Patterns of childhood and adolescent overweight and obesity during health transition in Vanuatu

Kelsey N Dancause[1,2,*], Miguel Vilar[2,3], Chim Chan[2], Christa DeHuff[2], Michelle Wilson[2,4], Laura E Soloway[2,5], Len Tarivonda[6], Ralph Regenvanu[7], Akira Kaneko[8,9], Ralph M Garruto[2] and J Koji Lum[2]

[1]McGill University/Douglas Hospital Research Center, 6875 LaSalle Blvd., Verdun, QC, Canada, H4H 1R3: [2]Department of Anthropology, Binghamton University, Binghamton, NY, USA: [3]Department of Anthropology, University of Pennsylvania, Philadelphia, PA, USA: [4]Department of Anthropology, Henry Ford Community College, Dearborn, MI, USA: [5]New York State Department of Health, New York State Cancer Registry, Albany, NY, USA: [6]Ministry of Health, Port Vila, Republic of Vanuatu: [7]Vanuatu National Cultural Council, Port Vila, Republic of Vanuatu: [8]Island Malaria Group, Karolinska Institutet, Stockholm, Sweden: [9]Global COE, Nagasaki University, Nagasaki, Japan

Abstract

Objective: Rapid economic development and subsequent changes in lifestyle and disease burdens ('health transition') is associated with increasing prevalence of obesity among both adults and children. However, because of continued infectious diseases and undernutrition during the early stages of transition, monitoring childhood obesity has not been prioritized in many countries and the scope of the problem is unknown. Therefore we sought to characterize patterns of childhood overweight and obesity in an early transitional area, the South Pacific archipelago of Vanuatu.
Design: We completed an anthropometric survey among children from three islands with varying levels of economic development, from rural areas (where adult obesity prevalence is low) to urban areas (where adult obesity prevalence is high).
Setting: The islands of Ambae (rural), Aneityum (rural with tourism) and Efate (urban).
Subjects: Boys and girls (*n* 513) aged 6–17 years.
Results: Height-, weight- and BMI-for-age did not vary among islands, and prevalence of overweight/obesity based on BMI was low. However, girls from Aneityum – a rural island where the tourism industry increased rapidly after malaria eradication – had increased central adiposity compared with girls from the other islands. This is contrary to adult patterns, which indicate higher obesity prevalence in urban areas. Multiple factors might contribute, including stunting, biological responses after malaria control, sleeping patterns, diet and physical activity levels.
Conclusions: Measures of central adiposity highlight an emerging obesity risk among girls in Vanuatu. The data highlight the synergistic relationship among infectious diseases, undernutrition and obesity during the early stages of health transition.

Keywords
Anthropometry
Pacific
Developing countries
Child health
Chronic disease risk

Overweight and obesity are escalating globally, and at increasingly younger ages[1–3]. The obesity epidemic is particularly troubling in developing countries, where increased reliance on energy-dense, nutrient-poor foods (nutrition transition)[4], coupled with continuing infectious diseases, contribute to a dual burden of undernutrition and obesity within the same households[5–8]. The synergistic links among infectious diseases, undernutrition and overweight are manifest across the lifespan. For example, malnourished women – both underweight and obese – are at risk of delivering infants with low birth weight[9,10]. The rapid catch-up growth that small infants exhibit is a risk for obesity in adulthood[11–13]. Risk of metabolic disorders is

also increased among children of undernourished mothers, especially if the child has excess (or even adequate) energy intake later in life and thus a dietary 'mismatch' compared with the mother[14–16]. Poor infant growth also contributes to increased infectious disease risk[5], and the immune response to continued infectious diseases strains children's energy and nutrient stores. However, while infectious disease control is necessary to ensure healthy growth and development[17], it is often also associated with increasing obesity prevalence shortly thereafter[18].

This combined burden of undernutrition, infectious diseases and overweight is characteristic of the early phases of health transition, a term that encompasses the

Corresponding author: Email kelsey.dancause@douglas.mcgill.ca, kelseydancause@gmail.com

shift from infectious to chronic diseases, changing dietary and physical activity patterns, and changing attitudes and technologies related to public health[19]. During this transition, childhood obesity is often understudied because limited public health resources are directed toward infectious diseases and undernutrition. However, childhood obesity has serious health consequences and monitoring it during the early phases of health transition is necessary if we are to implement timely prevention strategies.

The health transition is progressing rapidly in the Asia-Pacific region[20,21], and the South Pacific archipelago of Vanuatu is in its early stages. Chronic disease risk varies with level of economic development on Vanuatu's sixty-eight inhabited islands. Prevalence of adult overweight/obesity is high in urban areas – 61·2 % among men and 64·7 % among women in 1998[22] – but 74 % of Vanuatu's population lives in rural areas[23], where prevalence is markedly lower (23·4 % among men, 29·1 % among women)[22]. Among adults, risk is largely associated with a shift in diet from traditional root crops, fresh meat/fish and fruits to energy-dense foods such as tinned meat/fish, polished rice, instant noodles and packaged snacks[22].

The greatest public health priority for children has been the prevalence of underweight (15·9 %) and stunting (20·1 %)[24], which results largely from a combination of childhood infectious diseases, inadequate weaning foods[25] and household food insecurity[26]. To date, few studies have described the burden of overweight and obesity among children in Vanuatu. However, in 2008 about 38 % of the country's 214 000 residents were under 15 years of age[27] and attempts to understand the current and potential future impact of overweight and obesity in Vanuatu must include analyses of this understudied group. The gradients in chronic and infectious disease risk and economic development across the archipelago make Vanuatu a good natural experimental model[28] of health transition. Studies here might provide insights that are applicable to other transitional societies in the Asia-Pacific region and globally.

We completed an anthropometric survey of children from three islands varying in degree of economic development: Ambae (rural); Aneityum (rural with tourism); and Efate, home of the urban capital. On Ambae, as in most rural areas, families subsist largely through horticulture[29], and malaria is a recurring burden during the rainy season[30]. Families on Aneityum have similar livelihoods to those on Ambae, but the island has experienced a rapid boom in the tourism industry after malaria was eradicated in 1991[31]. With the growth of the tourism industry, exposure and access to Western foods has increased, which contributes to increasing prevalence of adult obesity[32]. Finally, families on Efate have for many decades had access to benefits of urban life, such as malaria prevention programmes (e.g. residual spraying) and access to antimalarial treatments, which have contributed to low malaria transmission, but also to Western

foods and sedentary recreation such as television, which contribute to obesity[22].

Considering the rapidity with which obesity prevalence increases during health transition, the lifelong consequences of excess weight in childhood and the limited resources in many developing countries to treat chronic diseases, assessments in developing countries must begin to incorporate thorough studies of childhood overweight and obesity. Such studies might allow us to develop and implement interventions before the obesity epidemics observed in developed countries become widespread throughout the developing world.

Experimental methods

Fieldwork was completed in June and July 2007 by a team of researchers from Binghamton University's Graduate Program in Biomedical Anthropology. We sampled six villages on the three islands: Sakau and Redcliff on South Ambae; Anelcauhat, Port Patrick and Umej on Aneityum; and Erakor on Efate. On Ambae and Aneityum, anthropometric surveys were organized in collaboration with malaria screenings conducted by a team from Karolinska Institutet and the Vanuatu Ministry of Health. Most residents of sampled villages voluntarily attend these screenings. In 2007, 90 % of the participants on Ambae and 88 % on Aneityum who attended the malariometric survey chose to complete the anthropometric survey afterwards. Our sample on Efate differed because no malariometric surveys were conducted there. Rather, members of the Vanuatu Ministry of Health and the research team contacted local church leaders in the village of Erakor and presented the study details, and church leaders invited community members to attend. Surveys on all islands included both adults and children, and included behavioural analyses (such as diet and physical activity patterns), described in detail elsewhere[29].

We surveyed 375 children aged 6–12 years and 138 adolescents aged 13–17 years (Table 1). We also collected weight for 202 children aged 0–5 years and height for eighty-three children aged 3–5 years from Ambae and Aneityum. Our among-island comparisons were focused on children aged 6–12 years, but our measurements for younger children and adolescents were analysed for discussion purposes. We measured height; weight; waist circumference; and triceps, subscapular and suprailiac skinfold thicknesses. Measuring methods were according to standard accepted guidelines[33]. Standing height (without shoes) was measured using a Seca 214 portable stadiometer (Seca, Hamburg, Germany) to the nearest 0·1 cm. Weight was measured using a Tanita TBF-521 Body Composition Analyser digital scale (Tanita, Arlington Heights, IL, USA). Participants wore light (tropical weather) clothing. Weight and height measurements were used to calculate BMI (kg/m²). Each skinfold was measured in millimetres three times with Lange skinfold callipers

Table 1 Characteristics of the sample: children (*n* 715) aged 0–17 years, Vanuatu

Age (years)	Sex	Ambae (rural)	Aneityum (rural w/tourism)	Efate (urban)
0–5	Boys	37	81	–
	Girls	33	51	–
6–12	Boys	34	89	51
	Girls	39	92	70
13–17	Boys	10	53	8
	Girls	13	44	10
Total island sample size		166	410	139
		South Ambae	Aneityum	Erakor, Efate
Total population in 1999*		967	821	977

*Data from the 1999 National Census (Vanuatu National Statistics Office, 1999). Until the 2009 census analysis is complete, this represents the most complete source of data for the sampled areas.

(Cambridge, MD, USA) and the mean of the three measurements used for analyses. Waist circumference (WC) was measured twice, 2 cm above the naval to the nearest 0·1 cm, and the mean of the two measurements used for analyses. WC measurements were taken over the clothing for some girls, who wore light dresses. Waist-to-height ratio (WHTR) was calculated by dividing WC by height.

Weight-for-age (WFA), height-for-age (HFA) and BMI-for-age (BMIA) were compared with WHO references[34], which were used to define stunting (HFA <-2 SD), underweight (BMIA <-2 SD), overweight (BMIA $>+1$ SD) and obesity (BMIA $>+2$ SD). Most children and parents reported age in years as opposed to reporting date of birth. In this case, children's anthropometric measurements were compared with mid-year WHO standards/references (e.g. values for a child with reported age '7 years' were compared with WHO values for 7 years 6 months), unless a more precise age or the date of birth was provided. This introduces an error of up to 6 months for each child, but more appropriately reflects the group average. We also estimated prevalence of stunting and underweight among children aged 0–5 years following WHO standards[35], but because of the imprecision of recorded ages and the very rapid growth rates of infants and young children[36], these results must be interpreted cautiously and are included only for comparison among islands.

To analyse past early growth patterns on the sampled islands, we compiled and re-analysed data collected by the Vanuatu Ministry of Health during its 1996 National Nutrition Survey[25]. First, we calculated weight-for-age, length-for-age and weight-for-length Z-scores (WAZ, LAZ, WLZ) based on WHO standards[35] for infants up to 10 months of age. We chose 10 months because 92 % of these children were still breast-feeding, whereas 31 % of children aged 11 and 12 months had been weaned. Because risk of stunting in Vanuatu increases greatly after weaning[24], focusing on breast-feeding children might better reflect early differences in infants' growth patterns rather than stunting subsequent to breast-feeding cessation. We also analysed 1996 data following methods used in the 1983 National Nutrition Survey (for which no raw data exist). The 1983 survey report[37] includes figures for under-5 stunting, wasting and underweight defined as percentage of median of National Center for Health Statistics standards[38]. We calculated these same figures for the 1996 data set to allow comparison between surveys.

Anthropometric measurements were analysed separately for girls and boys using Microsoft® Excel 2003 (Microsoft Corporation, Redmond, WA, USA) and the SPSS statistical software package version 18·0 (SPSS Inc., Chicago, IL, USA). ANOVA was used to test mean differences among age cohorts and islands. Categorical variables were analysed using Fisher's exact probability test. Statistical significance was defined as $P < 0.05$.

Results

Mean HFA, WFA and BMIA (Table 2) and measures of body composition (WC and skinfold thicknesses; data not shown) by age did not differ significantly among islands for boys or girls. Prevalence of underweight, stunting and overweight (Table 3) also did not differ significantly among islands, although the prevalence of stunting was significantly higher among girls than boys ($P = 0.017$). Only one child was obese based on WHO criteria.

We calculated WHTR for children aged 7–12 years; we excluded 6-year-olds because the measure might overestimate risk at this age[39]. We also calculated WHTR among adolescents because, although sample sizes in this group were small, WHTR is largely independent of age[40] so figures from this group as a whole might provide some useful comparative data. Mean WHTR (Table 4) differed significantly among islands for girls ($P = 0.036$) but not boys. For both children and adolescents, girls' mean WHTR was highest on Aneityum. Furthermore, the total percentage of girls with WHTR >0.5, the cut-off associated with increased health risks[39], was higher on Aneityum than Ambae and Efate, although the among-island differences only approached statistical significance ($P = 0.065$).

Re-analyses of past data sets
Despite small sample sizes, re-analyses of data for infants from Ambae, Aneityum and Efate randomly sampled in 1996[25] indicated that mean LAZ and WLZ differed significantly among islands (Table 5). Mean values did not

Table 2 Mean weight-, height- and BMI-for-age by island: children aged 6–12 years, Vanuatu

	Ambae			Aneityum			Efate		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
Boys									
Weight									
6 years	6	20·9	2·1	12	19·5	1·8	4	21·4	1·7
7 years	5	23·2	4·0	11	22·2	2·6	6	21·8	1·6
8 years	3	24·7	2·7	11	25·5	2·2	7	24·4	1·8
9 years	5	30·0	5·3	13	26·9	2·9	7	28·3	3·8
10 years	5	29·2	5·9	13	28·4	2·7	11	29·8	4·5
11 years	5	31·8	2·1	13	30·8	4·7	9	33·6	3·9
12 years	5	38·7	5·1	16	35·3	6·7	7	33·6	4·8
Height									
6 years	6	118·2	3·6	12	112·6	4·2	4	116·2	3·9
7 years	5	120·7	5·9	11	119·6	5·2	6	118·6	4·6
8 years	3	127·7	2·4	11	125·9	6·6	7	125·3	4·0
9 years	5	133·8	4·7	13	130·3	5·9	7	131·6	6·1
10 years	5	132·4	7·8	13	132·6	3·8	11	132·8	5·6
11 years	5	138·9	6·0	13	136·0	6·9	9	140·6	4·9
12 years	5	147·1	6·4	16	141·5	6·9	7	143·9	6·6
BMI									
6 years	6	14·9	0·8	12	15·3	1·1	4	15·9	1·6
7 years	5	17·3	3·6	11	15·5	1·1	6	15·5	0·7
8 years	3	15·1	1·1	11	16·1	0·7	7	15·5	0·8
9 years	5	16·7	2·1	13	15·8	1·2	7	16·3	0·8
10 years	5	16·5	1·8	13	16·1	1·0	11	16·8	1·6
11 years	5	16·5	0·5	13	16·6	1·2	9	16·9	1·1
12 years	5	17·9	1·5	16	17·5	1·6	7	16·2	1·3
Girls									
Weight									
6 years	4	19·5	2·7	22	19·1	1·8	1	19·7	
7 years	2	20·6	3·7	11	21·9	3·7	9	24·4	3·6
8 years	7	25·0	3·5	5	22·1	3·2	4	25·9	3·0
9 years	5	26·8	2·4	10	28·0	4·4	12	27·4	4·2
10 years	8	29·0	4·6	11	29·3	3·8	16	30·9	6·2
11 years	2	31·4	1·1	18	34·2	8·6	15	32·7	3·4
12 years	11	35·1	3·6	15	40·0	7·3	13	37·8	6·6
Height									
6 years	2	106·7	11·4	22	112·7	3·8	1	112·6	
7 years	2	117·2	6·0	11	118·3	7·0	9	124·0	4·3
8 years	5	129·8	7·9	5	119·1	7·7	4	126·2	5·9
9 years	4	126·2	4·3	10	128·4	7·2	12	130·2	3·9
10 years	7	133·5	5·7	11	132·9	5·5	16	136·4	6·1
11 years	2	140·4	1·3	18	139·3	7·6	15	140·7	5·0
12 years	10	142·7	5·3	15	147·4	5·6	13	145·7	7·4
BMI									
6 years	2	15·9	1·6	22	15·0	0·8	1	15·5	
7 years	2	14·9	1·2	11	15·6	1·1	9	15·8	1·9
8 years	5	15·3	0·9	5	15·5	0·9	4	16·3	1·3
9 years	4	16·3	1·2	10	17·0	2·2	12	16·1	1·9
10 years	7	16·2	1·5	11	16·5	1·3	16	16·5	2·1
11 years	2	15·9	0·3	18	17·4	2·8	15	16·5	1·2
12 years	10	17·1	0·8	15	18·3	2·3	13	17·7	2·3

differ between rural and urban/suburban Efate, nor among Ambae, rural Efate and urban/suburban Efate. However, LAZ was notably lower and WLZ higher on Aneityum compared with the other areas. Stunting (LAZ < −2SD) was observed among 23·5 % of infants on Aneityum, compared with 6·7 % on Efate and none on Ambae.

Table 6 includes figures for under-5 underweight, stunting and wasting between 1983 and 1996 to illustrate changes over time. Prevalence of stunting remained relatively the same on Ambae, Aneityum, and rural and suburban/urban Efate, and prevalence of wasting was reduced to low levels on Aneityum and Efate but increased slightly on Ambae. Changing patterns on Aneityum are likely associated with malaria control, discussed below.

Discussion

This shifting burden of overweight and obesity from high- to low- and middle-income countries exacerbates already existing global health disparities, because developing countries also continue to suffer undernutrition and

Table 3 Prevalence (and 95 % confidence intervals) of underweight, stunting and overweight/obesity among children aged 6–12 years, Vanuatu

	Boys			Girls		
	Ambae	Aneityum	Efate	Ambae	Aneityum	Efate
Underweight						
%	7·1	1·1	2·0	0	5·4	1·4
95 % CI	2·5, 19·0	0·2, 6·0	0·4, 10·5	0, 9·6	2·3, 12·1	0·3, 7·7
Stunted						
%	3·1	10·2	4·2	17·2	18·3	10·6
95 % CI	0·6, 15·8	5·5, 18·3	1·2, 14·0	7·6, 34·6	11·0, 28·9	4·6, 22·6
Overweight/obese						
%	3·0	4·5	6·0	0	7·6	11·4
95 % CI	0·5, 15·3	1·8, 11·0	2·1, 16·2	0, 10·7	3·7, 14·9	5·9, 21·0

Table 4 Waist-to-height ratio (WHTR) among children aged 7–12 and 13–17 years, Vanuatu

	Boys			Girls		
	Ambae	Aneityum	Efate	Ambae	Aneityum	Efate
7–12 years						
Mean WHTR	0·441	0·443	0·436	0·431	0·442	0·435
SD	0·026	0·026	0·025	0·022	0·035	0·033
WHTR >0·5 (%)	0	1·3	0	0	5·8	2·9
13–17 years						
Mean WHTR	0·426	0·428	0·417	0·445	0·456	0·451
SD	0·021	0·021	0·021	0·039	0·042	0·050
WHTR >0·5 (%)	0	0	0	15·4	22·7	10·0

Table 5 Mean *Z*-scores of weight-for-age (WAZ), length-for-age (LAZ) and weight-for-length (WLZ) of children up to 10 months of age in 1996, Vanuatu

Island	n	WAZ	LAZ	WLZ
Ambae	27	0·90	0·77	0·03
Aneityum	17	0·39	−0·75	1·25
Efate, rural	20	0·79	0·27	0·35
Efate, urban/suburban	25	0·91	0·78	0·16
P value		0·775	0·028	0·033

infectious diseases[41]. In Vanuatu, malaria remains mesoendemic across most islands and health-care infrastructure is poor in many rural areas. Furthermore, while the agricultural resources of Vanuatu provide enough food for the entire population, most families are dependent on what is available seasonally and the diet might lack variety due to dependence on a few staples[42]. The continued burden of stunting on Aneityum despite malaria eradication and on Efate despite low malaria transmission indicates that other infectious diseases and chronic undernutrition continue to be a problem for young children in these communities.

However, central adiposity also appears to be an emerging problem among adolescent girls in some areas. WHTR appears to provide a more sensitive indicator of anthropometric change than height, weight and BMI, which did not reveal consistent or significant differences among islands. We observed increased central adiposity among girls on Aneityum, where malaria eradication and increased tourism have contributed to rapid and recent changes in both behavioural patterns and population health. This mirrors findings from other studies of societies in transition – girls seem to be more susceptible to increased adiposity than boys during health transition, especially as they mature[43]. The distribution of body fat during adolescence holds important implications for later health risk. Central adiposity among children aged 6–14 years is associated with increased concentrations of hormones that contribute to insulin resistance[44]. Similarly, compared with children who had normal weight and WC, overweight children with central adiposity had seven times greater risk of developing the metabolic syndrome, whereas risk was not elevated among overweight children with normal WC[45].

One contributor to increased childhood adiposity is low birth weight and stunting, a pattern studied extensively since Hales and Barker[14] proposed that fetal growth patterns can impact chronic disease susceptibility throughout life[11,46]. Low birth weight is associated with increased WC in childhood[47], and rapid weight gain in infancy[48–50] is associated with strikingly greater total and central fat stores and a greater risk of insulin resistance in childhood[51], and with adult obesity[11], central obesity[52], and elevated blood pressure, glucose and serum lipids[53]. For example, a comparison of children born small for gestational age compared with children having average birth weights indicated that although the two groups had similar body composition at birth and similar

Table 6 Prevalence of stunting, wasting and underweight of children under 5 years of age in 1983 and 1996, Vanuatu

	Stunting					Wasting					Underweight				
	1983		1996			1983		1996			1983		1996		
	%	n/N	%	n/N	Dif. (%)	%	n/N	%	n/N	Dif. (%)	%	n/N	%	n/N	Dif. (%)
Ambae	11·3	6/53	10·1	8/79	↓ 1·2	3·8	2/53	11·4	9/79	↑ 7·6	22·6	12/53	24·4	19/78	↑ 1·8
Aneityum	10·5	4/38	10·0	2/20	↓ 0·5	2·6	1/38	0	0/19	↓ 2·6	23·7	9/38	4·8	1/21	↓ 18·9
Efate, rural	8·8	5/57	9·8	4/41	↑ 1·0	17·5	10/57	2·4	1/41	↓ 15·1	31·6	18/57	14·6	6/41	↓ 17·0
Efate, suburban/urban	4·2	4/95	4·8	3/62	↑ 0·6	12·6	12/95	6·6	4/61	↓ 6·0	21·1	20/95	11·1	7/63	↓ 10·0

Dif., difference; ↓, decreased prevalence; ↑, increased prevalence.

BMI by age 3 or 4 years, children who were small at birth had higher percentage body fat and more abdominal fat than those with average birth weight[51]. A similar study indicated that infants who were stunted had a 70 % increase in odds of being overweight at age 3–5 years[54]. This is particularly problematic in transitional societies where undernutrition and continued infectious disease burdens contribute to lower weight and shorter length at birth.

Although we do not know the birth weights or lengths of the children in our sample, we do have lengths/heights and weights of children randomly sampled in the summer of 1996 as part of the Vanuatu Ministry of Health Second National Nutrition Survey[25]. The early adolescents in our sample were born during or within a few years of this survey. These data indicate that infants on Aneityum in 1996 were shorter than their rural and urban counterparts, which might represent one factor contributing to adolescent central obesity in 2007. The problem of stunting persists today; among our 2007 sample, approximately 22 % of children aged 3–5 years on Ambae and 28 % on Aneityum were stunted. Prevalence of chronic diseases in the future likely will be influenced by the health outcomes of these children with increased risk.

Between 1983 and 1996, prevalence of stunting increased across the archipelago overall[25], and remained relatively the same on Ambae, Aneityum, and rural and suburban/urban Efate. The early introduction of solid foods and subsequent diarrhoea, and nutritionally inadequate weaning foods, are major causes of stunting in Vanuatu[25]. Stunting on Ambae and Efate in 1996 followed patterns observed in the rest of the archipelago: only one stunted child was still breast-feeding, and 80 % were over 20 months of age. By contrast, all of the stunted children on Aneityum were under 12 months of age and were still breast-feeding. Prevalence of wasting, indicating acute undernutrition, increased slightly on Ambae, perhaps reflecting the disruption of services and gardening due to cyclones[42]. However, prevalence decreased across most of the archipelago[25], and was reduced to low levels on Aneityum and Efate. The decrease in wasting was also responsible for decreases in underweight across most of the archipelago[25], but rates of wasting were already very low on Aneityum, so the major contributor to reduced underweight was likely malaria eradication. These data

suggest that malaria control on Aneityum, at least in the immediately proceeding five years, translated into weight gain rather than height gain.

This emphasizes the need to closely monitor childhood overweight and obesity after infectious disease control. While others have observed that obesity increases rapidly after malaria control[18], very little research has addressed the link between malaria and obesity. Studies showing that obese mice are resistant to cerebral malaria[55] might suggest that genetic susceptibility to obesity and malaria resistance are associated, but whether and how these observations relate to human subjects is unclear. Links between puberty and malaria might also contribute to the rapid changes observed among adolescents after malaria control. Studies among Kenyan adolescents suggest that resistance to malaria increases during puberty[56,57], and the selective pressures of malaria might contribute to the younger age at puberty among adolescents with African ancestry compared with European ancestry[56]. Perhaps the increased adiposity of girls on Aneityum is related in part to an underlying adaptive response to malaria that contributes to earlier puberty or higher than normal pubertal weight gain, which becomes evident once the burden of malaria is alleviated. These are all understudied areas that warrant further attention as the health transition progresses.

Other factors that might contribute to differences in adiposity include genetic profile, sleeping patterns, and diet and physical activity patterns. In the case of genetic profile, the population of Vanuatu is mostly Melanesian, but Aneityum has higher degrees of Polynesian admixture than other islands. Polynesians are among the largest people in the world, with heavy bone and skeletal muscle mass but also high degrees of body fatness[58]. Polynesian admixture might contribute to differences among the total population of Aneityum compared with other islands; however, we compared WHTR and WC among children from areas with higher Polynesian admixture v. areas with little Polynesian admixture and observed no differences between groups.

Second, some studies have shown that decreased time spent sleeping is associated with increased childhood obesity risk, and this association might be stronger among boys than girls[59]. Where lighting allows for night-time

activities, children might sleep less than in rural areas where sleep is determined largely by sunset and sunrise[43]. We would expect this to be a more important risk factor on Efate, where power plants supply electricity to most homes, compared with Ambae and Aneityum, where electricity is available to only a handful of families with generators.

Dietary and physical activity patterns also likely contribute to differences in childhood anthropometric patterns among islands. In many studies of communities in transition, boys are more physically active than girls, who become less active particularly in adolescence[43]. Children in our sample were regularly and moderately physically active, and spent less time in sedentary recreation than children sampled nationwide[29]. On Aneityum, 91% of boys and 84% of girls played sports at least once a week, and 51% and 46%, respectively, played at least three times each week. Children on Efate played sports even more often, but also participated in more sedentary recreation, such as watching television and videos, compared with children on Ambae and Aneityum (averaging 1·4 h/d *v.* 55 min/d and 45 min/d, respectively). Based on these data, physical activity patterns differed less among islands than expected, and cannot alone explain the differences between boys and girls on Aneityum. The same is true for dietary patterns, which were very similar between boys and girls[29]. Children on Aneityum were significantly more likely to have consumed tinned fish/meat in 24 h dietary recall compared with children on Ambae, and this is associated with increased prevalence of overweight among adults[32]. However, children on Efate were as likely as those on Aneityum to consume tinned meat/fish, and they ate more packaged snack foods than children on Aneityum, but their risk for central obesity was lower.

In short, we observed increased risk of central obesity among girls in transitional areas, and of the many possible contributing factors, none alone is sufficient to explain the patterns observed. Poor early growth and biological responses after infectious disease control might represent major contributing factors; poor early growth, in particular, might predispose children to central obesity, which is manifest with only subtle changes in diet, especially after malaria control. This underscores the point that monitoring, preventing and treating obesity should be viewed as more than a 'distraction' from treating undernutrition and infectious diseases[60]. In areas where infectious diseases and undernutrition have been the major public health concerns, these also contribute over the course of the lifespan to obesity and later chronic disease risk.

Study limitations and strengths

The villages in our study are small, and our analyses are thus limited by small sample sizes, particularly when assessing anthropometric measurements for single-year age cohorts. Our findings thus require replication with larger samples. Studies focusing specifically on adolescents, among whom risk appears to be elevated in our sample, might highlight the timing of increased risk, which we lack the power to assess with our sample.

Two main strengths of the present study, including the variety of anthropometric measurements collected and sampling multiple rural villages, might guide analyses in other early transitional areas. First, collecting a variety of anthropometric measurements, including measures of central adiposity, highlighted differences that were not evident in analyses of BMI, which might not be a sensitive enough measure in early transitional areas. Second, many studies focus on rural and urban differences, which might obscure important differences between rural areas. Our analyses suggest that risk can differ markedly between rural areas even if differences in health behaviours, such as diet and physical activity patterns, are subtle. In early transitional areas, focusing on rural areas where level of economic development is just beginning to increase might better highlight the factors contributing to health transition.

Synergism of health burdens during transition

Viewing the problem of underweight, infectious diseases and obesity as synergistic can direct prevention efforts that are beneficial at multiple levels. For example, because both undernutrition and obesity[9,10] among pregnant women contribute to risky fetal growth patterns, focusing on improving nutritional status of both underweight and obese women (and not just on increasing energy intake among underweight women) might reduce overall population obesity risk through improved infant health status. This requires an increased emphasis on food quality rather than quantity[8,43]. The root crops, fresh meat and fish, and fruits that form the traditional Vanuatu diet are more nutrient-dense and less energy-dense than the polished rice, instant noodles, tinned meat/fish and packaged snacks that are replacing them. Unfortunately, traditional staples are more expensive than many imported foods[61], which are also often preferred because they are easier to prepare and store. Programmes that help to reduce the cost of traditional foods and that encourage maintaining traditional agriculture might contribute not only to decreased obesity prevalence, but to overall improved nutrient intake of the population. Where such programmes exist, they have been directed mostly towards women, but by including men and local councils of chiefs, the entire community might become involved, thus encouraging population-wide health improvements[42]. The underlying message of the synergistic effects of infectious diseases, undernutrition and obesity encourages combining efforts of health officials from multiple areas[5]. Where public health resources are limited, recognizing childhood overweight as a public health problem, one that begins early in the lifespan and one that it is intertwined with infectious diseases and undernutrition, is an important step in implementing change.

Acknowledgements

References

1. Cole TJ, Bellizzi MC, Flegal KM *et al.* (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* **320**, 1240–1243.
2. Griffiths LJ, Hawkins SS, Cole TJ *et al.* (2010) Risk factors for rapid weight gain in preschool children: findings from a UK-wide prospective study. *Int J Obes (Lond)* **34**, 624–632.
3. World Health Organization (2010) *Global Strategy on Diet, Physical Activity and Health: Overweight and Obesity*. Geneva: WHO.
4. Popkin BM (2004) The nutrition transition: an overview of world patterns of change. *Nutr Rev* **62**, 7 Pt 2, S140–S143.
5. Amuna P & Zotor FB (2008) Epidemiological and nutrition transition in developing countries: impact on human health and development. *Proc Nutr Soc* **67**, 82–90.
6. Delisle HF (2008) Poverty: the double burden of malnutrition in mothers and the intergenerational impact. *Ann N Y Acad Sci* **1136**, 172–184.
7. Khan NC & Khoi HH (2008) Double burden of malnutrition: the Vietnamese perspective. *Asia Pac J Clin Nutr* **17**, Suppl. 1, S116–S118.
8. Uauy R, Kain J, Mericq V *et al.* (2008) Nutrition, child growth, and chronic disease prevention. *Ann Med* **40**, 11–20.
9. Flick AA, Brookfield KF, de la Torre L *et al.* (2010) Excessive weight gain among obese women and pregnancy outcomes. *Am J Perinatol* **27**, 333–338.
10. Freeman DJ (2010) Effects of maternal obesity on fetal growth and body composition: implications for programming and future health. *Semin Fetal Neonatal Med* **15**, 113–118.
11. Baird J, Fisher D, Lucas P *et al.* (2005) Being big or growing fast: systematic review of size and growth in infancy and later obesity. *BMJ* **331**, 929.
12. Fisher D, Baird J, Payne L *et al.* (2006) Are infant size and growth related to burden of disease in adulthood? A systematic review of literature. *Int J Epidemiol* **35**, 1196–1210.
13. Law C (2005) Early growth and chronic disease: a public health overview. *Matern Child Nutr* **1**, 169–176.
14. Hales CN & Barker DJ (1992) Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. *Diabetologia* **35**, 595–601.
15. Lebenthal E & Bier DM (2007) Novel concepts in the developmental origins of adult health and disease. *J Nutr* **137**, 1073–1075.
16. Stocker CJ, Arch JR & Cawthorne MA (2005) Fetal origins of insulin resistance and obesity. *Proc Nutr Soc* **64**, 143–151.
17. Schaible UE & Kaufmann SH (2007) Malnutrition and infection: complex mechanisms and global impacts. *PLoS Med* **4**, e115.
18. Hung LQ, de Vries PJ, Giao PT *et al.* (2005) Nutritional status following malaria control in a Vietnamese ethnic minority commune. *Eur J Clin Nutr* **59**, 891–899.
19. World Health Organization (2010) *Programmes and Projects: Glossary of Globalization, Trade and Health Terms, Health Transition*. Geneva: WHO.
20. Baker P & Garruto R (1992) Symposium on changes in disease patterns in the Western Pacific and Southeast Asia. *Hum Biol* **64**, 84.
21. Ohtsuka R & Ulijaszek SJ (2007) *Health Change in the Asia-Pacific Region: Biocultural and Epidemiological Approaches*. Cambridge: Cambridge University Press.
22. Carlot-Tary M (2000) *1998 Vanuatu Non-communicable Disease Survey Report. SPC Technical Paper*. Noumea: Secretariat of the Pacific Community.
23. Vanuatu National Statistics Office (2009) *2009 Census Household Listing Counts*. Port Vila: Vanuatu National Statistics Office.
24. Vanuatu Ministry of Health (2008) *Monitoring the Situation of Children and Women: Vanuatu Multiple Indicator Cluster Survey 2007 Final Report*. Port Vila: Vanuatu Ministry of Health.
25. Vanuatu Ministry of Health (1998) *Report of the Second National Nutrition Survey, 1996*. Port Vila: Vanuatu Ministry of Health.
26. Renzaho AM (2006) Food insecurity, malnutrition and mortality in Maewo and Ambae Islands, Vanuatu. *Public Health Nutr* **9**, 798–807.
27. United Nations (2010) *World Statistics Pocketbook: Vanuatu*. New York: UN Publications.
28. Garruto RM, Little MA, James GD *et al.* (1999) Natural experimental models: the global search for biomedical paradigms among traditional, modernizing, and modern populations. *Proc Natl Acad Sci USA* **96**, 10536–10543.
29. Dancause KN, Dehuff C, Soloway LE *et al.* (2011) Behavioral changes associated with economic development in the South Pacific: health transition in Vanuatu. *Am J Hum Biol* **23**, 366–376.
30. Maguire JD, Bangs MJ, Brennan L *et al.* (2006) Cross-sectional characterization of malaria in Sanma and Shefa Provinces, Republic of Vanuatu: malaria control implications. *P N G Med J* **49**, 22–31.
31. Kaneko A (2010) A community-directed strategy for sustainable malaria elimination on islands: short-term MDA integrated with ITNs and robust surveillance. *Acta Trop* **114**, 177–183.
32. Dancause K (2010) Modernization and population health: A natural experimental model of health transition in Vanuatu, South Pacific. Doctoral Dissertation, Binghamton University.
33. Lohman TG, Roche AF & Martorell R (1988) *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Books.
34. World Health Organization (2010) *Growth Reference Data for 5–19 Years*. Geneva: WHO.
35. World Health Organization (2010) *WHO Child Growth Standards*. Geneva: WHO.

36. Zemel BS, Riley EM & Stallings VA (1997) Evaluation of methodology for nutritional assessment in children: anthropometry, body composition, and energy expenditure. *Annu Rev Nutr* **17**, 211–235.

37. Hung M (1983) *Republic of Vanuatu National Nutrition Survey Report*. Port Vila: Vanuatu Ministry of Health.

38. Hamill PV, Drizd TA, Johnson CL *et al.* (1979) Physical growth: National Center for Health Statistics percentiles. *Am J Clin Nutr* **32**, 607–629.

39. McCarthy HD & Ashwell M (2006) A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message – 'keep your waist circumference to less than half your height'. *Int J Obes (Lond)* **30**, 988–992.

40. Ashwell M & Hsieh SD (2005) Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *Int J Food Sci Nutr* **56**, 303–307.

41. Ezzati M, Vander Hoorn S, Lawes CM *et al.* (2005) Rethinking the 'diseases of affluence' paradigm: global patterns of nutritional risks in relation to economic development. *PLoS Med* **2**, e133.

42. UNICEF (2005) *Vanuatu: A Situation Analysis of Children, Women and Youth*. Suva: UNICEF Pacific Office.

43. Poskitt EM (2009) Countries in transition: underweight to obesity non-stop? *Ann Trop Paediatr* **29**, 1–11.

44. Aeberli I, Spinas GA, Lehmann R *et al.* (2009) Diet determines features of the metabolic syndrome in 6- to 14-year-old children. *Int J Vitam Nutr Res* **79**, 14–23.

45. Maffeis C, Banzato C & Talamini G (2008) Waist-to-height ratio, a useful index to identify high metabolic risk in overweight children. *J Pediatr* **152**, 207–213.

46. Corvalan C, Kain J, Weisstaub G *et al.* (2009) Impact of growth patterns and early diet on obesity and cardiovascular risk factors in young children from developing countries. *Proc Nutr Soc* **68**, 327–337.

47. Lemos JO, Rondo PH, Pereira JA *et al.* (2010) The relationship between birth weight and insulin resistance in childhood. *Br J Nutr* **103**, 386–392.

48. Dubois L & Girard M (2006) Early determinants of overweight at 4.5 years in a population-based longitudinal study. *Int J Obes (Lond)* **30**, 610–617.

49. Stettler N, Kumanyika SK, Katz SH *et al.* (2003) Rapid weight gain during infancy and obesity in young adulthood in a cohort of African Americans. *Am J Clin Nutr* **77**, 1374–1378.

50. Yanovski JA (2003) Rapid weight gain during infancy as a predictor of adult obesity. *Am J Clin Nutr* **77**, 1350–1351.

51. Ibanez L, Ong K, Dunger DB *et al.* (2006) Early development of adiposity and insulin resistance after catch-up weight gain in small-for-gestational-age children. *J Clin Endocrinol Metab* **91**, 2153–2158.

52. Kuh D, Hardy R, Chaturvedi N *et al.* (2002) Birth weight, childhood growth and abdominal obesity in adult life. *Int J Obes Relat Metab Disord* **26**, 40–47.

53. Stein AD, Thompson AM & Waters A (2005) Childhood growth and chronic disease: evidence from countries undergoing the nutrition transition. *Matern Child Nutr* **1**, 177–184.

54. Gewa CA (2010) Childhood overweight and obesity among Kenyan pre-school children: association with maternal and early child nutritional factors. *Public Health Nutr* **13**, 496–503.

55. Robert V, Bourgouin C, Depoix D *et al.* (2008) Malaria and obesity: obese mice are resistant to cerebral malaria. *Malar J* **7**, 81.

56. Kurtis JD, Mtalib R, Onyango FK *et al.* (2001) Human resistance to *Plasmodium falciparum* increases during puberty and is predicted by dehydroepiandrosterone sulfate levels. *Infect Immun* **69**, 123–128.

57. Leenstra T, Phillips-Howard PA, Kariuki SK *et al.* (2003) Permethrin-treated bed nets in the prevention of malaria and anemia in adolescent schoolgirls in western Kenya. *Am J Trop Med Hyg* **68**, 86–93.

58. Rush EC, Freitas I & Plank LD (2009) Body size, body composition and fat distribution: comparative analysis of European, Maori, Pacific Island and Asian Indian adults. *Br J Nutr* **102**, 632–641.

59. Bibiloni MM, Martinez E, Llull R *et al.* (2011) Metabolic syndrome in adolescents in the Balearic Islands, a Mediterranean region. *Nutr Metab Cardiovasc Dis* **21**, 446–454.

60. Miranda JJ, Kinra S, Casas JP *et al.* (2008) Non-communicable diseases in low- and middle-income countries: context, determinants and health policy. *Trop Med Int Health* **13**, 1225–1234.

61. Government of Vanuatu (2010) *Millenium Development Goals: 2010 Report for Vanuatu*. Port Vila: Government of Vanuatu.