Obesity in Samoans and a perspective on its etiology in Polynesians1-3

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ABSTRACT For Samoans, modernization produces obesity and adiposity and concomitant increases in cardiovascular disease risk factors and outcomes. Massive adiposity and high prevalence of obesity characterizes modernizing adult Samoans. Mean body mass index (in kg/m²) at ages 25-54 y is 30-32 for males and 32-36 for females. Prevalence of overweight in female adults is 46% in traditional Western Samoans and 80% in migrants in Hawaii. Five-year longitudinal data show striking weight and fat gain, especially in younger adults and females. An evolutionary perspective on Polynesian adiposity is based on scenarios of the fates of sailors on the voyages of discovery and of settlers in the pioneer island villages. Efficient metabolisms producing rapid adipose-tissue growth could have increased survival among the first Polynesians. Rapid dietary and physical activity changes caused by modernization interacting with such population genetic predispositions may lead to the documented massive adiposity. Am J Clin Nutr 1991;53:1586S-94S.

KEY WORDS Obesity, adiposity, overweight, modernization, sex differences, adulthood, evolution, adaptation, Samoans, Polynesians

Introduction

Adult obesity or overweight is due to an increase in the amount and proportion of adipose tissue relative to normal body composition. Excessive adipose tissue or fat in adulthood is strongly associated with risk of cardiovascular diseases. Despite the apparent universal increase in adiposity with adult age, there is great population diversity in this increase and in the prevalence of obesity (1). Diversity in adiposity and obesity is probably caused by complex interactions between population and family genetic factors and diet and physical-activity patterns related to the socioeconomic environment (2). Recent studies support this generalization of strong genetic influences and indicate a role of the adult environment (3-6). However, this question remains: Are the genetic and environmental interactions that are putatively responsible for obesity similar across human populations?

Modernizing populations offer another opportunity to study the potential for gene and environment interactions in obesity (2, 7). Homogeneous genetic populations exposed to different environments because of migration and modernization may provide data on intrapopulation variability in obesity response and comparative data across populations on the level of obesity response. The purposes of this paper are to describe adult obesity and adiposity in Samoans, a Polynesian population experiencing modernization, and to suggest why Polynesians may be susceptible to massive obesity. Parts of this report are similar to several prior papers on adult obesity in Samoans (7-9) derived from the same overall project (10).

Methods

Population and samples

Two basic study designs are used for this report on Samoan adults. The cross-sectional study compares obesity and adiposity in four samples of males and females aged 20-74 y from different areas within the Samoan archipelago and Hawaii. The total Samoan sample includes 78 males and 89 females from the village of Salamumu on Upolu, Western Samoa; 137 males and 238 females from villages on the Manu’a Islands of American Samoa; 624 males and 848 females from villages on Tutuila, American Samoa; and 222 males and 290 females comparing in several areas on Oahu, HI. These populations and samples have been described in detail elsewhere, and there is a gradual increase in several measures of modernization from Western Samoa to Manu’a to Tutuila in Hawaii (7, 11-13). The longitudinal study pertains to 5-y changes in obesity and adiposity in a cohort of 180 males and 424 females from both Manu’a and Tutuila, American Samoa (14). The studies in different Samoan populations that provided data for this report were all approved by human subjects research review boards at various times throughout the duration of the Samoan project.

Anthropometrics and obesity criteria

Stature was measured using a portable GPM anthropometer (Pfister Imports, Ltd, New York). Weight was measured in light tropical clothing with a beam-balance scale and body mass index (BMI, in kg/m²) was calculated. Following the criteria from the National Health and Nutrition Examination Survey, 1976-1980 (NHANES II), overweight was defined as BMI ≥ 27.8 for males and ≥ 27.3 for females and severely overweight was defined as BMI ≥ 31.1 and ≥ 32.2 for males and females, respectively (15). Prevalence of overweight and severe overweight was calculated

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as percentages and incidence was measured from baseline. Use of the BMI and NHANES II criteria for overweight is solely for descriptive and comparative purposes. A human-population biology perspective provides a skeptical view of global standards in body-morphology research.

Triceps and subscapular skinfold thicknesses were measured with a Lange caliper (Pfister Imports, Ltd) by using standard techniques (16). Because of the massive adiposity of some modern Samoans, skinfold-thickness measurements were above the maximum capable measurement of the caliper; therefore, for description of the skinfold-site distributions, such thicknesses were treated as the maximum possible measurement.

Results

Mean BMI (Table 1) increased from 20 to 24 to 35 to 44 y of age in both sexes and all four samples. In some sex groups, most notably Tutuila males and females, mean BMI continued its cross-sectional increase into the older age groups. Over all ages in both sexes there was a steady increase in BMI from Western Samoa to Manu’a to Tutuila to Hawaii. Females 35–54 y of age from American Samoa and Hawaii were especially characterized by high mean BMI in contrast to their Western Samoa counterparts.

Prevalence of overweight in the four samples by sex was as follows: Western Samoan males 33.3%, females 46.1%; Manu’a males 56.2%, females 76.9%; Tutuila males 61.9%, females 79.4%; and Hawaiian males 75.2%, females 80%. Figure 1 displays the age-, sex-, and sample-specific percentages of overweight. In males prevalence of overweight was > 60% at ages 25–64 y in the most modernized Samoans. In males in Hawaii, 90% of those 35–44 y of age were overweight. Females had greater overall prevalence at every age than did males, and in the two American Samoan and the Hawaiian samples > 80% of females aged 35–54 y were overweight.

The prevalence of severe overweight over all ages in Western Samoa was 11.5% in males and 19.1% in females; in Manu’a, 25.5% in males and 50% in females; in Tutuila, 36.1% in males and 51.5% in females; and in Hawaii, 44.6% in males and 54.5% in females. Age-specific prevalence of severe overweight was the highest, 60–70%, in the American Samoan and Hawaiian samples of females aged 35–44 y (Fig 2). However, even in the Western Samoan females, prevalence of severely overweight increased steadily with cross-sectional age, from 5% in ages 20–24 y to 44% in ages 55–64 y. In males the highest prevalence was also in the most modernized men aged 35–54 y. Prevalence of severe overweight was the greatest at every age in the Hawaiian sample.

The 10th and 90th percentiles and means of triceps and subscapular skinfold thicknesses are shown by age in Figure 3 for males and females from the most traditional group, the Western Samoans, and the most modernized group, the Hawaiians. Hawaiian males and females had more subcutaneous fat at the triceps and subcapsular sites at all ages than did their Western Samoan counterparts. Females had thicker skinfold thicknesses at both sites than did males. Notably, the skinfold-thickness means for Hawaiian females of all adult ages averaged 25–35 mm for the triceps skinfold thickness and 30–40 mm for the subscapular skinfold thickness.

Five-year changes in BMI in American Samoan adults averaged 0.61 and 1.03 in males and females, respectively. The means (±SD) of 5-y change in BMI by sex and baseline age were the following: for males 18–34 y, 1.9 ± 2.7; 35–54 y, 0.6 ± 2.3; and 55+ y, −0.05 ± 1.9 and for females 18–34 y, 2.7 ± 2.7; 35–54 y, 0.8 ± 3.0; and 55+ y, −0.07 ± 2.5. The distributions of 5-y change in BMI by sex and age are displayed in Figure 4. For both males and females the distributions of 5-y BMI change shifted to a loss in body mass with increasing age, which reflects the mean values above. Approximately 83% of males and 91% of females 18–34 y of age at baseline and 65% of both males and females ages 35–54 at baseline increased in BMI over 5 y. Fewer than half of the older males and females increased in BMI.

The 5-y incidence of overweight was similar, 33–38%, for males and females aged 18–54 y but much less for the older males (8%) and females (20%) (Fig 5, top). However, 5-y incidence of severe overweight was highest in the males aged 18–34 y (38%) and in females aged 18–34 y (30%) and 35–54 y (27%) (Fig 5, bottom).

Five-year changes in weight, triceps, and subscapular skinfold thicknesses by age group are shown in Table 2. Five-year weight gain averaged 6.3 kg in younger males and almost 2 kg in 35–54-year-old males. There was an average weight loss in the oldest males. The age pattern of 5-y change was similar for triceps skinfold thickness; however, subscapular skinfold thickness increased over 5 y in all age groups, indicating a centripetal pattern of subcutaneous fat deposition with age. For females, weight and the two skinfold thicknesses increased in the two youngest age groups. In females the absolute weight-gain and skinfold-thickness increases were higher than in males, especially in the younger females 18–34 y of age. Subscapular skinfold thicknesses continued to increase throughout all ages, again indicating an aging pattern of centripetal subcutaneous fat deposition in female Samoans. It is noteworthy that these skinfold-thickness increases occurred in the younger females with baseline mean triceps and subscapular skinfold thicknesses of ~30–35 mm.

Discussion

These results strongly indicate that Samoans exposed to modern ways of life in American Samoa and Hawaii are characterized
by excessive adipose tissue, high mean BMI, and high prevalence of overweight and severe overweight throughout adulthood, especially for females. Although Western Samoans in certain age groups share some of these trends, overall they are leaner and less overweight. These cross-sectional data are consistent with earlier reports on Samoans that used different age groups, different obesity measurements, and slightly different samples (7, 9). Samoans in California also are characterized by large BMI and massive adiposity (8, 9).

A majority of American Samoans and Samoan immigrants
in Hawaii are obese by age 30 y and are not much different from older adults in those locations. Significant adult obesity appears to begin earlier in life for the Samoans most exposed to modernization. Samoan children in modern environments are fatter than those in traditional environments and have greater obesity compared with weight-for-height and BMI standards for US children (17, 18). In addition, large birth weights, averaging 3520 g, are found in American Samoa, and a large weight gain from birth to 6 mo of age characterizes Samoan infants in both Western and American Samoa (18–20).

The 5-y longitudinal results show a continued ability of Samoans to deposit adipose tissue, gain weight, and become over-
weight and severely overweight, especially as young adults. This occurs despite preexisting large body weight and significant adiposity. The Samoan means for 5-y change in BMI and weight in the 18–34-y and 35–54-y age groups are much greater than the 10-y changes recently reported for a cohort of US white and black adults from the NHANES I (1971–1975) Epidemiologic Followup Study (21).

Why do adult Samoans exposed to modernization have characteristic adiposity and overweight and continued rapid BMI, weight, and adiposity increases during early adulthood? Samoans in late 20th century neotraditional settings do not show the massive adiposity and high prevalence of overweight. This suggests that it is not simply an ethnic-group trait mediated solely by genetic factors but is a complex interaction between genetic susceptibilities and contemporary environments mediated by individual dietary and physical-activity patterns (2).

Contemporary environmental influences on Samoan adiposity have been demonstrated, including specific social and behavioral factors such as occupation-related physical activity, maintenance of traditional Sunday feasting of urban residents, and intensity of physical work (2, 7, 22, 23). Macroenvironmental influences assessed by residence and education also have been related to adult Samoan obesity and adiposity (2, 7, 14). For example, adult females 18–34 y of age with < 7 y of education have the greatest 5-y increase in weight gain (10.3 kg) compared with all other age and education groups (14). Clearly, behavioral factors related to changing socioeconomic environments exert strong effects on adiposity and obesity in Samoans and other modernizing populations (2).

This obesity response to modernization also has been shown in several other Polynesian populations, including some where neotraditional ways of life remain (24–33). Females tend to have a greater obesity response than do males, which is probably associated with significant reductions in their specific subsistence activities in modern settings. Males' specific subsistence activities change with wage-labor opportunities, but their overall level of physical activity is reduced to a lesser extent than is that of females (2).

The magnitude of Samoan and Polynesian adipose-tissue response to modernization is striking and appears to rank among the highest in representative study samples of human populations. Despite the demonstrated role of contemporary environmental factors on Polynesian adiposity, a consideration of historical and, thus, evolutionary factors may be the key in explaining Polynesian obesity.

Reconstructed voyages of exploration and discovery and establishment of island settlements suggest that the survival of sailors and island pioneers was by no means assured (34, 35). Combining Neel's (36, 37) thrifty-genotype concept concerning efficient metabolisms with Pacific archaeology and ethnohistory,
FIG 4. Five-year change in body mass index by age in Samoan adult males and females.
we and others (1, 2, 30, 33) posited an adaptive evolutionary scenario for Samoan adiposity.

Polynesian settlement required long ocean voyages into prevailing trade winds and unknown waters. The sailors on these early voyages of indeterminate length and unclear destinations may have experienced a significant risk of starvation and death when on-board food supplies dwindled and ceased. Overweight individuals and/or those with efficient metabolisms, presumably mediated by hyperinsulinemia, may have better survived such voyages because of their large store of energy reserves in the form of adipose tissue. Adipose tissue also would have been advantageous to these sailors because of its insulative value for buffering against the nighttime hypothermia. Surviving sailors of these discovery voyages and, thus, the first settlers may have been those able to use and store food energy efficiently, perhaps via thrifty-genotype mechanisms. Pre-voyage feasting to gain weight and selecting overweight or starvation-resistant sailors might also have been culturally adaptive strategies, producing a similar morphological and genetic sample of aboriginal Polynesian settlers. Once voyagers landed in Samoa, a new subsistence pattern had to be established. The establishment of agricul
culture brought from the west to the Polynesian islands may have taken time and experience, and if food shortages existed, there was further selection for metabolic efficiency upon the pioneers. The cyclic occurrence of severe tropical storms, destroying palm, breadfruit, and banana trees and ruining taro beds, would have produced occasional food shortages and selective advantages to those with thrifty genotypes.

If these speculations are even partially true, the present Samoan and Polynesian populations may be adapted through thrifty-genotype mechanisms to hyperinsulinemic responses to food. Exposure to the increased dietary diversity and the decreased physical activity of modernization (38, 39) may interact with these formerly adaptive responses and lead to the massive adiposity documented for Samoans and other Polynesians. A similar thrifty-genotype scenario has been suggested for the obesity, hyperinsulinemia, and non-insulin-dependent diabetes mellitus in Pima Indians (40).

A related question is whether Samoans and other Polynesians suffer the same morbidity and mortality associated with adiposity that we would expect from more well-studied populations. A brief answer must be equivocal. Blood pressure and hypertension prevalence are high in modern Samoans, and adiposity is the most significant correlate and predictor (12, 41, 42). Insulin levels and mortality because of diabetes are also high in modern Samoans (43, 44); however, total cholesterol levels are strikingly low relative to the obesity in Samoans and other Polynesians (45). Furthermore, mortality from cardiovascular diseases appears to be unrelated to obesity in Samoans (46, 47). It is noteworthy that a recent study shows ethnic-group differences in the association of insulin with blood pressure in Pima Indians, whites, and blacks (48), which suggests that there is population variability in these interrelations and a likelihood that Polynesians may also have different associations among these adiposity-related risk factors.

The primary limitation of this evolutionary scenario is that it cannot be tested. However, a combination of evidence from different types of scientific inquiry can help us evaluate its potential even in foreign field settings. Observational epidemiologic data on adiposity amount and distribution, fasting and postload insulin, glucose, lipids, and candidate genes are essential as are behavioral and socioeconomic data. More sophisticated studies

![Graph](image1)

**FIG 5.** Five-year incidence of obesity in Samoan males and females by age group. Top: overweight; bottom: severely overweight.

| TABLE 2 |
| Five-year changes in weight and triceps and subscapular skinfold thicknesses by age group* |

<table>
<thead>
<tr>
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<th>Weight</th>
<th>Triceps skinfold thickness</th>
<th>Subscapular skinfold thickness</th>
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<tr>
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<td>kg</td>
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<tr>
<td>Males</td>
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<tr>
<td>18–34 y (n = 50)</td>
<td>6.3 ± 8.3</td>
<td>2.4 ± 5.8</td>
<td>7.7 ± 9.4</td>
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<tr>
<td>35–54 y (n = 72)</td>
<td>1.8 ± 7.0</td>
<td>1.8 ± 7.2</td>
<td>5.9 ± 8.9</td>
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<tr>
<td>55+ y (n = 58)</td>
<td>−1.8 ± 5.7</td>
<td>−0.8 ± 6.2</td>
<td>3.5 ± 5.6</td>
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<tr>
<td>Females</td>
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<tr>
<td>18–34 y (n = 125)</td>
<td>7.7 ± 7.1</td>
<td>6.4 ± 7.5</td>
<td>12.7 ± 9.4</td>
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<tr>
<td>35–54 y (n = 211)</td>
<td>2.0 ± 7.8</td>
<td>1.1 ± 10.3</td>
<td>6.9 ± 10.4</td>
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<tr>
<td>55+ y (n = 88)</td>
<td>−2.3 ± 6.9</td>
<td>−2.8 ± 10.4</td>
<td>3.9 ± 11.5</td>
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*   $x \pm SD.$
in clinical settings, such as those on insulin secretory patterns, are needed. Familial studies may permit assessments of familial aggregation and estimation of genetic and nongenetic contributions. If such data are available, a putative evolutionary scenario based on archaeological and ethnohistorical data can be logically evaluated for consistency and plausibility. A thorough quantitative evaluation may be impossible unless a common unit of currency, perhaps caloric energy, is used in simulations of selective advantages. For Samoans and Polynesians, such integrated studies are only at the beginning stage.

James R Bindon provided an unpublished manuscript a guide to the presentation of some of these data, and he made several key suggestions for this paper.

References