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Associations between body mass index and body composition among Pacific adolescents in Aotearoa New Zealand

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Abstract

BMI and BMI z-scores are widely used to classify adolescent overweight and obesity (OWOB), but they do not distinguish fat from fat-free mass and may misclassify adiposity. This study aimed to examine how BMI and BMI z-scores relate to body composition among Pacific adolescents in Aotearoa New Zealand (A-NZ). Cross-sectional data from a A-NZ Pacific birth cohort were analysed, assessing body size, body composition, and demographics in 871 adolescents (median age 14.2 years).

Body composition was estimated using conventional and vector bioelectrical impedance analysis. Sex-stratified analytical comparisons included fractional polynomial regression of BMI z-scores with fat mass index (FMI) and fat-free mass index (FFMI), Hattori plots, and vector analysis parameters. From BMI z-scores, OWOB was defined in 337 (80.3%) females and 342 (75.8%) males. BMI z-scores fitted FFMI well, but important nonlinear patterns emerged between BMI z-scores and FMI. At any given BMI, Pacific adolescents displayed wide variation in FMI and FFMI combinations, with greater variability among males than females. Mean vector length shortened progressively with increasing body size. Phase angle increased from normal weight to overweight but plateaued from overweight to obesity. BMI-defined OWOB inadequately captured adiposity in this population.

Keywords: Adolescent health; Pacific population; Overweight and Obesity; Body Composition; Epidemiology; Body Mass Index

Introduction

Overweight and obesity (OWOB) refers to abnormal or excess adiposity that poses health risk [1]. It is a pressing public health crisis that drives adverse health outcomes across the life course, such as cardiovascular diseases, type 2 diabetes, and cancers, jeopardising global health progress [2]. The Pacific region is particularly affected. In 2022, the Global Obesity Observatory ranked several Pacific countries and territories among the highest globally for obesity among children and adolescents aged 5-19 years, with Niue (38.3%), the Cook Islands (37.5%), Nauru (33.4%), Tonga (32.6%), and Tokelau (32.3%) ranking among the top five [3,4]. OWOB is also a particular issue in Aotearoa New Zealand (A-NZ). Among those aged 10-19 years, A-NZ OWOB prevalence of 58.6% among adolescents ranks third among the Organisation for Economic Co-operation and Development (OECD) countries [5]. From the most recent New Zealand Health Survey (2024/25 NZHS) of children aged 0-14 years, 31.5% were classified as OWOB, with rates among Pacific children being substantially higher at 53.4% [6].

Several anthropometric measurements are used to reflect adiposity, such as waist circumference, waist-to-height ratio, skinfold thickness, mid-upper-arm circumference, and body mass index (BMI) [7]. Among these, BMI [calculated as weight(kg)/height(m)^2], originally named the Quetelet Index is the most widely used epidemiological measure for evaluating overweight/obesity in populations due to its simplicity and cost-effectiveness. But BMI fails to differentiate between fat mass (FM) and fat-free mass (FFM) [8]. This distinction is important because total body weight includes both FM and FFM, and BMI cannot determine the relative contribution of each component. FM refers to the total amount of fat tissue in the body and includes all adipose tissue – both essential fat (needed for normal physiological function) and storage fat (energy reserves). FFM contains all other components in the body, such as protein, bone mineral, water and cell mineral [9]. BMI may obscure adiposity-related risk among individuals classified as normal weight and overestimate risk among some individuals classified as obese [7,8,10,11]. The Centers for Disease Control and Prevention (CDC) reported mean FFM proportions of 74.8% in males and 67.5% in females among adolescents aged 12-15 years [12]. Adolescents with similar BMI can have varied and importantly different combinations of FM and FFM by ethnicity and sex [13–15]. Thus, obesity categorised by BMI may not be an accurate indicator of health risks linked to adiposity [8]. This limitation is of particular importance for population groups with documented higher fat-free mass for a given BMI, such as Pacific populations [16,17], and with adolescence characterised by complicated changes in body composition during growth [13].

Evidence on how BMI relates to body composition in adolescents shows variable results. Some studies find BMI reliably identifies FM and FFM [18], while others suggest that BMI has limited sensitivity for detecting excess body fat [19] and is also limited in detecting FFM deficiency [20]. Research among Pacific adolescents in A-NZ is scant. Existing studies have often combined adolescents with adults and children [16], even though adolescence is a particular growth period driven by pubertal development. In addition, previous A-NZ research has provided important cross-ethnic comparisons of body fatness at a given BMI among A-NZ European, Māori, and Pacific children [16]. However, less is known about how BMI z-scores relate to height-standardised body composition indices among Pacific adolescents in A-NZ. To reduce bias due to growth and pubertal development and to harmonise growth assessment in children and adolescents, BMI-for-age z-scores are calculated by researchers using age- and sex-specific reference distributions enabling valid comparisons by age and sex. While some prior studies indicate weak relationships between BMI and body fat in Pacific populations [16], the agreement between BMI z-scores and measurements of body composition in A-NZ Pacific adolescents remains unknown.

Bioelectrical impedance analysis (BIA) is a rapid, non-invasive, convenient, and inexpensive method to assess adolescent body composition with good accuracy [21]. Conventional BIA measures resistance (R) and reactance (Xc) to estimate FM and FFM using prediction equations. While body composition has been shown to vary by ethnicity, these equations were predominantly developed using Caucasian samples [22]. Besides conventional BIA, bioelectrical impedance vector analysis (BIVA) was developed as an alternative approach for assessing body composition without relying on predictive equations [20,21]. It works by normalizing R and Xc by height and plotting them directly on the R-Xc plane, thereby eliminating the influence of assumptions about constant tissue hydration and the need for regression-based adjustments [21]. Both BIA and BIVA are commonly used practical methods for assessing body composition in adolescents [22]. However, to our knowledge, no published research has applied BIVA specifically to Pacific adolescents in A-NZ.

To address the limited Pacific adolescent-specific evidence on the relationship between BMI z-scores and body composition, this study aims to examine the agreement between BMI z-scores and body composition measured by BIA and BIVA among 14-year-old Pacific adolescents in A-NZ, stratified by sex.

Methods

Study design

This study analyses cross-sectional data nested within the Pacific Islands Families (PIF) Study; a birth cohort study tracking the health and development of a cohort of Pacific infants and their families. These infants were born at Middlemore Hospital, South Auckland, A-NZ between 15 March and 17 December 2000 and have been followed-up regularly over childhood and adolescence.

Participants

All Pacific adolescents who participated in the PIF Study’s 14-year follow-up assessment wave were eligible for inclusion. Participants missing any body size or body composition data were excluded from the analyses. At the 14-year wave, 15 twin pairs were assessed. To avoid statistical dependency, only first-borns within these multiple births were included. Multiple-birth individuals may differ from singletons in their distribution of BMI and body-composition measures [23–25]. However, first-borns were retained here because the study focused on the relationship between BMI z-scores and body-composition measurements, rather than reporting from a representative sample.

Anthropometric measurements

Weight (Tanita BC545, Tokyo) and height (Seca 213 Hamburg, Germany) of Pacific adolescents in light clothing were measured repeatedly until results fell within a predetermined tolerance [26]. The mean of the repeated measurements was used in this research. BMI (kg/m^2) was calculated as weight (kg) divided by height squared (m^2) [2]. BMI z-scores were derived from WHO age- and sex-specific growth reference charts and categorised as: underweight, z-score < -2; normal weight, -2 ≤ z-score ≤ +1; overweight, +1 < z-score ≤ +2; and obese, z-score > +2. Biologically implausible values were defined as BMI z-scores < −5 or > +5 [27].

Body Composition Assessment with BIA and BIVA

R and Xc were measured at 50 kHz using a single frequency, standing hand-to-foot bioimpedance analyser (Model BIM4, ImpediMed, Brisbane, Queensland, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). As with the body size measurements, R and Xc were repeated until they met the predetermined tolerance [26]. FM and FFM, both in kgs, were derived using the prediction equation validated previously in Pacific children [16,26]. %FM and %FFM were calculated as 100 × FM/weight and 100 × FFM/weight, respectively. Fat mass index (FMI) and fat-free mass index (FFMI) were calculated as FM and FFM divided by height squared, in kg/m^2 respectively.

Phase angle (PhA) and impedance vector length Z are raw measurements in BIA and BIVA and calculated using R and Xc by the formula: $PhA = \tan^{-1}(Xc / R) \times (180 / \pi)$ in degrees, and $|Z| = \sqrt{(R/H)^2 + (Xc/H)^2}$ in Ohm/m [28]. R/H and Xc/H were calculated from R and Xc standardised by height [29]. PhA reflects cell membrane integrity and body cell mass, and has been associated with skeletal muscle quantity and quality [29]. Therefore, PhA provides information on cellular health and soft-tissue characteristics relevant to body-composition assessment [29]. Vector length is sensitive to body fluid status, providing complementary information on hydration and soft-tissue mass; shorter vectors generally indicate greater fluid content, whereas longer vectors indicate lower fluid content [28].

Pubertal development

Pubertal status was assessed using the self-reported Pubertal Development Scale (PDS) [30]. The PDS uses a four-point scale ranging from 1 (no development) to 4 (development completed). Total scores were calculated from sex-specific items, including underarm/pubic hair growth, breast development, and menarche for females, and underarm/pubic hair growth, voice deepening, and facial hair growth for males [31]. Participants were then classified as prepubertal, early pubertal, mid-pubertal, late pubertal, or post-pubertal.

Socio-demographic variables

Age was calculated as interview date minus date of birth. Biological sex at birth and child ethnicity was reported by the mother at baseline and used for analysis. Ethnicity was assessed using separate questions for Samoan, Tongan, Cook Islands Māori, Niuean, New Zealand Pākehā, Māori, and Other Ethnicities. Participants could select more than one ethnicity.

Procedures

The PIF Study cohort was drawn from births in which at least one parent was identified as being of a Pacific ethnicity and an A-NZ permanent resident. Recruitment occurred through Middlemore Hospital’s Birthing Unit, and consent was sought to make a home visit. The first maternal home visits were conducted at approximately six weeks postpartum by trained female bilingual interviewers fluent in Pacific language(s) and English, after informed consent was obtained. With written consent, subsequent home visits occurred including at 14 years postpartum. At this 14-year measurement wave, consent to interview the children was sought from mothers. With maternal consent and the child’s written informed assent, child interviews were conducted at their school, involving a questionnaire and physical measurements. Further detailed information about the PIF Study has been described elsewhere [26].

Statistical analysis

This research was informed by the STROBE guidelines for cross-sectional studies (www.strobe-statement.org). Participant flow and sample characteristics were described first, followed by summaries of the primary study variables, including demographics, anthropometry, and body composition parameters; analyses were stratified by sex. Continuous data were presented as mean±standard deviation (SD) and compared using Student’s t-test. The distributions of key anthropometric and body composition variables were also presented within the supplementary materials (Figure S2 and S3). Categorical variables were summarised as frequency (n) and percentage (%) and compared using Fisher’s exact test.

Because an external reference population was not available, standardised scores for FMI and FFMI were calculated within this dataset. These scores were based on the empirical distributions, stratified by sex, and used in analyses involving BMI z-scores, FMI, and FFMI. Exploratory scatterplots indicated nonlinear associations between BMI z-score and both FMI and FFMI. Thus agreement between BMI z-score and FMI, and between BMI z-score and FFMI was examined using fractional-polynomial regression, which flexibly captures curvature with a small number of predefined parameters. Fractional-polynomial powers were selected by the closed-test procedure, minimising overfitting. Standardised FMI and FFMI were regressed on standardised BMI z-score. Fractional-polynomial equations and scatterplots with fractional-polynomial prediction were presented to show the association numerically and visually.

Hattori plots were used to visualise FMI–FFMI combinations in relation to BMI [32,33]. FFMI was plotted against FMI, with diagonal iso-BMI reference lines representing selected constant BMI values. Because BMI can be decomposed as BMI = FMI + FFMI, these plots illustrate how different combinations of FMI and FFMI may correspond to similar BMI values. A combined plot was used to compare female and male distributions, with sex-stratified plots provided for within-sex visualisation. Fractional-polynomial regression was also used to present the FMI and FFMI relationship stratified by sex. Dispersion around the fitted line was summarised using the standard deviations. The Brown-Forsythe test for equality of variances was used to examine the heterogeneity in residual dispersion between sexes.

The R-Xc graph was used for semi-quantitative BIVA analysis. Impedance vector components R/H and Xc/H (Ω/m) were plotted with 95% confidence ellipses to compare subgroups by BMI z-score category. Vector length and PhA were calculated using BIVA software (available at http://www.renalgate.it/formule_calcolatori/bioimpedenza.htm). Subgroup mean vectors were compared using Hotelling's T^2 test. Separate 95% confidence ellipses were also used to depict group differences [28]. The Kruskal-Wallis test and Dunn's Test were utilised to compare the PhA and vector length across groups. Data analysis and graphical representations were performed using Stata/SE 17.0, except for the BIVA analysis which was performed using BIVA software. The BIVA method described previously was used to generate the confidence ellipses and to perform Hotelling's T^2 test. For all statistical analyses, $\alpha=0.05$ was used to determine significance.

Ethics

Ethical approval for this birth cohort was obtained from the Auckland Branch of the National Ethics Committee (ref. 99/055), the Royal New Zealand Plunket Society and the South Auckland Health Clinical Board. For the 14-year measurement wave, it was granted by the Southern Health and Disability Ethics Committee on 4 December 2013 (ref. 13/STH/159).

Results

Participants

At baseline, 1,376 mothers and 1,398 Pacific infants were recruited (including 22 twin births). Two thirds of adolescents participated in the 14-year measurement wave (.n=931; 66.6%); after excluding the second-born of twins (15 twin births) and retaining only first-borns, 916 participants were included. After excluding participants with missing data (n=45), 871 adolescents formed the analytical sample (see the participant flow in Figure S1 in the supplementary materials).

Sociodemographic, Anthropometric and Pubertal Development variables

The median age was 14.2 years (Q_1=13.9; Q_3=14.6 years), with 420 (48.2%) females. The majority of the sample were identified as being Samoan (56.9%); see Table S1.

Seven participants met the WHO criterion for biologically implausible values [27]. On audit, each had three repeated height and weight measurements with no missing data and between-occasion weight differences ≤ 0.5 kg and height differences ≤ 1 cm. These values were unlikely to be data-entry errors and thus retained in the analyses.

Using BMI categories, 125 (29.8%) females and 111 (24.6%) males were classified as overweight, and a further 212 (50.5%) females and 231 (51.2%) males were classified as obese; see Table 1. Only one (0.2%) participant was defined as ‘underweight’, and they were combined with the ‘normal’ group to avoid sparse cells and unstable estimates. Anthropometric and body composition measurements stratified by sex are shown in Table 1. For fat mass measurements (FM, %FM, FMI), females had higher average values than males ($p<0.001$). For fat-free mass measurements (FFM, %FFM, FFMI) females had lower average values than males ($p<0.001$). There was no difference between the sexes for BMI, BMI z-score, and BMI z-score categories. FMI and FFMI profiles by BMI classification, stratified by sex, were presented in Table S2.

Based on the PDS, the distribution of pubertal development category differed significantly by sex. Most females were classified as late pubertal (93.2%), while males were mainly classified as mid-pubertal (55.1%) or late pubertal (29.5%). Only a small proportion of participants were classified as prepubertal or post-pubertal.

[Table 1 here]

Relationships between BMI z-score and FMI, FFMI

Fractional polynomial regression revealed significant nonlinear relationships between BMI z-scores and FMI and FFMI. Figure 1 presents best fitted standardised BMI z-score relationships with standardised FMI for females (Figure 1a) and males (Figure 1b) and standardised FFMI for females (Figure 1c) and males (Figure 1d). The equations from these regressions appear in Table S3. Relative to the line of equality, fitted FMI mean values lie above BMI z-scores at the extremes (FMI underestimated) and below in the mid-range (FMI overestimated). However, for FFMI, the fitted relation to BMI z-score appears to be approximately linear for both sexes, with small deviations at extremes, suggesting that BMI z-score tracks FFMI more closely than FMI among Pacific adolescents.

[Figure 1 here]

FMI and FFMI combinations for BMI

Figure 2 shows FMI and FFMI among Pacific adolescents. Higher points represent greater FFMI and rightward points represent greater FMI; iso-BMI lines highlight that similar BMI can arise from different FMI–FFMI combinations. For example, at a BMI of approximately 27 kg/m², females had FMI values ranging from 7.21 kg/m² (26.7%) to 11.79 kg/m² (43.7%); and among males at a similar BMI, FMI ranged from 2.21 kg/m² (8.2%) to 7.99 kg/m² (29.6%), representing an approximately fourfold difference. The male distribution is in the upper left of the female distribution, showing higher FFMI and lower FMI levels in males than in females at given BMI z-score levels (i.e., along the iso-BMI line). The sex-stratified Hattori plots are provided in the supplementary materials as Figure S4.

[Figure 2 here]

Figure 3 displays a scatterplot of FMI and FFMI with points designated by BMI category for females and males, respectively. In both sexes, points form a diagonal band that shifts monotonically from normal weight to overweight to obese, toward higher FMI and FFMI. The male band is visibly wider (more dispersed), whereas the female band appears tighter (less dispersed). Statistical analysis supports this, with males having greater variability around the fractional polynomial fitted line than females (SD 2.94 vs. SD 2.27). The Brown-Forsythe test confirmed unequal dispersion ($p<0.001$). This indicates greater heterogeneity in the FFMI–FMI balance at comparable BMI among males (i.e., for a given overall size, males range more widely from relatively leaner to relatively fatter compared to females).

[Figure 3 here]

BIVA metrics across BMI groups

The R-Xc graph (Figure 4) showed significant differences in mean impedance vectors across BMI z-score categories in both sexes (Hotelling's T^2, $p<0.001$). Vector length differed by BMI z-score category; in both sexes, the mean vector shortened progressively from normal weight to overweight and from overweight to obese. PhA increased from normal weight to overweight in both sexes, although this increase was not statistically significant in males; from overweight to obesity, PhA was essentially unchanged. Detailed statistical results for differences in vector length and PhA across BMI z-score categories are presented in Table S4.

[Figure 4 here]

Discussion

This research identified the substantial variability between BMI z-scores and body composition parameters measured by BIA and BIVA among 14-year-old Pacific adolescents in A-NZ. The variation of FMI and FFMI combinations for a given BMI was similar to the evidence found in United States of America (USA) children and adolescents across different ethnic groups [13], and Chinese adolescents [14]. These results indicate possible misclassification of BMI for FMI and FFMI in adolescents, and uncertainty about the relative contributions of adiposity and fat-free composition. Further, the wider dispersion of FMI–FFMI combinations in males than in females indicates greater heterogeneity in how FM and FFM contribute to overall body size among males. This pattern was consistent with the descriptive results, which showed larger standard deviations for both FM and FFM in males than in females. However, these sex differences in variability were attenuated after FM and FFM were normalised for height to derive FMI and FFMI. Given that height also varied more among males, part of the wider variability in absolute FM and FFM may reflect differences in height. Nevertheless, the wider dispersion of FMI–FFMI combinations among males remained after height normalisation, suggesting that males may still have greater variability in their FM and FFM profiles. This pattern is consistent with evidence from a large cross-sectional study of Brazilian adolescents, which reported greater dispersion in lean mass among males than among females [34]. This finding is supported by biological evidence: males typically experience a longer pubertal period than females, characterised by greater gains in lean mass, which may contribute to greater variation in FFMI among males [35]. In this study, males were more widely distributed across pubertal stages than females, which may further support this interpretation.

Our study found that BMI z-scores tracked FFMI well among Pacific adolescents but not so for FMI, suggesting an underestimation of the FMI contribution at both low and high BMI z-scores. This pattern has been found in previous studies [36]. For example, research on Italian children aged 6-12 years found that the relationship between BMI z-score and excess adiposity (measured by percent body fat) was curvilinear: the association was weak at lower weight levels but stronger in the overweight and obese groups [36]. Conversely, a strong linear relationship between body fat and BMI index has been reported in Japanese children, especially in female adolescents [37], with BMI found to reflect changes in adiposity.

Our findings suggest that higher BMI of Pacific adolescents may, in part, reflect greater FFMI rather than excess adiposity. This is supported by previous research in A-NZ, which found that at the median BMI, Pacific children were leaner than Indian children [38]. Similarly, research in New Caledonia found that at the same BMI *z*-score, Pacific adolescents had lower percent body fat than their European counterparts [39]. On average, Pacific peoples have more muscle (a major component of FFM) and less fat than other ethnic groups of the same weight and height [16], which may explain these variations.

The current study also found sex differences. For a given BMI, Pacific adolescent males generally had higher FFMI and lower FMI than females, in agreement with other literature [15,40]. The higher FM among female adolescents may relate to the additional developmental changes and challenges due to fertility, such as menarche, the decrease of resting energy expenditure, the higher concentrations of leptin, and the development of breast tissue [15]. However, changes for males during adolescence are characterised by decreased body fat and increased height [40].

The BIVA results are consistent with the FMI findings and further indicate potential BMI-related misclassification. PhA is usually interpreted as an indicator of cellular mass/function and is positively related to muscle-related index in prior work [29]. In our data, at the lowest BMI z-scores, lower PhA together with a longer impedance vector is consistent with lower cellular lean mass and reduced conductive volume [41]. This pattern may coexist with relatively higher adiposity for size [41], aligning with the BMI z-score underestimation of FMI at this end. As BMI z-score increased, PhA increased and vectors shortened, consistent with rising FFMI [41]. At the highest BMI z-scores, vectors continued to shorten while PhA no longer increased, suggesting that additional weight gain contributed relatively more to FM than to proportional gains in cellular lean mass.

The evidence around the relationship between PhA and BMI is mixed in the existing literature. A study of Caucasian women found that PhA remained constant with increasing BMI [28]. By contrast, in a large German adolescent sample, PhA increased with increasing BMI but plateaued at a BMI of 30 kg/m², similar to our findings [42]. Evidence of sex differences in PhA among adolescents has been reported in the literature and has been attributed to greater body cell mass and higher hydration in males [43]. While a study of Brazilian adolescents found males to have higher PhA than females [43], our study did not find any sex differences in Pacific adolescents. In agreement with our study, a large study in Caucasian adolescents found no sex differences, but a difference was found in adults [42]. That study also found that change of age was the main predictor of the sex difference in phase angle for adolescents, however our study kept age constant.

In Pacific adolescents we found mean vector lengths shorten with increasing BMI z-score, consistent with existing findings [28]. We additionally found that vector length was significantly shorter in males compared to females. In contrast, a study of Brazilian adolescents reported shorter vector lengths in females than in males [43]. As shorter vector length is considered to reflect greater body water (mainly contained within FFM) and soft tissue, the shorter vectors observed in male adolescents are consistent with males generally having higher FFMI than females [9].

This research has a primary strength in that it is the first attempt to examine the relationship between BMI z-score and body composition measurements using BIA and BIVA in a large 14-year-old Pacific adolescent sample. However, there are also important limitations. First, the absence of age- and sex-matched reference standards for body composition in Pacific populations restricts absolute interpretation and limits comparability with studies that apply established references. For the same reason, BIVA tolerance ellipses specific to Pacific adolescents could not be constructed to classify participants against population-normative percentiles for tissue hydration or cellular integrity. Direct comparisons between BMI z-score categories and BIA/BIVA metrics are therefore not feasible. To mitigate these constraints, we used internally standardised metrics for regression and visualisation, and we relied on within-cohort distributions to visualise impedance vectors and phase angles to contextualize findings. We also report raw, sex-specific descriptive statistics for body composition in Table S5 to support future work. Second, the BIA prediction equation used in this study was developed in a sample of Pacific children aged 5-14 years. Because our sample was at the upper end of this age range, the BIA-derived measurements may be biased. Third, because the PIF Study cohort was recruited from South Auckland, the generalisability of these findings to Pacific adolescents in other parts of A-NZ or in other countries may be limited.

In conclusion, this research found that BMI may obscure the underlying contribution of FMI and FFMI in Pacific early adolescents, although it appears to reflect FFMI reasonably well in this ethnic group. BIA and BIVA provided more detailed information on body composition. They illustrated that at both extremes of the BMI *z*-score distribution, FMI was underestimated and that at a given BMI, female adolescents tended to have higher FMI but lower FFMI than their male counterparts. BIVA further suggested that increases in BMI z-score at the upper end of the distribution were largely driven by gains in FM. This study indicates that using BMI z-scores to define excess adiposity among Pacific adolescents, particularly at low BMI z-scores, may miss those whose FMI is high and therefore underestimate the risk of FM-related diseases, such as type 2 diabetes. Therefore, BMI is an imperfect proxy for adiposity in Pacific adolescents, particularly at BMI z-score extremes and among males. The routine inclusion of BIA and BIVA parameters rather than BMI could reduce misclassification and improve sensitivity and specificity. These measures will better characterise adiposity and improve risk stratification and developmental assessment in this population.

Author contributions

Concept and design: YD, ASH, PJS; data analysis: YD, PJS; drafting of the manuscript: YD, ASH, PJS. All authors contributed to interpretation of findings. All authors critically revised the manuscript for important intellectual content and approved the final version.

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Data availability statement

The PIF Study directorate holds the datasets used in this research. Access to these data should be applied for through the directorate (see: https://phrc.aut.ac.nz/our-research/pacific-islands-families-study).

Competing Interests Statement

The authors declare no competing interests.

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Table 1. Anthropometric, body composition, and pubertal characteristics of Pacific adolescents aged 14 years, stratified by sex. Missing data for pubertal development category were 69 and 81 for female and male.

Variables	**Female (n=420)** **Mean (± SD)**	**Male (n=451)** **Mean (± SD)**
Weight (kg)	78.4 (19.3)	81.9 (23.4)
Height (cm)[a]	165.1 (6.0)	171.6 (7.5)
BMI (kg/m^2)	28.7 (6.5)	27.6 (6.9)
BMI-Z	1.98 (1.11)	1.96 (1.28)

FM (kg)[a]	27.9 (11.1)	23.1 (13.4)
FM (%)[a]	34.5 (5.9)	26.3 (8.6)
FMI (kg/m^2)[a]	10.2 (3.9)	7.7 (4.3)
FFM (kg)[a]	50.5 (9.1)	58.9 (11.7)
FFM (%)[a]	65.6 (5.9)	73.7 (8.6)
FFMI (kg/m^2)[a]	18.5 (2.9)	19.9 (3.1)
BMI z-score categories	**n (%)**	**n (%)**
Underweight	0 (0.0)	1 (0.2)
Normal	83 (19.8)	108 (24.0)
Overweight	125 (29.8)	111 (24.6)
Obese	212 (50.5)	231 (51.2)
Pubertal development category[b]		
Prepubertal	2 (0.6)	8 (2.2)
Early pubertal	2 (0.6)	44 (11.9)
Mid-pubertal	9 (2.6)	204 (55.1))
Late pubertal	327 (93.2)	109 (29.5)
Post-pubertal	11 (3.1)	5 (1.4)

[a] $P < 0.001$ by Student’s t-test for the test of sex difference.

[b] $P < 0.001$ by Fisher’s exact test for the test of sex difference.

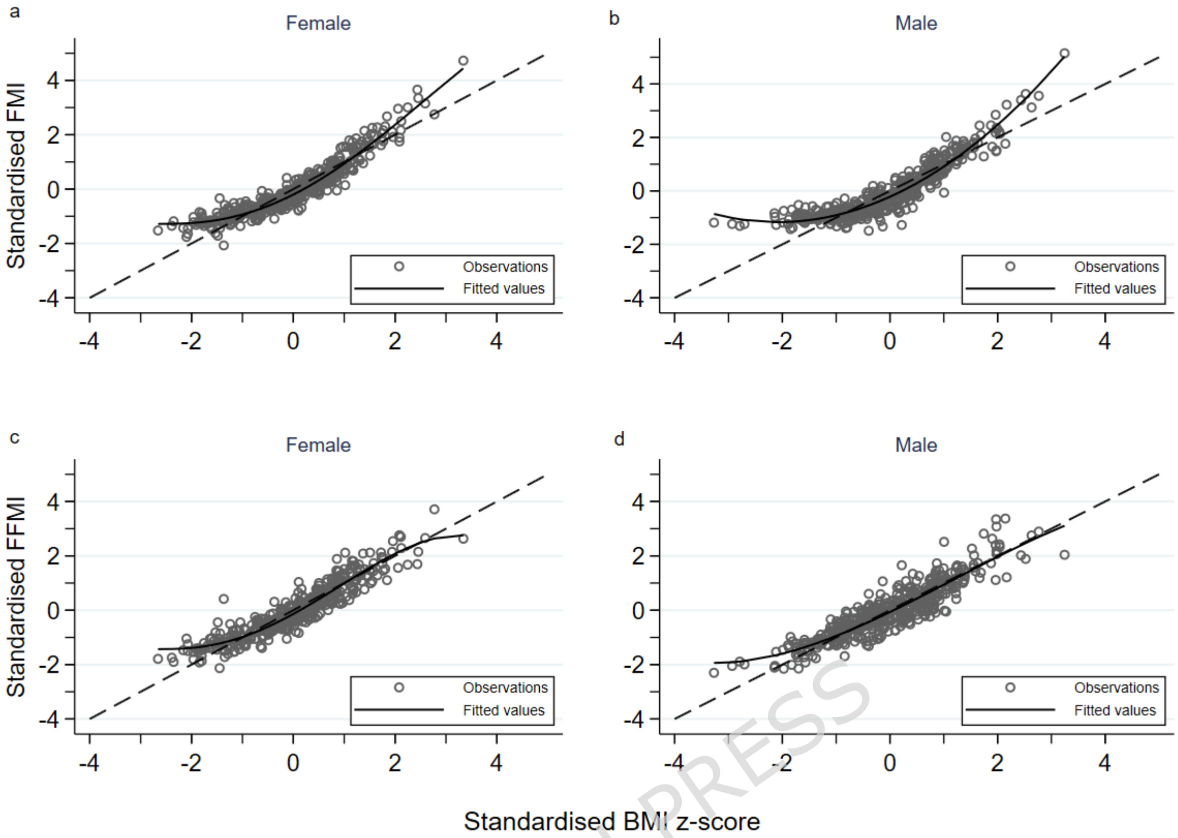

Figure 1. Relationships between standardised FMI (panel a & b) / FFMI (panel c & d) and standardised BMI z-score by sex among Pacific adolescents. Points show individual observations; the solid curve is a smoothed fit; the dashed line represents the equality level (y=x).

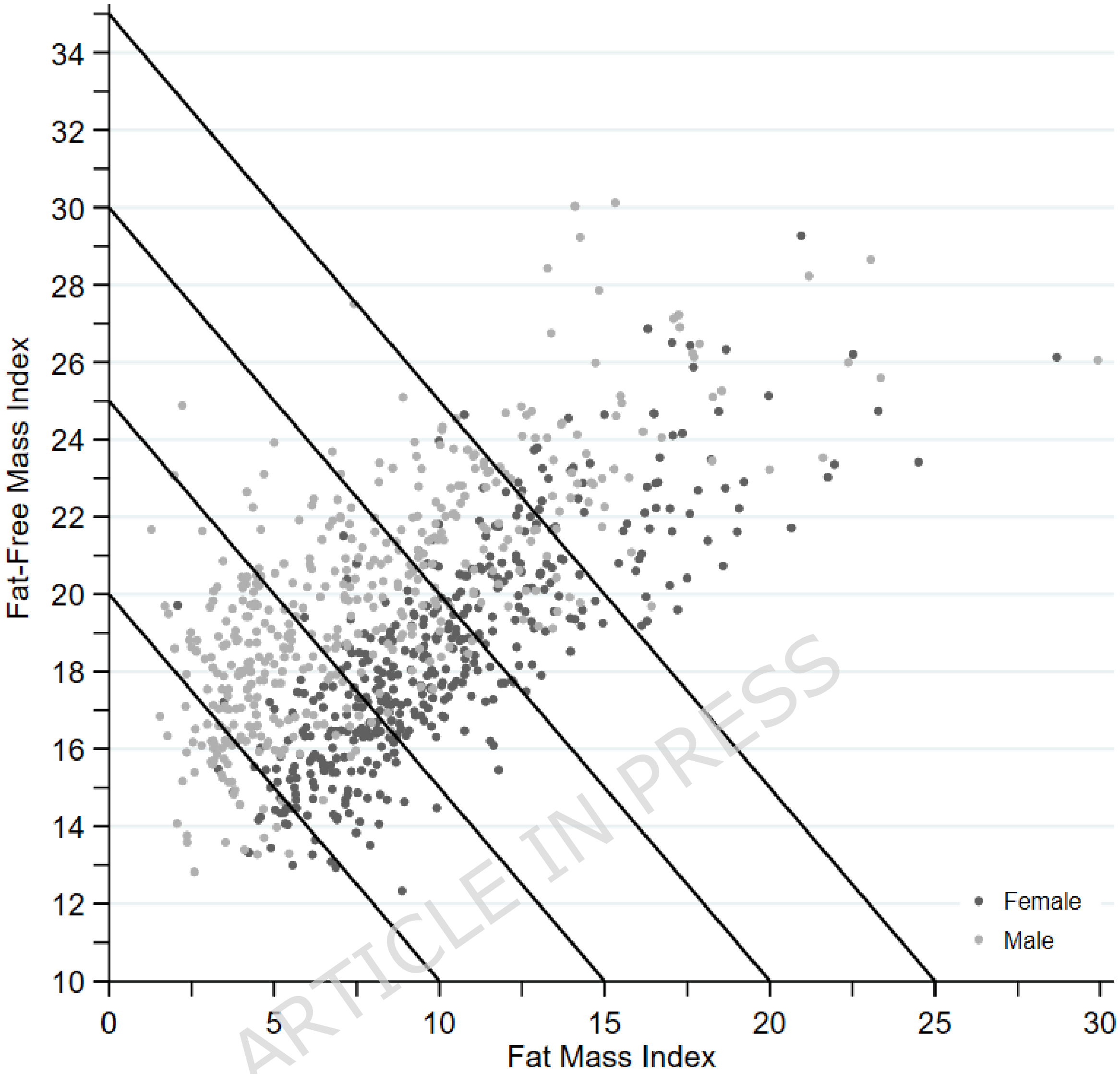

Figure 2. Hattori plot of FFMI (kg/m²) and FMI (kg/m²) among Pacific adolescents. Diagonal lines represent constant BMI values and illustrate different combinations of FMI and FFMI corresponding to similar BMI values.

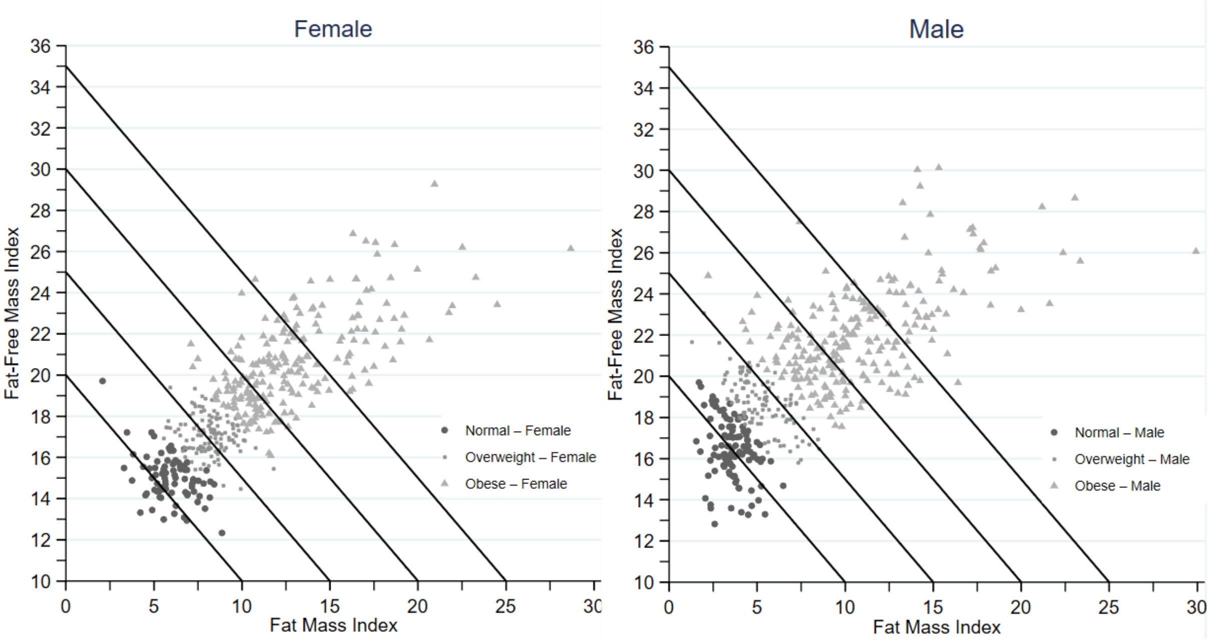

Figure 3. Hattori plot of FFMI (kg/m²) and FMI (kg/m²) among Pacific adolescents, stratified by sex. Diagonal lines represent constant BMI values and illustrate different combinations of FMI and FFMI corresponding to similar BMI values.

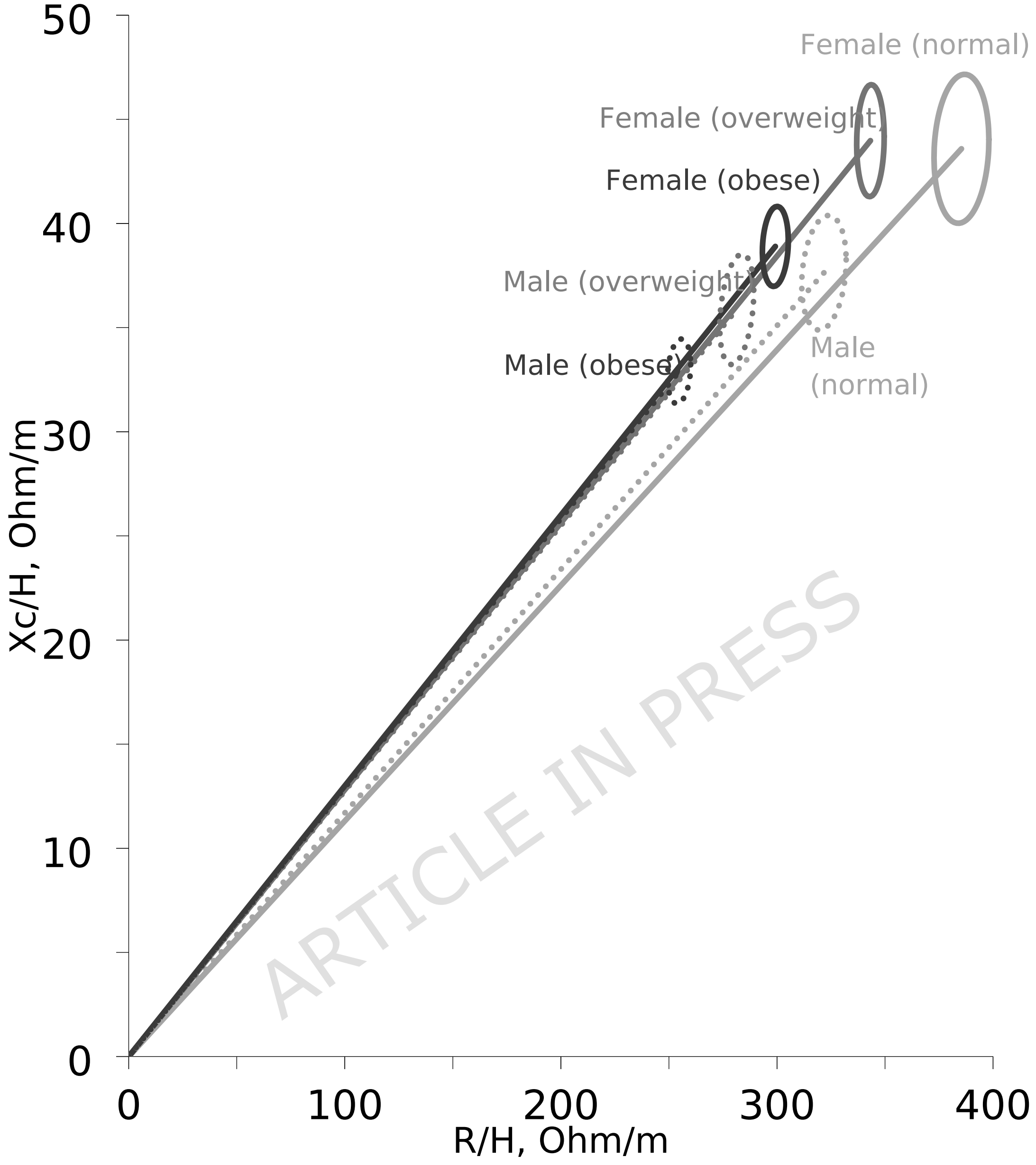

Figure 4. Mean bioimpedance vectors with 95% confidence ellipses across BMI z-score category groups by sex among Pacific adolescents. Solid vectors and ellipses represent females. Dashed vectors and ellipses represent males.