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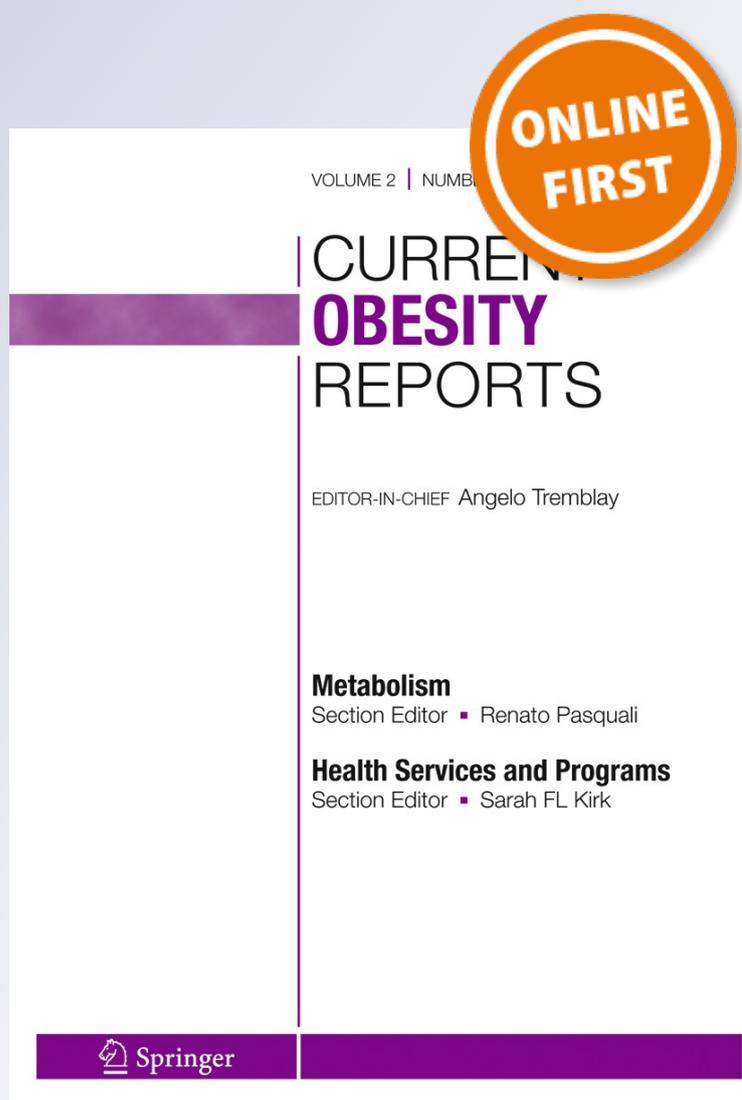
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Etiology of Obesity Over the Life Span: Ecologic and Genetic Highlights from New Zealand Cohorts

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Abstract The origins of the New Zealand population are highly diverse. New Zealand Māori are the indigenous peoples with a population of approximately half a million (~12 %), with the remainder comprising predominantly European/Caucasian (~50 %), Pacific Island Polynesian (~28 %) and Asian (~10 %) peoples. With a prevalence of overweight and obesity of 65 % for adults >15 years of age, of which 28 % have a BMI >30 kg/m², New Zealand has been ranked third highest in a global OECD obesity review, behind only the US and Mexico. Levels of childhood obesity are also significant, with 31 % of New Zealand's children either overweight or obese. Few gender differences exist, but there are significant differences between ethnicities (Asian>European Caucasian>Māori>Pacific) with disproportionate representation by those poorer and with less formal education. A high 62 % of Pacifica are obese and virtually the entire adult population has a BMI >25 kg/m². Public health measures to limit progressive increases in weight are unsuccessful, and clearly should be priority for government focused on disease prevention.

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Introduction

New Zealand is an island country which lies at a latitude of 42° South in the Pacific Ocean, with a population of only 4 million people. The origins of the population are highly diverse, but common to each is their arrival on the two main islands at stages throughout the last thousand years. New Zealand was originally part of Gondwanaland but drifted away from the main landmass before the evolution of mammals [1], and hence the primary flora and fauna of spectacular ferns, coniferous trees, and ground dwelling birdlife which evolved and flourished did so in the absence of man or other mammalian species. Māori were the first to inhabit New Zealand and as such are the indigenous peoples of the country with a population of approximately half a million people (~12 % of the total population; [2]), and in the last 100 years have been joined by significant numbers of European/Caucasian (~50 %), Asian (~10 %) and Pacific Island Polynesian (~28 %) peoples. Māori and other Polynesian populations are believed to have their origins in South East Asia (Fig. 1). Auckland, New Zealand's largest city, is by far the largest Polynesian community globally with significant immigration from islands including Samoa, Cook Islands, Tonga, and Fiji.

The healthy, outdoor lifestyle that New Zealand has long been known for, however, belies its contribution to the major global epidemic of overweight and obesity. In 2010, data from the organization for economic co-operation and development (OECD) countries report showed New Zealand to be ranked third in their between-countries comparison, with an obesity

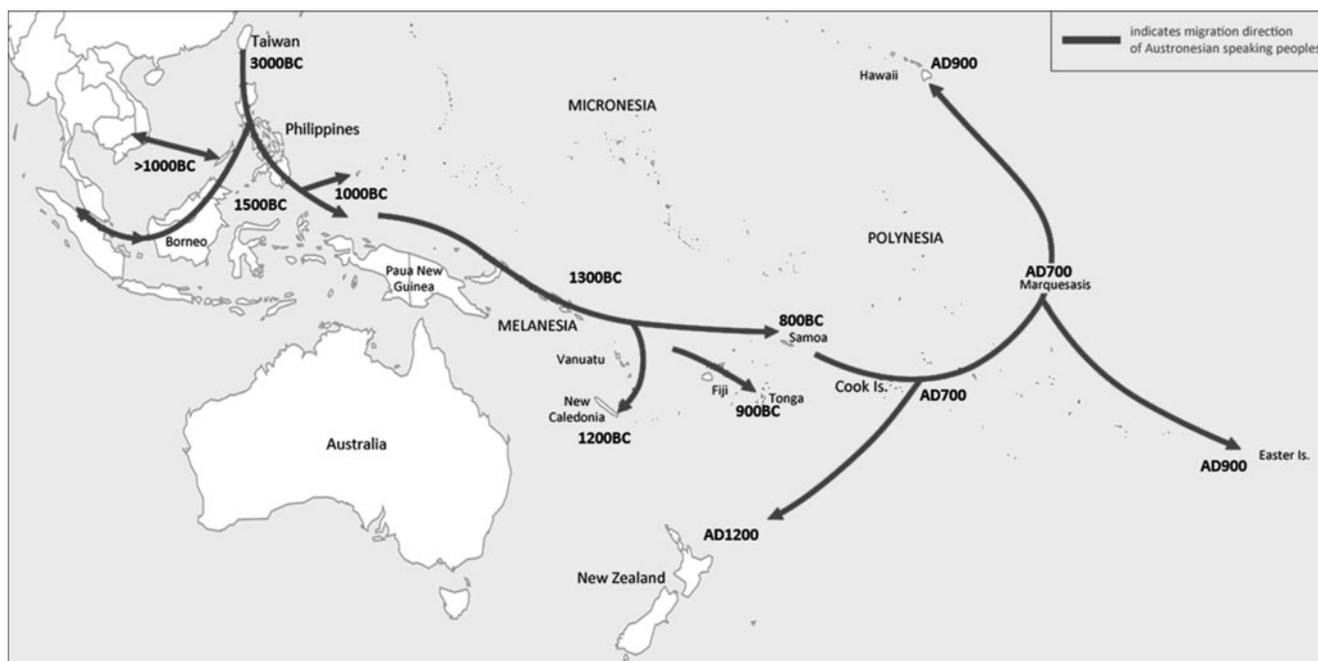


Fig. 1 Migration of Austronesian speaking people from Asia and the Pacific Islands to New Zealand. New Zealand Māori and other Polynesian populations are believed to have their origins in South East Asia [33]

(body mass index, BMI > 30 kg/m²) rate of 26.5 %, behind only the United States and Mexico [3]. This was considerably higher than the average rate of obesity within the OECD countries which is 17 %. According to the most recent New Zealand government survey conducted in 2011/12 (Fig. 2), when all adults of all ethnicities aged 15 years and above are included levels of overweight and obesity within New Zealand have now further increased to 65 %, of which 28 % are clinically obese [4••]. As with many countries obesity in New Zealand is greater in individuals who are poorer and with less formal education. The OECD relative inequality index reported overweight by education level to be 1.2, where the likelihood of overweight for an individual at the lowest end of the education spectrum is 20 % greater than an individual at the highest end [3]. In turn, this high level of obesity has significantly increased the risk of metabolic disorders [5] and the associated non communicable diseases such as type 2 diabetes (T2D) and cardiovascular disease (CVD). Current rates of T2D in New Zealand are high, with 7 % of the total population affected and almost 20 % of the population identified with some form of glucose metabolism disorder that classifies them with pre-diabetes [6].

In comparison, the island continent of Australia which is situated approximately 1500 miles to the north and commonly compared with NZ, has a larger population approaching 23 million people, and is equally ethnically diverse. Individuals predominantly of European or Asian (~10 % of the population) origin have arrived in Australia within the last 250 years, joining the indigenous population of 500,000 Australian Aboriginal peoples (~3 %) who have lived on this vast land

for more than 40,000 years. Obesity statistics are comparable across the two countries. Australia ranked 5th out of the 34 westernized countries from which OECD obesity statistics are available [3], behind US, Mexico, New Zealand, and Chile, with 24.6 % of the adult population recorded as obese. Prevalence of overweight and obesity in all adults >18 years is reported as 64 % in 2011–12 [7], comparable with that in New Zealand [4••].

Adults

The obesity rate in adults continues to increase in New Zealand. In 1997, 19 % of the population aged 15 years and above were obese. In the intervening 15 years this has climbed to 28 %, and the most recent data from the New Zealand adult health survey shows that only approximately one third of adult New Zealanders are lean (See Table 1, [4••]). The remaining two thirds are either overweight or obese, and the health service is gradually becoming overwhelmed with patients with obesity-related metabolic dysregulation and diabetes [6]. As with other countries obesity-related health costs have been spiraling [8, 9•]. Of the two thirds who are overweight/obese, there are some very revealing statistics which show significant ethnic inequalities [4••], and the origin of the obesity problem to now be in the young [10]. Interestingly there are few gender differences in rates of adult obesity [4••]. The significant differences between ethnicities have long been hypothesized to originate from factors such as genetic background, differences in food intake, and/or differences in

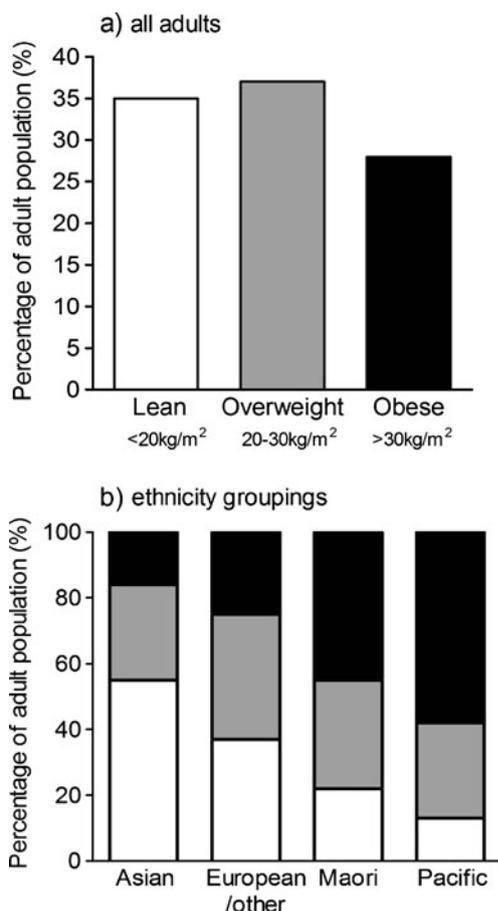


Fig. 2 Statistics from a national survey in 2011/12 show that overweight and obesity (BMI > 25 kg/m²) across the adult New Zealand population is now approaching 70 % (top panel), and that Māori and Pacific peoples have an even higher prevalence of ~80–90 % (bottom panel). Lean ; Overweight ; Obese ; (Data adapted from: NZ Ministry of Health. The Health of New Zealand adults 2011/12 - key findings of the NZ health survey. www.health.govt.nz) [4••]

Table 1 Prevalence of overweight and obesity in New Zealand adults and children in 2011/12, showing disparities between the main ethnicities [4••, 38••]

Group	% Lean		% Overweight		% Obese	
	men	women	men	women	men	women
Adults (15 yrs +)						
All	31	39	40	31	28	29
Māori	20	27	36	27	44	45
Pacific	15	15	26	20	59	64
Asian	45	58	35	24	16	16
European/other	31	40	43	33	26	26
Children (2-14 yrs)						
All	boys	girls	boys	girls	boys	girls
All	67	64	19	22	10	10
Māori	56	54	24	29	19	14
Pacific	51	46	26	30	23	24
Asian	71	72	13	16	9	5
European/other	73	69	18	20	6	7

physical activity, and to be driven by the significant country-wide differences in socio economic status (SES) [9•].

Gender

The obesity rate in New Zealand is similar in both men (28 %) and women (29 %) across the adult population [4••]. Despite this, as in many countries, interest and participation in weight loss interventions is far higher in women than men [11]. Whether women are more successful in long-term weight loss than men however is less well understood.

Ethnicity

There is a considerable literature addressing ethnic differences in BMI and body composition between populations within New Zealand. Pacific peoples and Māori have the highest rates of overweight and obesity, when classified both using conventional world health organization (WHO) BMI cut-offs [4••] and using estimates of adiposity based upon various body composition assessment methods. The Asian population in New Zealand has the lowest. Physical activity, in tandem with food intake, clearly may also be an important determinant of overweight and obesity. Interestingly, whilst the lowest levels of physical activity were reported in Pacific peoples, also the most obese group, low physical activity was also reported in the least obese group, the Asian population [4••]. Clearly the etiology of weight gain is complicated. In turn, the prevalence of adverse metabolic health in New Zealand adults also has clear ethnic disparities. In 2007, in a cohort of adults aged 35–74 years, 39 % of Pacific, 32 % of Māori and 16 % of European/others were identified to have metabolic syndrome, with either large waist circumference or high BMI accounting for most of the ethnic differences [12].

European/Caucasian

New Zealand Caucasians have similar levels of obesity (26 %) to several European countries, including the United Kingdom where obesity statistics for 2011 show 25 % of adults have a BMI > 30 kg/m² [13]. The most recent nutrition survey of 2011/12 reported that the average BMI for non-Māori, non-Pacific, non-Asian New Zealanders (European/other) was 27 kg/m². There are no government statistics within New Zealand for Caucasian ethnicity alone. Of this population of European/other, 38 % were overweight and 26 % were obese [4••].

Māori

Data from the 2011/12 nutrition survey show New Zealand Māori to have disproportionate levels of obesity. Of the adult population, 32 % are overweight and 44 % are now obese

[4••], although it is notable and of interest that this number is unchanged since an earlier survey in 2006. An important risk factor which interacts with ethnicity is SES, with disproportionate numbers of Māori being poor and with lower levels of formal education and obesity rates highest in the most deprived areas within this government survey. Clearly major lifestyle changes have occurred for Māori since the arrival of Europeans in New Zealand. The early Māori diet consisted primarily of fish and seafood, fowl, native fern root, and the cultivation of plants such as kūmara or sweet potato, taro and yam, which arrived as part of the Pacific migration. Clearly the change to today's Westernized and fast food society represents a major and relatively rapid change in dietary habits.

Pacific

Pacific people in Auckland come from Polynesian, Melanesian and Micronesian countries, represented in order of population size primarily by Samoan, Cook Island Māori, Tongan, Niuean, Fijian, and Tokelauan groups [14]. Data from the 2011/12 nutrition survey show individuals of Pacific origin to have the highest levels of obesity within New Zealand. An extraordinarily high 62 % of the adult population is obese [4••], and virtually the entire adult population (~90 %) has a BMI above 25 kg/m². After adjusting for age and gender, Pacific people are 2.5 times more likely to be obese than other New Zealanders. It has been believed that Pacific people value and therefore desire large bodies, however a study conducted in Auckland showed that Pacific adolescents and their parents did not desire obesity-sized bodies but rather a range of average-sized bodies that met their Pacific-defined view of health [15]. Irrespective of the origin, the Pacific population are greatly predisposed to T2D by their increased adiposity, with data from the most recent survey in 2006/07 showing that 10 % of Pacific peoples aged >15 years have been diagnosed with diabetes [2], 2–3 times the diagnosis rate for other New Zealanders.

Asian

Asians have the lowest proportions of overweight and obesity within New Zealand. Approximately ~45 % are overweight of which only ~16 % are obese [4••]. It is notable that this is a significantly greater proportion of the New Zealand Asian population than when previously assessed in 2002–03 when only 26 % had a BMI >25 kg/m² [2]. In terms of metabolic risk, however, this lower BMI average may under-represent the problem for this population. Recent statistics show that the New Zealand Asian population, particularly males, have a higher level of diagnosed T2D than the other ethnic groups despite lower prevalence of BMI-defined obesity [4••].

BMI as a Marker of Adiposity in New Zealand Populations

There are data to show that Asians may have a greater and Pacific people less adipose mass than other ethnicities when normalized for gender and BMI [16]. Cross-sectional analysis of body composition of a cohort of ~1000 European, Māori, Pacific Island, and Asian Indian adults in New Zealand showed that for a given body fat content, the BMI for the Asian population was 25 kg/m², for Europeans was 30 kg/m², and for Pacific Islanders 35 kg/m², respectively. Asian Indians had more total and abdominal fat, less lean body mass, skeletal muscle and bone mineral than all other ethnic groups [16]. The utility of BMI as a marker of adiposity and consequent poor health has been much debated for New Zealand Māori and Pacific populations. Earlier studies that compared the New Zealand European/Caucasian population showed that BMI overestimated percentage body fat in Māori and Pacific girls [17] and women [16, 18, 19] and Māori and Pacific boys [20] and men [21]. It has long been suggested that BMI cut-offs to define obesity should differ in persons of Polynesian descent compared with European Caucasians, a consequence of data supporting the hypothesis of a higher lean mass for a given BMI in Pacific and also Māori populations. Not all data supports this statement however. In a recent study of ~1500 participants of which two thirds were women, investigating BMI and waist circumference cut-offs in indigenous New Zealanders, perhaps surprisingly, no ethnic differences were observed [22]. The study showed that BMI and anthropometric measures of central adiposity such as waist circumference perform similarly as indicators of cardiovascular risk in both Māori and Caucasian populations, and authors argued that there is no justification for recommending higher BMI cut-offs for Māori since that would fail to identify many individuals with cardiovascular and associated risk factors [22].

Genetics of Obesity

Research into the possible genetic base of health inequalities between different ethnic groups within NZ, such as Māori and European/Caucasian populations, has been viewed by some as controversial, with both ethical and political concerns raised [23, 24]. Benefits include the obvious advantages of understanding potential genetic influences on health outcomes, whilst opponents raise possible adverse social costs, citing historical use of Darwinian concepts to explain and justify inequalities between different peoples [23]. Clearly culturally sensitive and appropriate approaches are necessary [25]. Whilst there are numbers of published studies investigating genetics of diseases such as cancer in Māori, where incidence and outcomes differ when compared with New Zealand Europeans and others [26], there is little data related to obesity or metabolic disorders such as T2D. A small study conducted more than 10 years ago investigated a candidate gene for

diabetes, the melanocortin-3 receptor gene (hMC3-R), in a family group of 12 Māori individuals with numerous members affected by morbid obesity and early onset T2D. However the results from genetic analysis of the family did not support a role for variations in this coding region in the development of T2D [27]. There is a high prevalence of T2D in Māori [6], often at an earlier age than expected [28]. Given the increased prevalence of T2D in the Māori population in New Zealand, Shand et al. carried out a study to compare plasma adiponectin levels between non-diabetic Māori and Caucasian subjects [29]. Adiponectin is an adipocytokine with insulin-sensitizing and anti-inflammatory effects [30]. Low plasma adiponectin levels are known to predispose to the development of T2D [31]. Māori people tend to have lower plasma adiponectin levels than Caucasian people of similar age, body shape, and insulin sensitivity [29].

Amylin gene mutations, known to predispose Chinese and Japanese populations to T2D, have also been shown to be associated with the disease in Māori, possibly due to the genetic origins of New Zealand Māori in South East Asia. Amylin is a hormone co-secreted with insulin from the pancreatic beta-cells and may represent an important susceptibility gene for T2D in Māori people [32]. It has been suggested that the genetics of populations with their origins in the Polynesian islands, including New Zealand Māori, has been shaped by migration events between islands which may have favored 'thrifty' genes [33]. Recent sequencing of the mitochondrial genome in a small group of 20 New Zealand Māori showed that they exhibited decreased mitochondrial genome diversity compared to other global populations, consistent with well known evolutionary bottleneck and founder effects. Global phylogenetic analysis revealed novel mitochondrial genome signatures with increased frequency of several mitochondrial coding variants, which may provide good candidates for future assessment of metabolic disease risk, including obesity-related conditions [33]. Whilst genetic studies of the Pacific populations of the Islands are relatively common, few studies of New Zealand based Pacific peoples exist. Quantitative trait loci (QTL) from a group of ~700 adults from Samoa mapped for adiposity-related phenotypes showed significant genetic correlations (0.82-0.96) between pairs of BMI, central adiposity, %body fat and the adipose peptide leptin [34]. Association of insulin-induced gene 2 (INSIG2) variants with obesity has been confirmed in several follow-up studies [35].

Children

More than 10 years ago, data from the 2002 New Zealand national children's nutrition survey (NCNS) showed that one third (31 %) of children aged 5 to 14 years were already either overweight or obese [36]. As with the adult cohorts, there was

an interaction with ethnicity such that Māori and Pacific children had increased risk. The highest prevalence of overweight/obesity was among Māori (41 %) and Pacific (62 %) children, with as many as two thirds of the latter being either overweight or obese. Being female and of lower socio-economic status (SES) were both risk factors for greater obesity, as were low physical activity and high television use, and skipping breakfast, purchasing school meals from local shops/takeaways and consuming a lot of fruit drinks/soft drinks [36]. In addition, a recent re-analysis of the 2002 NCNS has also revealed differences in adiposity between rural and urban children [37], with rural children having a significantly lower BMI, smaller waist circumference, and lower skinfold measurements. Possibly due to differences in the physical and social environment within New Zealand, the authors were unable to demonstrate significant differences in either physical activity or food intake in these young children. Some of these associations have also been seen in Project Energize, a recent study of children aged 5 or 10 years of age, investigating causes of obesity in a high Māori region of New Zealand (30 % Māori, 70 % European) [10]. A high percentage body fat was more prevalent in the older cohort, in lower school-SES, and to some extent in urban dwelling children. The recent 2012 update has shown similar numbers of children in the higher risk weight groups, with an increase particularly in obese children who now represent ~10 % of New Zealand's 2 to 14 year olds [38••]. Obesity rates are highest in Māori (17 %) and Pacific (23 %) children, and lowest in the Asian population where only ~7 % of children are obese (see Table 1).

Ethnicity

Māori

As noted above, rates of overweight and/or obesity are higher in Māori children (43 %) compared with the general population of New Zealand children (31 %) (see Table 1) [38••]. As with adults this discrepancy may in part be explained by the difference in SES between these two groups, with the New Zealand national census data having long shown that Māori are disproportionately represented in all negative socioeconomic indices [39]. In the 2002 New Zealand NCNS, Pacific and Māori children were shown to be significantly more likely to have behaviors associated with greater overweight and obesity than European or Asian children [40]. They were more likely to skip meals, to buy some/most of the food they consumed at school from the 'tuck-shop' or dairy, and to be high consumers of some fatty and sugary foods. Perhaps unexpectedly, when ethnic differences in physical activity were significant, the data showed Māori and Pacific children to be more active than age matched New Zealand European/other children [40]. Several studies have also shown that body composition and growth in Māori children

is different from New Zealand European/other children. A recent study showed that the BMI and % body fat (%BF) SD scores in cohorts of 5 and 10 year old children increased more in Māori children than in European children when measured over a 2 year period. The prevalence of overweight and obesity also increased within both ethnicities and age groups [41•].

Pacific

In 2002, the NCNS showed that levels of overweight and obesity in New Zealand Pacific children were the highest within New Zealand, at ~60 % [36]. The Pacific Island Families (PIF) study, conducted over the past 10 years within a cohort of Auckland residents showed ~70 % of Pacific children to be overweight or obese [42•]. In PIF ~1100 girls and boys were assessed longitudinally at 2, 4, 6, and 9 years of age and compared to WHO (2–5 years) and Centers for Disease Control (CDC, 5–10 years) growth curves using BMI 85th and 95th centiles as cut points [42•], and showed that the percentage of children whose weight and height were above the reference 50th growth centile also increased with age. The most recent and arguably most comprehensive survey conducted in 2011/12 has reported ~50 % of all Pacific children to be overweight and/or obese [38••] (see Table 1).

Asian

New Zealand Asian children have been shown to have a similar prevalence of overweight and obesity to European/other children, lower than either their Māori or Pacific classmates [43] and this was confirmed in the 2011/12 cohort [38••] (see Table 1). Only 7 % of Asian children are obese. Clear evidence from the adult population however shows that adipose gain in New Zealand Asians disproportionately increases their risk of obesity-driven diseases such as T2D, hence metabolic risk in these children may well be increased and greater than anthropometric indices predict.

Genetics of Obesity

There are few studies investigating genetic origins of obesity within the New Zealand population, particularly within pediatric populations. In ~500 New Zealand infants, the Auckland Birthweight Collaborative (ABC) study investigated variation in genes previously shown to be associated with obesity and/or diabetes in babies who suffered intrauterine growth retardation (IUGR) and hence born small for gestational age (SGA). These infants have long been shown to be at increased risk of rapid weight gain in infancy, obesity in later life and metabolic diseases such as diabetes in adulthood. The study showed that of 54 SNPs investigated, several of these genes were more prevalent in IUGR infants compared to those born at appropriate weight for gestational age (AGA) [44]. Whilst

the ABC study recruited 1714 mothers, only those of European/other ethnicity were included in this genetic analysis which occurred when the children were 11 years of age. Conversely, a recent update of this trial showed genetic risk variants to be less important in influencing early childhood BMI in those born SGA than in those born AGA, indicating at least in this New Zealand cohort, that environmental factors may be more important in influencing childhood BMI in those born SGA [45].

Conclusions

Overweight and obesity are continuing to rise in both New Zealand adults and children, with the most recent government statistics showing that 65 % of adults and 31 % of children overweight or obese in 2012. New Zealand is a multi-ethnic society and prevalence is greater in Māori and Pacific populations, which may be a consequence of these communities being disproportionately represented by individuals who are poorer and with less formal education than other ethnicities within the country. Pacific peoples, both within and outside New Zealand, have some of the highest prevalence figures for overweight/obesity globally and contribute to New Zealand's high ranking in International obesity datasets such as those released through the OECD. National public health measures which have attempted to ameliorate the progressive rise in weight gain across the New Zealand population have been almost universally unsuccessful, and clearly should be a priority target for government funding with focus on disease prevention.

Compliance with Ethics Guidelines

Conflict of Interest SD Poppitt holds the Fonterra Chair in Human Nutrition.

MP Silvestre declares that she has no conflict of interest.
A Liu declares that she has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of importance
- Of major importance

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