for predicting excess adiposity in New Zealand girls.

Introduction

Rapid and widespread increases in childhood overweight and obesity are a serious public health concern for many countries. To facilitate the comparison of prevalence estimates between populations, the International Obesity TaskForce released a series of body mass index (BMI) cut-off points defining overweight and obesity in young people that adjust for natural differences between sexes and across age groups [23]. However, there is a growing body of evidence indicating that universal BMI thresholds often correspond to different body fat levels in children from diverse ethnic backgrounds [31, 40, 49, 56, 57, 137, 180]. Indeed, several studies have concluded that ethnic-specific BMI cut-off points would provide a more appropriate representation of overweight and obesity in multiethnic populations [31, 40, 49, 88, 102].

Previously, we have shown that adjusting universal BMI standards for ethnicity improves diagnostic accuracy when screening for overweight in Maori, Pacific Island, East Asian, and South Asian girls [49]. A logical progression from these analyses is the formulation of ethnic-specific cut-off points that correspond to an equivalent level of body fat in all ethnicities, thereby standardising BMI-based estimates of overweight and obesity. Rush et al [180] used regression analysis to demonstrate the increase in BMI required for Maori and Pacific Island girls to match the same body fat percentage (%BF) as European girls at a range of BMI values. To our knowledge, no studies have derived ethnic-specific BMI cut-off points from the existing IOTF standards. The purpose of the present study was to develop adjusted BMI-for-age curves in Maori, Pacific Island, East Asian, and South Asian girls that correspond to the observed %BF of European girls at the IOTF cut-off points for overweight and obesity.

Methods

The participant recruitment and body composition methodology has been described in detail elsewhere [49], and consequently only a brief description is given here. A total

of 1,676 participants aged 5-16 y (school years 1-10) were randomly selected from 39 primary, intermediate, and secondary schools in Auckland, New Zealand. The ethnic composition of this sample was 680 European (40.6%), 355 Pacific Island (21.2%), 216 Maori (12.9%), 243 East Asian (14.5%), and 182 South Asian (10.9%). BMI was calculated as weight (kg) divided by squared height (m^2). Fat-free mass measurements were obtained using a hand-to-foot bioelectrical impedance analyser (Model BIM4, Impedimed, Capalaba, Australia) and prediction equations previously validated in all ethnic groups within the present study [51, 180]. Fat mass was derived as the difference between fat-free mass and body weight, and %BF was calculated as $100 \times$ fat mass/weight. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee. Written informed consent was provided by each participant and her legal guardian.

Data were analysed using SPSS for Windows version 12.0.1 (SPSS Inc., Chicago, IL). The relationship between BMI and %BF was assessed using stepwise multiple regression, with age (rounded to nearest half-year) and ethnicity as independent variables ($P_{in} > 0.05$, $P_{out} > 0.10$). BMI was log transformed due to the curvilinear relationship between BMI and %BF. To minimise colinearity complications, the $\log_{10}$BMI variable was centred about the mean by subtracting 1.31 (mean $\log_{10}$BMI) from each value. The variables for ethnicity were dummy coded E_1-E_4. For South Asian $E_1 = 1$, $E_2 = 0$ $E_3 = 0$ $E_4 = 0$; for Pacific Island $E_1 = 0$, $E_2 = 1$ $E_3 = 0$ $E_4 = 0$; for East Asian $E_1 = 0$, $E_2 = 0$ $E_3 = 1$ $E_4 = 0$; and for Maori $E_1 = 0$, $E_2 = 0$ $E_3 = 0$ $E_4 = 1$.

Results

Table 1 presents the coefficients of the stepwise multiple regression in the order the independent variables were entered into the equation. The final regression equation was as follows: %BF = $[59.5 \times (\log_{10}$BMI $- 1.31)]$ $+ [4.50 \times E_1] - [1.84 \times E_2] + [1.39 \times E_3] - [0.164 \times$ age$] - [0.731 \times E_4] + 28.9$; with an R^2 of 0.669 and a SEE of 3.73%. Hence, at a fixed BMI and age, South Asian ($E_1 = 1$) and East Asian ($E_3 = 1$) girls averaged 4.50% (95% CI: 3.89-5.11%) and 1.39% (0.841-1.94%) more body fat (respectively) than European girls, while Pacific Island ($E_2 = 1$) and Maori ($E_4 = 1$) girls averaged 1.84% (1.32-2.35%) and 0.731% (-0.014-1.31%) less body fat. The variance in

%BF explained by each term in the equation was as follows: $\log_{10}$BMI – 1.31, 58.3%; E_1, 11.1%; E_2, 2.8 %; E_3, 1.5 %; age, 1.0%; and E_4, 0.4%. Significant ($P < 0.05$) interactions between age and $\log_{10}$BMI, and between age and E_3 were excluded as they resulted in only minor improvements to the regression equation. There were no significant interactions between $\log_{10}$BMI and any of the dummy variables, indicating that there were no differences in the regression slopes between the ethnic groups. In other words, ethnic differences in the association between BMI and %BF were similar across the entire BMI distribution.

To demonstrate the ethnic variation in BMI thresholds for overweight and obesity, the expected %BF at each IOTF age and sex specific cut-off point was first calculated using the regression equation in European participants. Body fat levels increased steadily with age before reaching a plateau in older girls (range: overweight, 25.2% [5 years] to 36.1% [16 years]; obese, 28.1% to 41.0%). These %BF values were entered into the reversed equation in order to determine the BMI thresholds for Pacific Island, Maori, East Asian, and South Asian groups to achieve the same level of body fat (i.e. predicted %BF of European girls at IOTF thresholds for overweight and obesity) (Table 2). Pacific Island girls had the highest BMI cut-off points for overweight and obesity, equivalent to an average of 1.5 and 1.8 kg.m^{-2} greater than the IOTF recommendations, respectively. In contrast, the South Asian cut-off points were lowest at an average of 3.3 and 3.9 kg.m^{-2} below the IOTF criteria. Figure 1 shows the ethnic-specific BMI cut-off points for overweight and obesity in each group alongside the established IOTF standards.

Table 4-1. Stepwise multiple regression with %BF as the dependent variable.

E_1= 1 for South Asian; E_2 = 1 for Pacific; E_3 = 1 for East Asian; E_4 = 1 for Maori; SE standard error of estimate; r^2 = explained variance; β = coefficients.

Log_{10}BMI		E_1		E_2		E_3		Age		E_4		Intercept		r^2	SEE (%)
β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE		
51.5	1.02	–	–	–	–	–	–	–	–	–	–	27.2	0.100	0.602	4.09
53.5	0.967	4.60	0.304	–	–	–	–	–	–	–	–	26.7	0.099	0.650	3.83
55.9	1.01	4.29	0.302	-1.76	0.243	–	–	–	–	–	–	27.1	0.113	0.660	3.78
56.2	1.00	4.60	0.306	-1.49	0.247	1.40	0.272	–	–	–	–	26.8	0.126	0.666	3.75
58.9	1.21	4.66	0.305	-1.62	0.248	1.55	0.273	-0.153	0.0394	–	–	28.6	0.476	0.668	3.73
59.5	1.23	4.50	0.311	-1.84	0.263	1.39	0.280	-0.164	0.0395	-0.731	0.297	28.9	0.490	0.669	3.73

Table 4-2. Ethnic specific BMI cut-off points equivalent to the predicted %BF of European children at the IOTF BMI cut-off points for overweight and obesity.

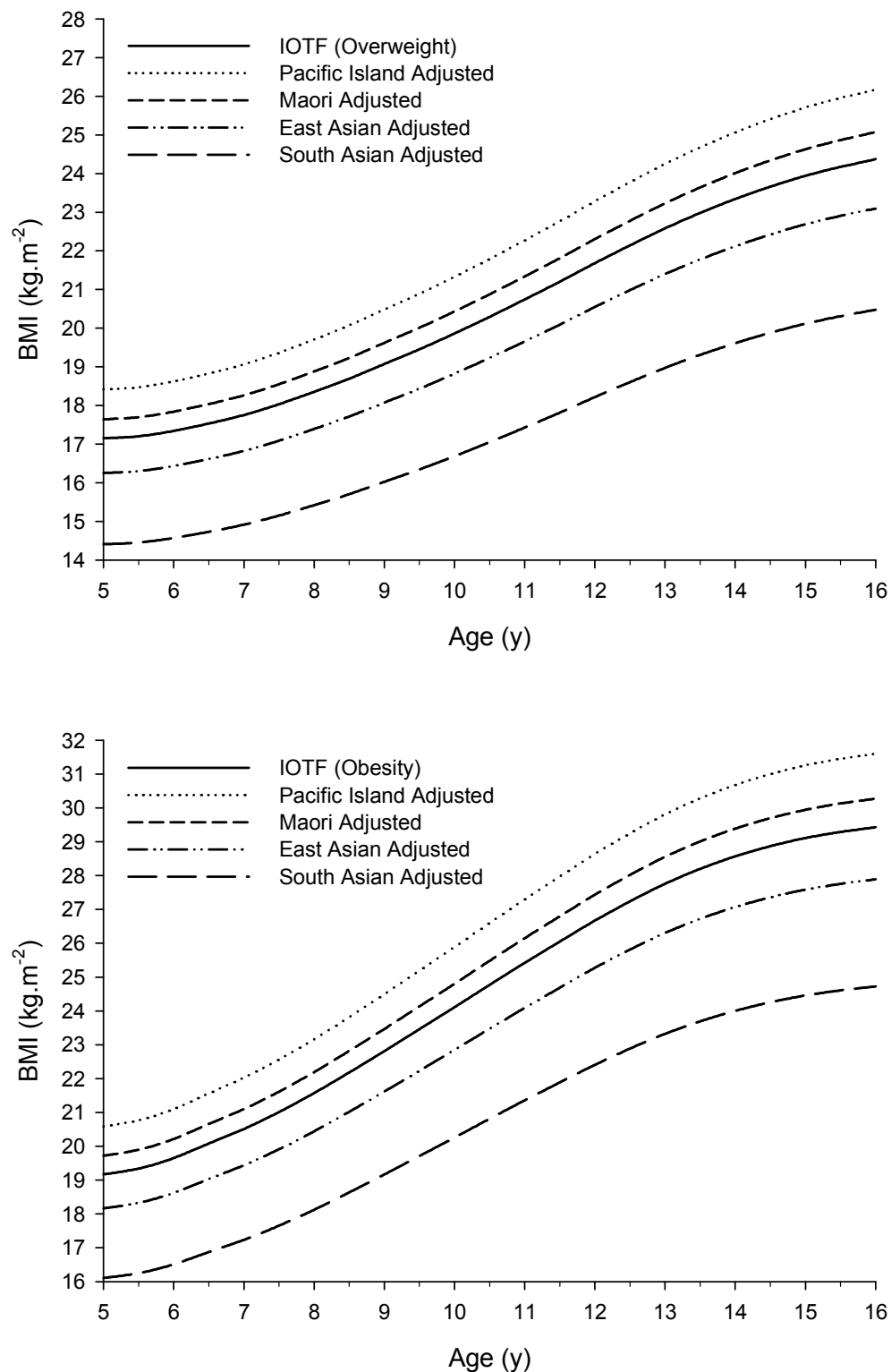| Age (y)	IOTF BMI		Predicted %BF		Pacific Island BMI		South Asian BMI		East Asian BMI		Maori BMI	
	OV	OB	OV	OB	OV	OB	OV	OB	OV	OB	OV	OB
5	17.15	19.17	25.21	28.09	18.42	20.58	14.41	16.11	16.25	18.17	17.64	19.72
5.5	17.20	19.34	25.37	28.40	18.47	20.77	14.45	16.25	16.30	18.33	17.69	19.89
6	17.34	19.65	25.66	28.89	18.62	21.10	14.57	16.51	16.43	18.62	17.84	20.21
6.5	17.53	20.08	26.03	29.54	18.82	21.56	14.73	16.87	16.61	19.03	18.03	20.66
7	17.75	20.51	26.43	30.16	19.06	22.02	14.91	17.23	16.82	19.44	18.26	21.10
7.5	18.03	21.01	26.92	30.87	19.36	22.56	15.15	17.65	17.09	19.91	18.55	21.61
8	18.35	21.57	27.45	31.63	19.70	23.16	15.42	18.12	17.39	20.44	18.88	22.19
8.5	18.69	22.18	28.01	32.43	20.07	23.82	15.70	18.64	17.71	21.02	19.23	22.82
9	19.07	22.81	28.61	33.24	20.48	24.49	16.02	19.16	18.07	21.62	19.62	23.46
9.5	19.45	23.46	29.20	34.05	20.89	25.19	16.34	19.71	18.43	22.23	20.01	24.13
10	19.86	24.11	29.82	34.84	21.33	25.89	16.69	20.26	18.82	22.85	20.43	24.80
10.5	20.29	24.77	30.46	35.62	21.79	26.60	17.05	20.81	19.23	23.47	20.87	25.48
11	20.74	25.42	31.11	36.37	22.27	27.30	17.43	21.36	19.65	24.09	21.34	26.15
11.5	21.20	26.05	31.76	37.08	22.76	27.97	17.81	21.89	20.09	24.69	21.81	26.80
12.0	21.68	26.67	32.42	37.77	23.28	28.64	18.21	22.41	20.54	25.27	22.30	27.44
12.5	22.14	27.24	33.04	38.40	23.77	29.25	18.60	22.89	20.98	25.81	22.78	28.02
13.0	22.58	27.76	33.63	38.97	24.25	29.81	18.97	23.32	21.40	26.31	23.23	28.56
13.5	22.98	28.20	34.17	39.46	24.68	30.28	19.31	23.69	21.78	26.72	23.64	29.01
14.0	23.34	28.57	34.65	39.88	25.06	30.68	19.61	24.00	22.12	27.07	24.01	29.39
14.5	23.66	28.87	35.09	40.23	25.41	31.00	19.88	24.26	22.42	27.36	24.34	29.70
15.0	23.94	29.11	35.47	40.53	25.71	31.26	20.11	24.46	22.69	27.59	24.63	29.95
15.5	24.17	29.29	35.80	40.77	25.95	31.45	20.31	24.61	22.90	27.76	24.86	30.13
16.0	24.37	29.43	36.10	40.97	26.17	31.60	20.48	24.73	23.09	27.89	25.07	30.27

Figure 4-1. IOTF and ethnic-specific BMI-for-age curves for overweight and obesity in girls aged 5-16 years.

Discussion

This study provides the first ethnic-specific BMI criteria for standardising youth overweight and obesity in a multiethnic population. The diverse ethnic composition of the sample enabled a wide range of body types to be compared: Pacific Island and Maori phenotypes are defined by a relatively low fat-to-fat-free mass ratio [49, 180], whereas Asians tend to exhibit the opposite characteristics [40, 49, 137]. In agreement with these observations, our results indicated that BMI thresholds for Maori and Pacific Island girls would need to be raised to match the equivalent body fatness of European girls at the IOTF BMI cut-off points, and lowered for East and South Asian girls. The adjusted BMI-for-age curves for South Asian girls, in particular, were over 3 $kg.m^{-2}$ lower than the corresponding IOTF definitions of overweight and obesity, suggesting that a significant proportion of South Asian girls with high body fat would be classified as normal weight by the IOTF criteria. This underestimation may prevent health services from targeting Asians with high body fat, and may reduce the likelihood that these 'at risk' individuals receive lifestyle interventions to prevent excessive fat accretion. Pacific Island girls are also likely to be misclassified, however it could be argued that overestimation of overweight/obesity status is preferable to overlooking those with excess adiposity. Nevertheless, labelling a young person as overweight raises the possibility of adverse psychosocial effects [61], and consequently every effort should be made to ensure that only those with excess body fat are classified as overweight or obese. Although cut-off points for all non-European groups were significantly different, we suggest that only South Asian, East Asian, and Pacific Island ethnicities showed sufficient divergence to warrant inclusion in an ethnic-specific BMI classification system for overweight and obesity in New Zealand girls.

To our knowledge, only one other study has modified the IOTF classification system to suit a specific population. Kim et al [102] proposed a series of BMI percentiles for Korean girls aged 8 to 18 years that corresponded to the IOTF thresholds for overweight and obesity in Asian adults at age 18 years (23 and 25 $kg.m^{-2}$, respectively). Similar to our observations in East and South Asian girls, the adjusted BMI-for-age curves for Korean girls were substantially lower than the IOTF cut-off points. However, it remains unclear whether or not these ethnic-specific BMI values correspond to

excess adiposity in Korean individuals. An advantage of the present study was the use of %BF to standardise the classification of weight status across diverse ethnicities. The %BF of European girls at the IOTF BMI cut-off points was selected as the appropriate criteria given that the IOTF standards are applied most frequently to children and adolescents of European descent. Nevertheless, these criteria are not necessarily the most suitable markers of increased health risk. While several studies have posited %BF thresholds (ranging from 20 to 30%) that are associated with an elevated risk of negative health outcomes [55, 85, 233, 236], the natural age-related increase in %BF observed in children and adolescents raises concerns about the appropriateness of a single %BF point. In the present study, %BF values corresponding to the IOTF criteria in European girls were age-dependent, ranging from 25% to 36% for overweight, and from 28% to 41% for obesity. The %BF-for-age curves reported in another investigation of the IOTF BMI cut-off points in New Zealand (predominantly European) children aged 3-18 years indicated a similar overall pattern in female subjects: 20-34% for overweight and 26-46% for obesity [213]. The findings from both studies suggest that application of a single %BF threshold may underestimate excess body fat in younger girls and overestimate it in older girls.

A limitation of the present study is that only female children and adolescents were assessed. It is possible that ethnic differences in BMI/%BF associations follow different patterns in boys. Rush et al [178] reported significant differences in body composition among European, Maori, and Pacific Island girls, but not among boys from the same ethnic groups. Conversely, there is evidence that differences in the %BF-BMI ratio exist between European and both East and South Asian boys [40, 137]. We suggest that similar research is required to establish the appropriate BMI thresholds for overweight and obesity in boys from these ethnicities. It would also be worthwhile to establish the ethnic adjustments necessary to standardise overweight and obesity in girls aged 2-4 and 17-18 years, thereby covering the entire age range of the IOTF BMI standards. Nevertheless, we suggest that the ethnic-specific BMI cut-off points provided in this study represent the most appropriate definition of overweight and obesity for New Zealand girls aged 5-16 years.

Furthermore, while we suggest that ethnic-specific BMI thresholds are more appropriate than IOTF values for classifying overweight and obesity in multi-ethnic populations, their association with negative health outcomes cannot be determined. The thresholds developed in this study should be viewed as a starting point; there is a clear need for research into the relationships between body composition variables and metabolic risk in young people from different ethnic groups. At present, little is known about how the health risk profiles of many non-European groups. While the delayed onset of many obesity-related complications makes this a challenging task, knowledge of ethnic variation in comorbidities associated with excess body fat would ensure that resulting thresholds represent an actual increase in metabolic risk.

In summary, this study provides the first ethnic-specific BMI cut-off points for defining overweight and obesity in a multiethnic population of girls. Based on a standardised level of body fat, our results indicate that the current IOTF standards for overweight would need to be raised by an average of 1.5 and 0.6 $kg.m^{-2}$ for Pacific Island and Maori girls (respectively), and lowered by an average of 3.3 and 1.1 $kg.m^{-2}$ for South and East Asian girls. Likewise, ethnic-specific BMI cut-off points for obesity were (on average) 1.8 and 0.7 $kg.m^{-2}$ greater than the IOTF thresholds for Pacific Island and Maori girls, and 3.9 and 1.3 $kg.m^{-2}$ lower for South and East Asian girls. Application of the amended thresholds would reduce the misclassification of excess adiposity common in ethnic groups that differ from the typical European phenotype. In line with views proposed for adults by a WHO expert consultation [244], we suggest retaining universal thresholds for international comparison, but adding additional thresholds for South and East Asian ethnic groups, which act as a trigger for public health action. Future directions would be to redefine BMI cut-offs with waist circumference for populations with a tendency for central fat accumulation.

Chapter 5: Weight Control Perceptions and Practices

Preface

While the primary aim of this thesis was to investigate the appropriateness of universal BMI thresholds for defining overweight and obesity in girls, knowledge of the weight related perceptions and practices of different ethnic groups is essential for understanding the barriers to behavioural changes for achieving a healthy body weight. This chapter compares the ability of body fat and BMI in predicting weight perceptions and behavioural outcomes in adolescent girls, providing a benchmark of ethnic variation in weight perceptions and weight loss practices. The paper resulting from this chapter is under consideration for publication in the *Journal of Adolescent Health*.

Abstract

Background: The purpose of this study was to examine the interactions between weight perceptions, weight control behaviours, and body fatness in a multiethnic sample of adolescent girls.

Methods: A cross-sectional sample of 954 girls (37.7% European, 21.6% Pacific Island, 15.8% East Asian, 10.2% Maori, 9.6% South Asian, and 5.0% from other ethnicities) aged 11-15 y participated in the study. Body mass index was derived from height and weight, while body fat was determined from hand-to-foot bioimpedance measurements. Weight perceptions, weight control behaviours, and pubertal stage were assessed by questionnaire.

Results: Body size and fatness varied significantly across ethnic groups. Although few differences in weight perceptions were observed between BMI and %BF percentile groups, a relatively high degree of weight misclassification was evident across all body fat categories. The number of girls trying to lose weight exceeded those who perceived themselves as being overweight, with the magnitude of the difference dependent on ethnicity. Of the girls trying to lose weight, the combination of dieting and exercise was the most common weight loss practice; however a substantial proportion reported

neither exercise nor dieting. Weight status perception was a stronger predictor of weight loss intent than actual body fat when controlling for all other factors.

Conclusions: Interventions and educational campaigns that assist girls in recognising a state of excess body fat are a priority for all ethnic groups to increase the likelihood that behavioural changes necessary to combat widespread overweight and obesity are adopted. However, such campaigns should focus on promoting a healthy weight rather than simply weight loss.

Introduction

Widespread increases in overweight and obesity have raised the incidence of chronic disease, generating serious public health consequences for many countries. The rapid rise in obesity among young people is particularly alarming given that adolescent obesity tends to persist into adulthood [111, 167]. Indeed, adolescence has been identified as a critical period for the establishment of lifelong health behaviours [6, 152] and is consequently a priority age group for initiatives that promote healthy lifestyles.

The physiological changes that characterise the adolescent years are often accompanied by a heightened awareness of peer approval and social norms. In adolescent girls, external pressures to be slim can raise the importance of body image and weight perceptions in the determination of self-concept, and can lead to the adoption of dieting and exercising for weight control [64, 136]. However, a number of studies suggest that discordance between perceptions of weight and actual weight status is common in young females [10, 74, 119, 154, 197]. Misconceptions of body size are of concern given the potential for negative health outcomes: girls who incorrectly perceive themselves to be overweight may face an elevated risk of eating disorders such as anorexia nervosa [229]. Conversely, overweight girls who are unable to recognise their condition are unlikely to initiate the lifestyle changes required to obtain a healthy body weight [205]. While both situations are clearly undesirable, given the current prevalence of overweight and obesity the potential to underestimate a state of excessive body fat presents the greater public health risk.

Previous efforts to quantify the prevalence and consequences of weight misclassification have been complicated by variation between ethnic groups. Desmond et al [35] reported that while 100% of overweight Caucasian girls correctly classified themselves, only 40% of overweight African American girls recognised their weight status. Similarly, Neumark-Sztainer et al [154] noted that African American adolescent girls were less likely than their Caucasian counterparts to perceive themselves as overweight despite a significantly higher prevalence of overweight. The tendency for adolescent girls of African American descent to misclassify their overweight status was further reinforced by Strauss [205] and Brener et al [10], the latter authors also observing high rates of misclassification among overweight Hispanic girls. In contrast, ethnic differences in the ability to recognise excess weight were not detected by Simeon et al [197] in a study of South Asian, African, and mixed ethnicity adolescent girls.

A potential shortcoming of previous comparisons of weight perceptions and body size in adolescent girls from multiple ethnic groups was the use of universal body mass index (BMI) thresholds to define overweight. The existence of physiological differences in the body composition of girls from different ethnic groups has raised concerns over the appropriateness of existing BMI classification systems. For example, young people of East Asian [40], South Asian [137] and Hispanic [56, 57] descent tend to have more body fat than Caucasians at an equivalent BMI. Conversely, Polynesian [180] and African-American [31] children and adolescents average less body fat than their Caucasian counterparts for the same BMI. It is therefore possible that the ethnic differences previously observed in the self-diagnosis of overweight may reflect differences in the accuracy of BMI standards for predicting body fat status in diverse populations. Moreover, pubertal development and socioeconomic status (SES) may also vary by ethnicity and contribute to the perceptions of overweight in adolescent girls.

Ethnic variation in weight loss practices has also been demonstrated in female adolescents. For example, several studies have shown that African American girls are less likely to diet to lose weight than Caucasian girls [35, 62, 205]. In addition,

Neumark-Sztainer et al [154] reported that Asian American girls were more likely to diet than Caucasian girls. While only one study compared exercise as a weight control practice in different ethnic groups, similar variation was observed among ethnicities: African American girls were less likely to exercise for weight loss than Caucasian girls [35]. Despite these differences, a positive association between BMI and weight loss behaviours appears to be a consistent theme across all adolescent girls [35, 63, 205]. Given the limitations of BMI-based weight classification in diverse ethnic groups, comparisons with body fat levels may provide a more accurate measure. To our knowledge, the relationship between weight control practices and body fat has yet to be investigated.

An investigation into the weight-related perceptions and practices of young people from different ethnicities is essential for understanding the barriers to initiating behavioural modifications to achieve a healthy body weight and developing targeted interventions. Thus, the purpose of the present study was to examine the interactions between weight perceptions, weight control, and body fatness in a multiethnic sample of adolescent girls. The effects of pubertal development and SES on diet and exercise behaviours were also assessed.

Methods

Participants

A total of 954 girls aged 11-15 y were randomly selected from 11 intermediate and secondary schools in Auckland, New Zealand. The ethnic composition of the sample was 37.7% European, 21.6% Pacific Island, 15.8% East Asian, 10.2% Maori, 9.6% South Asian, and 5.0% from other ethnicities. The East Asian ethnic group included 50.3% Chinese, 31.1% Korean, 9.9% Filipino, and 8.6% other East Asian girls; and the South Asian group included 91.3% Indian, 7.6% Sri Lankan, and 1.1% Nepalese. Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand schools. Participants from schools with a decile rating of 1-3 were categorised into the 'Low' SES group, while those from schools rated 4-7 and 8-10 were considered 'Middle' and 'High', respectively. Ethical approval for

this study was obtained from the Auckland University of Technology Ethics Committee. Written informed consent was provided by each participant and her legal guardian.

Instruments and Procedures

The height of each participant was measured to the nearest mm with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia). Weight in light clothing without shoes was measured to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was calculated as weight (kg) divided by squared height (m^2). Body fat measurements were obtained using hand-to-foot bioelectrical impedance analysis (BIA). Resistance (R) was measured at 50 kHz using a bioimpedance analyser (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). After swabbing the skin on the right hand and foot with alcohol, source electrodes were placed on the dorsal surface of the foot over the distal portion of the second metatarsal, and on the hand on the distal portion of the second metacarpal. Sensing electrodes were placed at the anterior ankle between the tibial and the fibular malleoli, and at the posterior wrist between the styloid processes of the radius and ulna. Testing was initiated after the participants emptied their bladder, and had been lying supine with their arms and legs abducted for at least 5 min. Testing was completed when repeated measurements of R were within 1 Ω of each other. Fat-free mass (FFM) was calculated from R, height, and weight using two separate ethnic-specific equations previously validated in New Zealand children: one specifically for Maori, Pacific Island, and European children [180] and another for East and South Asian children [50]. The procedures used in this study, including the BIA instrument, were identical to those used to develop the aforementioned FFM prediction equations. Fat mass (FM) was derived as the difference between FFM and body weight, and percentage body fat (%BF) was calculated as 100 $\times$ FM/weight. Given that there are no generally accepted definitions of adolescent overweight or obesity based on %BF, age-specific percentiles were used to group the sample according to body fat status. Overfat/overweight was defined as a %BF greater than the 85th percentile in the current sample.

Participants completed a brief survey that included four questions for assessing weight loss practices and weight perceptions: (1) What are you currently trying to do about your weight (Lose weight, Gain weight, Nothing)?; (2) In the last seven days, did you diet to lose weight (Yes, No)?; (3) In the last seven days, did you exercise to lose weight (Yes, No)?; and (4) What do you currently think about your weight (Underweight, Normal Weight, Overweight)? To determine pubertal stage, participants were presented with a series of Tanner illustrations and asked to identify their level of pubic hair development. Participants were also asked to provide the date of their first period (if menstruating). Based on these data, participants were grouped into four stages of pubertal development: Pre-pubertal (no pubic hair, not menstruating); Early Puberty (pubic hair, not menstruating); Late Puberty (pubic hair, menstruating for less than 24 months); and Post-pubertal (pubic hair, menstruating for more than 24 months) [151].

Statistical Analyses

Data were analysed using SPSS version 14.0 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, height, weight, BMI, and %BF) among ethnic groups were assessed by two-way ANOVA, with significant associations examined by pairwise comparisons using Bonferroni post hoc tests. Logistic regression analysis was used to investigate associations between the frequency of diet and exercise practices and age, ethnicity, SES, pubertal status, weight status, and body fat perception. Odds ratios for each category were adjusted for all six factors concurrently. Ethnic differences in the frequencies of age and SES categories were examined using chi-squared testing.

Results

Table 5-1 shows the physical characteristics of the study sample. South Asian girls were slightly younger than the other ethnicities ($P < 0.05$). Body size varied across the ethnic groups: Pacific Island girls were the tallest ($P < 0.05$), heaviest ($P < 0.01$), and had the highest BMI ($P < 0.01$); while East and South Asian girls were shorter ($P < 0.05$) and lighter ($P < 0.05$) than the four remaining ethnic groups, and had a lower BMI than Maori and Pacific Island girls ($P < 0.01$). South Asian and Pacific Island girls had

significantly more body fat than European and East Asian ($P < 0.01$), and European, East Asian, and Maori girls ($P < 0.05$), respectively.

Table 5-1. Participant characteristics grouped by ethnicity.
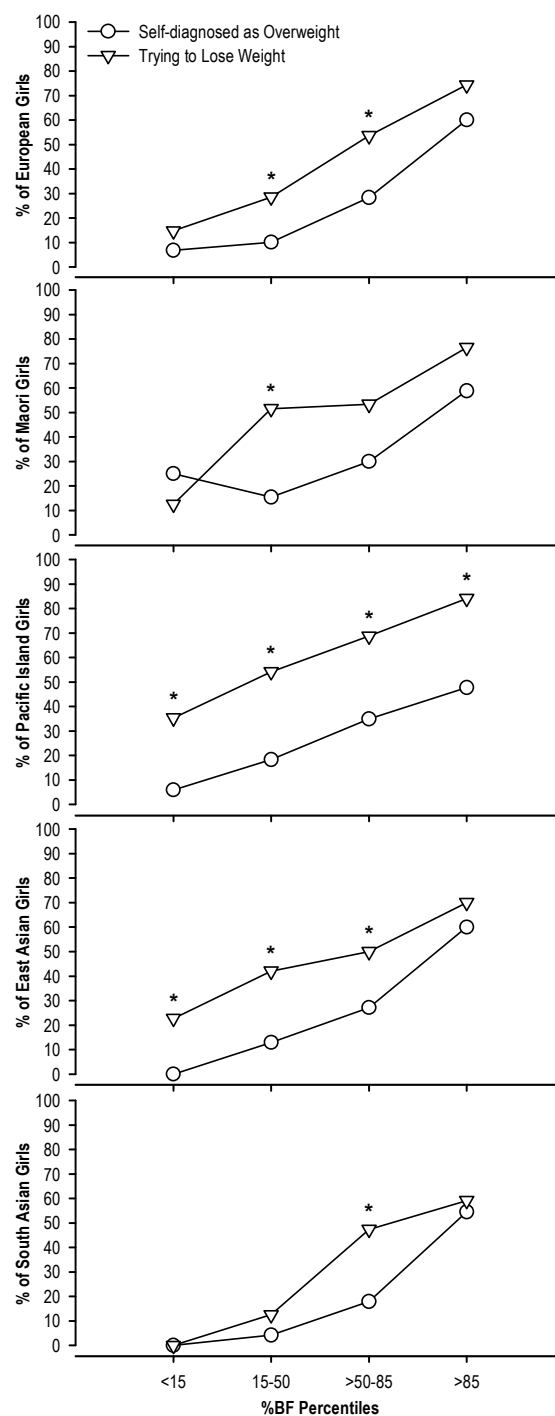
Data are presented as mean ± SD.

	European (N = 360)	Maori (N = 97)	Pacific Island (N = 206)	East Asian (N = 151)	South Asian (N = 92)	Other (N = 48)
Age (y)	13.6 ± 0.9	13.4 ± 1.0	13.7 ± 0.9	13.5 ± 1.1	12.9 ± 1.2	13.6 ± 1.1
Height (cm)	159.4 ± 7.1	160.0 ± 7.2	162.4 ± 5.3	155.0 ± 6.7	153.8 ± 8.1	157.6 ± 5.9
Weight (kg)	54.4 ± 11.6	60.0 ± 14.9	70.1 ± 15.8	48.7 ± 10.1	49.2 ± 13.5	54.0 ± 11.0
BMI (kg.m^{-2})	21.3 ± 3.9	23.3 ± 4.9	26.5 ± 5.3	20.2 ± 3.3	20.6 ± 4.4	21.7 ± 3.9
Body fat (%)	27.4 ± 6.4	28.5 ± 6.3	30.9 ± 5.9	27.4 ± 5.2	30.4 ± 6.6	29.5 ± 5.7

Table 5-2 shows the perceptions of weight status for the selected BMI and %BF percentile categories. BMI percentile groups were used instead of other BMI-based definitions of childhood overweight and obesity to enable direct comparisons with the %BF percentile groups. Overall, the majority of participants considered themselves to be a normal weight. While few differences in weight perceptions were observed between BMI and %BF percentile groups, there was a relatively high degree of weight misclassification across the distribution. For example, the percentage of girls with a %BF > 85th percentile who incorrectly perceived themselves to be normal weight or underweight was 39.7% and 4.4%, respectively. Conversely, 17.9% of girls with a %BF < 85th percentile believed that they were overweight.

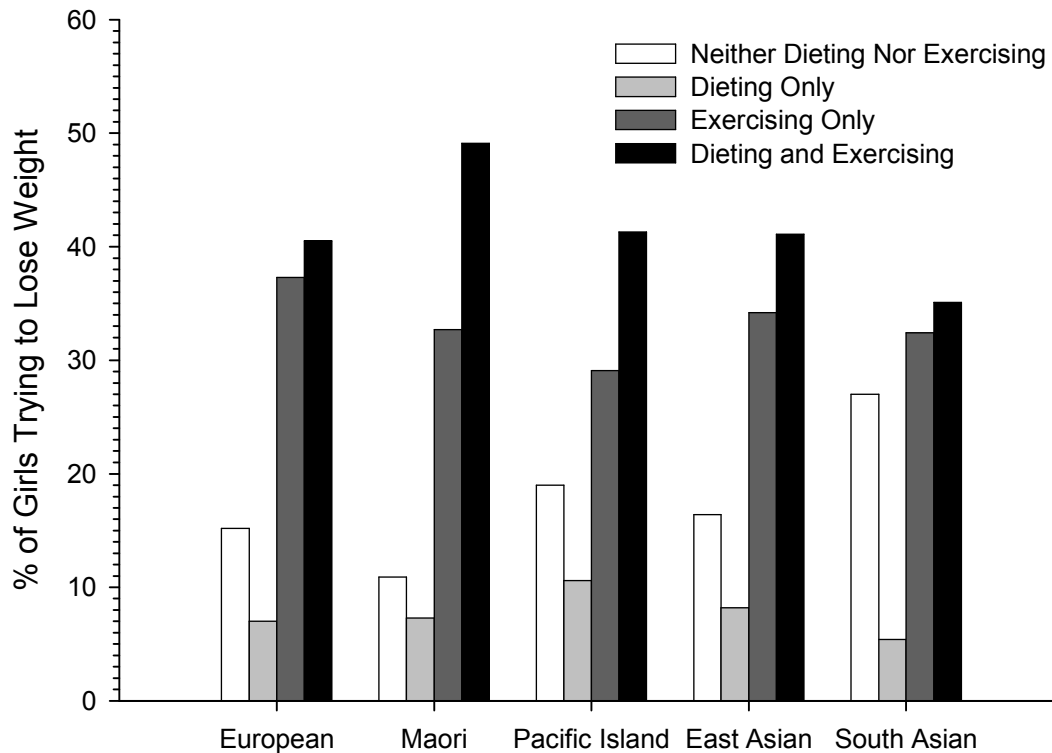**Table 5-2. Number of girls in each BMI and %BF category and their perceived weight status.**

	Self-diagnosis of Weight Status			
	Underweight (N = 76)	Normal Weight (N = 648)	Overweight (N = 221)	ALL (N = 945)
BMI Category				
<15th percentile	37	102	1	140
15-85th percentile	29	497	143	669
>85th percentile	10	49	77	136
%BF Category				
<15th percentile	17	114	11	142
15-85th percentile	53	480	134	667
>85th percentile	6	54	76	136

Subsequent analyses revealed that overweight perceptions also differed by ethnicity (European, 20.0%; Maori, 29.7%; Pacific Island, 30.1%; East Asian, 17.3%; South Asian, 20.0%; $P < 0.01$). Similarly, ethnic variation was observed in the number of girls participating in weight control practices (European, 37.8%; Maori, 50.0%; Pacific Island, 65.0%; East Asian, 43.6%; South Asian, 37.4%; $P < 0.01$). Figure 5-1 presents the differences in overweight perceptions and weight control practices across a range of %BF percentile groups. The proportion of girls who consider themselves to be overweight ranged from 0% to 25% in the <15th percentile group, and from 48% to 60% in the >85th percentile group; the latter finding indicating that many girls who are overfat do not recognise their condition. It is also clear that the number of girls actively trying to lose weight exceeds the number of girls self-diagnosed as overweight, with the extent of the divergence dependent on ethnicity. For example, the proportion of Pacific Island girls that engaged in weight control behaviours was consistently higher than the proportion self-perceived as overweight. In contrast, there was greater agreement between perceptions of overweight and weight-loss practices in South Asian girls (with the exception of those in the >50-85th percentile group).

Figure 5-1. Perceptions of overweight and the prevalence of weight control practices in adolescent girls.

*Significantly different from self-diagnosis of overweight ($P < 0.05$).

Figure 5-2. Prevalence of dieting and exercising in adolescent girls who are trying to lose weight.

To further investigate weight control practices in this sample, the frequency of dieting and exercising behaviours were compared in girls who were trying to lose weight (Figure 5-2). The combination of both dieting and exercise was the most common weight loss practice reported; although a substantial proportion also relied solely on exercise. Interestingly, 16.4% of girls who claimed they were trying to lose weight were neither dieting nor participating in exercise. Ethnic variation was also observed, with Maori girls most likely to combine dieting with exercise and South Asian girls most likely to do neither.

Table 5-3. Correlates of dieting to lose weight in adolescent girls.

	Number of Participants (%)		Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio[a] (95% CI)
	Non-dieting	Dieting		
Age				
11 y	42 (6.2%)	8 (3.0%)	1.00	1.00
12 y	81 (12.0%)	25 (9.4%)	1.62 (0.67-3.90)	1.25 (0.48-3.22)
13 y	205 (30.3%)	58 (21.8%)	1.49 (0.66-3.34)	0.94 (0.37-2.41)
14 y	237 (35.0%)	110 (41.4%)	2.44 (1.11-5.37)[b]	1.37 (0.52-3.58)
15 y	112 (16.5%)	65 (24.4%)	3.05 (1.35-6.89)[c]	1.42 (0.52-3.91)
Ethnicity				
European	278 (41.1%)	79 (29.7%)	1.00	1.00
Maori	66 (9.7%)	28 (10.5%)	1.49 (0.90-2.48)	1.22 (0.65-2.29)
Pacific Island	115 (17.0%)	86 (32.3%)	2.63 (1.81-3.83)[c]	1.79 (1.01-3.17)[b]
East Asian	114 (16.8%)	37 (13.9%)	1.14 (0.73-1.79)	1.16 (0.69-1.93)
South Asian	76 (11.2%)	16 (6.0%)	0.74 (0.41-1.34)	0.53 (0.26-1.10)
Other	28 (4.1%)	20 (7.5%)	2.51 (1.34-4.70)[c]	2.02 (0.95-4.30)
SES				
High	340 (50.2%)	116 (43.6%)	1.00	1.00
Middle	73 (10.8%)	20 (7.5%)	0.80 (0.47-1.38)	0.82 (0.43-1.57)
Low	264 (39.0%)	130 (48.9%)	1.44 (1.07-1.94)[b]	1.21 (0.76-1.93)
Pubertal Status				
Pre-pubertal	28 (4.7%)	5 (2.2%)	1.00	1.00
Early Puberty	140 (23.3%)	34 (15.1%)	1.36 (0.49-3.78)	1.27 (0.42-3.82)
Late Puberty	298 (49.7%)	97 (43.1%)	1.82 (0.69-4.85)	1.43 (0.48-4.30)
Post-pubertal	134 (22.3%)	89 (39.6%)	3.72 (1.38-10.00)[c]	1.95 (0.62-6.19)
Body Fat Status				
<85th percentile	608 (89.8%)	199 (74.8%)	1.00	1.00
>85th percentile	69 (10.2%)	67 (25.2%)	2.97 (2.04-4.31)[c]	2.09 (1.31-3.33)[c]
Weight Perception				
Underweight	58 (8.6%)	18 (6.8%)	1.00	1.00
Normal weight	511 (76.0%)	129 (49.0%)	0.81 (0.46-1.43)	0.88 (0.46-1.69)
Overweight	103 (15.3%)	116 (44.1%)	3.63 (2.01-6.56)[c]	3.39 (1.69-6.80)[c]

[a]Adjusted for all other factors.
[b]Significantly different from reference group ($P < 0.05$).
[c]Significantly different from reference group ($P < 0.01$).

Table 5-4. Correlates of exercising to lose weight in adolescent girls.

	Number of Participants (%)		Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio[a] (95% CI)
	Non-exercising	Exercising		
Age				
11 y	35 (7.4%)	15 (3.2%)	1.00	1.00
12 y	59 (12.5%)	49 (10.3%)	1.94 (0.95-3.96)	1.76 (0.81-3.80)
13 y	152 (32.3%)	113 (23.8%)	1.74 (0.90-3.33)	1.33 (0.62-2.85)
14 y	153 (32.5%)	194 (40.8%)	2.96 (1.56-5.62)[c]	2.34 (1.06-5.15)[b]
15 y	72 (15.3%)	104 (21.9%)	3.37 (1.72-6.62)[c]	2.09 (0.90-4.85)
Ethnicity				
European	190 (40.3%)	165 (34.7%)	1.00	1.00
Maori	49 (10.4%)	47 (9.9%)	1.11 (0.70-1.73)	0.93 (0.55-1.59)
Pacific Island	77 (16.3%)	127 (26.7%)	1.90 (1.34-2.70)[c]	1.43 (0.85-2.39)
East Asian	73 (15.5%)	78 (16.4%)	1.23 (0.84-1.80)	1.16 (0.75-1.77)
South Asian	58 (12.3%)	34 (7.2%)	0.68 (0.42-1.08)	0.54 (0.31-0.95)[b]
Other	24 (5.1%)	24 (5.1%)	1.15 (0.63-2.11)	0.89 (0.44-1.78)
SES				
High	234 (49.7%)	219 (46.1%)	1.00	1.00
Middle	50 (10.6%)	43 (9.1%)	0.92 (0.59-1.44)	0.95 (0.57-1.58)
Low	187 (39.7%)	213 (44.8%)	1.22 (0.93-1.59)	1.28 (0.86-1.92)
Pubertal Status				
Pre-pubertal	19 (4.6%)	14 (3.4%)	1.00	1.00
Early Puberty	113 (27.1%)	61 (14.9%)	0.73 (0.34-1.56)	0.64 (0.28-1.43)
Late Puberty	198 (47.5%)	198 (48.4%)	1.36 (0.66-2.78)	0.96 (0.43-2.15)
Post-pubertal	87 (20.9%)	136 (33.3%)	2.12 (1.01-4.45)[b]	1.07 (0.45-2.54)
Body Fat Status				
<85th percentile	423 (89.8%)	386 (81.3%)	1.00	1.00
>85th percentile	48 (10.2%)	89 (18.7%)	2.03 (1.39-2.96)[c]	1.57 (0.99-2.48)
Weight Perception				
Underweight	45 (9.6%)	31 (6.6%)	1.00	1.00
Normal weight	350 (74.9%)	292 (62.0%)	1.21 (0.75-1.96)	1.24 (0.71-2.14)
Overweight	72 (15.4%)	148 (31.4%)	2.98 (1.74-5.11)[c]	2.52 (1.35-4.71)[c]

[a]Adjusted for all other factors.
[b]Significantly different from reference group ($P < 0.05$).
[c]Significantly different from reference group ($P < 0.01$).

Table 5-3 displays the unadjusted and adjusted odd ratios for dieting to lose weight within each of the variables assessed in this study. Unadjusted analyses revealed significant associations between dieting and age, ethnicity, SES, pubertal status, body fat status, and weight perception. However, ethnicity, body fat status, and weight perception were the only variables that remained significant after controlling for variation in all other factors. The adjusted data indicate that Pacific Island girls were 1.8 times more likely to diet than European girls, with no significant differences between European girls and any other ethnic group. In addition, participants were more than two times more likely to diet if they had a %BF greater than the 85th percentile. Perception of weight status had the greatest effect on the odds of dieting in this sample, with girls self-diagnosed as overweight more than three times as likely to diet than those who perceived themselves to be underweight.

The odds ratios associated with exercising to lose weight were also calculated (Table 5-4). The effects of age, ethnicity, pubertal status, body fat status, and weight perception were significant in the unadjusted model. Age, ethnicity, and weight perception remained significant in the fully adjusted model. Older girls were more than twice as likely to participate in exercise as younger girls, and South Asian girls were less likely to exercise than European girls. As with dieting, weight perception showed the strongest association with exercising practices. Girls classified as overfat were also more likely to exercise, although this association was just outside the threshold of statistical significance.

Discussion

Given the escalating prevalence of youth obesity around the world and the severity of related complications, it is essential that young people are able to recognise a state of excess body fat. Indeed, an underestimation of weight status will likely prevent overweight adolescents seeking advice and initiating behavioral changes. The results presented in this study provide an indication of a mismatch between perceived weight status and actual body fat levels in a large proportion of adolescent girls. This builds upon earlier work which investigated such relationships with BMI and/or weight in limited ethnic groups [10, 74, 119, 154, 197]. Nearly half of the girls with high body fat

thought they were normal or underweight, and a reasonable proportion who did not have excess body fat thought that they were overweight. In addition, there were noticeable differences among ethnicities: the frequency of girls with high body fat who did not recognise their condition ranged from 40% in European and East Asian girls to 52.3% in Pacific Island girls. Such variation in the perception of excess body fatness may reflect fundamental differences in cultural norms; a large body size has been considered to be an outward sign of wealth and prestige in traditional Pacific Island families, although this viewpoint has tended to become diluted in westernised societies [29]. Thus, being large may not carry the same negative implications in Pacific Island communities than in those from other ethnicities [11]. Overall, the identification ethnic differences in the ability to classify overweight status will assist in prioritising groups for initiatives to improve self awareness; however, qualitative research into the underlying cultural norms that influence perceptions of body size may be necessary to ensure that such interventions are appropriate for each ethnicity.

The ethnic variation we observed in the underestimation of excess body fat is consistent with previous research using universal BMI standards to define obesity in adolescent girls from multiple ethnic groups [10, 35, 154, 205]. Furthermore, the degree of divergence between perceived and measured body size was similar regardless of whether BMI or %BF percentiles were used. These findings were unexpected given the evidence that BMI is not an equivalent predictor of body fat across multiple ethnicities [31, 40, 56, 57, 137, 180]. We suggest that these results may reflect the use of weight-related terminology (under-, normal-, and over-weight) for describing body fat status and the closer relationship between these terms and a weight-related index such as BMI when compared with %BF. Nevertheless, the potential diagnostic error associated with the use of BMI in multiethnic populations does not appear to be a major factor when assessing the perceptions of overweight in adolescent girls.

The results from this study also revealed that a relatively large proportion of girls who did not perceive themselves as overweight were actively trying to lose weight. This trend may be symptomatic of the firmly established societal desire to be slim, a

pressure that tends to assume particular importance in adolescent girls [204]. With continuous exposure to images and expectations of unrealistic body shapes that promote weight loss regardless of body size [64, 136], engaging in unnecessary weight loss practices is perceived as acceptable and even desirable in some adolescent peer groups [155]. Another potential explanation is that some non-overweight girls may be persisting with weight loss practices from a period when they were overweight. Our data also clearly indicated that the extent of the divergence between weight perceptions and weight loss practices across the different %BF percentiles was dependent on ethnicity. The number of Pacific Island girls trying to lose weight, for example, was consistently higher across all body fat categories than the number who considered themselves overweight. This points to an embedded cultural expectation that Pacific Island girls should be trying to lose weight, regardless of their personal perceptions. In contrast, South Asian girls had a high level of agreement between perception and practice in all but the >50-85th percentile group. Together, these findings reinforce the need to communicate weight related issues with care in adolescent girls, and the importance of tailored approaches for populations with diverse ethnicities and cultures.

An understanding of the behavioral responses to a perception of overweight is valuable for determining acceptable approaches to promote weight loss and achieve a healthy body weight. Of the girls who were attempting to lose weight, the combination of dieting and exercising was the most common weight loss practice reported across all ethnic groups, followed by exercising. This finding suggests that dieting and exercising are both acceptable methods of weight control for adolescent girls from multiple ethnic groups. Interestingly, the number of girls who were trying to lose weight but reported neither dieting nor exercise to do so exceeded those which reported dieting alone. It is also possible that some of the girls who were dieting and or exercising for weight loss may not have done so in the previous seven days, and thus these behaviours were not picked up in the assessments. Whether this subset of girls are participating in other weight control behaviours or simply recognise their condition but are not motivated to make behavioural changes cannot be determined from this study. Clearly, additional research which focuses on the qualitative aspects of approaches to

weight loss would be helpful for understanding why a particular behaviour was initiated.

This study is the first to investigate both dieting and exercise practices for weight loss and to compare these with measurements of body fat and weight perceptions in multiple ethnic groups. Although participants were more likely to be exercising or dieting to lose weight if they were classified as overfat, our results indicate that an individual's weight status perception was a stronger predictor of weight loss intent than actual body fat, when controlling for all other factors. This finding demonstrates that self-diagnostic inaccuracies in classifying weight status would be likely to flow on to weight control behaviours, and thus, the importance of educating girls about how to correctly classify their body size. While ethnic- and age- variation in the frequency of dieting and exercise was also observed, the effects of SES and pubertal status were only significant when analysed separately.

Overall, adolescent girls from a diverse range of ethnic groups tended to be poor at accurately classifying their weight status. The presence of weight misclassification across the range of body fat categories (normal weight girls perceiving themselves as overweight and girls with high body fat perceiving themselves as normal or underweight) demonstrates the conflicting issues of body size perceptions that exist in this group. Thus, interventions in this subgroup of the population should focus on delivering clear, consistent messages that promote a healthy weight rather than simply weight loss. With regard to weight loss practices, evidence of strong positive relationships between measured body fat status and the frequency of weight loss practices across all ethnic groups was promising. However, given that perceived weight status was more strongly associated with dieting and exercising behaviours, and that a substantial proportion of girls were unable to correctly classify themselves as overweight, educational programmes that assist girls in recognising a state of excess body fat are a priority to increase the likelihood that behavioural changes necessary to combat widespread overweight and obesity are adopted.

Chapter 6: Physical Activity and Active Transport

Preface

It is generally accepted that physical activity is a key determinant of body fatness, with reduced levels predisposing to the development of obesity. Adolescent girls, in particular, are well known for being an at-risk group for physical inactivity. The final chapter of this thesis describes the physical activity data collected in the main study, whereby an objective measurement tool was used to characterise the physical activity of a diverse sample of girls. Sealed multiday memory pedometers were used to monitor daily step counts for five consecutive days. These devices are gaining acceptance as a cost-effective, objective tool for obtaining valid and reliable estimates of physical activity in large samples. Daily step counts were subsequently compared to participation in active transport: a popular context for increasing habitual activity in children. The paper resulting from this chapter was published in 2008 in the *International Journal of Behavioural Nutrition and Physical Activity*.

Abstract

Background: It is well established that the risk of insufficient physical activity is greater in girls than in boys, especially during the adolescent years. The promotion of active transport (AT) to and from school has been posited as a practical and convenient solution for increasing girls' total daily activity. However, there is limited information describing the associations between AT choices and girls' physical activity across a range of age, ethnic, and socioeconomic groups. The objectives of this study were to (1) investigate physical activity patterns in a large multiethnic sample of female children and adolescents, and to (2) estimate the physical activity associated with AT to and from school.

Methods: A total of 1,513 girls aged 5-16 years wore sealed multiday memory (MDM) pedometers for three weekdays and two weekend days. The ethnic composition of this sample was 637 European (42.1%), 272 Pacific Island (18.0%), 207 East Asian (13.7%), 179 Maori (11.8%), 142 South Asian (9.4%), and 76 from other ethnic groups (5%). Pedometer compliance and school-related AT were assessed by questionnaire.

Results: Mean (± SD) weekday step counts (12,597 ± 3,630) were higher and less variable than mean weekend steps (9,528 ± 4,407). A consistent decline in daily step counts was observed with age: after adjustment for ethnicity and SES, girls in school years 9-10 achieved 2,469 (weekday) and 4,011 (weekend) fewer steps than girls in years 1-2. Daily step counts also varied by ethnicity, with Maori girls the most active and South Asian girls the least active. Overall, 44.9% of participants used AT for school-related travel. Girls who used AT to and from school averaged 1,052 more weekday steps (95% CI: 284, 1,821; $P = 0.001$) than those who did not use AT. However, the increases in steps associated with AT were significant only in older girls (school years 5-10) and in those of Maori or European descent.

Conclusions: Our data suggest that adolescent-aged girls and girls of Asian descent are priority groups for future physical activity interventions. While the apparent benefits of school-related AT vary among demographic groups, promoting AT in girls appears to be a worthwhile strategy.

Introduction

Participation in regular physical activity is associated with numerous positive health outcomes in children and adolescents, including improvements to cardiovascular profiles and psychological wellbeing [224]. Conversely, insufficient physical activity is a major contributor to the burden of disease, predisposing young people to the development of obesity, diabetes, and other chronic diseases later in life. In spite of these consequences, research indicates that physical activity participation by children and adolescents continues to decline in many countries [48].

An understanding of the determinants of low physical activity in youth is essential for designing effective interventions to target those most at risk. However, obtaining objective physical activity data in a large sample can prove a challenging task. Step-counting pedometers offer a simple, cost-effective solution, providing an objective assessment of physical activity that correlates well with accelerometers [101] and observational techniques [193]. Although unable to detect the frequency or intensity of activity, the use of steps.day^{-1} as a standard physical activity unit facilitates direct comparisons between population groups. Indeed, the practical nature of daily step

count targets has increased the popularity of pedometers for quantifying physical activity in large samples and as a motivational tool for health promotion. Recent models incorporate a multiday memory (MDM) function that allows step counts on weekdays and weekend days to be analysed separately. This is an important consideration given the significant differences in physical activity behaviour between day types [53, 72, 97].

One of the most consistent observations in previous pedometry research is that girls accumulate significantly fewer steps than boys [53, 116, 225, 235]. This finding suggests that girls are an at-risk group for physical inactivity, and thus, a research priority. Of particular concern are the low step counts recorded in adolescent girls, an observation preceded by a steep decline in weekday activity between childhood and adolescence [116]. During the pre-pubescent years, age-related trends are less clear. Vincent et al [225] reported that weekday step counts were relatively stable with age in American, Australian, and Swedish children. While our previous observations of weekday steps in New Zealand children showed similar trends, we noted a significant decrease in weekend step counts with age [53]. Accordingly, children may experience a more pronounced reduction in steps counts with age on weekends than on weekdays. To our knowledge, no studies have assessed both weekday and weekend step counts in a large sample of children and adolescents. Participation in health behaviours such as physical activity can also vary substantially across ethnic [77] and SES groups [185]. Indeed, ethnic identity and socioeconomic status are key dimensions of health inequalities [141]. Research into the associations between pedometer steps and age also requires the potential effects of ethnicity and SES to be characterised.

Despite being largely overlooked in previous surveys of physical activity, active transport (AT) to and from school has become a popular context for increasing habitual activity in young people of all ages and physical abilities [220]. In elementary schools, for example, walking school buses have been widely adopted as a means to encourage physical activity and reduce traffic congestion [104]. Promotion of AT may be particularly beneficial for girls to accumulate steps, given that they are less likely than boys to participate in behaviours that require vigorous physical activity [97, 200, 218].

However, research on the impact of AT on girls' daily activity levels has been equivocal. While there is evidence supporting AT in female children [25, 161] and adolescents [219], other studies have found no advantages of AT in girls [26, 139]. Such discrepancies between studies may reflect differences in sample characteristics and assessment techniques, although all studies implemented accelerometers as the primary measure of physical activity. Regardless, there are currently no data quantifying the association between school-related AT and daily steps in children or adolescents.

Given recent efforts to promote activity in girls through pedometer-based interventions [192], it is essential that the correlates of daily step counts in this population group are well understood. Thus, the objectives of the present study were (1) to investigate weekday and weekend step counts in female children and adolescents from five ethnic groups, and (2) to examine the association between AT and daily steps in girls.

Methods

Participants

A total of 1,648 girls aged 5-16 years (mean age = 11.58 ± 2.77) were randomly selected from 39 primary (school years 1-6; ages 5-10 years), intermediate (school years 7-8; ages 11-12 years), and secondary (school years 9-10; ages 13-14 years) schools in Auckland, New Zealand. Of this initial group, 27 participants (1.6%) lost their pedometer during testing, and 108 (6.6%) provided incomplete data, resulting in a final sample size of 1,513. The ethnic composition of this sample was 637 European (42.1%), 272 Pacific Island (18.0%), 207 East Asian (13.7%), 179 Maori (11.8%), 142 South Asian (9.4%), and 76 children from other ethnic groups (5%). The East Asian ethnic group included Chinese (48.3%), Korean (29.0%), Filipino (12.1%), and other East Asian (10.6%) children; and the South Asian group included Indian (91.5%), Sri Lankan (7.0%), Bangladeshi (0.7%), and Nepalese (0.7%) children. Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand schools. Participants from schools with a decile rating of 1-3 were categorised into the 'Low' SES group, while those from schools rated 4-7 and 8-10 were considered 'Middle'

and 'High', respectively. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee. Written informed consent was provided by each participant and her legal guardian.

Physical Activity Measurements

Daily physical activity was assessed using the New Lifestyles NL-2000 (Lee's Summit, MO) MDM pedometer. The NL-2000 provides similar accuracy and better precision [54] than the widely used Yamax Digiwalker series while offering the additional benefits of a MDM function, whereby step counts are automatically recorded each day for seven days. Each NL-2000 pedometer was checked for defects prior to use in the study by observing the recorded step count after walking 100 paces [225]. Instrumental error did not exceed 3% in any of the pedometers. Approximately 40 children per week were tested between the months of August-December, 2004 and August-December, 2005 (excluding school holidays). Participants were given a short explanation about the study and a demonstration on how to attach a pre-sealed pedometer to the waistline, and were instructed to wear their pedometer all day for seven consecutive days (except when sleeping or swimming). On the seventh day of testing, researchers visited participants at their school to collect the devices and record the number of steps taken on each day. This resulted in a maximum of five full days of data (three weekdays and two weekend days).

Intermediate and Secondary school participants were given a compliance questionnaire at the time of pedometer collection to record any times the device was not worn during the monitoring period. The low reliability of self-report techniques in children [183] necessitated the use of a proxy compliance questionnaire in elementary school participants. Parents/caregivers of participants less than ten years of age completed a questionnaire the night before the pedometer was due for collection to assess compliance outside the school environment. Non-compliance of elementary children during school hours was considered negligible due to active teacher assistance. Participants who removed their pedometer for more than one hour on any day had the steps accumulated on that day removed from analysis. Additionally, participants with more than one weekday and one weekend lost due to incomplete

data were excluded from the final data set. Finally, daily step counts below 1,000 or above 30,000 were regarded as outliers to allow for the possibility that non-compliant individuals were not identified [175]. Information on AT patterns was collected by questionnaire. Intermediate and secondary school participants were asked which travel modes they usually used to travel to and from school (both routes assessed separately), and the parents/caregivers of participants at elementary school completed an equivalent proxy questionnaire.

Statistical Analyses

Data were analysed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, SES) among ethnic groups were assessed by two-way ANOVA and significant associations were examined by pairwise comparisons using *t*-tests. One-way ANOVA and Bonferroni *post hoc* tests were used to determine where significant differences in step counts existed among ethnic, age, socioeconomic, and AT groups. Associations among weekday and weekend step counts, ethnicity, SES, and school year group were assessed using factorial repeated measures ANOVA. Chi squared analysis was used to examine significant differences in the frequency of using active transport modes to travel to/from school across ethnic, SES, and school year groups. A *P* value less than 0.05 was used to indicate statistical significance.

Results

Age differences were present among the ethnic groups ($P < 0.001$), with East Asian girls significantly older (12.33 ± 2.43) than European (11.31 ± 2.92) and Maori (11.32 ± 2.60) girls. The average decile of Pacific Island girls was lower than that all other ethnic groups, followed by Maori, South Asian, Other, East Asian, and European girls. In addition, the mean decile varied by school year group ($P < 0.001$), with year 9-10 girls averaging the highest decile (6.87 ± 3.51) and year 7-8 girls averaging the lowest decile (4.48 ± 2.4). The frequencies of the different ethnic groups also varied significantly across school year levels ($P < 0.001$). However, no significant differences in pedometer compliance were detected across ethnic ($P = 0.228$), age ($P = 0.394$), or SES ($P = 0.105$) groups.

Table 6-1. Pedometer-determined physical activity (steps.day^{-1}).

	Weekday Steps		Weekend Steps	
	n	Mean ± SD	*n*	Mean ± SD
Ethnicity[ab]				
European	617	12830 ± 3486	580	10433 ± 4175
East Asian	196	11121 ± 3203	185	7599 ± 3730
South Asian	136	11314 ± 3089	136	7673 ± 3224
Maori	172	14096 ± 3764	150	10868 ± 5410
Pacific Island	254	12992 ± 3973	235	9189 ± 4749
Other	72	12071 ± 3203	69	8988 ± 3146
School Year[ab]				
1-2	161	14572 ± 2714	150	12512 ± 4109
3-4	196	14394 ± 3377	187	11309 ± 4384
5-6	200	13566 ± 3529	194	10027 ± 4079
7-8	231	11882 ± 3288	222	7514 ± 3050
9-10	659	11537 ± 3567	602	8812 ± 4423
Socioeconomic Status[ab]				
Low	565	12711 ± 3738	524	8724 ± 4406
Middle	259	13405 ± 3581	253	10410 ± 4422
High	623	12157 ± 3487	578	9871 ± 4289
Total	1447	12597 ± 3630	1355	9528 ± 4407

[a]Significantly different for weekday steps ($P < 0.005$).
[b]Significantly different for weekend steps ($P < 0.005$).

Table 6-1 gives the mean weekday and weekend step counts for the present sample grouped according to ethnicity, school year group, and SES. Mean weekday steps were consistently higher and tended to have smaller standard deviations than mean weekend steps across all subgroups. However, the magnitude of the difference between weekday and weekend steps varied significantly by school year group and SES ($P < 0.001$). In particular, the mean difference in step counts between day types tended to be greater for older girls and for those from lower SES groups. There were significant differences in weekday steps among the ethnic groups: Maori girls were the most active, followed by Pacific Islanders, and then Europeans. For weekend activity,

Maori and European girls averaged the highest step counts, followed by Pacific Islanders. South and East Asian girls were the least active ethnic groups during weekdays and the weekend. Both weekday and weekend step counts decreased with school year group. Average weekday steps were highest for girls from the middle SES group, followed by the low, and the high groups. However, girls from the middle and high SES groups were more active than girls from the low SES group during weekends.

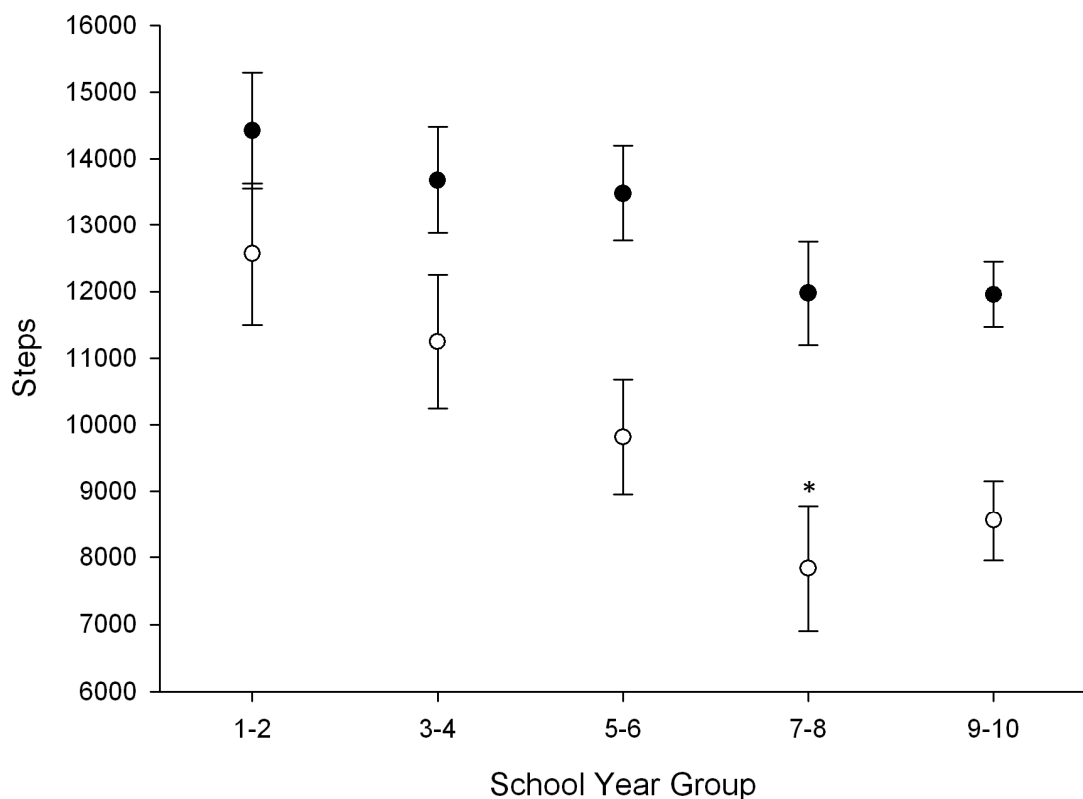**Table 6-2. Factorial repeated measures ANOVA (Ethnicity by Year by SES by Day).**

Source	F	P
Within Subjects		
Day	176.123	0.000[b]
Day x Ethnicity	0.546	0.742
Day x School Year Group	2.960	0.019[a]
Day x SES	6.414	0.002[a]
Day x Ethnicity x School Year Group	1.231	0.219
Day x Ethnicity x SES	1.830	0.051
Day x School Year Group X SES	0.997	0.432
Day x Ethnicity x School Year Group x SES	0.981	0.501
Between Subjects		
Ethnicity	8.425	0.000[b]
School Year Group	17.416	0.000[b]
SES	1.046	0.352
Ethnicity x School Year Group	1.015	0.440
Ethnicity x SES	0.878	0.553
School Year Group x SES	2.290	0.026[a]
Ethnicity x School Year Group x SES	1.097	0.323

[a]Significant ($P < 0.05$) level.
[b]Significant ($P < 0.005$) level.

To investigate the interactions among the key demographic factors associated with activity in this sample, ethnicity (European, Maori, Pacific Island, East Asian, and South Asian), school year group (1-2, 3-4, 5-6, 7-8, and 9-10), SES (high, medium, and low) and day (weekday and weekend) were entered into a 5 x 5 x 3 x 2 factorial repeated measures ANOVA (Ethnicity by School Year by SES by Day; Table 6-2). Mean step

counts differed significantly between weekdays and weekends, with significant interactions between day and school year group, and day and SES, but not between day and ethnicity. This indicates that the significant decrease in activity observed on weekend days varies by school year group and SES, but not by ethnicity. Analysis of the between subject variance revealed a significant association between overall mean step count and both school year and ethnicity, with a significant interaction between school year and SES. Inspection of the estimated marginal means for the latter interaction revealed that the distribution of mean steps across SES groups was noticeably different between years 1-2 (Low SES: 13,508, Middle SES: 12,434, High SES: 14,597) and years 9-10 (9,474, 11,563, 9,758), but was similar for the other school year groups.
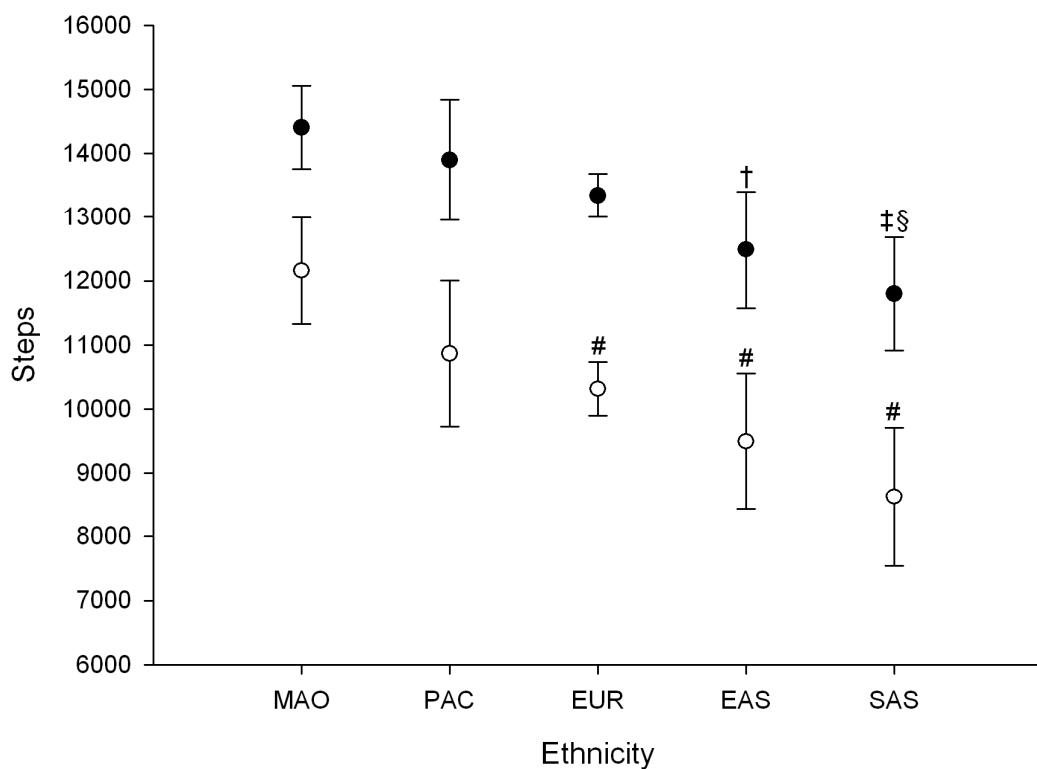

Figure 6-1. Physical activity during weekdays (●) and weekends (O) vs. school year group (adjusted for ethnicity and SES).

*Significantly lower than the previous school year group for weekend steps (P < 0.05).

Figure 6-1 shows the pedometer-determined physical activity of girls during weekdays and weekends according to school year group when adjusted for differences in ethnic

and SES group. Weekend steps were consistently lower than weekday steps across all the school year groups. With increasing school year group, there was a tendency for both weekday and weekend steps to decrease. On average, girls in years 9-10 accumulated 2,469 less steps on weekdays (95% CI: 1,112, 3,826; $P < 0.001$), and 4,011 less steps on weekends (95% CI: 2,345, 5,677; $P < 0.001$) than girls in years 1-2. The steepest decline in activity for adjacent groups occurred between school years 5-6 and 7-8, with the latter group averaging 1,549 fewer steps on weekdays (95% CI: 16, 3,002; $P = 0.052$) and 1,983 fewer steps on weekend days (95% CI: 179, 3,780; $P = 0.024$) than their younger counterparts. The increase in weekday and weekend steps between years 7-8 and years 9-10 was not significant.

Figure 6-2. Physical activity during weekdays (●) and weekends (O) vs. ethnic group (adjusted for school year group and SES).

†Significantly lower than MAO for weekday steps (P < 0.05).
‡Significantly lower than MAO for weekday steps (P < 0.005).
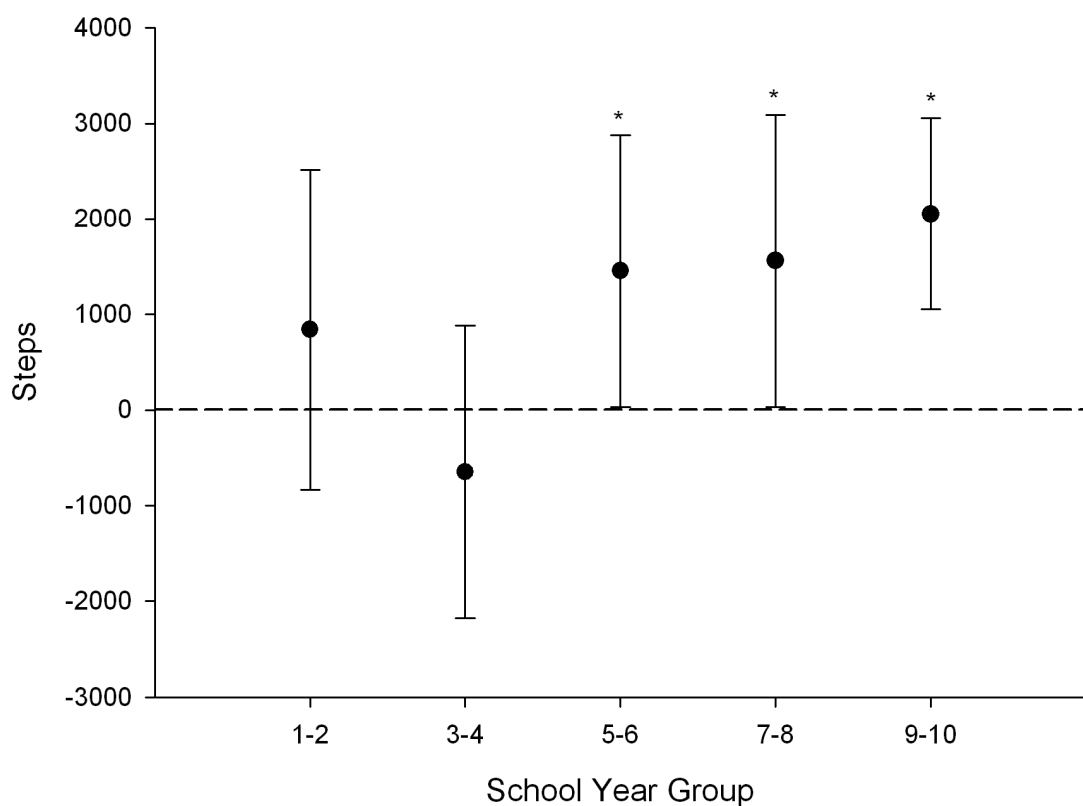§Significantly lower than PAC and EUR for weekday steps (P < 0.05).
#Significantly lower than MAO for weekend steps (P < 0.005).

Figure 6-2 shows the pedometer-determined physical activity of girls from five ethnic groups on weekday and weekend days after adjustment for differences in school year group and SES. Girls from all ethnic groups achieved significantly lower step counts on weekend days than on weekdays. South Asian girls accumulated the least activity on weekdays and the weekend, averaging 11,797 (95% CI: 10,882, 12,685) steps and 8,623 (95% CI: 7,541, 9,706) steps, respectively. In comparison, Maori girls had the highest step counts, accumulating an average of 14,407 (95% CI: 13,758, 15,056) steps on weekdays, and 12,159 (95% CI: 11,329, 12,989) on weekends.

Overall, 44.9% of the girls in this study used AT modes to travel at least one way when commuting to and from school. Of this group, 69.4% actively transported both to and from school, and 30.6% actively transported one way only. Walking was the most common mode of AT (97.3%), followed by cycling (2.7%). The frequency of AT groups varied significantly across ethnicities ($P < 0.001$), school year groups ($P = 0.001$), and SES groups ($P < 0.001$). Of all the ethnic groups, Maori were the most likely to use AT to travel either one or both ways to and from school (55.0%). Frequencies of AT for other ethnic groups were relatively similar, ranging from 41.5% (Pacific Island) to 47.4% (South Asian). Across school year groups, the frequency of AT steadily increased from years 1-2 (39.8%) until years 7-8 (52.9%), before decreasing at years 9-10 (42.9%). Girls belonging to the low or medium SES groups were also significantly more likely to use AT (47.7% and 46.2%, respectively) than those belonging to the high SES group (41.8%).

Multifactor ANOVA revealed significant differences in daily weekday steps among AT groups after adjustment for SES, school year, and ethnicity ($P < 0.001$). Girls that used AT both to and from school averaged 1,052 more weekday steps (95% CI: 284, 1,821; $P = 0.001$) than those who did not use AT. While the difference in steps between girls who used AT one way only and those who did not use AT was similar in magnitude (834), the relatively low number of girls that use AT one way reduced the statistical power of the comparison (95% CI: -177, 1,845; $P = 0.092$). Significant interactions were observed between AT and ethnicity ($P = 0.038$), and between AT and school year group ($P = 0.003$), but not between AT and SES ($P = 0.472$). This indicates that the difference

in weekday steps between AT groups varies with ethnicity and school year group, but not SES group. Identical analysis for daily weekend steps showed no significant association with AT ($P = 0.550$): girls that used AT both to and from school and those who used AT one way only averaged 280 (95% CI: -572, 1,132; $P = 1.000$) more and 261 (95% CI: -1,458, 937; $P = 1.000$) fewer weekend steps (respectively) than girls that did not use AT.

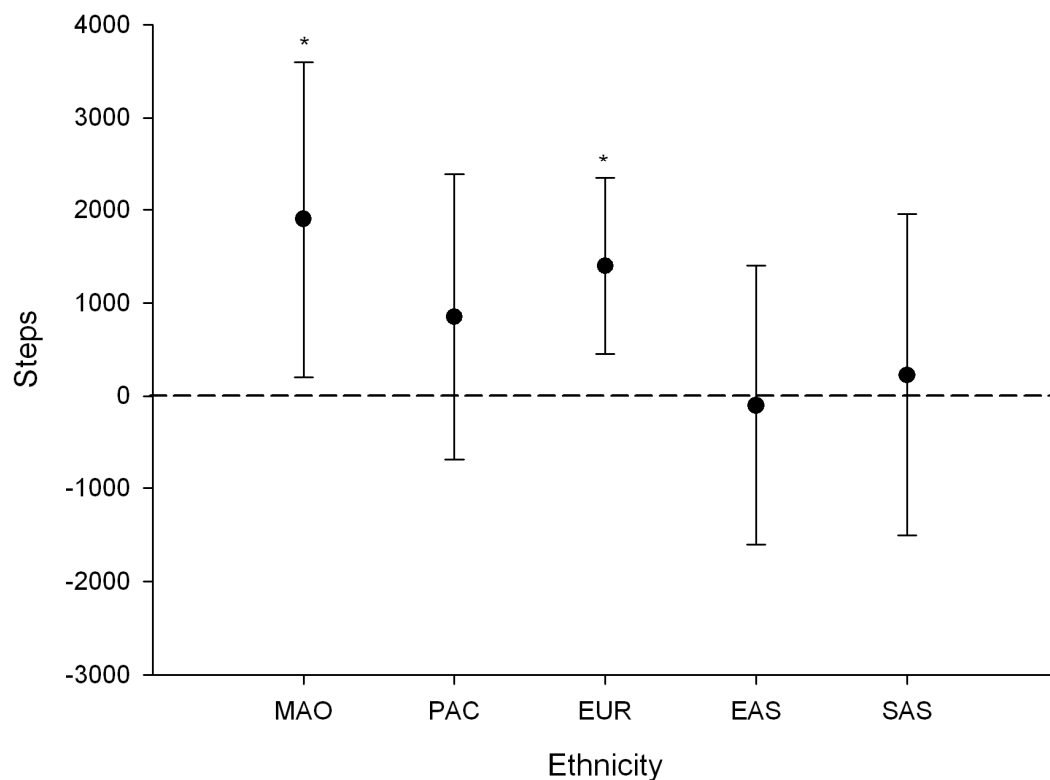

Figure 6-3. Differences in weekday activity between AT and non-AT girls grouped by school year (adjusted for ethnicity and SES).

*Significantly higher mean step counts in AT girls than in non-AT girls.

Figure 6-3 and Figure 6-4 show the mean difference in daily weekday steps between AT groups (AT to and from school – no AT) across school year groups (after adjustment for ethnicity and SES), and ethnic groups (after adjustment for school year and SES). For girls in Years 1-4 there were no significant differences in weekday step counts between AT groups. However, older girls that used AT to travel to and from school achieved significantly more steps on weekdays than those that did not use AT. The

largest difference in weekday steps between these AT groups was observed for girls in years 9-10, who averaged 2,053 more steps (95% CI: 1,049, 3,057). This was followed by girls in years 7-8 who averaged 1,559 more steps (95% CI: 27, 3,091), and girls in years 5-6, who averaged 1,455 more steps (95% CI: 33, 2,877). There were no significant step count differences for girls that used AT for one trip when compared to those that did not use AT. When analysed according to ethnic group, only Maori and European girls had significant differences in weekday steps counts between AT groups. Maori girls that used AT to travel to and from school averaged 1,900 (13.9%) more steps (95% CI: 202, 3,598), and European girls averaged 1,398 (11.0%) more steps (95% CI: 453, 2,344) than those from the same ethnicity that did not use AT to travel either to or from school.

Figure 6-4. Differences in weekday activity between AT and non-AT girls grouped by ethnicity (adjusted for school year and SES).

*Significantly higher mean step counts in AT girls than in non-AT girls.

Discussion

The first objective of this study was to examine weekday and weekend step counts in a multiethnic sample of female children and adolescents. Several key patterns were identified that characterise the physical activity behaviours of girls and thereby provide a basis for developing strategies to promote activity in this population. The most consistent finding was that girls accumulated considerably fewer steps on weekends than on weekdays. This pattern was evident for all demographic groups, with the greatest step count difference between day types observed for older girls and those from lower SES groups. While differences in activity between day types have been observed using both pedometers [53] and other objective measurement techniques [72, 97], comparisons of weekday and weekend activity in diverse samples are limited. The present study provides evidence that the effect of day type on girls' activity is significant across a range of ethnic, school year, and SES groups, and thus, provides support for widespread initiatives to encourage activity during the weekend.

An inverse relationship between school year and mean steps was observed. Interestingly, the age-related decline in steps was more pronounced for weekends than weekdays. Between years 1-2 and 9-10, our results suggest that population daily step counts for New Zealand girls would decrease by 8.2-25.0% on weekdays and by 20.4-41.8% on weekend days (95% CI). Within this age range, the steepest decline in activity occurred between primary and intermediate schools (years 5-6 and years 7-8), corresponding to a likely population decrease of 0.1-21.1% on weekdays and 2.0-35.4% on weekend days. Similarly, in a sample of 1,046 American girls aged 6-18 years, Le Masurier et al [116] reported that weekday pedometer steps were relatively constant during the elementary years before falling off in school years 7-12. Taken together, these findings suggest that the transition from primary to intermediate school may be an important intervention period for arresting the decline in school-centred activity. It is also possible that the onset of puberty triggers a physiological mechanism for conserving energy that contributes to a reduction in physical activity. In any case, the steady decrease in weekend step counts observed between school years 1-8 highlights the need for physical activity in the home environment to be promoted from an early age.

Given New Zealand's ethnic diversity and the substantial health inequalities across different ethnic groups [141], it is imperative to determine ethnic variation when assessing health risk factors like physical activity. A major strength of this study was the ability to compare activity behaviours across five diverse ethnic groups. Girls from Asian ethnic groups accumulated fewer steps than all other ethnic groups, with South Asian girls of particular concern. The development of tailored physical activity interventions for motivating Asian girls in a culturally appropriate manner may help to redress these imbalances. The findings from the present study in children and adolescents extend results from our previous research in children, where we noted that Asian boys and girls aged 5-12 years accumulated fewer steps than their European, Pacific, or Maori counterparts [53]. Earlier studies investigating the influence of ethnic background on physical activity suggest that white adolescents are generally more active than ethnic minorities, with less consistent results for children [184]. Vincent et al [225] also reported significant differences in weekday step counts between children from America, Australia, and Sweden. Clearly, representation of all major ethnic groups within a chosen population is necessary when characterising pedometer determined physical activity. Furthermore, there is a need for more in depth research into underlying cultural and social determinants of physical activity behaviours.

The second objective of this study was to evaluate AT practices in New Zealand girls. Although active commuting to and from school provides an opportunity for children and adolescents of all physical abilities to engage in physical activity on a regular basis [220], less than half of the present sample regularly used AT modes for school-related travel. Particularly low utilisation rates were reported for school years 1-2, possibly due to the perceived risks of allowing young girls to walk unsupervised, and the logistics of accompanying children given the high prevalence of working parents [202]. Between years 7-8 and years 9-10, a marked decline in AT rates was observed. This decease may reflect the transition from intermediate to secondary schools, the latter having larger catchment areas which may preclude some girls from walking the distance to/from school. In addition, girls from high socioeconomic backgrounds were less likely to utilise AT than those from middle or low SES groups. These results are in

accordance with an earlier study in Auckland school children that reported comparatively lower rates of walking home from school among children from the higher socioeconomic stratums [171]. Interestingly, the latter authors found no differences in parental perceptions of risk among the various sociodemographic groups. While there is evidence that underprivileged families have less access to motorised transport [171], socioeconomic differences in parental employment obligations and social norms may also be contributing factors. Reasons for the relatively high AT participation among Maori girls are also unclear, but may be related to the overrepresentation of Maori in low SES regions [202], and/or the importance placed on physical activity participation in this ethnic group.

Recent efforts to promote activity among young people by way of school-related AT are based on the assumption that walking to and from school results in meaningful increases in daily physical activity. Pedometers are the ideal instrument to assess such changes given the ambulatory nature of this transport mode. Our data indicate that for a given SES, school year, and ethnicity, using AT modes to commute both to and from school would be associated with a population increase of 2.2-14.4% steps for New Zealand girls. Estimates of the change in weekday steps between girls who do not use AT and those who use it either to or from school are similar but less precise (-1.4-14.6%). Overall, walking to and from school appears to be an effective means for girls to accumulate steps on weekdays. These findings are in agreement with most [25, 162, 219] but not all [26, 139] previous investigations of AT in young people. In any case, it is likely that the availability of AT for all school children (regardless of their physical fitness or demographic group), coupled with the ensuing environmental benefits of reduced traffic congestion and lower carbon dioxide emissions, will continue to drive the popularity of initiatives encouraging active commuting to and from school.

While AT was associated with higher weekday step counts overall, the strength of the association varied according to school year group and ethnicity. For example, while we would expect AT to and from school to increase population steps anywhere from 0.3% to 28.7% in girls above year 4 (allowing for differences in SES and ethnicity), for younger girls the true benefit of AT is less clear, ranging from -15.0% to 18.0%. The

trend towards a stronger relationship between step counts and AT with increasing school year may reflect older girls walking further to/from school than younger girls, either because of greater distances to commute or less parental restrictions on distances travelled by AT. Similarly, our results suggest that AT would be associated with positive changes to weekday steps for Maori and European girls, with more variable outcomes for Pacific Island, East Asian, and South Asian girls. Such findings highlight the importance of assessing activity behaviour within demographic subgroups, and suggest that tailoring AT initiatives to the groups likely to experience the greatest benefits may be worthwhile. However, it should be noted that the 95% confidence intervals for the change in steps with AT were relatively wide in most instances. Thus, AT may be advantageous even in groups that showed no significant associations with weekday steps. One such example is the year 1-2 group: although it is possible that AT reduces daily activity by as much as 834 steps in some individuals, approximately half of New Zealand girls in school years 1-2 should benefit by more than the mean difference of 841 steps (6.0%).

It has previously been hypothesised that AT in children may potentiate physical activity participation. Cooper et al [26] reported that AT was associated with elevated physical activity throughout the school day in boys. Conversely, it is possible that active children are more likely to walk to/from school than inactive children, and that AT is an indicator rather than a cause of higher activity levels. The cross-sectional design of our study precludes establishment of the causative effects of behavioural variables such as AT. However, the lack of significant step count differences between AT groups on weekends (non-AT days) would suggest that overall activity levels have little or no influence on AT participation, and that any extra weekday physical activity as a result of AT does not persist into the weekend. Clearly, more study is needed to realise the potential downstream benefits of school-related AT.

It should be noted that potential predictors of AT participation (such as distance from school, seasonal variation, availability of motorised transport, and parental employment obligations etc) were not examined. Adjustment for differences in the distance from school, in particular, may offset the observed variation in the association

between AT and physical activity across ethnic and school year groups (or reveal significant variation across SES groups). In addition, the applicability of the present results to children in other countries is uncertain. Identifying the potential differences in cultural or societal influences on physical activity behaviour between populations requires further study.

In summary, this study provides the first investigation of weekday and weekend step counts in female children and adolescents. The low number of steps accumulated on weekends suggests that physical activity promotion in the home environment is a priority. Furthermore, the low physical activity levels of older school girls warrant attention, as do those of Asian girls. AT to and from school appears to be an effective approach for increasing weekday step counts in girls, although the activity benefits for young girls and Asian ethnic groups are unclear. Together, these findings highlight the importance of assessing activity behaviour across a range of demographic groups, and provide impetus for tailoring initiatives to the groups most likely to benefit.

Chapter 7: General Discussion

Summary

Overweight and obesity among children and adolescents has escalated into a serious public health issue for many countries. Accurately defining this condition in populations with multiple ethnic groups can be a challenging task given the substantial differences in body composition among diverse ethnic groups. For example, Asian children tend to exhibit a relatively high level of body fat for a given body size, whereas Pacific Island and Maori children show the opposite characteristics. Although BMI cut-off points adjusted for sex and age are freely available, concern has been raised regarding their suitability for classifying childhood overweight or obesity in multiethnic populations such as New Zealand. The primary aim of this thesis was to investigate the appropriateness of universal and ethnic-specific BMI classification systems for predicting excess body fat in New Zealand girls from five ethnic groups. Table 7-1 summarises Chapters 2 to 4, which encompass the characterisation of BMI/%BF relationships, the investigation of the diagnostic accuracy of universal BMI thresholds, and the development of ethnic-specific methods. Secondary objectives were to examine associations between weight control practices, weight perceptions, and body fatness, and to compare physical activity levels with participation in active transport. A summary of the two chapters relating to these aspects of the thesis (Chapters 5 and 6) is presented in Table 7-2.

Chapter 2 describes the preliminary study that formulated a BIA equation for predicting FFM in young Chinese and Indian populations. While the technique of BIA offers a portable and practical means to estimate body composition in large-scale surveys, it was clear from the existing literature that the distinctive body composition characteristics of Chinese and Indian children could impair the effective application of BIA equations developed in other population groups. As expected, previously published prediction equations were relatively inaccurate when applied to our sample, with the degree of bias tending to increase significantly at the extremes of the FFM distribution. In contrast, the FFM prediction equation developed in this study showed

excellent accuracy with good potential for cross-validation in independent samples of Chinese and Indian children. We concluded that the present equation should be used to estimate FFM from bioimpedance measurements in Chinese and Indian children. This had direct implications for the main study in this thesis, which used BIA to evaluate body fatness in girls from five ethnicities including those of Asian descent.

Chapter 3 presents the first set of results from the main descriptive study in this thesis, as well as incorporating data from the Body-Size and Steps in Children (BASIC) study. The BMI and %BF of 1,676 girls aged 5-16 years was measured and compared between New Zealand's major ethnic groupings (European, Maori, Pacific Island, East Asian, and South Asian). After identifying significant differences in the ratio of %BF to BMI among the five ethnicities, the performance of IOTF and CDC BMI standards for predicting excess body fat in each group was determined. Results indicated that universal cut-off points lacked sensitivity in East and South Asian girls, and were insufficiently specific for Pacific Island and Maori girls. However, ethnic adjustment of the BMI standards improved diagnostic accuracy in both instances. This finding, coupled with high areas under the ROC curves across the five ethnic groups, suggested that BMI can act as an acceptable proxy for %BF in multiethnic populations given the use of ethnic-specific thresholds.

Chapter 4 builds upon the findings from the previous chapter by formulating a series of BMI cut-off points adjusted for ethnic differences in body composition. Using the same dataset, a regression equation was developed that enabled %BF to be predicted from BMI, ethnicity, and age. First, the %BF of European girls at the IOTF BMI cut-off points for overweight and obesity was determined. These data were then entered into the reversed equation to give ethnically-adjusted BMI-for-age curves standardised for %BF levels. Results indicated that the existing BMI thresholds for overweight and obesity need to be lowered by 3.3 and 3.9 $kg.m^{-2}$ for South Asian girls and raised by 1.5 and 1.8 $kg.m^{-2}$ for Pacific Island girls, respectively. The application of these thresholds has the potential to substantially impact prevalence values, and ultimately the public health priorities for obesity prevention strategies, programmes, monitoring, and evaluation.

Chapter 5 examines the weight perceptions and weight loss practices of girls aged 11-15 years from the main sample, departing from the measurement focus of previous chapters in order to provide a wider look at the issues associated with excess weight during adolescence. These variables were identified as a key priority during this developmental period given the marked changes that occur in self-perception and normative social influences. Adolescent girls, in particular, tend to be susceptible to external weight-related pressures, yet there is limited information describing the associations between weight perceptions and actual body fatness. Further, the role that ethnicity plays in determining weight control behaviours in this demographic is not well understood. Our results showed that perceived weight status was often inconsistent with the actual degree of adiposity; a particularly concerning finding at the high end of the %BF distribution given the potential to impede initiation of behavioral changes, and the large proportion that may be affected. We also observed that the number of girls trying to lose weight exceeded those who perceived themselves as overweight in all ethnic groups. Of the girls who were trying to lose weight, most participated in both exercise and dieting, although a significant proportion reported doing neither. While there were several correlates of dieting and exercising in this sample, weight perception was the strongest predictor of both practices. It was concluded that programmes which assist adolescent girls in recognising a state of excess body fat, with a focus on promoting a healthy weight rather than weight loss, were warranted in all ethnic groups.

Chapter 6 represents the final analysis of this dataset: an investigation of physical activity patterns of girls aged 5-16 years and their association with active transport. Multiday memory pedometers provided an objective estimate of physical activity. In agreement with previous research, girls achieved fewer steps on weekends than on weekdays. Significant differences in step counts were also observed among ethnic, age, and SES groups; two potential target areas were older girls and girls of Asian descent. The effect of active transport to and from school on daily step count was dependent on demographic factors (year group and ethnicity). Overall, active transport was associated with an average of 1,052 more steps each day across the entire sample, providing support for initiatives that encourage girls to walk to and from school.

Table 7-1. Summary of findings from Chapters 2-4 of the thesis.

Chapter	Title	Sample	Aim(s)	Summary of Findings
Chapter 2	Validity of BIA in Chinese and Indian	39 boys, 40 girls 5-14 years	• Develop an equation for predicting FFM from bioimpedance measurements in NZ Chinese and Indian children. • Compare the performance of the new equation with existing equations developed in other ethnic groups.	• A single equation was developed that showed excellent predictive ability and negligible bias in both ethnic groups. • None of the existing equations were suitable for use in NZ Chinese and Indian children.
Chapter 3	Diagnostic Accuracy of BMI	1,676 girls 5-16 years	• Characterise the relationships between BMI and %BF in girls from five ethnic groups. • Determine the sensitivity and specificity of universal BMI standards for predicting excess %BF in each ethnicity. • Examine the appropriateness of ethnic-specific BMI cut-off points in girls.	• South and East Asians averaged 4.2% and 1.3% more %BF than Europeans for a given BMI, while Pacific Islanders averaged 1.8% less %BF. • International BMI thresholds for overweight showed low sensitivity in South and East Asian girls and low specificity in Pacific Island and Maori girls. • Diagnostic performance was improved by adjusting for ethnicity.
Chapter 4	Ethnic-Specific BMI Cut-Off Points	1,676 girls 5-16 years	• Develop ethnic-specific BMI cut-off points for overweight and obesity in girls from five ethnic groups.	• Compared with international standards, the ethnic-specific BMI cut-off points were considerably lower for South and East Asian girls and higher for Pacific Island and Maori girls.

Table 7-2. Summary of findings from Chapters 5-6 of the thesis.

Chapter	Title	Sample	Aims	Summary of Findings
Chapter 5	Weight Control Perceptions and Practices	954 girls 11-15 years	• Examine the interactions between weight perceptions, weight control, and body fatness in a multiethnic sample of adolescent girls. • Examine the effect of pubertal development and SES on diet and exercise behaviours.	• A relatively high degree of weight misclassification was observed across all body sizes, with similar agreement achieved whether using %BF or BMI. • The number of girls trying to lose weight exceeded the number who perceived themselves as overweight. • Combined dieting and exercising was the most common weight loss practice. • Weight perception was a stronger predictor of weight loss intent that actual weight status. • Effects of puberty and SES on diet and exercise were only significant when analysed separately.
Chapter 6	Physical Activity and Active Transport	1,513 girls 5-16 years	• Investigate weekday and weekend step counts in female children and adolescents from five ethnic groups. • Examine the association between active transport and daily steps in girls.	• Weekend step counts were significantly lower and more variable than weekday step counts. • Older girls and South Asian girls were relatively inactive subgroups. • Active transport to and from school was associated with increased step counts.

Significance of Findings

The underlying justification for the research described in this thesis is clear: obesity is a serious condition that has reached epidemic proportions in many populations, generating a major public health concern. Young people are an obvious priority given recent increases in this condition, and its tendency to persist into adulthood. The first step towards identifying solutions is to have an understanding of the nature and extent of the problem. To this end, it is essential that we have accurate population estimates of overweight and obesity for children and adolescents. Previous research has shown that different ethnic groups can exhibit markedly different body composition characteristics, and that this variation may confound BMI-based estimates of overweight and obesity. This is particularly relevant in New Zealand given the wide variety of ethnic groups represented in our population. While this multicultural constitution raises the probability of obesity measurement complications, it also represents a unique opportunity to compare BMI/%BF profiles among a diverse range of phenotypes.

Before this investigation could be undertaken, it was necessary to verify that the instrument used to measure %BF did not introduce its own ethnic-related bias. In recent years, BIA has emerged as a feasible method for obtaining body fat measurements in large samples. However, its accuracy is dependent on the utilisation of FFM prediction equations that are specific to the population in question. Prior to the present study, only published equations developed in young European, Maori, and Pacific Island New Zealanders [180], and two equations in Asian samples overseas [103, 129], were available, with none for South Asian populations. It was clear that an equation needed to be generated that could produce accurate estimates of body fat in East and South Asian youth living in New Zealand. The study detailed in Chapter 2 developed a new equation in a sample of Chinese and Indian children, and is the only published BIA equation for these two ethnic groups to date. As a consequence, we now have the ability to estimate body fat via bioimpedance measurements in young people from all major ethnic groups in New Zealand. This has considerable implications for our estimates of childhood obesity, as body fat is stronger predictor of health risk

than weight-based indices. Although our equation is most applicable to Chinese and Indian children living in New Zealand, we suggest that it should also be the preferable option when using BIA in other Asian populations.

The development of an appropriate BIA equation enabled body fat measurements to be determined in a large sample of young New Zealanders; the Girls ABC study included 1081 female adolescents aged 11-16 years. In addition, data obtained from the 595 female participants of the BASIC study (5-11-year-old children) were incorporated into the analyses to provide a more comprehensive profile of New Zealand girls. By comparing the sensitivity and specificity of international BMI cut-off points for predicting excess %BF in European, Maori, Pacific Island, East Asian, and South Asian girls, we were able to demonstrate the inconsistencies (in terms of %BF) of using a universal definition of overweight in multiethnic populations. This is the first time the diagnostic accuracy of existing standards has been compared among multiple ethnicities. Despite the poor performance of the universal thresholds, our results showed that BMI can be an acceptable screening tool for detecting excess adiposity given appropriate threshold values. The hypothetical effects of adjusting for ethnicity on our estimates of obesity are displayed in Figure 3-3. The prevalence of obesity in Maori and Pacific Island girls fell considerably, which may have repercussions for monitoring and surveillance of 'high risk' groups. Arguably more serious was the predicted change in East and South Asian overweight, with adjusted prevalence estimates almost doubling in both cases. These findings indicate that we may need to reconsider the priority groups for obesity prevention in government strategies. Overall, Maori and Pacific Island are still leading the majority of negative health statistics and should continue to be targeted by public health resources; however, our results suggest that childhood obesity may also be a critical problem in Asian communities. Unless we target our efforts towards Asian children we may face serious public health difficulties in this rapidly growing population.

While the preceding chapter provided the rationale for and implications of ethnic-specific definitions of excess body fat, it did not address the development of tangible BMI thresholds for overweight and obesity in each ethnic group. In order to enable

practical application, a series of BMI-for-age curves were standardised to match the %BF of Europeans at the IOTF cut-off points. The results from these analyses reveal for the first time the changes that would need to occur for existing standards to correspond to an equivalent level of body fatness in all major New Zealand ethnicities. We suggest that the use of these curves as a screening tool for lifestyle interventions would result in substantial improvements to diagnostic ability in young females, especially among South Asian and Pacific Island populations. We are hopeful that these analyses will incite further discussion and investigation of ethnic-specific thresholds for population groups not evaluated here, and ultimately research into the dose response relationships between BMI, %BF, and health risk for all major ethnic groups.

Although the primary purpose of this thesis centred on the measurement of excess body fat in young New Zealanders, several variables relating to the behaviours and barriers for achieving weight loss were also examined as part of the Girls ABC Study. Weight loss perceptions and practices of adolescent girls were considered to be important areas of research given compelling evidence that this population tend to be particularly influenced by external weight-related pressures. Equally, determining whether or not overweight girls were able to recognise their condition was of interest from the perspective of engaging those at the high end of the body fat distribution to initiate lifestyle changes. Our results provide the first indication of a mismatch between perceived weight status and actual body fat levels in a large proportion of adolescent girls from multiple ethnic groups. Furthermore, we show that perceived weight status is a stronger correlate of dieting and exercising behaviours than actual body fatness or any of the other sociodemographic variables analysed, suggesting that overweight girls may be difficult to engage if they have yet to perceive their body weight is an issue. In terms of maximising the efficacy of interventions and programmes to combat overweight and obesity among youth, educational campaigns to raise awareness about the signs of excess body fat would likely be a beneficial addition. However, the promotion of a healthy lifestyle rather than dieting or extreme exercise is recommended to discourage unhealthy weight loss in girls who are not at risk of overweight.

Estimates of physical activity were also obtained in the Girls ABC Study. When combining daily step counts with those collected in the BASIC Study some interesting patterns were revealed. For example, the decrease in activity from childhood to adolescence was substantial, especially between Years 5-6 and Years 7-8. This interval marks the transition from primary to intermediate school, and may reflect inherent differences in physical activity opportunities between schools. However, the dramatic decline in weekend step counts indicates that out-of-school activity also suffers as girls reach maturity. This period of development is a clear target for intervention, as is physical activity in the home environment. The relatively low step counts in Asian girls reinforce the message from the preceding body composition analyses that these ethnic groups need to be a public health priority. Additional findings suggest that promoting active transport to and from school may be an effective method to increase girls' activity, offering an additional 1,000 steps each day. The latter figure provides support for existing initiatives that target walking to and from school.

Limitations

There are several limitations in this thesis that should be noted. Firstly, the sample assessed in the main study was not representative of girls in the New Zealand population. However, our study population was large and encompassed a wide range of ages and ethnic groups. In addition, anthropometric measurements of our participants were similar to representative norms. For the main study, schools were selected according to their ethnic composition in order to ensure sufficient numbers in each of the five ethnic groups of interest. Schools in the BASIC Study were purposively selected to mirror the socioeconomic and geographical distribution of schools in the Auckland region. A relatively large number of schools participated in both the Girls ABC (11 schools) and BASIC studies (28 schools) to enable a range of conditions and to minimise the school effect. Nevertheless, care should be taken when generalising these results to the wider population.

It could also be argued that the selection of female participants only is a limitation of the study, as it is probable that boys show distinct body composition and physical activity characteristics. An alternative viewpoint is that girls should be targeted as a

priority group as they are less active than boys. Furthermore, by limiting the sample to young females we were able to obtain a sufficient number of participants to assess the diagnostic accuracy of BMI and formulate ethnic-specific BMI cut-off points for overweight and obesity. If both genders were sampled it is unlikely that the sample sizes for each gender would be adequate to permit these analyses.

In addition, it would have been preferable to select girls as young as two years and as old as 18 years to align with the current IOTF guidelines. Given the age range of our sample, we are only able to comment on the ethnic differences in obesity screening methods in girls aged between five and 16 years. The main reasons behind this choice of age range were pragmatic. New Zealand children enter the schooling system at five years of age; to sample younger children would require partnerships with early childhood centres. This would introduce practical difficulties as not all children attend such centres, and those that do often attend infrequently. Young adults aged 17 and 18 were not selected as these ages represent the optional school years 12 and 13. In senior years girls rarely attend a common compulsory class (most branch into various optional classes) making it more difficult to coordinate data collection procedures. In the year 9-11 girls, questionnaires were administered, anthropometric measurements taken, and pedometers distributed during compulsory health and physical education classes.

The classification of all individuals into five ethnic groupings could also be questioned given the diverse populations represented in each, and the potential variation in physical characteristics. In addition, differences have even been observed in populations from the same ethnic group living in different countries. For example, there is evidence that Chinese children living in Singapore have more body fat at a given BMI than those living in Beijing [40]. Nonetheless, it was necessary to divide the sample into five relatively broad groups to allow comparisons to be made with sufficient statistical power.

The use of a more advanced instrument to measure physical activity (such as accelerometers) could have provided a more comprehensive description of the activity

patterns within the sample. Although pedometers provide a valid measure of daily activity, they are unable to distinguish frequency, intensity, or duration of physical activity. Measurement of these contexts would have added to our understanding of the forms physical activity typically takes in girls. The ability to record activity participation within the day would also be especially useful when assessing the benefits of a specific mode such as active transport. Nonetheless, pedometer step counts are well suited for the measurement of ambulatory activity such as active transport and can be easily compared between studies. Given the large sample size and limited budget available, pedometers were the only feasible option for obtaining objective physical activity data in the present study.

Future Directions

The preliminary study in this thesis developed a BIA equation for estimating FFM in Chinese and Indian children living in New Zealand. Given that there are 2.5 billion people of Chinese and Indian descent throughout the world (36.8% of the total population), it is important that this equation is cross-validated in these ethnic groups within their native population. Indeed, a portable and cost-effective measure of body fatness would be especially useful in India, where the population is facing a dramatic increase in obesity and type 2 diabetes. While the data presented in this thesis suggest that the equation has good cross-validation potential, comparison with a criterion measure of FFM in indigenous Chinese and Indian groups is essential.

The ethnic-specific BMI cut-off points for overweight and obesity presented in this thesis were generated using the %BF of European girls at the IOTF BMI-for-age curves as the standardisation criteria. These thresholds should be viewed as a starting point in this field of research. At present, screening for excess fat in paediatric populations remains controversial because of the limited evidence directly relating body composition in childhood to health outcomes in later life. Until we know more about the dose response relationships between body composition and health risk in all ethnic groups, we cannot be sure that our ethnic specific thresholds represent elevated metabolic risk. Clearly, there is a need for research into the associations between body composition variables and metabolic risk in young people from different ethnic groups,

and how these manifest as health outcomes in adulthood. While the delayed onset of many obesity-related complications makes this a challenging task, short-term indicators such as blood pressure, blood lipid profile, blood glucose can now be measured relatively easily. Knowledge of the %BF/health risk profile for each ethnicity would provide an excellent foundation for developing BMI-based definitions of obesity, and would correct for any natural variation in health risk among different ethnic groups.

Ideally, the publication of the present BMI-for-age curves will prompt other researchers to continue developing ethnic-specific BMI thresholds for boys and for the age groups not evaluated in this thesis (0-5 years and 17-18 years). Even if the health risk associated with excess adiposity is not assessed, replication of the analyses presented here in other populations and the subsequent customisation of BMI-based definitions of obesity could only result in improvements to existing prevalence estimates. In fact, it may be worthwhile to question the maximum age provided by the IOTF (18 years), as it is certain that the age-related increases in BMI extend beyond this ceiling. It is possible that the existing criterion for overweight and obesity pass through 25 and 30 $kg.m^{-2}$ at too early an age, although which age would be more appropriate is open to debate. A better understanding of the associations between BMI, %BF, and health risk during early adulthood may help to elucidate this issue.

As this thesis revolves around a large descriptive survey, several key findings have emerged that could be used as rationale for future intervention studies. An education programme that assists adolescent girls to recognise the warning signs of unhealthy body fat levels may increase the probability that overweight girls will seek to prevent additional fat accretion. Such a programme would need to promote the maintenance of a healthy lifestyle while discouraging dieting or excessive exercise. Culturally-appropriate initiatives that increase physical activity in Asian girls are also justified, as are interventions that prevent the significant decreases in activity that occur between weekdays and weekends and between childhood and adolescence. A randomised controlled trial of the effects of actively transporting to and from school would provide

the evidence required for the development and continuation of walking and cycling programmes in girls.

Conclusions

The results presented in this thesis represent a substantial contribution to the body of knowledge in the field of paediatric body composition and obesity. The first novel aspect was the development of a prediction equation that enables BIA to be used as a portable and convenient measure of body fatness in all New Zealand children. Furthermore, the observed ethnic variation in the association between body fat and BMI contradicted the effectiveness of universal BMI definitions of overweight in female children and adolescents. A new series of ethnic-specific BMI-for-age curves are posited that correspond to an equivalent degree of excess body fatness in girls from New Zealand's five major ethnic groups. The present findings also suggest that programmes that assist adolescent girls to recognise the indicators of excess adiposity are warranted, as are initiatives that promote both school- and home-based physical activity in Asian girls and in girls at the intermediate and secondary level. Overall, this thesis provides original insight into obesity and its determinants in New Zealand girls, improving our understanding of this critical area of research.

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Appendix A: Published Journal Articles

Ethnicity and body fatness in New Zealanders

Elizabeth Duncan, Grant Schofield, Scott Duncan, Gregory Kolt, Elaine Rush

Abstract

In light of alarming rises in the prevalence of obesity worldwide, tackling the obesity 'epidemic' is now a national health priority in many countries. Increasingly, population measures that provide accurate estimates of body fatness are required to assist public health organisations in identifying at-risk groups and developing appropriate preventative strategies. Body mass index (BMI) remains the most cost-effective and practical tool in this regard.

The World Health Organization (WHO) has issued universal BMI standards for defining 'overweight' and 'obesity' in adults (BMI $=25$ kg.m^{-2}, and $=30$ kg.m^{-2}, respectively) based on the risk of obesity-related disease in Europeans. Although widely used, there is mounting evidence suggesting that these standards are not appropriate for all populations. Research indicates that the associations between BMI, percent body fat (%BF), and health risks can vary across different ethnicities. Accordingly, ethnic-specific and country-specific BMI cut-offs for overweight and obesity may be necessary to attain valid prevalence estimates. In New Zealand, this area is largely unexplored in both young people and Asian populations. There is a need for large-scale longitudinal studies investigating the relationships between excessive body fatness and related health outcomes across all major ethnic groups in New Zealand.

The obesity epidemic

The prevalence of obesity has rapidly reached epidemic proportions in both developed and developing countries around the world. The World Health Organization (WHO) estimates that there are now more than 300 million obese people worldwide—an increase of 100 million since 1995.[1]

This rising level of obesity has increased the incidence of obesity-related morbidities, such as cardiovascular disease, Type 2 diabetes, and hypertension, thus imposing a major burden on healthcare systems and lowering the quality of life for those affected. Furthermore, it is predicted that rates of obesity in the next 20 years could be as high as 45–50% in the USA, and 30–40% in Australia and England.[2]

New Zealand is no exception to these trends. National survey results show an 88% increase in the number of obese adults since 1989,[3] to a stage where more than half of all adults are overweight and obesity-related illnesses cost the health care system an estimated $303 million each year.[4]

Maori and Pacific Island (PI) adults appear particularly susceptible, with obesity rates 1.9 and 2.5 times (respectively) higher than that of New Zealand Europeans.[5] Similar patterns have been observed in younger New Zealanders. Results from the 2002 National Children's Nutrition Survey indicated that Maori and PI children were 3.0 and 5.3 times (respectively) more likely to be obese than children from other

ethnicities.[7] Overall, 21.3% of New Zealand children aged 5-14 years were classified as overweight, with a further 9.8% obese.

Body Mass Index as a measure of obesity

Obesity is defined as a condition of excessive fat accumulation to the extent that health and wellbeing may be impaired.[8] In population research, body fatness (BF) is most commonly estimated using body mass index (BMI), a simple anthropometric measurement of weight (kg) divided by squared height (m^2), which tends to correlate well with both percent body fatness (%BF) and health-risk.[9–13] Although more accurate techniques are available; such as four compartment models that measure bone mineral content, body water, and body density independently; BMI remains the most cost-effective and practical tool in studies of this type.

In 1998, the WHO provided international BMI standards for classifying overweight and obesity in adults based on the risk of obesity-related disease for Europeans at each BMI category.[8] Overweight was defined as BMI $=25$ $kg.m^{-2}$ and obesity as BMI $=30kg.m^{-2}$, with the latter corresponding to approximately 25% and 35% BF in young European men and women, respectively.[14] An obvious limitation of this measure is its inability to distinguish between fat and fat-free mass. As such, standard BMI cut-offs for overweight and obesity may not represent the same levels of BF in populations that differ significantly from the typical European phenotype.

For young people, different BMI standards are required. The US Centers for Disease Control and Prevention issued age- and sex-specific BMI charts for defining overweight and obesity in those aged 2 to 20 years based on the 85th and 95th percentile of an American reference population.[15] Alternative thresholds have been provided by the International Obesity Task Force (IOTF) using the mean of the BMI-age curves from six major countries.[16] At a given age, individuals are classified as overweight or obese if they have a BMI greater than the mean BMI-age curve that passes through 25 $kg.m^{-2}$ or 30 $kg.m^{-2}$ (respectively) at age 18 years. The intention of these IOTF cut-offs was to establish a higher degree of international applicability, although the averaging of the six diverse datasets could be considered arbitrary.

Obesity and ethnicity

The WHO BMI thresholds for overweight and obesity are widely used in field research; however, their relevance to all populations is questionable. It is generally accepted that associations between BMI and BF are dependent on age and gender. More recently, these associations have been shown to vary with ethnicity. For example, Pacific Islanders tend to have lower levels of BF than Europeans at a given BMI.[17–19] Conversely, many Asian ethnic groups have higher levels of BF than Europeans at specific BMI, thus putting them at greater risk of obesity-related disease at relatively low BMI scores.[20–22]

Even at the same level of BF, risk profiles may differ between ethnic groups.[23] This may be explained by ethnic-specific variation in the patterns of fat distribution. Indeed, central fat accumulation (ie, an android fat pattern) appears to be a greater predictor of obesity-related health risks than overall fatness.[24,25]

Research indicates that, in general, Asian adults are more prone to visceral and central obesity than Europeans.[26,27] In particular, Hughes et al[28] found that Asian Indians had

a greater predisposition for central obesity than Malay and Chinese Asians. Likewise, there is evidence that Asian children[29] and adolescents[30] have a greater central fat mass when compared with Europeans and other ethnic groups. In accordance with a higher %BF at a given body size, and a more centralised pattern of fat distribution, elevated disease risks have been observed in Asian populations at BMI scores well below the WHO thresholds defining overweight and obesity.

In response, the WHO released provisional recommendations that overweight and obese BMI cut-off points for Asian populations in the Asia-Pacific region be reduced to =23, and =25 kg.m^{-2}, respectively.[31] Although a good starting point, these guidelines do not take into consideration variance among different Asian populations.

More recently, a WHO expert consultation on BMI in Asian populations concluded that there is no single cut-off point appropriate for defining overweight or obesity in all Asian groups.[22] Recommendations from the consultation include: (1) retaining current WHO BMI cut-off points for international classification; (2) adding 'action points' of =23 and =27.5 kg.m^{-2} (representing 'increased' and 'high' risk) as a trigger for public health action; (3) developing ethnic- and country-specific BMI action points; and (4) refining BMI action points with waist circumference in populations predisposed to central obesity.

Obesity in young people

Compared with adults, less is known about the body composition of children and adolescents. There is, however, evidence that BMI is not an equivalent measure of BF among young people from different ethnic groups. At a given BMI, Chinese[32] and Hispanic[33,34] youth have a higher level of BF than Europeans, who in turn have more BF than African-Americans,[35] and Maori and Pacific Islanders.[36] These disparities may evolve, or at least increase, during puberty. For example, Ellis et al[37] observed that ethnic differences in body composition between Hispanics, African-Americans, and Europeans were much less pronounced in children younger than 8 years of age (pre-puberty).

Sexual maturation processes (that occur during puberty) affect body composition, and can alter the associations between BMI and fat mass.[35,38 40] Thus, differences in body composition observed during childhood and adolescence may, in part, reflect ethnic-specific growth and development patterns.[41] In a 6-year follow-up study of Chinese children, Wang et al[42] noted that overweight prevalence (defined according to IOTF age- and sex-specific BMI cut-off points) decreased as children became adolescents. This apparent reduction in overweight may be due to different BMI-age relationships between the study and the IOTF reference populations.

Although the authors did not determine pubertal stage, they suggested that Chinese adolescents tend to mature later than the IOTF reference populations, thereby causing them to be misclassified. Consequently, the IOTF cut-offs may not be appropriate for these populations. For future studies, consideration of sexual maturation may be beneficial.

Explaining ethnic-specific relations between Body Mass Index and percentage of body fatness

Several factors have been proposed to help explain the dependency of the BMI/%BF relation on ethnicity. First, body build/frame size (as measured by wrist and knee girths) tends to vary among different ethnic groups. A number of studies have noted that ethnic populations with relatively high levels of BF at a given BMI also have a more slender build.[43,44] Furthermore, Deurenberg et al[45] found that correcting for body build eliminated most of the ethnic-specific differences associated with %BF prediction equations for bioelectrical impedance analysis (BIA) in Chinese, Malay, and Indian Singaporeans.

In contrast, earlier research concluded that the prediction of %BF from BMI was only slightly improved by the inclusion of body build parameters.[46,47] It is possible that the effects of body build were not observed in these studies due to low inter-group and/or high intra-group variability.[44]

A second factor that may contribute to ethnic-specific relationships between BMI and %BF is variation in sitting height relative to total height. Individuals with long legs (low sitting height) generally have a lower BMI and, as such, %BF may be underestimated from BMI.[48] Relative sitting height tends to be higher in Asian ethnic groups, although the effects on BMI are inconclusive—most likely due to the large intra-group variation in this parameter.[43,44]

Given that differences in body build may explain a large proportion of the ethnic variation in relationships between BMI and %BF, frame size represents an alternative criterion to ethnicity on which to base BMI cut-offs. As ethnicity is self-identified, individuals may affiliate with an ethnic group with which they have no genetic relation. As such, classification according to body build (rather than ethnic group) may help control for inaccuracies when defining ethnicity. However, it is unlikely that collecting data on frame size will be practical in population studies.

Finally, there may be differences in physical activity level among ethnic groups. More active individuals are likely to have a higher proportion of muscle mass, and therefore the potential for overestimation of %BF from BMI.[44] Such a tendency may only be observable in athletes performing high levels of activity. Nevertheless, future studies should include anthropometric measures of body build and physical activity levels in order to increase our understanding of differences in the BMI/%BF relationship among ethnic groups.

New Zealand's issues regarding body fatness and ethnicity

New Zealand has an ethnically diverse population comprising mainly New Zealand Europeans (80.0%), Maori (14.7%), Asians (6.6%), and Pacific Islanders (6.5%).[49] Despite this diversity, ethnic variation in BF and other body composition variables has yet to be investigated in all major ethnic groups.

However, researchers have compared ethnic differences in BMI and %BF among Maori, PI, and European populations. Several studies have found that Maori and PI adults tend to be leaner (ie, have a lower %BF, and higher fat-free mass) than New Zealand Europeans of the same body size.[17-19]

Similar results have been observed in children. Rush et al[56] noted that Maori and PI girls have (on average) 3.7% less BF than New Zealand European girls of the same body size. Furthermore, a related study by Tyrell et al[6] found a small, but statistically significant, difference in the relationship between BMI and %BF in New Zealand European, Maori, and PI schoolchildren aged 5–10 years; although they suggested that the effects of ethnicity were not clinically relevant.

Even though Maori and Pacific Islanders tend to have a higher proportion of lean mass to fat mass than New Zealand Europeans at a given BMI, as a population they maintain a greater absolute fat mass. Indeed, when higher BMI thresholds are applied to Maori and PI peoples to counteract the high lean-to-fat mass ratio (26 $kg.m^{-2}$ and 32 $kg.m^{-2}$ for 'overweight' and 'obesity', respectively), these two groups remain twice as likely to be obese than the 'European and Other' group.[5] Not surprisingly, Maori and PI populations also have a much higher prevalence of type 2 diabetes when compared to Europeans.[50] However, it is noteworthy that the prevalence of type 2 diabetes among New Zealand Indians exceeds that seen in Maori and Pacific Islanders.

The high prevalence of diabetes among Indians is in line with the elevated levels of BF at a given body size seen among Asian populations overseas. This is an issue of increasing importance to New Zealand given that Asian people make up the fastest growing ethnic group, more than doubling in number between 1991 and 2001.[49] Furthermore, Asians are projected to account for 13% of New Zealand's population by 2021.

In spite of their population growth, Asian ethnic groups have been largely neglected by New Zealand health and research policies. For example, only Maori and PI children were over-sampled in the 2002 National Children's Nutrition Survey. In addition, Maori and PI children were analysed separately, whereas children of Asian decent were grouped with New Zealand Europeans. This is a common theme in national surveys by government organisations; such as the Ministry of Health, and Sport and Recreation New Zealand. In order to understand the public health needs of Asian populations in New Zealand, and to tailor preventative health strategies, it is vital that future surveys distinguish between these ethnic groups.

At present, standard BMI thresholds for 'overweight' and 'obesity' are applied to Asian populations as there are no robust New Zealand data available on the relationship between BMI and body composition variables in this ethnic group. Consequently, Asian groups at risk for health complications (accompanying their overweight and obesity conditions) may not be targeted in interventions to prevent/treat obesity. The only evidence available is from a study by Tyrell et al[6] that included two small groups of Asian children in their investigation of the relationship between BMI and body composition in Maori, Pacific Islanders, and New Zealand Europeans. Although results were not presented, the authors commented that Asian Indian children tended to have a higher %BF at a given BMI compared with New Zealand Europeans. However, caution must be taken when interpreting this statement given the small sample size and the fact that %BF was estimated from bioelectrical impedance analysis using a prediction equation that was not specifically developed for Asian Indian children.

The recommendations put forward by the recent WHO expert consultation[22] offer promise for the classification of overweight and obesity in New Zealand's multiethnic society. For clinicians assessing the health status of individuals, BMI thresholds should be refined by consideration of ethnicity and other risk factors such as waist circumference. At a population level, implementation of additional BMI action points will better reflect the continuum of BF and associated health risk. However, valid comparisons with overseas statistics will only be possible if the criteria used to define overweight and obesity are consistent. In these instances, the retention of the standard WHO cut-offs (25 and 30 kg.m^2) is advisable. Ultimately, national BMI action points should be developed for all major ethnic groups in New Zealand based on large-scale population studies of BMI, BF, and health risk.

Conclusions

Accurate assessment of overweight and obesity is vital to assist public health organisations in identifying at-risk groups and to facilitate development of appropriate preventative strategies. At a population level, BF is most commonly assessed using BMI. Although WHO established universal BMI standards for defining overweight and obesity, studies have shown that these BMI thresholds do not provide an equivalent measure of BF and associated health risk across different ethnic groups. Consequently, WHO recently recommended the use of additional BMI cut-offs as public health action points, such as ethnic- and country-specific BMI cut-offs for overweight and obesity.

In New Zealand, knowledge of the ethnic variation in BF and other body composition variables is restricted to New Zealand European, Maori, and PI ethnic groups. New Zealand Asians are of particular interest because of their rapid population growth, and the lack of published data on their BMI/%BF relationships. Furthermore, compared with Europeans, Asians from other countries show elevated levels of BF and greater morbidity and mortality at a given BMI.

In conclusion, large-scale studies are needed to determine the relations between BMI, %BF, BF distribution, and health risk across all major ethnic groups in New Zealand. For young people, these studies should also consider maturational stage. Resulting data will enable development of ethnic-specific BMI thresholds for overweight and obesity—however this is only a starting point.

There is also a clear lack of knowledge concerning ethnic variation in other areas, such as physical activity and diet. An understanding of these issues is imperative for tailoring preventative interventions that will counteract the burgeoning epidemic of obesity in New Zealand.

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Validity of bioelectrical impedance for predicting fat-free mass in Chinese and Indian children

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Objective: Despite the increasing popularity of bioelectrical impedance analysis (BIA) as a field measure of body composition, the accuracy of BIA has yet to be investigated in Chinese and Indian children. The objective of this study was to develop an equation for predicting fat-free mass (FFM) from bioimpedance measurements in New Zealand Chinese and Indian children and to compare its performance with existing equations developed in other ethnic groups. *Design:* FFM derived from total body water by deuterium dilution was used as the reference standard for developing a BIA-based prediction equation in 79 healthy Chinese and Indian children (39 M, 40 F) aged 5–14 years. Nineteen published equations for predicting FFM or total body water from BIA were cross-validated in this sample. *Results:* Using all possible subsets regression a single equation was developed that included height^2/resistance and body weight as in dependent variables (R^2 = 0.98; SEE = 1.49 kg; CV = 5.4%). Predicted residual error sum of squares (PRESS) analysis indicated that the equation had good potential for cross-validation in independent samples of Chinese and Indian children, with excellent predictive ability and negligible bias in each ethnic group. None of the published equations examined produced bias in FFM prediction that was statistically equivalent to zero and uncorrelated with FFM in our sample. The equation developed in this study showed excellent accuracy and precision for predicting the FFM of New Zealand Chinese and Indian children. *Conclusions:* Prediction equations that have been generated specifically for children of Chinese and Indian descent are recommended when using BIA to estimate the body composition of these ethnic groups.

Key words: Chinese, Indian, ethnicity, body composition, child, bioimpedance, validation, regression equation.

Introduction

The assessment of body composition has become increasingly important in epidemiological research as many countries reach a crisis point in the prevalence of overweight and obesity. Accurate estimates of body fatness are vital for public health organisations to identify at-risk groups and to facilitate the development of preventative strategies. In field settings, inexpensive techniques such as body mass index (BMI), skinfold thickness, and bioelectrical impedance analysis (BIA) are routinely used to assess nutritional status and screen for overweight and obesity. BIA is particularly useful in pediatric populations as it provides rapid and non-invasive estimates of fat-free mass (FFM). Over the last two decades, numerous studies have used criterion measures of body composition, such as isotope dilution, dual-energy-x ray absorptiometry, and hydrodensitometry, to validate BIA equations for predicting FFM (and hence body fatness) in young people.

In order to provide valid and reliable measures of body composition in young people, it is essential that models for predicting body composition from bioimpedance measurements are population-specific.

Indeed, individual FFM prediction models may not provide consistent results when applied to groups with significantly different body compositions [1, 2]. Given that the body build of different ethnic populations can vary substantially [3–6], it is important that equations for predicting FFM are validated before use in multiple ethnic groups. The majority of published BIA equations for young people were developed in predominantly Caucasian populations [7–15], though models also exist for Japanese [16, 17], African [18], and African-American [19, 20] children. Several other equations were derived from samples with a significant proportion of Polynesian [21, 22] and African American [23, 24] children. In addition, Horlick et al [25] developed equations in a sample that was comprised of four ethnic groups (African American, Hispanic, Asian, and Caucasian children).

To date, the accuracy of existing BIA equations for

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assessing the body composition of Chinese and Indian children has not been investigated. Previous research indicates that the body composition of Asian children and adolescents differs substantially from the typical Caucasian phenotype, with more slender body builds and a higher ratio of fat-to-FFM at a given BMI observed in those of Asian descent [26–30]. Indeed, a recent study by Rush et al [1] found that BIA equations developed in Caucasian populations did not accurately predict the FFM of Indian adults, and that ethnic-specific equations were preferable. This suggests that BIA models developed in Caucasian children may not be valid in Chinese and Indian subjects. Thus, the purpose of the present study was to develop a valid equation for predicting FFM from bioimpedance measurements in Chinese and Indian children and compare its performance with existing equations developed in other ethnic groups.

Subjects and methods

Participants were 80 healthy Chinese and Indian children recruited through schools in Auckland, New Zealand. Children were only considered for selection if all four grandparents were of Chinese or Indian descent (as determined by a parent questionnaire). Two children from each sex and ethnicity were selected for each year of age from 5–15 years. Subjects with a wide range of body weights (14.1–60.2 kg) and heights (101.8–182.2 cm) were chosen to ensure that the resulting equation was applicable to children with variable body sizes. Overall, 79 of the 80 participants provided suitable samples for deuterium (^{2}H) dilution analysis (39 Chinese [19 M, 20 F] and 40 Indian [20 M, 20 F]). All participants and their legal guardians provided written informed consent. Ethical approval was obtained from the Auckland University of Technology Ethics Committee.

Height (H) and sitting height (H_s) were measured to the nearest 0.1 cm with a portable stadiometer (Design No. 1013522, Surgical and Medical products, Seven Hills, Australia) using standard anthropometric technique. Weight (± 0.1 kg) was measured in light clothing on a digital scale (Seca 770, Seca, Hamburg, Germany). Each body composition measure was recorded by the same researcher a minimum of two times per participant to reduce artificial variation within each technique. Total body water (TBW) was measured using ^{2}H dilution following methods described previously [21]. Briefly, a baseline urine sample was collected, and 0.05g ^{2}H$_2$O per kg of body weight was given orally. A second urine sample was collected five hours post-dose following emptying of the bladder at least one hour beforehand. Samples were prepared for analysis using the chromium reduction method in an elemental analyzer furnace (Eurovector EuroEA3000, Milan, Italy) [31]. The ^{2}H isotopic enrichment of samples was measured using isotope ratio mass spectrometry (GV Instruments Iso-Prime, Manchester, UK). FFM was determined from the ^{2}H dilution space by assuming that this volume is 4% larger than TBW [32], and by using the appropriate age- and sex-specific hydration factor for FFM [33, 34]. Resistance (R) and reactance (X) were measured using single frequency (50 kHz) hand-to-foot bioimpedance analyzer (BIM4, Impedimed, Capalaba, Australia) according to procedures outlined in Rush et al [21].

Data were analyzed using SAS version 9.1.3 for Windows (SAS Institute Inc., Cary, NC). Descriptive statistics were calculated for age, H, H_s, weight, BMI, FFM, FM, percentage body fat (%BF), R, and height^2/resistance (H^2/R). Differences in participant characteristics between sex and ethnic groups were assessed using two-tailed independent samples t-tests. FFM derived from measurements of TBW by ^{2}H dilution was used as the criterion reference for the development of prediction equations based on BIA measurements. These equations were developed for predicting FFM, as opposed to FM, because of the functional relationship between BIA and hydrated lean body tissues. FM and %BF were calculated as weight FFM and (weight FFM)/weight*100, respectively. Preliminary regression analysis in Chinese and Indian children indicated no differences in the predictor variables entering the models for each ethnic group. Therefore, Chinese and Indian ethnicities were combined in subsequent analyses.

The study population was randomly divided into validation (2/3 of the total sample) and cross-validation (1/3 of the total sample) groups. Using all-possible subsets regression analysis in the validation group, a set of prospective prediction equations for FFM was formulated from the following independent variables: weight, age, H, H_s, R, reactance (X), H^2/R, H_s^2/R, sex (F = 0, M = 1), and ethnicity (Indian = 0, Chinese = 1). As a prerequisite, potential predictor variables were first screened for a linear relationship with FFM. Selection of the appropriate number of variables was based on Mallows' Cp statistic and the Schwarz Bayesian criterion (SBC). A high adjusted R^2 value, low standard error of estimate (SEE), Cp similar to the number of regressors in the model, and low SBC indicate an optimal model. A variance inflation factor (VIF) for each independent variable was calculated to assess multicollinearity. The performance of the resulting FFM equation in the cross-validation group was determined by calculating the pure error. The final equation was developed in the total sample using the independent variables determined from the initial equation, and then validated statistically using the PRESS (predicted residual error sum of squares) procedure in both ethnic groups (separately and combined). All R^2 values presented were adjusted by degrees of freedom.

Published BIA equations for predicting FFM or TBW in healthy participants that fell within the 5–14 year age range were tested in the study sample. Predictive equations were selected if they were widely used, were generated in large samples, or were developed in Asian or New Zealand samples. Models that included anthropometric variables other than

Table 1. Participant characteristics grouped by sex and ethnicity (mean ± SD)[a].

	Boys			Girls	
	All children (n = 79)	Chinese (n = 19)	Indian (n = 20)	Chinese (n = 20)	Indian (n = 20)
Age (y)	9.9 ± 2.9 (5.9–15.6)	9.1 ± 2.3 (5.9–13.4)	10.5 ± 3.2 (5.9–15.6)	9.7 ± 3.1 (5.5–14.8)	10.1 ± 2.9 (5.5–13.4)
H (cm)	136.4 ± 18.2 (101.8–182.2)	133.3 ± 15.2 (110.9–165.1)	141.4 ± 20.4 (115.6–182.2)	133.3 ± 19.6 (101.8–163.9)	137.5 ± 17.1 (105.7–166.3)
Hs (cm)	71.8 ± 9.0 (50.5 – 92.5)	69.6 ± 8.8 (42.0 – 85.1)	72.1 ± 9.9 (50.5 – 92.5)	72.6 ± 9.0 (58.0 – 86.1)	72.8 ± 8.5 (60.2 – 88.8)
Weight (kg)	34.1 ± 13.9 (14.1–78.3)	31.8 ± 10.2 (17.9–59.8)	39.1 ± 19.8 (18.6–78.3)	32.4 ± 12.2 (14.1–52.6)	33.2 ± 11.0 (16.8–60.2)
BMI (kg/m²)	17.6 ± 3.1 (13.6–27.5)	17.4 ± 2.2 (13.7–21.9)	18.3 ± 4.5 (13.9–27.5)	17.4 ± 2.5 (13.6–21.2)	17.1 ± 2.6 (14.4–23.8)
FFM (kg)	29.4 ± 13.7 (11.4–57.5)	25.0 ± 8.4 (15.2–47.0)	29.4 ± 13.7 (15.4–57.5)	23.7 ± 8.2 (11.4–36.8)	23.3 ± 7.6 (12.8–39.9)
FM (kg)	8.8 ± 4.9 (2.2–24.9)	6.8 ± 2.8 (2.2–12.8)	9.7 ± 7.0 (2.5–24.9)	8.7 ± 4.3 (2.7–15.8)	9.9 ± 4.1 (4.0–20.3)
%BF	24.9 ± 6.4 (9.3–40.3)	21.2 ± 6.1 (9.3–31.1)	23.1 ± 6.9 (12.1–39.9)	25.9 ± 4.3 (18.9–35.2)	29.3 ± 5.5 (20.8–40.3)

[a]H, height; Hs, sitting height; BMI, body mass index; FFM, fat-free mass; FM, fat mass; %BF, percentage body fat.

height and weight were excluded. Equations that predicted TBW [8, 15, 16, 18, 23] were converted to FFM after dividing by age-specific hydration factors for FFM [33, 34]. Bias (predicted – observed FFM) was calculated to assess the relative under- or overestimation of each equation. Power analyses using a bias SD averaged from the 19 published equations revealed that the sample size of 79 was sufficient to enable the detection of absolute bias greater than 0.67 kg (α = 0.05, 1 – β = 0.80, SD = 2.09 kg). The pure error and the 95% limits of agreement (mean bias ± 1.96 × bias SD) were also calculated to provide an indication of the overall precision of measurement. The consistency of bias at the extremes of the FFM distribution was investigated using correlation analysis, and, where necessary, modified Bland-Altman plots.

Results

Table 1 shows the participant characteristics grouped by sex and ethnicity. There were no significant differences in age, H, H_s, weight, BMI, FFM, or FM between sexes or ethnic groups. Chinese girls averaged 4.6% more body fat (P = 0.009) than Chinese boys, and Indian girls averaged 6.2% more body fat than Indian boys (P = 0.003). There were no significant differences between Chinese and Indian boys for any of the independent variables, however Indian girls averaged 3.4% more body fat than Chinese girls (P = 0.034). Covariance analysis revealed no significant

Table 2. Prediction equations for FFM developed in 2/3 of the sample (and cross-validated in the remaining 1/3) and in the total sample[a].

Validation sub-sample (n = 53)	
Observed FFM	24.74 ± 8.80 kg
FFM prediction equation	FFM = (0.545 × H²/R) + (0.311 × weight) – 0.077 R^2 = 0.969, SEE = 1.57 kg, CV = 6.2%
Predicted FFM	25.43 ± 8.67 kg
Cross-validation sub-sample (n = 26)	
Observed FFM	26.65 ± 12.00 kg
	pure error = 1.39 kg, CV = 5.2%
Predicted FFM	26.67 ± 11.66 kg
Total sample (n = 79)	
Observed FFM	25.37 ± 9.93 kg
FFM prediction equation	FFM = (0.533 × H²/R) + (0.329 × weight) – 0.004 R^2 = 0.978, SEE = 1.49 kg, CV = 5.4%
Predicted FFM	25.37 ± 9.82 kg

differences in FFM at a fixed BMI and age between Chinese and Indian boys or girls.

The study population was randomly split into validation and cross-validation groups in order to develop equations for predicting FFM. The validation group consisted of 26 Chinese (13 M, 13 F) and 27 Indian (13 M, 14 F) children, and the cross-validation group consisted of 13 Chinese (6 M, 7 F) and 13 Indian (7 M, 6 F) children. These groups did not differ significantly for any of the variables listed in Table 1. An equation was developed in the validation group using all possible subsets regression that included H^2/R and weight for predicting FFM ($R^2 = 0.97$, SEE =

1.6 kg, CV = 6.2%; Table 2). The VIF for these two predictor variables was less than 10, indicating that collinearity was not a concern. Models that included age, sex, ethnicity, H, H_s, BMI, R, X, or H_s^2/R variables were not selected due to high Cp and SBC values. When the validation equation was applied to the cross-validation group, the predicted FFM (26.67 ± 11.66 kg) was not significantly different from the observed FFM (26.65 ± 12.00 kg). In addition, the pure error was lower than the SEE in the original validation group, indicating that the equation performed better in the independent sample. Given these results, a single equation was developed in the total sample

Table 3. Description of published BIA equations for the prediction of FFM evaluated in the present study[a].

Reference	BI instrument	Study characteristics	Criterion method	Equation for FFM (kg)	R^2	SEE (kg)
Bray et al [23]	Xitron	10–12 y (C, AA) $n = 129$ M/F	ID	$[(0.4 \times H^2/R) + (0.148 \times W) + 3.32]/HF$	?[b]	?[b]
Cordain et al [7]	BIA 101	9–14 y (C) $n = 14$ M, 16 F	UWW	$(0.81 \times H^2/R) + 6.86$	0.69	4.08
Danford et al [8]	BIA-101	5–9 y (C) $n = 11$ M, 15 F	ID	$[(0.45 \times H^2/R) + (0.11 \times W) + 1.84]/HF$	?[b]	?[b]
Deurenberg et al [9]	BIA-101	7–25 y (C) $n = 130$ M, 116 F	UWW	$(0.438 \times H^2/R) + (0.308 \times W) + (1.6 \times sex) + (0.070 \times H) - 8.5$ (sex: M = 1, F = 0)	0.99	2.39
Deurenberg et al [10]	BIA-101	7–15 y (C) $n = 166$ M/F	UWW	$(0.406 \times H^2/R) + (0.360 \times W) + (0.056 \times H) + (0.56 \times sex) - 6.48$ (sex: M = 1, F = 0)	0.97	1.68
Horlick et al [25]	BIA-101	4–18 y (C, AA, H, A) $n = 640$ M, 597 F	DEXA	$[(0.459 \times H^2/R) + (0.064 \times W) + 3.474]/[(0.769 - (0.009 \times age) - (0.016 \times sex)]$ (sex: M = 1, F = 0)	0.997	0.93
Houtkooper et al [11]	BIA-101	10–19 y (C) $n = 225$ M/F	ID, UWW	$(0.61 \times H^2/R) + (0.25 \times W) + 1.31$	0.95	2.1
Kim et al [17]	SIF-891	9–14 y (J) $n = 141$ M	UWW	$(0.56 \times H^2/Z) + (0.20 \times W) + 1.66$	0.971	1.59
Kushner et al [15]	BIA-101	0–66 y (C, SA) $n = 175$ M/F	ID	$[(0.59 \times H^2/R) + (0.065 \times W) + 0.04]/HF$	?[b]	?[b]
Leman et al [18]	BIA-101	5–8 y (Af) $n = 17$ M, 22 F	ID	$[(0.35 \times H^2/R) + (0.24 \times W) - (0.74 \times sex) + 1.67]/HF$ (sex: M = 0, F = 1)	?[b]	?[b]
Lewy et al [19]	BIA-101	M 11.4 ± 1.4 y F 10.2 ± 0.4 y $n = 19$ M, 17 F (AA)	DEXA	$(0.84 \times H^2/R) + 1.10$	0.97	1.47
Masuda & Komiya [16]	TP-95K	3–6 y (J) $n = 39$ M, 31 F	D	$[(0.149 \times H^2/R) + (0.244 \times W) + (0.460 \times age) + (0.501 \times sex) + 1.628]/HF$ (sex: M = 1, F = 0)	?[b]	?[b]
Morrison et al [20]	BIA-101	11.2 ± 2.7 y (AA) $n = 61$ F	DEXA	$(0.78 \times H^2/R) + (0.10 \times X) + (0.18 \times W) - 8.78$	0.99	1.95
Pietrobelli et al [12]	Human-Im	7–14 y (C) $n = 50$ M, 25 F	DEXA	$(0.694 \times H^2/Z) - (1.097 \times sex) + 5.344$ (sex: M = 0, F = 1)	0.90	5.12
Rush et al [21]	BIM-4	5–14 y (C, P) $n = 59$ M, 61 F	ID	$(0.622 \times H^2/R) + (0.234 \times W) + 1.166$	0.96	2.45
Schaefer et al [13]	Holtain	3.9–19.3 y (C) $n = 59$ M, 61 F	TBK	$(0.65 \times H^2/R) + (0.68 \times age) + 0.15$	0.975	1.98
Sun et al [24]	BIA-101	12–94 y (C, AA) $n = 669$ M, 944 F	ID, UWW, DEXA	$(0.65 \times H^2/R) + (0.26 \times W) + (0.02 \times R) - 10.68$ (sex: M) $(0.69 \times H^2/R) + (0.17 \times W) + (0.02 \times R) - 9.53$ (sex: F)	0.90 3.9	0.83 2.9
Suprasongsin et al [14]	BIA-101	10–22 y (C) $n = 21$ M, 21 F	ID	$(0.524 \times H^2/R) + (0.415 \times W) - 0.32$	0.96	2.8
Tyrell et al [22]	TBF-105	5–10.9 y (C, P) $n = 82$ M/F	DEXA	$(0.31 \times H^2/Z) - (0.17 \times H) + (0.11 \times W) + (0.942 \times sex) - 14.96$ (sex: M = 2, F = 1)	0.97	–

[a]C, Caucasian; A. Asian; P. Polynesian; SA, South American; AA, African American; Af, African; J, Japanese; SEE, standard error of estimate; H, height (cm); W, weight (kg); R, resistance (Ω); Z, impedance (Ω); X, reactance (Ω); ID, isotope dilution, TBK, total body potassium, UWW, underwater weighing; HF, hydration factor; BIA-101, RJL Systems, Inc., Clinton Township, MI; Xitron, Xitron Technologies, San Diego, CA; BIM-4, Impedimed, Capalaba, Australia; Holtain, Holtain Ltd, Crymych, UK; Human Im, DS Medigroup, Milan, Italy; TBF-105, Tanita Corp, Tokyo, Japan; TP-95K, Toyo Physical, Fukuoka, Japan; SIF-891, Selco, Yokohama, Japan.
[b]Statistics based on a TBW prediction equation are not presented

(n = 79) using the variables determined from the initial equation (R^2 – 0.98, SEE – 1.49 kg, CV – 5.4%; Table 2). The H^2/R term accounted for 62.1% of the variability of the equation while weight alone accounted for 54.1% of the variability. The bias of the final equation was 0.00 ± 1.47 kg, with 95% limits of agreement of ± 2.88 kg. The PRESS statistic for the total sample (1.54 kg) was comparable to the SEE, which implied good potential for cross-validation in independent samples. Individual PRESS statistics for Chinese and Indian children revealed a similar level of performance in each ethnic group (1.52 kg and 1.75 kg, respectively). Furthermore, the PRESS residuals for each ethnic group (Chinese, –0.03 kg; Indian, 0.02 kg) and the total sample (0.00 kg) were close to zero, with no noticeable trends at the upper and lower ends of the FFM distribution. This suggests that prediction bias will not be a factor if the final equation is applied to independent populations of Chinese and Indian children.

Nineteen published BIA-based equations for predicting FFM were evaluated in the present population of Chinese and Indian children. Most of the equations showed acceptable correlation between observed and predicted FFM in their samples, with the SEE statistics ranging from 0.93 to 5.12 kg (Table 3). When applied to our sample of Chinese and Indian children, the predicted FFM from each equation was highly correlated with the observed FFM (Table 4). FFM was underestimated by twelve equations [8, 10, 12, 13, 15–20, 22, 24] and overestimated by five [7, 9, 11, 14, 25].

Only predictive models by Bray et al [23] and Rush et al [21] produced bias that was not significantly different from zero. The pure error of these equations was 2.21 kg [23] and 1.59 kg [21]. For both equations, there was a significant negative correlation between the bias and observed FFM, indicating that FFM was underestimated at high values of FFM and overestimated at low values of FFM in our sample. The modified Bland-Altman plots presented in Figure 1a, 1b show the magnitude of the slope between the bias and observed FFM for the Bray et al [23] (slope = –0.19) and Rush et al [21] (slope – –0.02) equations. For example, at one and two SDs above the mean, we would expect the equation by Bray et al [23] to underpredict FFM by 2.2 and 4.0 kg, and by 0.4 and 1.0 kg for the equation by Rush et al [21]. At one and two SDs below the mean, we would expect the equation by Bray et al [23] to overpredict FFM by 1.5 and 3.3 kg, and by 0.9 and 1.5 kg for the equation by Rush et al [21].

Discussion

The continuing development of BIA as a field measure of body composition offers researchers a practical means to monitor the prevalence of excess adiposity in large samples. However, the accuracy of FFM estimation from bioimpedance measurements has yet to be investigated in Chinese and Indian children. To our knowledge, the BIA equation developed in the present study is the first to be validated in these population groups. Using H^2/R and weight as the pre-

Table 4. Cross-validation of published BIA equations for the prediction of FFM in Chinese and Indian children in the present study[a].
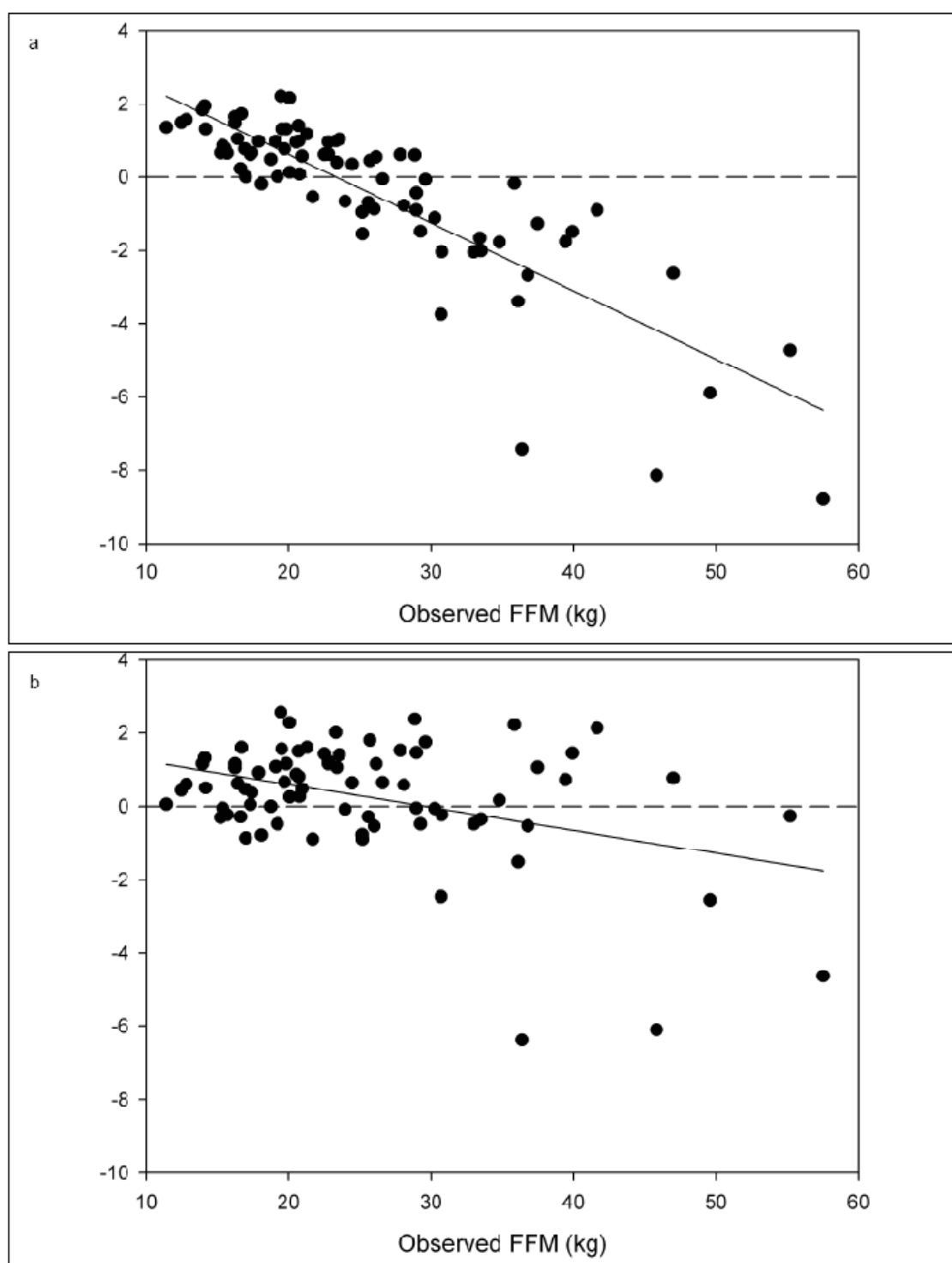
Equation	Predicted FFM (kg)	$r_{y,y'}$	Bias (kg)[b]	P[c]	Pure error (kg)[d]	Limits of agreement (kg)	$r_{y-y',y}$
Bray et al [23]	24.99 ± 8.17	0.989	–0.38	0.132	2.21	–4.67, 3.92	–0.842 (P = 0.000)
Cordain et al [7]	28.33 + 8.20	0.976	2.96	0.000	3.95	–2.19, 8.11	–0.733 (P = 0.000)
Danford et al [8]	23.08 ± 8.15	0.988	–2.28	0.000	3.22	–6.75, 2.19	–0.828 (P = 0.000)
Deurenberg et al [9]	26.47 ± 10.89	0.990	1.10	0.000	2.08	2.37, 4.57	0.478 (P = 0.000)
Deurenberg et al [10]	24.45 ± 9.96	0.989	–0.91	0.000	1.70	–3.75, 1.93	–0.057 (P = 0.619)
Horlick et al [25]	26.83 ± 9.35	0.987	1.47	0.000	2.19	–1.76, 4.69	–0.429 (P = 0.000)
Houtkooper et al [11]	26.01 ± 9.51	0.988	0.64	0.000	1.65	–2.37, 3.65	–0.572 (P = 0.000)
Kim et al [17]	23.27 ± 8.30	0.988	–2.10	0.000	3.00	–6.32, 2.13	–0.803 (P = 0.000)
Kushner et al [15]	23.58 ± 9.23	0.983	–1.78	0.000	2.58	–5.46, 1.90	–0.456 (P = 0.000)
Leman et al [18]	24.76 ± 9.25	0.991	–0.64	0.000	1.60	–3.54, 2.26	–0.518 (P = 0.000)
Lewy et al [19]	23.36 ± 8.51	0.976	–2.01	0.000	3.17	–6.84, 2.83	–0.660 (P = 0.000)
Masuda & Komiya [16]	24.62 ± 8.18	0.987	–0.75	0.004	2.38	–5.20, 3.71	–0.819 (P = 0.000)
Morrison et al [20]	24.09 ± 10.12	0.988	–1.27	0.000	2.03	–4.39, 1.85	0.038 (P = 0.738)
Pietrobelli et al [12]	23.61 ± 7.00	0.976	–1.76	0.000	3.86	–8.54, 5.02	–0.897 (P = 0.000)
Rush et al [21]	25.63 ± 9.42	0.988	0.27	0.133	1.59	–2.82, 3.36	–0.397 (P = 0.000)
Schaefer et al [13]	24.08 ± 8.29	0.977	–1.29	0.000	2.84	–6.29, 3.71	–0.720 (P = 0.000)
Sun et al [24]	29.90 ± 8.41	0.984	–4.53	0.000	3.17	–8.94, –0.12	0.737 (P = 0.000)
Suprasongsin et al [14]	27.72 ± 10.90	0.989	2.36	0.000	2.99	–1.24, 5.96	0.462 (P = 0.000)
Tyrrell et al [22]	21.57 ± 7.60	0.979	–3.79	0.000	4.79	–9.55, 1.97	–0.849 (P = 0.000)

[a]FFM, fat-free mass; $r_{y,y'}$, correlation coefficient between criterion FFM and predicted FFM; $r_{y-y',y'}$ correlation coefficient between the bias and the criterion FFM.
[b]Bias = predicted – observed FFM.
[c]P value for a sample one sample t test that bias – 0.
[d]Pure error = $\sqrt{\sum}$predicted – observed)2/n, where n is the number of subjects in the sample.

Figure 1a, 1b. Modified Bland-Altman plots depicting bias in predicted FFM in Chinese and Indian children versus observed FFM. Figure 1a FFM equation by Bray et al [23] bias = (−0.186 × FFM) + 4.339. Figure1b FFM equation by Rush et al [21] bias = (−0.022 × FFM) + 0.533. The zero reference line is included (dashed line).

dictor variables, we obtained accurate and precise estimates of FFM in the sample of 79 children. Further analyses using the PRESS procedure indicated that the equation was also likely to perform well in independent samples of Chinese and Indian children, with no evidence of prediction bias across the FFM distribution for each ethnic group, or for the combined sample. The limits of agreement of ±2.88 kg indicate that between-subject differences in FFM less than 5.76 kg could not be confidently interpreted as true differences. This finding is consistent with the view that BIA is better suited for population research than for the evaluation of FFM in individuals [7, 10, 13, 15, 25]. However, it is likely that the limits of agreement would narrow with a larger sample.

While Indian girls in our study were significantly fatter than Chinese girls, preliminary regression analysis revealed that the same independent variables entered the models for predicting FFM in both groups. Neither ethnicity nor its interaction with sex featured in the final prediction model, indicating that ethnicity did not explain a significant amount of the variation in FFM regardless of sex. In this study, a single model was developed that produced valid results in Chinese and Indian children, suggesting that ethnic variation in %BF does not necessarily affect the relationship between FFM and bioimpedance parameters. Age and sex also had limited effects on model performance and were consequently excluded from the final equation. Although body water (and therefore bioimpedance) does vary by age and sex, the ^{2}H-derived FFM used as the criterion measure was adjusted by age- and sex-specific hydration factors [33, 34].

The development of a model that performs well in Chinese and Indian children would be of limited significance if existing equations were capable of providing acceptable estimates of FFM in these ethnic groups. Comparing the predictive ability of a series of equations developed in subjects from diverse ethnic groups also provides insight into the adaptability of BIA as a measure of body composition. Nineteen equations previously validated in pediatric subjects were tested, all of which featured either H^2/R or H^2/Z as the major predictor variable. This was expected given that these terms provide an index of the conductive volume of the body, which (in theory) is linearly related to TBW and FFM. Surprisingly, the two equations developed specifically for Japanese children [16, 17] did not perform well in our Asian sample. Only models by Bray et al [23] and Rush et al [21] predicted the FFM of Chinese and Indian children without significant bias. Although these equations had the same predictor variables as our equation for Chinese and Indian children, neither was developed in Asian subjects. Bray et al [23] used a sample of Caucasian and African-American children aged 10–12 years to generate their equation, while Rush et al [21] used Caucasian and Polynesian children aged 5–15 years. The pure error values of 2.21 and 1.59 kg produced by the Bray et al [23] and Rush et al [21]

equations (respectively) were comparable to the SEE of the equation developed in our final sample (1.49 kg). However, the degree of bias increased significantly at the extremes of the FFM distribution for both models. This is arguably more important than the precision of measurement with regard to the applicability of equations to population research, and suggests that these equations are not ideally suited for use in Chinese and Indian children.

It should be noted that the FFM prediction equation proposed in the present study was generated in Chinese and Indian children living in New Zealand. Thus, the applicability of this equation to indigenous Chinese and Indian populations is uncertain. While there are no data comparing the body composition of New Zealand Chinese and Indian children with their native populations, the body composition of Asian populations may vary with their country of residence. For example, Lauderdale and Rathouz [35] reported that the mean BMI of Asian men and women born in America was significantly higher than that of 'foreign' Asians, and Deurenberg et al [27] has shown that the body composition of Chinese children residing in different countries varied significantly. In the present study, all four grandparents of each child were required to be Chinese or Indian to ensure that participants were as equivalent to their native populations as possible. Nonetheless, cross-validation of the FFM equation from the present study in independent samples of indigenous Chinese and Indian children from urban and rural areas is recommended.

Given the age range of the participants in this study (5–14 years), it is also relevant to consider the potential effects of maturation on bioimpedance. The rapid changes in body composition that accompany pubertal development can have a marked effect on bioimpedance parameters. Indeed, there is evidence that puberty is more important than age with regard to bioimpedance in 10–15-year-old girls, even after correction for maturational increases in BMI [36]. Changes to the bioelectrical properties of tissue during sexual maturation are associated with a reduction in the hydration of FFM [37, 38]. While maturational stage was not assessed in this study, the age-specific hydration factors used to estimate FFM from ^{2}H were developed from reference populations that included both pre- and post-pubertal children, thereby adjusting for pubertal changes in hydration [33]. Nonetheless, differences in the mean age of maturation and/or the effect of puberty on tissue hydration between the present sample and the reference populations could result in systematic bias. Until the associations between age, maturation, and tissue hydration in Chinese and Indian children are elucidated, the implications of hydration error for BIA prediction equations in these ethnic groups remain unclear.

In summary, we propose a new model for the prediction of FFM from bioimpedance measurements in Chinese and Indian children living in Western countries. To our knowledge, this is the first BIA based equation for the estimation of FFM in children from

these ethnic groups. Our equation is applicable over a wide range of body sizes and ages, and is more suitable than BMI for assessing body fatness in field research. The use of predictive models developed in other populations is not recommended for Chinese and Indian children given their performance in the present sample. Data from this study suggest that with the use of appropriate equations, BIA can provide a practical, valid measure of body composition in young Chinese and Indian subjects.

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Research

Pedometer-determined physical activity and active transport in girls

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Abstract

Background: It is well established that the risk of insufficient physical activity is greater in girls than in boys, especially during the adolescent years. The promotion of active transport (AT) to and from school has been posited as a practical and convenient solution for increasing girls' total daily activity. However, there is limited information describing the associations between AT choices and girls' physical activity across a range of age, ethnic, and socioeconomic groups. The objectives of this study were to (1) investigate physical activity patterns in a large multiethnic sample of female children and adolescents, and to (2) estimate the physical activity associated with AT to and from school.

Methods: A total of 1,513 girls aged 5–16 years wore sealed multiday memory (MDM) pedometers for three weekdays and two weekend days. The ethnic composition of this sample was 637 European (42.1%), 272 Pacific Island (18.0%), 207 East Asian (13.7%), 179 Maori (11.8%), 142 South Asian (9.4%), and 76 from other ethnic groups (5%). Pedometer compliance and school-related AT were assessed by questionnaire.

Results: Mean weekday step counts (12,597 ± 3,630) were higher and less variable than mean weekend steps (9,528 ± 4,407). A consistent decline in daily step counts was observed with age: after adjustment for ethnicity and SES, girls in school years 9–10 achieved 2,469 (weekday) and 4,011 (weekend) fewer steps than girls in years 1–2. Daily step counts also varied by ethnicity, with Maori girls the most active and South Asian girls the least active. Overall, 44.9% of participants used AT for school-related travel. Girls who used AT to and from school averaged 1,052 more weekday steps than those who did not use AT. However, the increases in steps associated with AT were significant only in older girls (school years 5–10) and in those of Maori or European descent.

Conclusion: Our data suggest that adolescent-aged girls and girls of Asian descent are priority groups for future physical activity interventions. While the apparent benefits of school-related AT vary among demographic groups, promoting AT in girls appears to be a worthwhile strategy.

Background

Participation in regular physical activity is associated with numerous positive health outcomes in children and adolescents, including improvements to cardiovascular profiles and psychological wellbeing [1]. Conversely, insufficient physical activity is a major contributor to the burden of disease, predisposing young people to the development of obesity, diabetes, and other chronic diseases later in life. In spite of these consequences, research indicates that physical activity participation by children and adolescents continues to decline in many countries [2].

An understanding of the determinants of low physical activity in youth is essential for designing effective interventions to target those most at risk. However, obtaining objective physical activity data in a large sample can prove a challenging task. Step-counting pedometers offer a simple, cost-effective solution, providing an objective assessment of physical activity that correlates well with accelerometers [3] and observational techniques [4]. Although unable to detect the frequency or intensity of activity, the use of steps.day^{-1} as a standard physical activity unit facilitates direct comparisons between population groups. Indeed, the practical nature of daily step count targets has increased the popularity of pedometers for quantifying physical activity in large samples and as a motivational tool for health promotion. Recent models incorporate a multiday memory (MDM) function that allows step counts on weekdays and weekend days to be analysed separately. This is an important consideration given the significant differences in physical activity behaviour between day types [5-7].

One of the most consistent observations in previous pedometry research is that girls accumulate significantly fewer steps than boys [5,8-10]. This finding suggests that girls are an at-risk group for physical inactivity, and thus, a research priority. Of particular concern are the low step counts recorded in adolescent girls, an observation preceded by a steep decline in weekday activity between childhood and adolescence [8]. During the pre-pubescent years, age-related trends are less clear. Vincent *et al.*[9] reported that weekday step counts were relatively stable with age in American, Australian, and Swedish children. While our previous observations of weekday steps in New Zealand children showed similar trends, we noted a significant decrease in weekend step counts with age [5]. Accordingly, children may experience a more pronounced reduction in steps counts with age on weekends than on weekdays. To our knowledge, no studies have assessed both weekday and weekend step counts in a large sample of children and adolescents. Participation in health behaviours such as physical activity can also vary substantially across ethnic [11] and SES groups [12]. Indeed, eth-

nic identity and socioeconomic status are key dimensions of health inequalities [13]. Research into the associations between pedometer steps and age also requires the potential effects of ethnicity and SES to be characterised.

Despite being largely overlooked in previous surveys of physical activity, active transport (AT) to and from school has become a popular context for increasing habitual activity in young people of all ages and physical abilities [14]. In elementary schools, for example, walking school buses have been widely adopted as a means to encourage physical activity and reduce traffic congestion [15]. Promotion of AT may be particularly beneficial for girls to accumulate steps, given that they are less likely than boys to participate in behaviours that require vigorous physical activity [7,16,17]. However, research on the impact of AT on girls daily activity levels has been equivocal. Although there is evidence supporting AT in female children [18,19] and adolescents [20], other studies have found no advantages of AT in girls [21,22]. Such discrepancies between studies may reflect differences in sample characteristics and assessment techniques. Regardless, there are currently no data quantifying the association between school related AT and daily steps in children or adolescents.

Given recent efforts to promote activity in girls through pedometer-based interventions [23], it is essential that the correlates of daily step counts in this population group are well understood. Thus, the objectives of the present study were (1) to investigate weekday and weekend step counts in female children and adolescents from five ethnic groups, and (2) to examine the association between AT and daily steps in girls.

Methods
Participants

A total of 1,648 girls aged 5–16 years (mean age = 11.58 ± 2.77) were randomly selected from 39 primary (school years 1–6; ages 5–10 years), intermediate (school years 7–8; ages 11–12 years), and secondary (school years 9–10; ages 13–14 years) schools in Auckland, New Zealand. Of this initial group, 27 participants (1.6%) lost their pedometer during testing, and 108 (6.6%) provided incomplete data, resulting in a final sample size of 1,513. The ethnic composition of this sample was 637 European (42.1%), 272 Pacific Island (18.0%), 207 East Asian (13.7%), 179 Maori (11.8%), 142 South Asian (9.4%), and 76 children from other ethnic groups (5%). The East Asian ethnic group included Chinese (48.3%), Korean (29.0%), Filipino (12.1%), and other East Asian (10.6%) children; and the South Asian group included Indian (91.5%), Sri Lankan (7.0%), Bangladeshi (0.7%), and Nepalese (0.7%) children. Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand schools. Participants

from schools with a decile rating of 1–3 were categorised into the 'Low' SES group, while those from schools rated 4–7 and 8–10 were considered 'Middle' and 'High', respectively. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee. Written informed consent was provided by each participant and her legal guardian.

Physical activity
Daily physical activity was assessed using the New Lifestyles NL-2000 (Lee's Summit, MO) MDM pedometer. The NL-2000 provides similar accuracy and better precision [24] than the widely used Yamax Digiwalker series while offering the additional benefits of a MDM function, whereby step counts are automatically recorded each day for seven days. Each NL-2000 pedometer was checked for defects prior to use in the study by observing the recorded step count after walking 100 paces [9]. Instrumental error did not exceed 3% in any of the pedometers. Approximately 40 children per week were tested between the months of August, 2004 and August, 2005 (excluding school holidays). Participants were given a short explanation about the study and a demonstration on how to attach a pre-sealed pedometer to the waistline, and were instructed to wear their pedometer all day for seven consecutive days (except when sleeping or swimming). On the seventh day of testing, researchers visited participants at their school to collect the devices and record the number of steps taken on each day. This resulted in a maximum of five full days of data (three weekdays and two weekend days).

Intermediate and Secondary school participants were given a compliance questionnaire at the time of pedometer collection to record any times the device was not worn during the monitoring period. The low reliability of self-report techniques in children [25] necessitated the use of a proxy compliance questionnaire in elementary school participants. Parents/caregivers of participants less than ten years of age completed a questionnaire the night before the pedometer was due for collection to assess compliance outside the school environment. Non-compliance of elementary children during school hours was considered negligible due to active teacher assistance. Participants who removed their pedometer for more than one hour on any day had the steps accumulated on that day removed from analysis. Additionally, participants with more than one weekday and one weekend lost due to incomplete data were excluded from the final data set. Finally, daily step counts below 1,000 or above 30,000 were regarded as outliers to allow for the possibility that non-compliant individuals were not identified [26]. Information on AT patterns was collected by questionnaire. Intermediate and secondary school participants were asked which travel modes they usually used to travel

to and from school (both routes assessed separately), and the parents/caregivers of participants at elementary school completed an equivalent proxy questionnaire.

Statistical analyses
Data were analysed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, SES) among ethnic groups were assessed by two-way ANOVA and significant associations were examined by pairwise comparisons using *t*-tests. One-way ANOVA and Bonferroni *post hoc* tests were used to determine where significant differences in step counts existed among ethnic, age, socioeconomic, and AT groups. Associations among weekday and weekend step counts, ethnicity, SES, and school year group were assessed using factorial repeated measures ANOVA. Chi squared analysis was used to examine significant differences in the frequency of using active transport modes to travel to/from school across ethnic, SES, and school year groups. A P value less than 0.05 was used to indicate statistical significance.

Results
Age differences were present among the ethnic groups ($P < 0.001$), with East Asian girls significantly older (12.33 ± 2.43) than European (11.31 ± 2.92) and Maori (11.32 ± 2.60) girls. The average decile of Pacific Island girls was lower than that all other ethnic groups, followed by Maori, South Asian, Other, East Asian, and European girls. In addition, the mean decile varied by school year group ($P < 0.001$), with year 9–10 girls averaging the highest decile (6.87 ± 3.51) and year 7–8 girls averaging the lowest decile (4.48 ± 2.4). The frequencies of the different ethnic groups also varied significantly across school year levels ($P < 0.001$). However, no significant differences in pedometer compliance were detected across ethnic ($P = 0.228$), age ($P = 0.394$), or SES ($P = 0.105$) groups.

Table 1 gives the mean weekday and weekend step counts for the present sample grouped according to ethnicity, school year group, and SES. Mean weekday steps were consistently higher and tended to have smaller standard deviations than mean weekend steps across all subgroups. However, the magnitude of the difference between weekday and weekend steps varied significantly by school year group and SES ($P < 0.001$). In particular, the mean difference in step counts between day types tended to be greater for older girls and for those from lower SES groups. There were significant differences in weekday steps among the ethnic groups: Maori girls were the most active, followed by Pacific Islanders, and then Europeans. For weekend activity, Maori and European girls averaged the highest step counts, followed by Pacific Islanders. South and East Asian girls were the least active ethnic groups during weekdays and the weekend. Both weekday and weekend step

Table 1: Pedometer-determined physical activity (steps.day⁻¹)

	Weekday Steps		Weekend Steps	
	N	Mean ± SD	N	Mean ± SD
Total	1447	12597 ± 3630	1355	9528 ± 4407
Ethnicity* **				
European	617	12830 ± 3486	580	10433 ± 4175
East Asian	196	11121 ± 3203	185	7599 ± 3730
South Asian	136	11314 ± 3089	136	7673 ± 3224
Maori	172	14096 ± 3764	150	10868 ± 5410
Pacific Island	251	12992 ± 3973	235	9189 ± 4749
Other	72	12071 ± 3203	69	8988 ± 3146
School Yr * **				
1–2	161	14572 ± 2714	150	12512 ± 4109
3–4	196	14394 ± 3377	187	11309 ± 4384
5–6	200	13566 ± 3529	194	10027 ± 4079
7–8	231	11882 ± 3288	222	7514 ± 3050
9–10	659	11537 ± 3567	602	8812 ± 4423
Socioeconomic status* **				
Low	565	12711 ± 3738	524	8724 ± 4406
Middle	259	13405 ± 3581	253	10410 ± 4422
High	623	12157 ± 3487	578	9871 ± 4289

* Significantly different for weekday steps ($P < 0.005$).
** Significantly different for weekend steps ($P < 0.005$).

counts decreased with school year group. Average weekday steps were highest for girls from the middle SES group, followed by the low, and the high groups. However, girls from the middle and high SES groups were more active than girls from the low SES group during weekends.
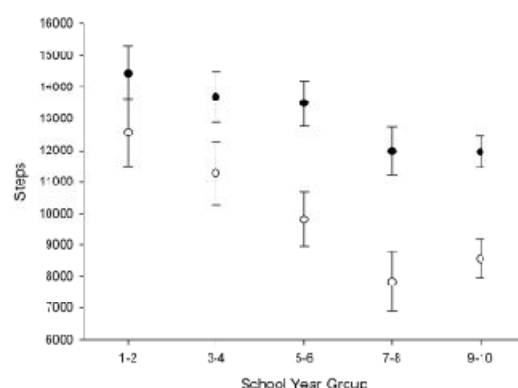
To investigate the interactions among the key demographic factors associated with activity in this sample, ethnicity (European, Maori, Pacific Island, East Asian, and South Asian), school year group (1–2, 3–4, 5–6, 7–8, and 9–10), SES (high, medium, and low) and day (weekday and weekend) were entered into a 5 × 5 × 3 × 2 factorial repeated measures ANOVA (Ethnicity by School Year by SES by Day; Table 2). Mean step counts differed significantly between weekdays and weekends, with significant interactions between day and school year group, and day and SES, but not between day and ethnicity. This indicates that the significant decrease in activity observed on weekend days varies by school year group and SES, but not by ethnicity. Analysis of the between subject variance revealed a significant association between overall mean step count and both school year and ethnicity, with a significant interaction between school year and SES. Inspection of the estimated marginal means for the latter interaction revealed that the distribution of mean steps across SES groups was noticeably different between years 1–2 (Low SES: 13,508, Middle SES: 12,434, High SES: 14,597) and years 9–10 (9,474, 11,563, 9,758), but was similar for the other school year groups.

Figure 1 shows the pedometer-determined physical activity of girls during weekdays and weekends according to school year group when adjusted for differences in ethnic and SES group. Weekend steps were consistently lower than weekday steps across all the school year groups. With increasing school year group, there was a tendency for both weekday and weekend steps to decrease. On average, girls in years 9–10 accumulated 2,469 less steps on week

Table 2: Results of a factorial repeated measures ANOVA (Ethnicity by School Year Group by SES)

Source	F	P
Within Subjects		
Day	176.123	0.000**
Day × Ethnicity	0.546	0.742
Day × School Year Group	2.960	0.019*
Day × SES	6.414	0.002*
Day × Ethnicity × School Year Group	1.231	0.219
Day × Ethnicity × SES	1.830	0.051
Day × School Year Group × SES	0.997	0.432
Day × Ethnicity × School Year Group × SES	0.981	0.501
Between Subjects		
Ethnicity	8.425	0.000**
School Year Group	17.416	0.000**
SES	1.046	0.352
Ethnicity × School Year Group	1.015	0.440
Ethnicity × SES	0.878	0.553
School Year Group × SES	2.290	0.026*
Ethnicity × School Year Group × SES	1.097	0.323

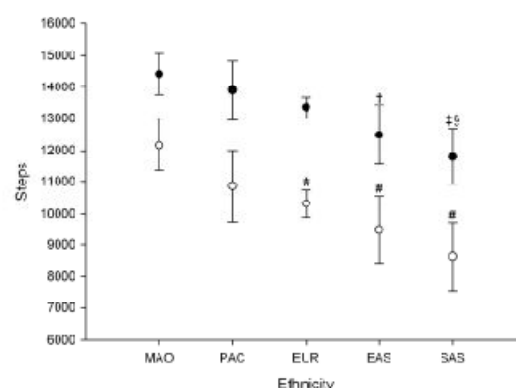*Significant ($P < 0.05$) level
**Significant ($P < 0.005$) level

Figure 1
Physical activity during weekdays (●) and weekends
(○) vs. school year group (adjusted for ethnicity and
SES). *Significantly lower than the previous school year
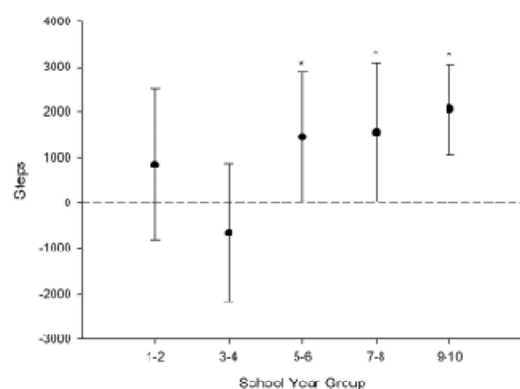group for weekend steps (P < 0.05).

Figure 2
Physical activity during weekdays (●) and weekends
(○) vs. ethnic group (adjusted for school year group
and SES). †Significantly lower than MAO for weekday steps
(P < 0.05). ‡Significantly lower than MAO for weekday steps
(P < 0.005). §Significantly lower than PAC and EUR for week-
day steps (P < 0.05). #Significantly lower than MAO for
weekend steps (P < 0.005).

days (95% CI: 1,112, 3,826; P < 0.001), and 4,011 less
steps on weekends (95% CI: 2,345, 5,677; P < 0.001) than
girls in years 1–2. The steepest decline in activity for adja-
cent groups occurred between school years 5–6 and 7–8,
with the latter group averaging 1,549 fewer steps on week-
days (95% CI: 16, 3,002; P = 0.052) and 1,983 fewer steps
on weekend days (95% CI: 179, 3,780; P = 0.024) than
their younger counterparts. The increase in weekday and
weekend steps between years 7–8 and years 9–10 was not
significant.

Figure 2 shows the pedometer-determined physical activ-
ity of girls from five ethnic groups on weekday and week-
end days after adjustment for differences in school year
group and SES. Girls from all ethnic groups achieved sig-
nificantly lower step counts on weekend days than on
weekdays. South Asian girls accumulated the least activity
on weekdays and the weekend, averaging 11,797 (95%
CI: 10,882, 12,685) steps and 8,623 (95% CI: 7,541,
9,706) steps, respectively. In comparison, Maori girls had
the highest step counts, accumulating an average of
14,407 (95% CI: 13,758, 15,056) steps on weekdays, and
12,159 (95% CI: 11,329, 12,989) on weekends.

Overall, 44.9% of the girls in this study used AT modes to
travel at least one way when commuting to and from
school. Of this group, 69.4% actively transported both to
and from school, and 30.6% actively transported one way
only. Walking was the most common mode of AT
(97.3%), followed by cycling (2.7%). The frequency of AT
groups varied significantly across ethnicities (P < 0.001),
school year groups (P = 0.001), and SES groups (P <

0.001). Of all the ethnic groups, Maori were the most
likely to use AT to travel either one or both ways to and
from school (55.0%). Frequencies of AT for other ethnic
groups were relatively similar, ranging from 41.5%
(Pacific Island) to 47.4% (South Asian). Across school
year groups, the frequency of AT steadily increased from
years 1–2 (39.8%) until years 7–8 (52.9%), before
decreasing at years 9–10 (42.9%). Girls belonging to the
low or medium SES groups were also significantly more
likely to use AT (47.7% and 46.2%, respectively) than
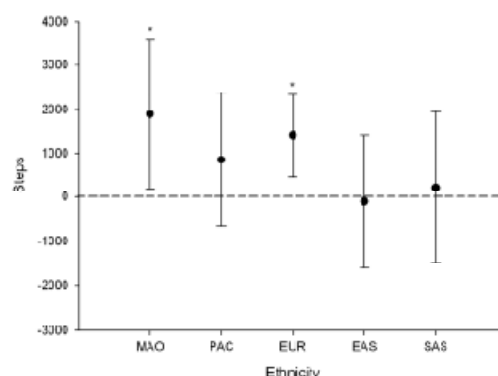those belonging to the high SES group (41.8%).

Multifactor ANOVA revealed significant differences in
daily weekday steps among AT groups after adjustment for
SES, school year, and ethnicity (P < 0.001). Girls that used
AT both to and from school averaged 1,052 more weekday
steps (95% CI: 284, 1,821; P = 0.001) than those who did
not use AT. While the difference in steps between girls
who used AT one way only and those who did not use AT
was similar in magnitude (834), the relatively low
number of girls that use AT one way reduced the statistical
power of the comparison (95% CI: -177, 1,845; P =
0.092). Significant interactions were observed between AT
and ethnicity (P = 0.038), and between AT and school
year group (P = 0.003), but not between AT and SES (P =
0.472). This indicates that the difference in weekday steps
between AT groups varies with ethnicity and school year
group, but not SES group. Identical analysis for daily
weekend steps showed no significant association with AT

(P = 0.550); girls that used AT both to and from school and those who used AT one way only averaged 280 (95% CI: -572, 1,132; P = 1.000) more and 261 (95% CI: -1,458, 937; P = 1.000) fewer weekend steps (respectively) than girls that did not use AT.

Figures 3 and 4 show the mean difference in daily weekday steps between AT groups (AT to and from school – no AT) across school year groups (after adjustment for ethnicity and SES), and ethnic groups (after adjustment for school year and SES). For girls in years 1–4 there were no significant differences in weekday step counts between AT groups. However, older girls that used AT to travel to and from school achieved significantly more steps on weekdays than those that did not use AT. The largest difference in weekday steps between these AT groups was observed for girls in years 9–10, who averaged 2,053 more steps (95% CI: 1,049, 3,057). This was followed by girls in years 7–8 who averaged 1,559 more steps (95% CI: 27, 3,091), and girls in years 5–6, who averaged 1,455 more steps (95% CI: 33, 2,877). There were no significant step count differences for girls that used AT for one trip when compared to those that did not use AT. When analysed according to ethnic group, only Maori and European girls had significant differences in weekday steps counts between AT groups. Maori girls that used AT to travel to and from school averaged 1,900 (13.9%) more steps (95% CI: 202, 3,598), and European girls averaged 1,398 (11.0%) more steps (95% CI: 453, 2,344) than those from the same ethnicity that did not use AT to travel either to or from school.

Figure 4
Differences in weekday activity between AT and non-AT girls grouped by ethnicity (adjusted for school year group and SES). *Significantly higher mean step counts in AT girls than in non-AT girls.

Discussion

The first objective of this study was to examine weekday and weekend step counts in a multiethnic sample of female children and adolescents. Several key patterns were identified that characterise the physical activity behaviours of girls and thereby provide a basis for developing strategies to promote activity in this population. The most consistent finding was that girls accumulated considerably fewer steps on weekends than on weekdays. This pattern was evident for all demographic groups, with the greatest step count difference between day types observed for older girls and those from lower SES groups. While differences in activity between day types have been observed using both pedometers [5] and other objective measurement techniques [6,7], comparisons of weekday and weekend activity in diverse samples are limited. The present study provides evidence that the effect of day type on girls' activity is significant across a range of ethnic, school year, and SES groups, and thus, provides support for widespread initiatives to encourage activity during the weekend.

With increasing school year, an inverse relationship with mean steps was observed. Interestingly, the age-related decline in steps was more pronounced for weekends than weekdays. Between years 1–2 and 9–10, our results suggest that population daily step counts for New Zealand girls would decrease by 8.2–25.0% on weekdays and by 20.4–41.8% on weekend days (95% CI). Within this age range, the steepest decline in activity occurred between primary and intermediate schools (years 5–6 and years 7–

Figure 3
Differences in weekday activity between AT and non-AT girls grouped by school year (adjusted for ethnicity and SES). *Significantly higher mean step counts in AT girls than in non-AT girls.

8), corresponding to a likely population decrease of 0.1–21.1% on weekdays and 2.0–35.4% on weekend days. Similarly, in a sample of 1,046 American girls aged 6–18 years, Le Masurier et al [8] reported that weekday pedometer steps were relatively constant during the elementary years before falling off in school years 7–12. Taken together, these findings suggest that the transition from primary to intermediate school may be an important intervention period for arresting the decline in school-centred activity. It is also possible that the onset of puberty triggers a physiological mechanism for conserving energy that contributes to a reduction in physical activity. In any case, the steady decrease in weekend step counts observed between school years 1–8 highlights the need for physical activity in the home environment to be promoted from an early age.

Given New Zealand's ethnic diversity and the substantial health inequalities across different ethnic groups [13], it is imperative to determine ethnic variation when assessing health risk factors like physical activity. A major strength of this study was the ability to compare activity behaviours across five diverse ethnic groups. Girls from Asian ethnic groups accumulated fewer steps than all other ethnic groups, with South Asian girls of particular concern. The development of tailored physical activity interventions for motivating Asian girls in a culturally appropriate manner may help to redress these imbalances. The findings from the present study in children and adolescents extend results from our previous research in children, where we noted that Asian boys and girls aged 5–12 years accumulated fewer steps than their European, Pacific, or Maori counterparts [5]. Earlier studies investigating the influence of ethnic background on physical activity suggest that white adolescents are generally more active than ethnic minorities, with less consistent results for children [27]. Vincent *et al.*[9] also reported significant differences in weekday step counts between children from America, Australia, and Sweden. Clearly, representation of all major ethnic groups within a chosen population is necessary when characterising pedometer determined physical activity. Furthermore, there is a need for more in depth research into underlying cultural and social determinants of physical activity behaviours.

The second objective of this study was to evaluate AT practices in New Zealand girls. Although active commuting to and from school provides an opportunity for children and adolescents of all physical abilities to engage in physical activity on a regular basis [14], less than half of the present sample regularly used AT modes for school-related travel. Particularly low utilisation rates were reported for school years 1–2, possibly due to the perceived risks of allowing young girls to walk unsupervised, and the logistics of accompanied walking given the high prevalence of work-

ing parents [28]. Between years 7–8 and years 9–10, a marked decline in AT rates was observed. This decease may reflect the transition from intermediate to secondary schools, the latter having larger catchment areas which may preclude some girls from walking the distance to/from school. In addition, girls from high socioeconomic backgrounds were less likely to utilise AT than those from middle or low SES groups. These results are in accordance with an earlier study in Auckland school children that reported comparatively lower rates of walking home from school among children from the higher socioeconomic stratums [29]. Interestingly, the latter authors found no differences in parental perceptions of risk among the various sociodemographic groups. While there is evidence that underprivileged families have less access to motorised transport [29], socioeconomic differences in parental employment obligations and social norms may also be contributing factors. Reasons for the relatively high AT participation among Maori girls are also unclear, but may be related to the overrepresentation of Maori in low SES regions [28], and/or the importance placed on physical activity participation in this ethnic group.

Recent efforts to promote activity among young people by way of school-related AT are based on the assumption that walking to and from school results in meaningful increases in daily physical activity. Pedometers are the ideal instrument to assess such changes given the ambulatory nature of this transport mode. Our data indicate that for a given SES, school year, and ethnicity, using AT modes to commute both to and from school would be associated with a population increase of 2.2–14.4% steps for New Zealand girls. Estimates of the change in weekday steps between girls who do not use AT and those who use it either to or from school are similar but less precise (-1.4–14.6%). Overall, walking to and from school appears to be an effective means for girls to accumulate steps on weekdays. These findings are in agreement with most [18,20,19] but not all [21,22] previous investigations of AT in young people. In any case, it is likely that the availability of AT for all school children (regardless of their physical fitness or demographic group), coupled with the ensuing environmental benefits of reduced traffic congestion and lower carbon dioxide emissions, will continue to drive the popularity of initiatives encouraging active commuting to and from school.

While AT was associated with higher weekday step counts overall, the strength of the association varied according to school year group and ethnicity. For example, while we would expect AT to and from school to increase population steps anywhere from 0.3% to 28.7% in girls above year 4 (allowing for differences in SES and ethnicity), for younger girls the true benefit of AT is less clear, ranging from -15.0% to 18.0%. The trend towards a stronger rela-

tionship between step counts and AT with increasing school year may reflect older girls walking further to/from school than younger girls, either because of greater distances to commute or less parental restrictions on distances travelled by AT. Similarly, our results suggest that AT would be associated with positive changes to weekday steps for Maori and European girls, with more variable outcomes for Pacific Island, East Asian, and South Asian girls. Such findings highlight the importance of assessing activity behaviour within demographic subgroups, and suggest that tailoring AT initiatives to the groups likely to experience the greatest benefits may be worthwhile. However, it should be noted that the 95% confidence intervals for the change in steps with AT were relatively wide in most instances. Thus, AT may be advantageous even in groups that showed no significant associations with weekday steps.

It has previously been hypothesised that AT in children may potentiate physical activity participation. Cooper *et al.*[21] reported that AT was associated with elevated physical activity throughout the school day in boys. Conversely, it is possible that active children are more likely to walk to/from school than inactive children, and that AT is an indicator rather than a cause of higher activity levels. The cross-sectional design of our study precludes establishment of the causative effects of behavioural variables such as AT. However, the lack of significant step count differences between AT groups on weekends (non-AT days) would suggest that overall activity levels have little or no influence on AT participation, and that any extra weekday physical activity as a result of AT does not persist into the weekend. Clearly, more study is needed to realise the potential downstream benefits of school-related AT.

It should be noted that potential predictors of AT participation (such as distance from school, seasonal variation, availability of motorised transport, and parental employment obligations etc) were not examined. Adjustment for differences in the distance from school, in particular, may offset the observed variation in the association between AT and physical activity across ethnic and school year groups (or reveal significant variation across SES groups). In addition, the applicability of the present results to children in other countries is uncertain. Identifying the potential differences in cultural or societal influences on physical activity behaviour between populations requires further study.

Conclusion
In summary, this study provides the first investigation of weekday and weekend step counts in female children and adolescents. The low number of steps accumulated on weekends suggests that physical activity promotion in the home environment is a priority. Furthermore, the low

physical activity levels of older school girls warrant attention, as do those of South Asian girls. AT to and from school appears to be an effective approach for increasing weekday step counts in girls, although the activity benefits for young girls and Asian ethnic groups are unclear. Together, these findings highlight the importance of assessing activity behaviour across a range of demographic groups, and provide impetus for tailoring initiatives to the groups most likely to benefit.

Abbreviations
ANOVA: Analysis of variance;

AT: Active transport;

SES: Socioeconomic status;

MDM: Multiday memory.

Competing interests
The author(s) declare that they have no competing interests.

Authors' contributions
All authors were involved in the conception and design of the study. EKD and JSD were responsible for data collection and statistical analyses. All authors contributed to writing and approved the final manuscript.

Acknowledgements

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Appendix B: Ethics Approval (BIA Validation Study)

MEMORANDUM

Academic Services

To:	Elaine Rush
From:	**Madeline Banda**
Date:	15 October 2004
Subject:	04/189 Validation of bioelectrical impedance measurements for the assessment of body composition in New Zealand Chinese and Indian children aged 5-15 years

Dear Elaine

Thank you for providing clarification and/or amendment of your ethics application as requested by AUTEC.

Your application is approved for a period of two years until 15 October 2006.

You are required to submit the following to AUTEC:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in <u>all</u> correspondence and telephone queries.

Yours sincerely

Madeline Banda
Executive Secretary
AUTEC
Cc: Elizabeth Duncan

From the desk of …	Private Bag 92006, Auckland 1020	Tel: 64 9 917 9999
Madeline Banda	New Zealand	ext 8044
Academic Services	E–mail: madeline.banda@aut.ac.nz	Fax: 64 9 917 9812
Student Services		

Appendix C: Information Sheet (BIA Validation Study)

A Study of the Body Size & Shape of New Zealand School Children

Any questions?

If you have any questions about this study please feel free to call us at AUT

Elizabeth Duncan 917 9999 ext 7848
Dr Elaine Rush 917 9999 ext 8091

Concerns regarding the ethical conduct of this research should be directed to Madeline Banda, Executive Secretary, AUTEC, Ph: 917 9999 ext 8044 E-mail: madeline.banda@aut.ac.nz.

Information Sheet

Your child is invited to take part in a study about children's body shape and size being conducted at Mt Roskill Primary School, Mt Roskill Intermediate School, and Mt Roskill Grammar School by the Auckland University of Technology (AUT). This study will form an important part of a doctoral research project.

This study has been approved by the AUT Ethics Committee on 11/10/04, Approval Number 04/189.

Why are we doing this study?

Very little is known about the size and shape of young New Zealanders, especially those from Asian ethnic groups. The main aim of this study is to collect information on the body size and composition of Chinese and Indian children aged 5-15 years.

By allowing your child to participate in this study you will help us develop appropriate measures of body size for young people living in New Zealand.

Who is in this study?

Two groups of children will be studied: Indian and Chinese.

The study is being carried out with a number of schools and community centres in the Auckland region.

What is involved in the study?

If you allow your child to take part in this study, researchers from AUT will visit at school to make some body composition measurements. We will also ask you to complete a few questions about your child's age and ethnic background.

Height, weight, waist and hip circumferences will be measured. Body water will also be measured using two techniques:

- The first involves a small, battery-powered instrument that is attached to special stickers on the wrist and ankle. Your child will not feel anything during this procedure.
- For the second technique, your child will be given a specially prepared drink at the start of the school day that contains water purified to increase the concentration of deuterium (a stable isotope of hydrogen found naturally in water). This drink tastes just like normal water. Female researchers will then ask participants for two small urine samples (one just before having the drink, and one towards the end of the school day). These urine samples will be sent to Dunedin for analysis and then disposed of appropriately. From these measurements of body water, lean muscle and fat mass can be calculated.

All techniques have been used many times in children, and will not harm your child at all.

Does your child have to take part in this study?

Your child's participation is voluntary. If you do allow your child to participate you are free to withdraw them at any time without affecting your relations with your school or AUT.

It will not cost you anything to take part in this study.

What will happen to the results?

You will receive a personalised feedback sheet with your child's body composition measurements, averaged results from the school, and an explanation of what these all mean.

The information collected will be kept completely confidential. No information that could identify your child will be used in any reports on this study. Each participant will be assigned a code number and the results will be stored according this code on a computer at AUT. The parent questionnaires will be stored in a locked file.

Appendix D: Consent Form (BIA Validation Study)

Consent Form

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Children's Body Size & Shape Study

Project Team: Elizabeth Duncan, Amy Flower, Dr Elaine Rush,

<u>**Statement of Consent**</u>

- I have read and understood the information provided about this research project.
- I have had the opportunity to ask questions and to have them answered.
- I understand that I may withdraw my child from the study at any time without being disadvantaged in any way.
- I give consent to for my child to participate in this study.
- I give consent for the confidential information collected in this study to be used by AUT for research purposes, with the understanding that my child will remain anonymous.

_____
Name of Child

_____
Name of Parent or Primary Caregiver

_____
Signature of Child

_____
Signature of Parent or Primary Caregiver

_____
Date

_____
Date

Please put the completed consent form in the envelope provided & return it to the school office.

This study has been approved by the Auckland University of Technology Ethics Committee on 11/10/04, Approval Number 04/189.

Appendix E: Ethics Approval (Girls ABC Study)

MEMORANDUM

Academic Services

To:	Grant Schofield
From:	**Madeline Banda**
Date:	27 September 2004
Subject:	04/171 Body composition, physical activity, and dietary patterns of New Zealand adolescent girls: an ethnic comparative study

Dear Grant

Thank you for providing clarification and or amendment of your ethics application as requested by AUTEC.

Your application is approved for a period of two years until 27/09/06.

You are required to submit the following to AUTEC:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in <u>all</u> correspondence and telephone queries.

Yours sincerely

Madeline Banda
Executive Secretary
AUTEC
CC: 0315093 Elizabeth Duncan

From the desk of …	Private Bag 92006, Auckland 1020	Tel: 64 9 917 9999
Madeline Banda	New Zealand	ext 8044
Academic Services	E-mail: madeline.banda@aut.ac.nz	Fax: 64 9 917 9812
Student Services		

Appendix F: Information Sheet (Girls ABC Study)

Information Sheet

PHYSICAL ACTIVITY, EATING HABITS & BODY COMPOSITION OF NEW ZEALAND ADOLESCENT GIRLS

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project Team: Elizabeth Duncan, BTech(Hons), Grant Schofield, PhD & Elaine Rush, PhD.

You are invited to participate in a study being conducted at … by Auckland University of Technology (AUT). This study will compare physical activity levels, eating habits, and body composition of girls from New Zealand's major ethnic groups. The following pages will provide you with an outline of the study. Please discuss your involvement in this study with your parents or caregivers.

Background Information

This study will investigate health behaviours and related lifestyle factors in young people. The information you give will help us determine the best way for young New Zealanders from different ethnic groups to maintain a healthy weight, and develop better health education for young people like yourself.

Overall aim:
- To investigate associations between ethnicity, physical activity, body composition, dietary habits, and lifestyle of New Zealand adolescent girls.

Specific objectives:
- To measure the physical activity patterns of female adolescents using a step counting device (pedometer).
- To measure the dietary habits of female adolescents.
- To measure the body composition of female adolescents.
- To relate the body composition of female adolescents from New Zealand's five major ethnic groups with lifestyle factors and related health behaviours (dietary habits and physical activity patterns).
- To provide participants with an individualised report of their results.

What the Study Involves

The research team will visit participants during health class at their school (time to be arranged with the School Principal).

Participants will be asked to complete the physical and written measures listed on the following page, as well as wear a pedometer like this one

All measures will take place in a separate testing room in the school to ensure participants' privacy. Care will be taken to ensure that all measures are performed discreetly.

Information Sheet

- Wearing a Pedometer:

Participants will wear a small electronic device called a pedometer for 3 weekdays and 2 weekend days. Pedometers are about the size of a matchbox, and record the number of steps taken. They are worn at the waistline throughout the day, and are completely safe. Each night participants will spend 2 minutes completing a pedometer compliance diary. At the end of the monitoring period, the research team will return to the school and collect participants' pedometers and pedometer compliance diary.

- Written Measures:

Participants will complete a short questionnaire with questions on: physical activity, lifestyle, demographics, and dietary habits. Participants will also answer a question on their stage of puberty. This involves looking at standard pictures, and writing down the number of the picture which best describes their stage of development. Please note that this does **not** require undressing. Participants' will complete this question in a separate testing station within the testing room, to ensure complete privacy.

- Physical Measures:

Includes height, weight, waist and hip size, and knee and wrist width.

We will also measure participants' body composition using a technique called bioelectrical impedance analysis. For this procedure, participants will lie down for several minutes in the testing room while a battery powered meter measures body composition through surface attachments on the wrist and ankle. This technique is completely safe, painless, and has been used many times in children and adolescents. Body measurements (weight, waist and hip size, and knee and wrist width will be performed discreetly by trained female researchers).

All the written and physical measures will take approximately 45 minutes, and will be completed during health class.

Based on the results of all these procedures, a 1-page, individualised health report will be given to each participant.

Confidentiality and Anonymity

All information that is collected will be kept private and confidential. However, you will be given access to any information we collect. Research records will be kept in a locked file; only Dr Schofield, Dr Rush, and Mrs Duncan will have access to them. In any report that is written, no material that could be used to personally identify you will be used. All information you provide will be treated confidentially and as a participant you will remain anonymous.

Voluntary Nature of the Study

Your participation in this study is entirely voluntary. Whether or not you participate will not affect your current or future relations with your School or AUT. If you decide to participate, you are free to withdraw from the study at any time without penalty.

Becoming a Participant

If you would like to participate in this study please fill in the consent form with your parents or primary caregiver and return it to your teacher.

Information Sheet

Contacts and Questions

Please feel free to contact us anytime to ask questions or voice concerns about the study. The primary researchers will be available to discuss the project with all parents/caregivers between 8:30-9:30 on _____ at _____.

Elizabeth Duncan   Grant Schofield
Division of Sport and Recreation   Division of Sport and Recreation
Faculty of Health   Faculty of Health
Auckland University of Technology   Auckland University of Technology
Ph: 64-9-917-9999 ext 7848   Ph: 64-9-917-9999 ext 7307
E-mail: elizabeth.duncan@aut.ac.nz   E-mail: grant.schofield@aut.ac.nz

Concerns regarding the conduct of this research should be directed to:

Madeline Banda
Executive Secretary
AUT Ethics Committee
Ph: 917 9999 ext 8044
Email: madeline.banda@aut.ac.nz

This study has been approved by the Auckland University of Technology Ethics Committee on _____
AUTEC Reference Number _____

Appendix G: Consent Form (Girls ABC Study)

Consent Form

AUT

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

PHYSICAL ACTIVITY, EATING HABITS & BODY COMPOSITION OF NEW ZEALAND ADOLESCENT GIRLS

Project Team: Elizabeth Duncan, BTech(Hons), Grant Schofield, PhD & Elaine Rush, PhD.

Statement of Consent

- I have read and understood the information provided about this research project.
- I have had the opportunity to ask questions and to have them answered.
- I understand that I may withdraw from the study at any time without being disadvantaged in any way.
- I give consent to be selected as a participant in this study.
- I give consent for the confidential information collected in this study to be used by AUT for research purposes, with the understanding that I will remain anonymous.

_____   _____
Name of Student   Name of Parent or Primary Caregiver

_____   _____
Signature of Student   Signature of Parent or Primary Caregiver

_____   _____
Date   Date

If you do become a participant in this study, do you wish to receive a personal report on your results?

Yes ☐
No ☐

Please put completed consent forms in the envelope provided & return to them to your school office ☺

Appendix H: Feedback Form (Girls ABC Study)

PHYSICAL ACTIVITY, EATING HABITS, & BODY COMPOSITION OF NZ GIRLS

Primary Researcher: Elizabeth Duncan

Feedback Form

Dear Rachel,

This form summarises the information we have collected about you. The school averages are also listed in the right-hand column.

The Frequently Asked Questions on the other side of this page may help if you are unsure of what this information means.

AUT Research Team

Physical Activity

Weekday 1	17066 steps
Weekday 2	15674 steps
Weekday 3	15880 steps
Weekend 1	18532 steps
Weekend 2	13708 steps

Body Composition

Weight	58.0 kg
Height	1.69 m
BMI	20.4 kg/m^2
%BF	20.2 %

Body Fat Distribution

Waist Size	71.7 cm
Hip Size	93.5 cm
WHR	0.77

Westlake Girls High School Averages

Weekday steps	10615 steps
Weekend steps	8597 steps
BMI	21.5 kg/m^2
%BF	24.7 %
WHR	0.74

Frequently Asked Questions

Q: How many steps should I be doing each day?
A: At present, there is very little information about the number of steps young people need to do each day to obtain health benefits. In adults, 10,000 steps per day appears to be a good target to improve health and lose excess weight. However, young people require a higher level of activity than adults. Overseas studies show that children tend to achieve about 12,000 to 15,000 steps per day, with boys more active than girls. This study will provide the first step count information for New Zealand adolescents.

Q: What does BMI mean?
A: BMI stands for Body Mass Index. It is a measure of how much weight you have when taking your height into account. BMI is used around the world to describe body size. However, it is considered most useful when looking at population groups as opposed to individuals, as it does not distinguish between lean and fat mass. Thus, if you have a high BMI, it does not necessarily mean that you are overweight. For example, Pacific Island and Maori people tend to have more muscle and larger bones (more lean mass) than Europeans, and may be misclassified using BMI. In contrast, Asian ethnic groups tend to have less lean mass and may also be misclassified. This is the reason we also measured your percentage body fat (see next question).

Q: What does %BF mean?
A: Percentage body fat (%BF) refers to the amount of fat you have compared with other body tissue, such as muscle and bone. Young people generally gain more fat as they age, with girls tending to have higher %BF than boys. Studies have suggested that a %BF greater than 30% for girls can be unhealthy. The best way to ensure that you maintain a healthy %BF is to be physically active and to make sure that you eat a wide range of food with lots of fruit and vegetables.

Q: What does WHR mean?
A: WHR stands for waist-to-hip ratio (waist size divided by hip size). A higher WHR means that fat tends to gather around the stomach (common in men), whereas a lower WHR means that fat tends to gather around the hips and bottom (common in women). Risk of health problems in both children and adults generally increases as WHR becomes higher, as it means more fat is located around the heart. However, specific WHR values that are healthy for young New Zealanders are not yet known.

Q: Whom can I contact if I am worried about my health?
A: The best person to advise you about your health is your local doctor.

Q: Whom can I contact for more information about physical activity and nutrition?
A: Some good sources of information include: Sport and Recreation New Zealand (www.sparc.org.nz), the Ministry of Health (www.moh.govt.nz), the National Heart Foundation (www.heartfoundation.org.nz), and the Nutrition Society of New Zealand (www.nutritionsociety.ac.nz).

Appendix I: Demographics and Lifestyle Questionnaire (Girls ABC Study)

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

PHYSICAL ACTIVITY, EATING HABITS & BODY COMPOSITION OF NZ GIRLS

This survey is about health behaviours and lifestyle. It has been developed so you can tell us about the environment you live in and what you do that may affect your health.

All answers you provide will remain completely **private** and **confidential**.

Name ....

PE Teacher .... Form Room ....

1. What is your birth date?

_____ / _____ / _____
(day/month/year)

2. Which ethnic group(s) do you belong to?

NZ European	□
NZ Maori	□
Pacific	□
Chinese	□
Indian	□
Other (please state below)	□

_____

3. Which country were you born in?

New Zealand	□
Other (please state below)	□

_____

4. If you were **not** born in New Zealand, which year did you move to New Zealand?

_____

5. What is the total number of people living at your household/property including you?

_____

6. How many parents/caregivers are living at your household?

1	□
2	□
3 or more	□

7. Are you living in a rented property?

Yes	□
No	□

8. How many rooms in your household have a TV?

None	□
1	□
2	□
3 or more	□

9. Do you have a TV in the room where you sleep?

Yes	□
No	□

10. How long do you usually spend watching TV on a school night?

0 hours	□
0-1 hour	□
1-2 hours	□
2-3 hours	□
3 or more hours	□

Please Turn Over →

11. How long do you usually spend doing homework on a school night?

0 hours ☐
0-1 hour ☐
1-2 hours ☐
2-3 hours ☐
3 or more hours ☐

12. How long do you usually spend talking on the phone or texting on a cellphone on a school night?

0 hours ☐
0-1 hour ☐
1-2 hours ☐
2-3 hours ☐
3 or more hours ☐

13. How long do you usually spend on a home computer on a school night?

0 hours ☐
0-1 hour ☐
1-2 hours ☐
2-3 hours ☐
3 or more hours ☐

14. What time do you usually:
Go to bed on a **weekday**? _____
Get up on a **weekday**? _____
Go to bed on **Saturday**? _____
Get up on **Sunday**? _____

15. How do you usually travel **to** school? *(tick one only)*

Car ☐
Bus ☐
Bicycle ☐
Walk ☐
Other *(please state)* _____

16. How do you usually travel **from** school? *(tick one only)*

Car ☐
Bus ☐
Bicycle ☐
Walk ☐
Other *(please state)* _____

17. Do your parents/caregivers have a car?

Yes ☐
No ☐

18. How many days do you play/practise sport during **school lunchtime** in a week (Mon→Fri)?

None ☐
1-2 days ☐
3-4 days ☐
Everyday ☐

19. How many days do you play/practise sport or do other exercise activities (e.g. gym) **outside of school hours** in a full week (Mon→Sun)?

None ☐
1-2 days ☐
3-4 days ☐
5 or more days ☐

20. How many days did you eat breakfast in the last full week (Mon→Sun)?

None ☐
1-2 days ☐
3-4 days ☐
5-6 days ☐
Everyday ☐

21. How many days did you eat lunch in the last full week (Mon→Sun)?

None ☐
1-2 days ☐
3-4 days ☐
5-6 days ☐
Everyday ☐

22. How many days did you buy lunch at school in the last school week (Mon→Fri)?

None ☐
1-2 days ☐
3-4 days ☐
Everyday ☐

23. How many servings of fruit do you eat each day?

> A "serving" of fruit means 1 medium piece of fruit or 2 small pieces.

I don't eat fruit	☐
Less than 1 serving	☐
2 servings	☐
3 servings	☐
4 servings	☐
5 or more servings	☐

24. How many servings of vegetables or salad do you eat each day?

> A "serving" of vegetables or salad means ½ a cup of cooked veges, or a cup of salad

I don't eat veges or salad	☐
Less than 1 serving	☐
2 servings	☐
3 servings	☐
4 servings	☐
5 or more servings	☐

25. How many times did you eat takeaways or fast food in the last full week (Mon→Sun)?

Never	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

26. How many times did you have a **non-diet** fizzy drink (e.g. Coca Cola) in the last full week (Mon→Sun)?

Never	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

27. How many times did you have a sweet drink (e.g. fruit juice, cordial, sports drink) in the last full week (Mon→Sun)?

Never	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

28. How many times did you have an energy drink (e.g. V, Red Bull) in the last full week (Mon→Sun)?

Never	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

29. How many times did you eat fries or potato chips in the last full week (Mon→Sun)?

Never	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

30. How many times did you eat biscuits, cake, sweet slices or doughnuts in the last full week (Mon→Sun)?

None	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

31. How many times did you eat chocolate or other sweets in the last full week (Mon→Sun)?

None	☐
1-2	☐
3-4	☐
5-6	☐
7-13	☐
14 or more	☐

32. Which of the following are you trying to do about your weight?

    Lose weight   □
    Gain weight   □
    Stay the same weight   □
    I am not trying to do anything
    about my weight   □

33. During the last 30 days did you **diet** to lose weight or to keep from gaining weight?

    Yes   □
    No   □

34. During the past 30 days, did you **exercise** to lose weight or to keep from gaining weight?

    Yes   □
    No   □

35. Do you consider yourself to be:

    Underweight   □
    Normal weight   □
    Overweight   □

36. Which of the following best describes your **mother's** current employment status?

    Working full time   □
    Working part time   □
    Retired   □
    Home duties   □
    Not working (but not retired) □
    Other *(please state below)*   □

_____

37. Which of the following best describes your **father's** current employment status?

    Working full time   □
    Working part time   □
    Retired   □
    Home duties   □
    Not working (but not retired) □
    Other *(please state below)*   □

38. What is your **mother's** highest qualification?

    No qualification   □
    High school qualification (at least 5th Form School Certificate)   □
    Trade Qualification   □
    Tertiary qualification (e.g. University, Polytechnic)   □
    Other *(please state)* _____   □

39. What is your **father's** highest qualification?

    No qualification   □
    High school qualification (at least 5th Form School Certificate)   □
    Trade Qualification   □
    Tertiary qualification (e.g. University, Polytechnic)   □
    Other *(please state)* _____   □

Thank you for filling out this questionnaire ☺

Appendix J: Compliance Diary (Girls ABC Study)

Code _____

Date _____

AUT PEDOMETER COMPLIANCE DIARY

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Pedometer number_____

Date pedometer returned _____

The pedometer is to be worn all day on Friday, Saturday, Sunday, Monday, Tuesday and Wednesday. Please bring it to school along with this pedometer diary on _____ and take it to _____.

It is important that you wear the pedometer at all times (except when sleeping, or when it will get wet). If for some reason you did take it off at any other time please indicate on your pedometer diary.

Please set aside several minutes each night to complete your daily pedometer diary.

Daily Pedometer Diary for Saturday

1. Did you do any of the following activities today? (tick all that apply)

    Played an after school sport   □
    Rode a bike   □
    Swimming   □
    Running   □
    Walking   □
    Other   □ *(Please state)* _____

2. Did you put the pedometer on when you got dressed this morning?
    Yes   □
    No   □

3. Did you wear the pedometer all day today?
    Yes   □
    No   □ If no, how long did you have it off? _____

Code _____

Date _____

Daily Pedometer Diary for Sunday

1. Did you do any of the following activities today? (tick all that apply)
    Played an after school sport   ☐
    Rode a bike   ☐
    Swimming   ☐
    Running   ☐
    Walking   ☐
    Gym   ☐
    Other   ☐ *(Please state)* _____

2. Did you take the pedometer off before going to bed last night?
    Yes   ☐
    No   ☐

3. Did you put the pedometer on when you got dressed this morning?
    Yes   ☐
    No   ☐

4. Did you wear the pedometer all day today?
    Yes   ☐
    No   ☐ If no, how long did you have it off? _____

Daily Pedometer Diary for Monday

1. How did you travel **to** school today?
    Walk   ☐
    Bicycle   ☐
    Bus   ☐
    Car   ☐
    Other   ☐ *(Please state)* _____

2. How did you travel **from** school today?
    Walk   ☐
    Bicycle   ☐
    Bus   ☐
    Car   ☐
    Other   ☐ *(Please state)* _____

3. Did you do any of the following activities today? (tick all that apply)
    Played an after school sport   ☐
    Rode a bike   ☐
    Swimming   ☐
    Running   ☐
    Walking   ☐
    Gym   ☐
    Other   ☐ *(Please state)* _____

4. Did you take the pedometer off before going to bed last night?
    Yes   ☐
    No   ☐

5. Did you put the pedometer on when you got dressed this morning?
    Yes   ☐
    No   ☐

6. Did you wear the pedometer all day today?
    Yes   ☐
    No   ☐ If no, how long did you have it off? _____

Code _____

Date _____

Daily Pedometer Diary for Tuesday

1. How did you travel **to** school today?
   - Walk ☐
   - Bicycle ☐
   - Bus ☐
   - Car ☐
   - Other ☐ *(Please state)* _____

2. How did you travel **from** school today?
   - Walk ☐
   - Bicycle ☐
   - Bus ☐
   - Car ☐
   - Other ☐ *(Please state)* _____

3. Did you do any of the following activities today? (tick all that apply)
   - Played an after school sport ☐
   - Rode a bike ☐
   - Swimming ☐
   - Running ☐
   - Walking ☐
   - Gym ☐
   - Other ☐ *(Please state)* _____

4. Did you take the pedometer off before going to bed last night?
   - Yes ☐
   - No ☐

5. Did you put the pedometer on when you got dressed this morning?
   - Yes ☐
   - No ☐

6. Did you wear the pedometer all day today?
   - Yes ☐
   - No ☐ If no, how long did you have it off? _____

Code _____

Date _____

Daily Pedometer Diary for Wednesday

1. How did you travel **to** school today?
   Walk   □
   Bicycle   □
   Bus   □
   Car   □
   Other   □ *(Please state)* _____

2. How did you travel **from** school today?
   Walk   □
   Bicycle   □
   Bus   □
   Car   □
   Other   □ *(Please state)* _____

3. Did you do any of the following activities today? (tick all that apply)
   Played an after school sport   □
   Rode a bike   □
   Swimming   □
   Running   □
   Walking   □
   Gym   □
   Other   □ *(Please state)* _____

4. Did you take the pedometer off before going to bed last night?
   Yes   □
   No   □

5. Did you put the pedometer on when you got dressed this morning?
   Yes   □
   No   □

6. Did you wear the pedometer all day today?
   Yes   □
   No   □ If no, how long did you have it off? _____

Appendix K: Tanner Stage Diagrams (Girls ABC Study)