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Article

Associations between socioeconomic resources and adiposity traits in adults: Evidence from Samoa

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ABSTRACT

In low- and middle-income countries, earlier in economic development, obesity tends to be more prevalent in high socioeconomic resource groups compared to low. Later in development, the distribution of obesity tends to show the opposite pattern, becoming more prevalent in those with low socioeconomic resources. This shift in obesity prevalence tends to occur between a gross national income per capita (GNI) of US$1,000 to $4,000 dollars. Whether a similar pattern occurs in Pacific Island countries has not been well documented. In Samoa, the GNI rose to US$3,200 dollars in 2010 at which time over 80% of adults were overweight or obese. We aimed to understand the association of socioeconomic resources, assessed by household assets, with adult body mass index (BMI) and abdominal circumference (AC) in Samoa. Data were from a genome-wide association study for obesity among 3,370 Samoans aged 24.5-<65 years in 2010. Household asset scores were calculated based on ownership of consumer durables, housing construction, and access to basic services. Sex-stratified multivariate linear regressions were used to assess adiposity trait differences by household asset ownership, after controlling for age, education, and household urbanicity. Higher asset ownership was associated with higher BMI and AC and the positive relationship remained robust after controlling for potential confounders. Despite significant economic growth preceding the year 2010 in Samoa, the obesity burden had not shifted to low socioeconomic groups in a similar way that has been observed in countries further along in the economic transition. The mechanism by which socioeconomic resources influence adiposity is complex and may be particularly complicated in Samoa by migrant remittances received both as cash and household assets. Social and physical environments may constrain the positive health behavior change necessary to reduce obesity even in the context of high socioeconomic position, a situation that requires further investigation.

1. Introduction

The high and increasing prevalence of cardiometabolic non-communicable diseases constitutes a health and socioeconomic crisis in Pacific Island countries, attributing to more than 70% of deaths and an estimated US$84 billion dollars loss in economic productivity between 2006 and 2015 (Anderson, 2013; World Bank Group, 2014). Samoa is an example of an independent Pacific Island country that continues to undergo significant economic and epidemiologic transitions. Between 1975 and 2016, mean body mass index (BMI) increased from 25.45 to 30.63 kg/m^2 among males and 27.64 to 34.34 kg/m^2 among females in Samoa (NCDRisC, 2017). Diets are becoming increasingly modernized, with an increased availability of total energy in the Samoan food system and vegetable oils now providing the largest proportion of fat in the diet (DiBello et al., 2009; Seiden, Hawley, Schulz, Raifman, & McGarvey, 2012; Sievert, Lawrence, Naika, & Baker, 2019; Wang et al., 2017). Samoa has transitioned from a lower-middle to upper-middle income country, with the total cost of health care expected to increase from US $342 to $577 dollars per person between 2015 and 2040 (IHME, 2018). In anticipation of the substantial and rising socioeconomic costs of

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obesity in this setting, integrated action and interventions are urgently needed to reduce the health and economic burden.

Globally, the burden of obesity is shifting from high to low socioeconomic groups as the overall wealth of countries increases and food systems change (McLaren, 2007; Popkin, Adair, & Ng, 2012). Consumption of low-quality and non-local industrial foods is increasing, particularly among the lower socioeconomic groups, as a consequence of their lower prices, long shelf life, and hedonic properties (Drewnowski & Specter, 2004; Popkin & Gordon-Larsen, 2004; Swinburn et al., 2019). A systematic review of studies between 1988 and 2004, which used the human development index (a composite measure of income per capita, literacy rate and life expectancy), observed that in countries with less socioeconomic development and a lower-human development index socioeconomic status was positively associated with obesity. In contrast, in high-human development index countries, inverse associations between socioeconomic status and obesity were observed, although this was seen in females, but not males (McLaren, 2007). Other published studies replicate this finding, and provide evidence that the shift in higher obesity levels from higher to lower socioeconomic groups tends to occur at an earlier stage of economic development among females than males (Dinsa, Goryakin, Fumagalli, & Suhrcke, 2012; Monteiro, Conde, Lu, & Popkin, 2004; Monteiro, Moura, Conde, & Popkin, 2004). A systematic review of studies among females between 1989 and 2003 reported that higher rates of obesity among females with low socioeconomic status (based on education, occupation, and/or income) compared to high were observed at a gross national income per capita (GNI) of about US$2,500 dollars, which is the mid-point value for lower-middle-income economies (McLaren, 2007; Monteiro, & Conde et al., 2004; Monteiro, & Moura et al., 2004). Another systematic review of studies published between 2004 and 2010 observed a similar difference in the distribution of obesity across socioeconomic groups in countries with a GNI between US$1,000 and $4,000 dollars for females, but not males (Dinsa et al., 2012).

A shift in the distribution of obesity across socioeconomic groups has not been well documented in Pacific Island countries despite rapid economic development and increasing adiposity levels (Bixby et al., 2019; NCDRisC, 2017). Cross-sectional analyses from the 1990s found inverse associations between obesity levels and household assets only among females in American Samoa when the estimated gross domestic product per capita was US$2,600 dollars (no GNI estimate available) (Ezeamama, Viali, Tuitele, & McGarvey, 2006; IndexMundi, 2018). In contrast, among men from Samoa when the GNI was US$570 dollars (World Bank Group, 2019), there were several positive associations of hypertension and obesity with education, employment and household asset ownership. In the analyses, there were notably no associations between socioeconomic factors and cardiometabolic risk factors in men from American Samoan with a more developed economy, nor females from Samoa with a less developed economy (Ezeamama et al., 2006). Using 2010 data from Samoa, as we present here, is ideal to assess how socioeconomic resources may be related to obesity 20 years later in economic development because 1) Samoa's 2010 GNI was US$3,200 dollars and this falls within the range where shifts in the obesity burden have been previously observed in other settings, and 2) adult obesity levels have changed fast and reached extremely high levels during a period of global and Pacific economic development and food system changes (Hawley et al., 2014; Hawley & McGarvey, 2015; Lin et al., 2017; NCDRisC, 2017).

While the systematic reviews described above use income as a metric for socioeconomic development, researchers in low- and middle-income countries are increasingly relying on asset-based assessments of material wealth to capture a spectrum of economic resources available to individual and households (Howe et al., 2012; Hruschka, Gerkey, & Hadley, 2015). The use of asset indices avoids issues of recall bias and mismeasurement that may occur with income (McKenzie, 2005) and is standard for estimating the long-term economic capacity of households in global surveys such as the Demographic and Health Survey (Rutstein, Johnson, & Gwatkin, 2000; Rutstein, Johnson, & MEASURE, 2004) and the World Health Survey (Üstün, Chatterji, Mechbal, & Murray, 2003, p. 797). Similar asset indicators have been previously shown to provide sensitive measures of socioeconomic resources in Samoa (Ezeamama et al., 2006; Samoa Bureau of Statistics, 2014).

The purpose of this report is to understand how socioeconomic resources are related to adult BMI and abdominal circumference (AC) in Samoa. We used an asset-based approach to assess resources based on the reported household ownership of consumer durables, housing construction and access to basic sanitation services in 2010. Considering the high burden of obesity in the highest socioeconomic group and economic growth in Samoa prior to 2010 (Ezeamama et al., 2006; World Bank Group, 2019), we hypothesized that adults with the lowest household assets would have the highest adiposity levels in 2010.

2. Materials and methods

2.1. Study location

Samoa is an upper-middle-income country with an estimated GNI per capita of US$4,160 dollars in 2018 (Samoa Bureau of Statistics, 2018; World Bank Group, 2019). It is comprised of two main islands, 'Upolu and Savai'i, and several islets, with the majority (77.8%) of the 195,979 people inhabiting the island of 'Upolu (Samoa Bureau of Statistics, 2016). The two official languages are Samoan and English, and the literacy rate is 97% (Samoa Bureau of Statistics, 2012a, 2012b, 2016).

2.2. Sample design

This study uses data from the on-going *Soifua Manuia ("Good Health")* project, which began with a 2010 genome-wide association study (GWAS) for adiposity in Samoa. The study design, sample selection, and data collection methods have been previously reported (Hawley et al., 2014). Briefly, 3,475 eligible participants (n = 1,437 males, n = 2,038 females) were recruited across the four census regions in Samoa: Savai'i (SAV), Rest of 'Upolu (ROU), Northwest 'Upolu (NWU), and the Apia Urban Area (AUA). Eligible participants were of Samoan ethnicity based on self-report of four Samoan grandparents, 24.5 to <65 years old, non-pregnant, with no severe physical or cognitive impairments that would prohibit completion of the survey measures, and willing and able to complete the interview portion of the study in Samoan. The study sample was representative of the wider Samoan population in terms of marital status, educational attainment, and access to basic household amenities, but had a greater proportion of females, residents from the more rural ROU and SAV, and older participants compared to 2011 census data (Samoa Bureau of Statistics, 2012a, 2012b).

2.3. Ethical approval and informed consent

The study was approved by the Health Research Committee of the Samoa Ministry of Health and the Brown University Institutional Review Board (Hawley et al., 2014). All participants gave written consent to a Samoan language consent form faciliatetd by Samoan research assistants.

2.4. Study sample

For the present study, adults with missing data on any variable of interest were excluded. Of the 3,475 GWAS participants, 38 were missing anthropometric measurements (height, weight, and/or abdominal circumference), and 31 were missing questionnaire information (marital status and education). There were 36 adults who had incomplete information for household consumer durable items and thus, had a missing value for the household asset score. The final analytic sample, therefore, included 3,370 adults.

2.5. Assessment of exposure

Household asset ownership was the exposure variable used to describe socioeconomic resources. Adults were asked to report the ownership of a European style house, indoor plumbing, a non-traditional stove (gas or electric as opposed to the traditional Samoa ground oven or '*umu*'), refrigerator, freezer, stereo, portable stereo, television, videocassette recorder, couch, carpet, washing machine, landline phone, and car (4-wheeled motor vehicle). Then, a summed asset score was calculated based on the ownership of the 14 consumer durables. For the ease of interpretability, we categorized the asset scores into tertiles based on score distribution: 0 to 5 (n = 975), 6 to 8 (n = 1249) and 9 to 14 (n = 1208) to indicate low, medium, or high asset scores, respectively. Household asset score tertile was positively associated with the reported annual household income, where adults with low household assets had the lowest reported total annual household income compared to those with medium and high household assets (data not shown). This type of index has been previously used to study the adult populations in Samoa and American Samoa (Choh, Gage, McGarvey, & Comuzzie, 2001; Ezeamama et al., 2006; Galanis, McGarvey, Quested, Sio, & Afele-Fa'amuli, 1999) and is a sensitive measure of economic status in modernizing societies (Filmer & Scott, 2008; Gwatkin, Rutstein, Johnson, Pande, & Wagstaff, 2000). Thus, a summed asset score was used in this study rather than conducting a principal component analysis, which has been commonly down with asset-based wealth scores (Hruschka, Hadley, & Hackman, 2017).

2.6. Assessment of outcome

BMI and AC were the outcome variables used to describe adiposity. Participants were measured in light island clothing. Height was measured to the nearest 0.1 mm using a portable GPM anthropometer (Pfister imports, New York, NY) and weight to the nearest 0.1 kg using a Tanita HD 351 digital weight scale (Tanita Corporation of America, IL). Duplicate measures of height and weight were averaged to calculate BMI (kg/m^2). Locating the waistline in adults with overweight and obesity is difficult when there is excessive central adipose tissue. Thus rather than waist circumference, AC was measured at the level of the umbilicus in duplicate and the measures were averaged.

2.7. Assessment of covariates

We used a directed acyclic graph to hypothesize and identify potential confounders and mediators in the association between household assets and adiposity among adults in Samoa (Savitz & Wellenius, 2016; VanderWeele & Robins, 2007). Individual characteristics and socioeconomic circumstances hypothesized to have an effect on household assets and adiposity were age, sex, educational attainment, and census region of the main village residence. These variables were selected *a priori* for inclusion in regression models as potential confounders. In light of prior literature in this field, we considered the marital status and health-related behaviors (smoking, alcohol intake, diet, and physical activity) to be potential mediators in the relationship between household assets and adiposity and did not control for these variables in order to avoid introducing confounding.

Age was used as a continuous variable centered at 45 years old and also categorized into 10 year age groups: 24.5 to <35, 35 to <45, 45 to <55, and 55 to <65 years old. Sex assigned at birth was reported as either female or male. Highest educational attainment of participants categorized as: less than secondary education (including only primary school or some secondary); secondary education completed (including those with some non-degree, post-secondary schooling); and tertiary education completed or beyond (college, university or postgraduate degree). A gradient of urbanization is apparent across the four census regions in Samoa and therefore, census region was used to estimate urbanicity. In line with the characteristics of the regions, we classified SAV as the most rural region, ROU as a rural, NWU as peri-urban, and AUA as the urban region.

2.8. Statistical analyses

Guided by the existing literature, the analyses for the study were sex-stratified and proceeded in the following steps. First, we performed bivariate analyses to examine differences in individual characteristics and socioeconomic circumstances across household asset score tertiles using the generalized linear regression for continuous variables and the Chi-square test for categorical variables. Second, we examined the age-adjusted mean BMI and AC by household asset score tertiles using least-square means linear regression models. Finally, we examined differences in BMI and AC by household assets and the independent socioeconomic correlates of each adiposity trait using sex-stratified multivariable linear regression models. Given the complexity of assessing socioeconomic circumstances in this setting, we also explored potential interactions between household asset score tertile and the socioeconomic correlates to model age-adjusted BMI and AC among males and females. Notably, we performed additional sensitivity analyses to model the adiposity traits by sex and found that the positive associations remained robust when household assets score was included as quintiles and as a continuous variable (data not shown, all $p < 0.001$) and when an interaction term for age as a continuous variable and household assets tertile was included (all p for interaction >0.05). Thus, we report only the findings with the household asset tertiles and models do not include an interaction term for age and household assets. P values less than 0.05 were considered significant. All analyses were performed using the statistical software package SAS version 9.4 (SAS Institute Inc., Cary, NC).

3. Results

Overall, the majority of Samoan adults were married and had completed secondary education or beyond. Fewer females in the lowest household assets tertile completed secondary education and lived in the peri-urban NWU and urban AUA regions compared to those with high assets (Table 1). By contrast, the majority of the males with low household assets were over the age of 45 years, currently married, completed secondary education, currently smoked, and lived in the rural census regions of SAV and ROU.

The mean BMI was 34.76 ± 6.73 kg/m^2 for females and 31.22 ± 5.84 kg/m^2 for males, while AC was 108.20 ± 14.43 cm and 101.94 ± 14.92 cm for females and males, respectively. After adjusting for age, the mean BMI and AC were lowest among adults with low household assets (Fig. 1). With each increasing tertile of household assets, both the age-adjusted mean BMI and mean AC showed linear increases in males and females (p for trend <0.001). Males tended to have lower BMI and AC than females across all tertiles of household assets, but the difference in AC was greatest between males with high assets (mean: 105.66 cm, 95% CI: 104.47-106.85) and with low assets (mean: 97.94 cm, 95% CI: 96.59-99.29).

After adjusting for age, education, and census region, household assets remained positively associated with BMI and AC among both females and males (Table 2). Females with high assets had a 2.69 kg/m^2 higher BMI (95% CI: 1.91-3.47) and 4.85 cm higher AC (95% CI: 3.20-6.50) compared to those with low assets. Males with high assets had a 2.36 kg/m^2 higher BMI (95% CI: 1.58-3.14) and 6.09 cm higher AC (95% CI: 4.18-8.00) compared to males with low assets.

The highest level of educational attainment was not an independent correlate of adiposity among females, but males who completed tertiary education had a 1.98 kg/m^2 higher adjusted BMI (95% CI: 0.08-3.20) and 4.47 cm higher adjusted AC (95% CI: 1.48-7.47) compared to those who did not complete secondary education. Independent of other demographic and socioeconomic characteristics, census region was significantly associated with BMI and AC among females and males. Males living in the urban AUA region had 2.02 kg/m^2 higher BMI (95%

Table 1
Sex-stratified characteristics by household asset score tertile among 3,370 adults in Samoa, 2010.

Characteristic	Total	Female (n = 1,985) by tertile[a]				Male (n = 1,385) by tertile[a]			
		Low	Medium	High	P[†]	Low	Medium	High	P[†]
n	3370	569	751	665		394	480	511	
Age group (years), %					0.118				<0.001
24.5-<35	24.18	20.74	26.10	23.76		18.78	24.17	29.94	
35-<45	25.93	30.23	26.50	26.92		24.11	22.08	24.07	
45-<55	27.45	28.65	28.10	25.71		34.01	27.29	22.50	
55-<65	22.43	20.39	19.31	23.61		23.10	26.46	23.48	
Married/cohabitating, %	82.79	87.17	86.15	86.17	0.837	82.99	74.79	75.93	0.008
Education category, %					<0.001				<0.001
Secondary education not completed	24.07	29.17	22.10	13.53		41.88	32.39	13.50	
Secondary education completed	68.75	68.01	72.97	75.19		56.60	61.88	70.84	
Tertiary education completed and beyond	7.18	2.81	4.93	11.28		1.52	5.83	15.66	
Current smoker	34.01	21.27	21.97	22.41	0.889	57.36	49.79	48.14	0.016
Ever consumed alcohol	15.93	1.41	2.53	3.31	0.099	35.28	36.04	34.44	0.870
Census region, %					<0.001				<0.001
Savaii	22.49	36.03	24.23	11.28		30.96	22.92	12.52	
Rest of Upolu	26.56	27.77	28.50	22.86		30.71	25.42	25.05	
Northwest Upolu	30.68	26.01	27.03	37.29		25.89	31.67	35.42	
Apia urban area	20.27	10.19	20.24	28.57		12.44	20.00	27.01	

Values are counts and percentages in parentheses or means ± SD.
[†]P values for generalized linear regression (for continuous variables) or Chi-square test (for categorical variables).
[a] Household asset score is the sum of consumer durables owned (stove type, refrigerator, portable stereo, stereo, television, videocassette recorder, landline phone, carpet, car/4-wheeled motorized vehicle, couch, European style house, plumbing, freezer, and washing machine). The score is out of a maximum of 14 and was categorized into tertiles based on score distribution: low (mean:3.34, SD: 1.52), medium (mean:7.12, SD:0.81), and high (mean:10.42, SD:1.40).

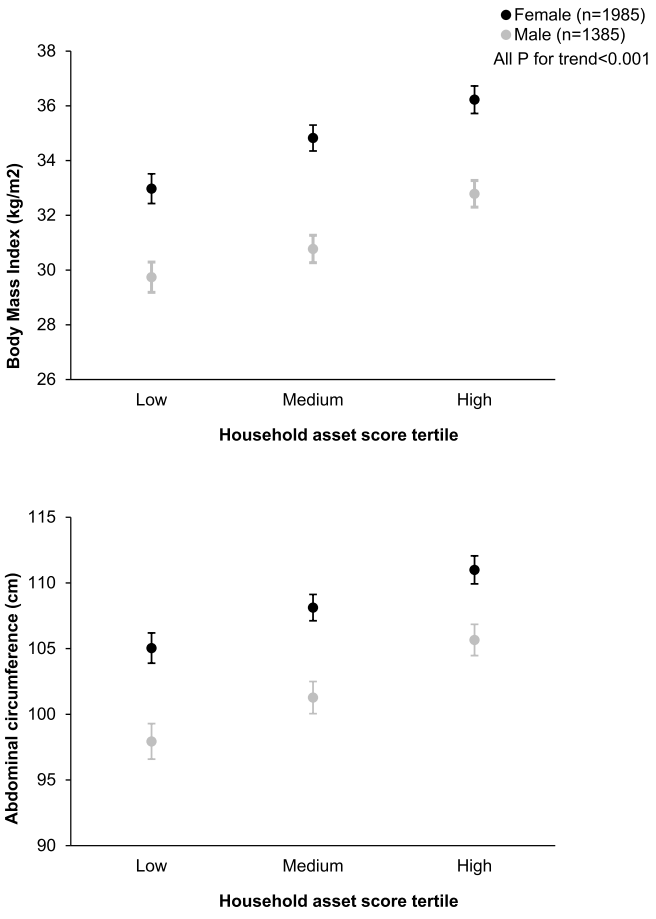

Fig. 1. Age-adjusted means and 95% confidence intervals of body mass index and abdominal circumference by household asset score tertile among Samoan adults, 2010.

CI: 1.09-2.94) and 5.01 cm higher AC (95% CI: 2.75-7.27) compared to those in the most rural SAV region. The association with census region was slightly weaker among females, with those in the urban AUA region having a 1.81 kg/m^2 higher BMI (95% CI: 0.89-2.72) and 3.98 cm higher AC (95% CI: 2.05-5.92) than in SAV. For each independent variable in the model, the variance inflation factors were <2, suggesting little multicollinearity. Among males, the model explains approximately 10.3% and 18.0% of the variation in BMI and AC, whereas, 4.9% and 6.9% of the variation in BMI and AC, respectively, among females can be explained by the regression models.

Considering the complex relationships of socioeconomic factors and adiposity, we next explored multiplicative interactions between household assets, education level, and census region to model age-adjusted BMI and AC. One significant interaction was observed between household assets and census region for AC among males (Fig. 2). While increasing urbanization appears to have an additional positive effect on mean AC among males with high household assets, there is a weaker positive association between household assets and AC in males living in the most rural SAV and most urban AUA. After adjusting for multiple comparisons using the Tukey test, interactions between household assets, education level, and census region for BMI and AC among females did not reach statistical significance at the level of 0.05 (data not shown).

4. Discussion and conclusions

Global trends suggest that once the gross national income per capita reaches between US$1,000 and $4,000 dollars, societies may experience a shift in the obesity burden from high to low socioeconomic groups (Dinsa et al., 2012; Monteiro, & Conde et al., 2004; Monteiro, & Moura et al., 2004). This shift is secondary to changes in occupation and/or diet with economic development and higher incomes, both of which contribute to adiposity increases. Contrary to our hypothesis, socioeconomic resources, assessed by household assets, were positively associated with adiposity traits among both female and male adults in Samoa in 2010, when the gross national income per capita was US$3,200 dollars. We also did not detect any differences in the associations of socioeconomic circumstances, assessed by education and urbanicity, and adiposity among women relative to men in Samoa in 2010. The mean difference in BMI between females with high assets compared to

Table 2
Correlates of body mass index and abdominal circumference among adults in Samoa, 2010.

	Body mass index (kg/m^2)				Abdominal Circumference (cm)			
	$\widehat{\beta}$ (95% CI)	P‡	VIF	R^2	$\widehat{\beta}$ (SE)	P*	VIF	R^2
Female				0.049				0.069
Intercept	31.77 (30.88-32.66)	<0.001	0		102.13 (100.25-104.02)	<0.001	0	
Household asset score tertile[a]								
Low (mean:3.34, SD: 1.52)	Reference				Reference			
Medium (mean:7.12, SD:0.81)	1.61 (0.88-2.33)	<0.001	1.48		2.54 (1.01-4.08)	0.001	1.48	
High (mean:10.42, SD:1.40)	2.69 (1.91-3.47)	<0.001	1.62		4.85 (3.20-6.50)	<0.001	1.62	
Education category								
Secondary education not completed	Reference				Reference			
Secondary education completed	0.64 (-0.13 – 1.40)	0.102	1.40		1.79 (0.17-3.41)	0.030	1.40	
Tertiary education completed and beyond	1.09 (-0.29–2.47)	0.121	1.36		1.08 (-1.83 – 4.00)	0.467	1.36	
Census Region								
Savai'i					Reference			
Rest of 'Upolu	0.93 (0.10-1.76)	0.028	1.60		2.51 (0.75-4.27)	0.005	1.60	
Northwest upolu	1.19 (0.37-2.01)	0.005	1.68		2.47 (0.73-4.20)	0.005	1.68	
Apia urban area	1.81 (0.89-2.72)	<0.001	1.60		3.98 (2.05-5.92)	<0.001	1.60	
Age (centered at 45 years)	0.05 (0.02-0.07)	0.001	1.14		0.26 (0.20-0.32)	<0.001	1.14	
Male				0.103				0.180
Intercept	28.47 (27.61-29.33)	<0.001	0		94.86 (92.77-96.96)	<0.001	0	
Household asset score tertile§								
Low (mean:3.34, SD: 1.52)	Reference				Reference			
Medium (mean:7.12, SD:0.81)	0.76 (0.01-1.51)	0.047	1.48		2.68 (0.85-4.51)	0.004	1.48	
High (mean:10.42, SD:1.40)	2.36 (1.58-3.14)	<0.001	1.67		6.09 (4.18-8.00)	<0.001	1.67	
Education category								
Secondary education not completed	Reference				Reference			
Secondary education completed	0.77 (0.05-1.47)	0.036	1.36		1.71 (-0.03 – 3.44)	0.054	1.36	
Tertiary education completed and beyond	1.98 (0.075-3.20)	0.002	1.33		4.47 (1.48-7.47)	0.003	1.33	
Census Region								
Savai'i	Reference				Reference			
Rest of 'Upolu	0.98 (0.12-1.83)	0.025	1.68		2.44 (0.35-4.52)	0.022	1.68	
Northwest upolu	0.92 (0.09-1.76)	0.031	1.77		2.35 (0.30-4.40)	0.025	1.77	
Apia urban area	2.02 (1.09-2.94)	<0.001	1.63		5.01 (2.75-7.27)	<0.001	1.63	
Age (centered at 45 years)	0.12 (0.09-0.15)	<0.001	1.12		0.50 (0.44-0.57)	<0.001	1.12	

Values are counts and percentages in parentheses or means ± SD.
*P values for generalized linear regression.
[a] Material lifestyle score is the sum of consumer durables owned (stove type, refrigerator, portable stereo, stereo, television, videocassette recorder, landline phone, carpet, car/4-wheeled motorized vehicle, couch, European style house, plumbing, freezer, and washing machine). The score is out of a maximum of 14 and was categorized into tertiles based on score distribution.

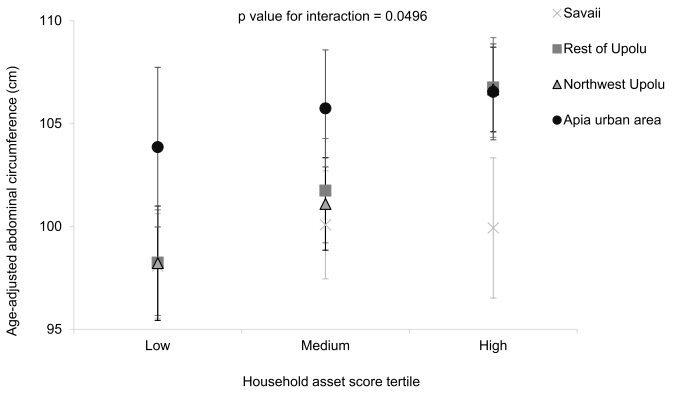

Fig. 2. Association between age-adjusted mean abdominal circumference and household asset score tertile by census region in men.

low assets was similar to that observed among males (2.69 vs. 2.36 m/kg^2), despite females having higher BMI than males across asset score tertiles.

The findings observed here are consistent with earlier work. Data from 1990 to 1995 indicated that in Samoa, with a less developed economy, higher socioeconomic status was associated with increased odds of obesity in males and the development of any incident cardiovascular disease risk factor in both males and females during this period (Ezeamama et al., 2006). However, in American Samoa with a more developed economy, low socioeconomic status was associated with higher odds of obesity at baseline only in females and with a similar incidence of obesity after 4-years of follow-up. We interpreted this as indicating positive health influences among females associated with economic development in the 1990s in American Samoa, but the inverse among adults in Samoa during the same time period (Ezeamama et al., 2006). Despite only being separated by 100 km, the two countries of the Samoan archipelago have different political-economic histories and different timing of economic development and nutrition transition events ((Baker, Hanna, & Baker, 1986), Galanis et al., 1999; Keighley et al., 2007; DiBello et al., 2009; Baylin et al., 2013; Wang et al., 2017).

Here we used a household asset-based approach to assess socioeconomic resources and found that the asset tertiles were associated with higher levels of adiposity traits among both Samoan females and males in 2010, with no evidence of a trend toward lower BMI and AC with increasing assets. While the samples and analyses are not directly comparable due to the ongoing Samoan economic and health transitions, it is noteworthy that the cross-sectional positive associations seen in males 10–15 years previously persist for males and are present also for females in Samoa (Ezeamama et al., 2006). These findings are consistent with the observation that the reversal in the relationship between wealth and BMI occurs at different wealth levels in different world regions (Hruschka, 2017). While other published studies have highlighted sex differences in the timing of the shift in obesity burden, we did not observe sex differences in our data. Rather both females and males experienced increasing obesity burden with increasing wealth. Global trends suggest that sex differences usually only emerge once the shift or inverse relationship is first observed in females (Hruschka, 2017). The shift has only been robustly observed among females, while there is

mixed evidence for men pointing more to a flattening of the relationship between wealth and BMI (Dinsa et al., 2012; Hruschka, 2017; Monteiro, & Conde et al., 2004; Monteiro, & Moura et al., 2004). Previous research hypothesized that wage penalties, nutritional deprivation in early life, and differences in ideal body size may explain why inverse associations between obesity and socioeconomic status tend to occur faster and earlier in development for females than males (Case & Menendez, 2009; Dinsa et al., 2012; Kim & Leigh, 2010; Sabia & Rees, 2012; Villar & Quintana-Domeque, 2009). As economic development progresses in Samoa, these may be key factors to consider in prevention efforts.

In addition to household assets, the highest level of educational attainment and urbanicity were independent correlates of higher adiposity among adults in 2010. One multiplicative interaction was observed between household asset tertile and census region in relation to AC among males, suggesting the potential for joint effects of urbanicity and asset ownership on adiposity traits. With a growing body of literature in other modernizing societies, researchers have detected and accounted for additional effects of urban residence to better understand the complex relationship between multiple socioeconomic factors and obesity (Dahly, Gordon-Larsen, Popkin, Kaufman, & Adair, 2010; Howe et al., 2012). For example, in the Cebu Longitudinal Health and National Survey, socioeconomic status was positively associated with obesity among Filipino females in a lower-income context, but inversely associated in a higher income context (Dahly et al., 2010). Once the residence was accounted for, household assets remained positively associated with central adiposity among the most rural females, while the inverse relationship was weakened in more urban females living in Cebu (Dahly et al., 2010). As economic development and the nutritional transitions continue to progress in Samoa, the relationships between socioeconomic factors and adiposity may change and require further investigation within this context.

If Samoa were to have followed the trends observed in other low- and middle-income countries, we might have anticipated that adults with higher socioeconomic resources and circumstances may have begun to modify their nutritional and health care behaviors which might have led to lower adiposity. There are however, several reasons why this trend may not be observed here. First, Samoa is still within the range of between US$1,000 to $4,000 dollars where the burden shift in obesity may be observed. Following 2010, the country continues to undergo significant nutritional and economic transitions; the GNI increased to US $4,190 dollars in 2018 (World Bank Group, 2019). We may be able to explore these questions with data currently being collected as part of a follow-up study of a subset of the adult participants included here, and determine if there is evidence of a general or sex-specific shift in the relationships between adiposity and various socioeconomic factors.

Second, the reported household assets used here as a measure of socioeconomic resources may have been purchased with cash, representing disposable income, but also may have been received as gifts. Most Pacific Island countries are heavily dependent on migrant remittances (Macpherson, 2013; McKenzie, 2007, pp. 99–121; Yoshino, Taghizadeh-Hesary, & Otsuka, 2019). Private remittances valued at $244 million Western Samoan tala (nearly US$98 million dollars) were reportedly sent to individuals in Samoa as either cash and in-kind (good carried into the country) between July 2009 and February 2010 (Central Bank of Samoa, 2010). Remittances are directed toward household livelihoods, investments and the accumulation of assets for both extended family and direct household members living in the Pacific, providing social protection through family networks which in turn, may shape the socioeconomic resources and circumstances under which people live and influence health (Connell & Brown, 2005; McKenzie, 2007, pp. 99–121). If the household assets measured here were, in fact, received in the form of gifts they may not be a good measure of the increased disposable income that may be necessary to make positive health behavior changes in diet and exercise to reduce obesity risk. Additionally, little is known about the reciprocity triggered by remittances. Some who receive remittances may be expected to reciprocate with cash, comparable gifts, or other monetary or social contributions, and distribute such resources to the extended family (Macpherson, 2013). In prior work from the 1990s in Samoa we showed that social and biological measures of psychosocial stress were associated with the expectations to meet family resource obligations and contributed to poor health outcomes (Bergey, Steele, Bereiter, Viali, & McGarvey, 2011; Bitton, McGarvey, & Viali, 2006; Chin-Hong & McGarvey, 1996). While the assets score here approximates material resources, further research is needed to determine if and how disposable income and cash resources may be necessary to drive behavior change by improving access to nutritious food or providing additional opportunities to engage in physical activity for shifts in adiposity to be observed.

Third, traditional subsistence-based livelihoods coexist with, and are not replaced by, a growing, modern cash economy in Samoa (Samoa Bureau of Statistics, 2012a, 2012b, 2014, 2016). According to the Population and Housing Census conducted in 2011, 5.8% of females and 94.2% of males in the economically active population aged 15 years and older produced food for subsistence or sale activities (Samoa Bureau of Statistics, 2012a, 2012b). The majority of the economically active adults in the peri-urban NWU and urban AUA regions are reported to depend on employment and other economic activities because families no longer have access to lands and subsistence supplies (Samoa Bureau of Statistics, 2012a, 2012b). Whereas, in the rural ROU and SAV regions, it is still a common activity to work in plantations, farms, and fishing subsistence for daily family support or sale to earn cash (Samoa Bureau of Statistics, 2012a, 2012b). Lower income families are more likely to be engaged in subsistence farming activities, which come with considerable, intensive physical activity and its health benefits, perhaps adding to the protection of this group from obesity and related conditions (Keighley, McGarvey, Turituri, & Viali, 2006).

Finally, the nutritional, social, and physical environment may simply not be conducive for positive behavior change in female or male adults in Samoa to occur at sufficient levels for adiposity levels to shift. Food systems in Samoa are changing with the increased availability of imported, low-cost foods and these foods tend to be regarded as being of higher value than locally grown foods (FAO, 2018; Fiti, 2014; Seiden et al., 2012). There also exist varying degrees of health literacy in combination with sets of cultural attitudes, body size ideals, and access to health care, which may hamper the ability of adults to moderate behaviors, seek health care, and adhere to interventions (Brewis, McGarvey, Jones, & Swinburn, 1998; Brewis & McGarvey, 2000; Hardin, 2015; Hawley & McGarvey, 2015). Moreover, previous economics research suggests that discrimination in labor and marriage markets may contribute to the shift and reversal in the BMI-wealth association, with observed shifts in the burden of obesity in populations where there exists discrimination against adults with high BMI (Hruschka, 2017). Since Samoan's excess body weight has been documented to have minimal impact on social interactions (Schrimpf et al., 2019) and equal opportunity of employment has been documented in Samoa (Samoa Bureau of Statistics, 2012a, 2012b), there is potentially minimal discrimination and this may be another explanation for no shift in adult adiposity levels in this setting.

The findings presented here should be interpreted within the context of some limitations. While there were efforts to acquire a nationally representative sample in 2010, this study was a convenience sample and has limits to its generalizability (Hawley et al., 2014). Compared to the national population of adults aged 25-<64 years old reported in the Population and Housing Census 2011, the study sample did include a similar proportion of adults residing in AUA (20.3 vs 20.3%), NWU (30.7 vs. 33.4%), ROU (26.6 vs. 23.3%), and SAV (22.5 vs. 23.1%) (Samoa Bureau of Statistics, 2012a, 2012b). A higher proportion of females (60.9%) was included in the analytic sample compared to the national adult population in Samoa (48.0%) and a higher proportion of adults aged 45-<65 years old were sampled (49.8 vs. 39.9%) (Samoa Bureau of Statistics, 2012a, 2012b). We recognize that BMI and AC are imperfect

measures of adiposity and with the cross-sectional study design in 2010, these traits reflect a point in time as well as prior accumulation of previous behaviors, social, and environmental exposures. While we calculated a summed asset score similar to previous studies in Samoa and American Samoa, principal component analysis is another common method that may be used to generate asset-based wealth indicators in this population setting (Hruschka et al., 2017). We acknowledge that there are multiple dimensions of socioeconomic position and wealth that influence health (Hruschka et al., 2017) and the analyses were limited to the available data in 2010 to examine the role of household assets, education, and urbanicity. The analyses did not include income given that the interpretation of income is likely to be more complex in growing economies such as Samoa, where income distributions are changing rapidly (Howe et al., 2012). It is important for future research to inquire and account for the ownership of land, cattle, and other forms of capital because traditional subsistence-based livelihoods coexist with the modern cash economy. Additionally, religious practice was not measured, but is common in Samoa (Samoa Bureau of Statistics, 2014) and may influence socioeconomic factors and shape behaviors related to health through a number of mechanisms such as cash offerings to religious organizations, perceived social support, and beliefs about disease causation and therapies (Cassel, Braun, Ka'opua, Soa, & Nigg, 2014; Hardin, 2016).

We note, however, several strengths of this analysis. The large sample size allows for analyses to be stratified by sex in order to have sufficient power to detect sex-specific differences in adiposity traits across various socioeconomic indicators. Perhaps most importantly, this study aligns with the current efforts of Pacific Island leaders to reduce the burden of obesity and to use data that will inform future interventions and policies (SPC, 2016). The data help to provide a strong foundation to drive strategic decisions and to support existing programs focused on the scale-up of national obesity prevention and health programs. Moreover, Samoa is a unique population to study the association of socioeconomic factors and obesity because of ongoing health transitions with changes in diet, physical activity, and patterns of morbidity and mortality (Galanis et al., 1999; McGarvey, 2012). Lessons learned from research in this setting will help us to understand the global public health impact of obesity as countries progress further along in their nutritional and economic transitions.

In conclusion, the striking patterns of high adiposity in adults with any socioeconomic circumstance among Samoan adults calls for urgent general screening and interventions to reduce the burden. Despite significant economic growth and development, there is a unanimously positive association between adiposity traits and household assets, which raises new research questions about the downstream effects of remittances on health in this setting. The findings highlight the importance of monitoring the influence of socioeconomic factors on adiposity and additional cardiometabolic disease markers to better inform policies and identify population-level targets for interventions in the context of economic development in Samoa. While Samoan adults with the highest assets appear to have the highest levels of adiposity traits compared to those with low assets in this study, there should be public health actions taken to develop and disseminate a variety of messages targeting different audiences to continue the promotion of healthy lifestyles (consumption of diverse, local diet, physical activity, and minimal alcohol and tobacco use) and support obesity control interventions and prevention programs. A 7–8 year follow-up of a subset of the adult participants is in progress and there are analyses planned to better understand the causal nature of the likely bi-directional relationships of the multilevel socioeconomic factors on cardiometabolic noncommunicable diseases among Samoans.

CRediT authorship contribution statement

Courtney C. Choy: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Nicola L. Hawley:** Investigation, Writing - original draft, Writing - review & editing, Project administration. **Take Naseri:** Writing - review & editing. **Muagututi'a Sefuiva Reupena:** Writing - review & editing, Project administration. **Stephen T. McGarvey:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2020.100556.

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