Medical and Nutritional Surveys in The Kingdom of Tonga; Comparison of Physiological and Nutritional Status of Adult Tongans in Urbanized (Kolofo-ou) and Rural (Uiha) Areas

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Summary The physiological and nutritional status of adult Tongans in rural (Uiha, 50 males and 58 females) and urbanized (Kolofo-ou, 77 males and 71 females) areas were surveyed in 1977 and 1979, respectively. Adult Tongans of both sexes in the two districts had considerably large physiques. Being different from the obesity found in peoples of industrialized countries, the obese state of adult Tongans was associated with large muscularity, low incidence of glucosuria, ECG abnormalities and hypertension, and normal plasma cholesterol levels. However, modernization has started to have an influence upon the health of adult Tongans; relatively high levels in parameters relating to obesity as well as higher incidence of hypertension were observed in adult Tongans in Kolofo-ou as compared to adult Uiha islanders.

Key Words The Kingdom of Tonga, rural and urbanized areas, adult Tongans, physiological and nutritional status, obesity

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A detailed comparative study of the lifestyles led in two nations with similar food habits, yet different in the stage of current industrialization, would be most profitable for those nations to plan their future nutritional policies.

The Kingdom of Tonga, among many countries in the world, has several points in common with Japan: both countries are sovereign nations in the Pacific Area with monoracial populaces consuming plants and fishes. However, marked differences are found between Tongans and Japanese in consumption of foodstuffs supplying starch as well as in physical characteristics; in contrast to the Japanese relying on rice as the major starchy food, Tongans depend on yam, taro, cassava, banana and papaya as major starchy foods and become much heavier than Japanese in adulthood. In addition, while Japan is currently in a more advanced stage of industrialization as compared to The Kingdom of Tonga, a report by the Tonga Government (1) has suggested that Tongan islanders enjoy better health than Japanese.

Therefore, it is of interest to investigate the mechanisms by which Tongans become obese and how such a physical situation is influenced by modernization. As regards the above research, comprehensive medical, nutritional and socio-economical surveys on the lifestyle of the Tongan population have been performed. In the surveys of 1976 and 1977, the physiological and social situations of the remote islander adults in Uiha island were examined, and in a survey done in 1979, Tongan adults were examined in metropolitan Kolofo-ou, Tongatapu, which has started to be influenced by modernization. The data indicate that adult Tongans have extremely large physiques, which seems to be due to consumption of high-energy and relatively low-protein meals containing large amounts of starchy roots. However, the specific obesity found seems to be lost with the modernization of lifestyles including work as well as eating habits.

**EXPERIMENTAL**

**Subjects.** In August, 1977, according to the population distribution in relation to age, 108 people were selected from a total of 238 aged 30 yrs or over in Uiha island, Ha’apai group of islands, The Kingdom of Tonga. The selected people (50 males and 58 females) were subjected to medical and nutrition surveys.

In August, 1979, 244 people were selected from 458 aged 30 yrs or over in Kolofo-ou, Nuku’alofa, Tongatapu island, The Kingdom of Tonga. The selected people (77 males and 71 females) had been living in this district for over 20 yrs and participated in the medical and nutritional surveys.

**Measurements.** Body weight, height, cornea-turbid ring score (2), number of vertical wrinkles in a 1 cm width in the frontal area of the ear shell (2), visual acuity, hand-grip strength, arm-pulling strength, vertical-jump height, vital capacity and blood pressure were measured using the usual anthropometrical methods. Skinfold thickness at upper arm, back (subscapular region), abdomen (umbilical region) and hand dorsum was measured by an Eiken-skinfold meter. Body density was obtained
using the following equations (3); 1.0923–0.000514 × SI, and SI (skinfold index) = [upper arm skinfold (mm) + subscapular skinfold (mm)] × S (body surface area, m²) ÷ W (body weight, kg) × 100. Body surface area was calculated according to the equation of Du Bois. Body fat was obtained according to Brozek’s equation; body fat (%) = (4.570/D – 4.142) × 100, D = body density. The Rohler index was also obtained. Electrocardiography (ECG) was performed using Fukuda Cardiograph-501 D (Fukuda-sangyo Co., Tokyo) and urine analyses of protein, glucose and hematuria, etc. were performed using a Multistics (Sankyo Pharmaceutical Ind., Co., Tokyo). Age of menarch and menopause was taken for female subjects. Some of these items were surveyed only in Kolofo-ou.

Blood samples were obtained from subjects in Kolofo-ou, and plasma was separated and frozen in liquid nitrogen until determination for total (4) and high-density lipoprotein (HDL)-cholesterol (5) at the Univ. of Tsukuba.

Basal metabolic rate (BMR) was measured for participants in Kolofo-ou surveys, who had body weights of 102–125 kg. Five males (30–44 yrs, 104–125 kg, 172–185 cm) and 4 females (39–49 yrs, 102–125 kg, 154–168 cm) were selected. They woke up at around 7 a.m. and lay down on sleeping mats after urination. Expired air was collected in Douglas bags for 20 min. Concentrations of O₂ and CO₂ in expired air were analyzed by a breath-analyzer (B-30, Fukuda-sangyo, Co.), and ventilation volume was determined by a gas meter. Room temperature and atmospheric pressure were 21–22°C and 735–744 mmHg, respectively, during the experimental period (August 25–29th, 1979).

Energy consumption during bicycle ergometer exercise was also measured in the surveys in Kolofo-ou for participants who had 90–110 kg body weights. Ten males (30–50 yrs, 90–110 kg, 161–185 cm) and 6 females (32–42 yrs, 90–95 kg, 152–171 cm) were used as subjects. Work with a bicycle ergometer (Monark Co., Stockholm) at 300 kpm/min and 30 rotations/min was done for 6 min, and expired air was collected for the final 2 min of the work.

Twenty-four-h urine was collected from the heavy subjects (5 males and 4 females) used for BMR measurements. Analysis was done for total nitrogen by the Kjeldahl method, for urea and ammonium nitrogen by the Berthelot reaction, for sodium by flame photometry, for chlorine by the method of Mohr, and for creatinine by the method of Folin. The lean body mass of the subjects was calculated using Forbes’ formula from the creatinine content of 24-h urine (6).

The significance of the difference between values for Kolofo-ou and Uieha was assessed on the basis of Student’s t-test.

RESULTS

Comparison of physical characteristics and parameters for the obese state of Tongan adults in urbanized and rural areas

The body structure of Tongan adults was considerably large (Fig. 1). In both males and females, there was no great difference in body height between urban
Tongans and Uiha islanders, however, urban Tongans had relatively larger levels of parameters relating to states of obesity such as body weight (Fig. 1), skinfold thickness (Fig. 2), body fat content and Rohler index (Fig. 3), as compared to Uiha islanders, through most age brackets. Skinfold thickness was much larger in females than in males in the two areas. Skinfold thickness in the umbilical area was measured only in adults in Kolofo-ou (Fig. 5). Body density (Fig. 3) was lower in urban females than in Uiha females and was also lower in females than in males in the two districts.

**Comparison of physiological states of Tongan adults in urbanized and rural areas**

Vital capacity and vertical-jump height were slightly lower in urban Tongans than in Uiha islanders (Fig. 4). As for muscular strength such as hand-grip strength (Fig. 4), urban Tongans had much higher values than did Uiha islanders for most age brackets. Arm-pulling strength was measured only in adults in Kolofo-ou (Fig. 3).
Fig. 2. Skinfold thickness at upper arm and subscapular areas of Tongan adults in Kolofo-ou and Uiha island. Open-circled point and vertical line represent mean and SD of values for each decade, respectively. \( a, b, c, d \) Significantly different from Kolofo-ou \( (p<0.05, b p<0.02, c p<0.01, d p<0.001) \).

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Fig 3. Body fat, body density and Rohler index of Tongan adults in Kolofo-ou and Uiha island. Open-circled point and vertical line represent mean and SD of values for each decade, respectively. *a,b,c,d* Significantly different from Kolofo-ou (* p < 0.05, b p < 0.02, c < 0.01, d p < 0.001).

Fig 4. Hand-grip strength, vertical-jump height and vital capacity of Tongan adults in Kolofo-ou and Uiha island. Open-circled point and vertical line represent mean and SD of values for each decade, respectively. *a,c,d* Significantly different from Kolofo-ou (*a* $p < 0.05$, *c* $p < 0.01$, *d* $p < 0.001$).

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5). It was maintained during 30–49 yrs in males and 30–59 yrs in females and declined gradually thereafter. Systolic and diastolic blood pressures of Tongans generally increased with aging in males and females in Kolofo-ou and Uiha island (Fig. 6). However, the mean blood pressure levels in urban Tongans tended to become steadily higher than those in Uiha islanders at the respective age bracket.

The number of hypertensive persons, based on the WHO criteria for hypertension 150/95 mmHg (systolic/diastolic), was 19 (7 males and 12 females) out of 148 urban Tongans. On the other hand, only 3 persons were hypertensive out of 108 subjects in Uiha island.

Abnormal findings in urine analysis were also revealed to be much more prevalent in urban Tongans. A positive sugar reaction, however, was detected in only 5 persons out of the total of male and female subjects looked at in Kolofo-ou and Uiha island.

Visual acuity of Tongans decreased with aging, and urban Tongans showed significantly lower visual acuity than did Uiha islanders (Fig. 7). There was no significant difference in age for menarch and menopause between females in Kolofo-ou and Uiha (Fig. 8), but the age for menarch was slightly lower in young adult females in Kolofo-ou than in those in Uiha. The other parameters for evaluation of aging process such as cornea-turbid ring score, number of vertical wrinklers in frontal area of ear shell, and skinfold thickness of hand dorsum were measured only for urban Tongans (Fig. 9). These data showed that urban Tongans followed the
usual aging process.

Plasma total and HDL-cholesterol concentrations in urban Tongans

Plasma cholesterol concentrations were determined only for urban Tongans (Fig. 9). Both males and females showed normal mean levels in plasma total and HDL-cholesterol. In Tongans aged 50 yrs or over, females had relatively higher total and HDL-cholesterol levels as compared to males of corresponding age.

Urinary levels of nitrogen compounds, Na$^+$ and K$^+$ in 24-h urine from heavy urban Tongans

Heavy urban Tongans showed mean urinary creatinine levels of 1,692 mg in males and 1,229 mg in females per day. Lean body mass calculated from the urinary creatinine was about 55 kg (49% of body weight) for males and about 50 kg (45% of body weight) for females (Table 1). Urinary excretion of total nitrogen was 7.5 g for males and 10.6 g for females per day, which correspond respectively to 47 g and 66 g of protein. Urinary NaCl excretion was estimated at about 15 g for males and 10 g for females per day.

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Fig 7. Plasma cholesterol level, number of wrinkles in 1 cm in frontal area of ear shell, cornea turbid score and skinfold thickness at hand dorsum of Tongan adults in Kolofo-ou. Open-circled point and vertical line represent mean and SD of values for each decade, respectively.
Fig. 8. Visual acuity of Tongan adults in Kolofo-ou and Uiha island. Each point represents mean of values for each decade. *Significantly different from Kolofo-ou (* p < 0.05, ** p < 0.001).

Fig. 9. Age for menarche and menopause of Tongan adults in Kolofo-ou and Uiha island.

*Basal metabolism and oxygen consumption during bicycle ergometer exercise in heavy urban Tongans*

Data are shown in Table 2. Mean BMRs calculated from $\dot{V}O_2$ values were about 40.7 kcal/m$^2$/h, 93.8 kcal/h, 19.8 kcal/kg/day or 2,250 kcal/day for heavy males and 51.1 kcal/m$^2$/h, 108.6 kcal/h, 23.3 kcal/kg/day or 2,600 kcal/day for heavy females in Kolofo-ou.

Mean $\dot{V}O_2$ values for bicycle ergometer exercise at 300 kpm/min were
Table 1. Urinary nitrogen compounds, Na⁺ and K⁺ and estimated lean body mass in heavy Tongan adults in Kolofo-ou (1979).

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
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<tbody>
<tr>
<td>Age (yr)</td>
<td>35.2 ± 5.4</td>
<td>43.0 ± 4.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.7 ± 4.7</td>
<td>161.5 ± 5.0</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>113.6 ± 9.4</td>
<td>111.8 ± 10.4</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>2.3 ± 0.0</td>
<td>2.1 ± 0.1</td>
</tr>
<tr>
<td>Skinfold thickness (mm)</td>
<td>62.0 ± 4.4</td>
<td>89.9 ± 6.9</td>
</tr>
<tr>
<td>Body density</td>
<td>1.022 ± 0.008</td>
<td>1.000 ± 0.012</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>33.2 ± 3.4</td>
<td>43.0 ± 5.5</td>
</tr>
<tr>
<td>Rohrer index</td>
<td>199.7 ± 18.3</td>
<td>266.4 ± 25.3</td>
</tr>
<tr>
<td>Creatinine (mg/day)</td>
<td>1,692 ± 644</td>
<td>1,229 ± 175</td>
</tr>
<tr>
<td>Total N (g/day)</td>
<td>7.52 ± 2.36</td>
<td>10.59 ± 2.86</td>
</tr>
<tr>
<td>Urea N (g/day)</td>
<td>3.08 ± 0.95</td>
<td>5.41 ± 0.63</td>
</tr>
<tr>
<td>Ammonia N (mg/day)</td>
<td>121 ± 55</td>
<td>135 ± 34</td>
</tr>
<tr>
<td>Na⁺ (mEq/day)</td>
<td>123 ± 71</td>
<td>90 ± 30</td>
</tr>
<tr>
<td>NaCl by Na⁺ (g/day)</td>
<td>7.3 ± 4.0</td>
<td>5.3 ± 1.7</td>
</tr>
<tr>
<td>by Cl⁻ (g/day)</td>
<td>8.0 ± 5.4</td>
<td>5.3 ± 1.8</td>
</tr>
<tr>
<td>K⁺ (mEq/day)</td>
<td>70 ± 27</td>
<td>93 ± 20</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>56.6 ± 18.7</td>
<td>43.1 ± 5.1</td>
</tr>
</tbody>
</table>

Mean ± SD. 1 Upper arm + subscapular.

Table 2. BMR and metabolism during bicycle ergometer exercise in heavy Tongan adults in Kolofo-ou (1979).

<table>
<thead>
<tr>
<th></th>
<th>Basal metabolism</th>
<th>Metabolism during exercise</th>
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<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>No.</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>35.2 ± 5.4</td>
<td>43.0 ± 4.3</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>113.6 ± 9.4</td>
<td>111.8 ± 10.4</td>
</tr>
<tr>
<td>VE¹-ATPS² (ml/min)</td>
<td>8.64 ± 0.6</td>
<td>9.74 ± 0.5</td>
</tr>
<tr>
<td>VE-STPD³ (ml/min)</td>
<td>7.63 ± 0.6</td>
<td>8.56 ± 0.5</td>
</tr>
<tr>
<td>VE-BTPD⁴ (ml/min)</td>
<td>9.45 ± 0.7</td>
<td>10.67 ± 0.6</td>
</tr>
<tr>
<td>VO₂ (ml/min)</td>
<td>324 ± 47</td>
<td>375 ± 86</td>
</tr>
<tr>
<td>VCO₂ (ml/min)</td>
<td>265 ± 65</td>
<td>243 ± 26</td>
</tr>
<tr>
<td>RQ</td>
<td>0.81 ± 0.11</td>
<td>0.68 ± 0.20</td>
</tr>
<tr>
<td>Ventilation volume</td>
<td>8.7 ± 0.3</td>
<td>9.8 ± 0.6</td>
</tr>
</tbody>
</table>

Mean ± SD. 1 Volume of expired gas. 2 Ambient temperature and pressure, saturated with water vapor. 3 Standard temperature and pressure, dry. 4 Body temperature and pressure, dry.

calculated at 1.7 liters/min for males and 1.5 liters/min for females with heavy body weights.

DISCUSSION

Adult people in The Kingdom of Tonga are of significantly large physique. The data on skinfold thickness indicate that the most Tongan adults of either sex could be considered obese. The extent of obesity was far higher in females than in males, and relatively lower in Uiha islanders than in urban Tongans of either sex. Some of the characteristics of the obese state of Tongan adults could be seen in the data obtained from heavy urban Tongan adults of 100 kg or more body weight (Table 1). That is, not only body fat content but also lean body mass was very great in these extremely heavy Tongans of either sex.

In male Tongan adults of heavy body weight, basal metabolism per m² body surface area was high and almost comparable to that of athletes and physical workers who have been reported to have 10–15% higher basal metabolism as compared to ordinary persons (7). Much higher basal metabolism per m² was obtained in heavy female Tongan adults as compared with heavy male adults, but the reason for this is not clear. Emotional stress at the time of measurement might be considered to be one of the reasons, because it is rare for female Tongans to come into contact with foreign males.

Metabolism of Tongan adults in Kolofo-ou during bicycle ergometer exercise at 300 kpm/min was 17 ml O₂/kg/min for males and 16 ml O₂/kg/min for females, values higher than those reported for Japanese male farmers (12–14 ml O₂/kg/min) (8). Thus, data on basal metabolism and metabolism during exercise obtained for heavy Tongans might support the high lean body mass found.

A possible large muscularity of Tongan adults also seems to be suggested in their relatively strong hand-grip strength and arm-pulling strength as compared with rural Japanese adults (9). Such Tongans’ obesity associated with large muscularity and low vital capacity might be due to frequent isometric muscular work such as digging earth for cultivation, cutting trees and coconut shells, etc. as well as very slow-paced walking.

The specific obesity seems still to be maintained in Uiha islanders who depend on traditional foodstuffs and who have high physical capacity. In contract, with advancing modernization, obesity in urban Tongans seems to have started to change from the specific obesity, “healthy” obesity, toward “unhealthy” obesity usually found in industrialized countries. Tongan adults in rural areas (Uiha island) showed fewer symptoms of so-called degenerative disease than those in urban areas (Kolofo-ou). A food survey carried out on Uiha islanders indicated that they consume ordinary traditional foodstuffs consisting of starchy roots, banana, fishes and coconuts which supply sufficient vitamins and minerals with low salt (10). Their protein intake was estimated to be low on the basis of kg body weight as compared with Japanese adults (11), but the nutritional efficiency of protein seems to be high.
because of the high energy intake (12), mostly from starchy roots. Tongan adults in Kolofo-ou consume similar foodstuffs to Uiha islanders. However, recently they have frequently been found to partake of so-called modern foodstuffs such as polished cereals, canned beef, sucrose, table salt, etc. (13).

Although not yet quantitatively determined, daily energy expenditure seemed to have been decreased in urban areas due to social modernization. An occupational survey revealed that male adults in Uiha island were generally farmers and fishermen. But male adults in Kolofo-ou were engaged in a variety of occupations such as government officer (28 out of 78 male subjects), laborer (12), merchant and businessman (6), driver (3), carpenter (2), priest (1), lawyer (1) and farmers (18). On the other hand, all female Uiha islanders were housewives, the situation being almost the same in Kolofo-ou. However, about 10% of female adults had jobs such as government officer, teacher, and skilled laborer, etc. in Kolofo-ou. In addition, housewives in Uiha island usually work in the bush to cultivate and harvest farm products. However, those in Kolofo-ou have had a declining amount of agricultural work to do. Pedometry of adults in Kolofo-ou showed 9,000, 12,700 and 13,300 steps per day in three males and 6,400 and 10,500 steps per day in two females. This indicates less physical activity in certain groups of adult Tongans in urban areas as compared with mean daily steps of 10,000 in both male and female middle-aged and elderly Japanese farmers (9).

Thus, the higher prevalence of unfavourable health in urban Tongan adults than in Uiha islanders might in part be caused by the modernized lifestyle which has been rapidly developing in urban areas of The Kingdom of Tonga.

In general, Tongan adults in both Kolofo-ou and Uiha island showed similar or less prevalence in abnormal findings in ECG, hypertension and glucosuria as compared to Japanese adults (9). Plasma total and HDL-cholesterol concentrations of Tongan adults also showed a normal distribution. These findings from generally obese Tongan adults are very interesting, because obesity in industrialized countries has been characterized as causing a high incidence of ECG abnormality, hypercholesterolemia, glucosuria, hypertension, etc.

Hyperinsulinemia is responsible for excess deposition of body fat. Plasma insulin response to the ingestion of baked patatoes has been revealed to be more intensive than with boiled rice (14–16). Tongans consume large amounts of starchy roots such as yam, taro and cassava as well as banana (10, 13), which might be as digestible as potatoes. Thus, high energy intake from these digestive starchy foodstuffs may be, in part, responsible for the build-up of obesity in Togan adults.

From the results on indices for the aging process in urban Tongan adults, it may be tentatively concluded that the aging process in Tongans seems to be steady and slow and that many physiological functions seem to be maintained until a relatively advanced age.

Thus, it will be interesting to investigate further the alterations in physical and physiological states, food intake and lifestyle of Tongan adults in both rural and urban areas to reveal the factors involved in the maintenance or destruction of
“healthy” obesity in Tongans. In addition, in order to explore the mechanism(s) that allow development of “healthy” obesity in Tongans, it may be important to investigate not only plasma insulin responses by Tongans to the ingestion of starchy roots, by comparison to ingestion of rice, but also the developmental characteristics of physical and physiological parameters of young Tongans during growth ages in both rural and urban areas.

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