Basal Metabolic Rate and Dietary Seasonality Among Tibetan Nomads

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ABSTRACT
The results of 51 overnight measurements of basal metabolic rate (BMR) in a sample of pastoral nomad residents permanently in Phala, Tibetan Autonomous Region, China, are reported. Past studies demonstrated a culturally driven seasonality of diet, with very low summer and very high winter caloric intake. The study was designed to test the hypothesis that the ability of Phala nomads to subsist on low caloric intake for several summer months without signs of malnutrition is explained by lower summer BMR. However, BMR measurements of 40 nomads 40-69 years of age during the summer and measurement of 11 nomads during the winter of 1995 provided no evidence for low summer BMR to compensate for the low summer caloric intake. BMR is both seasons is within the normal range predicted by international equations. The BMR of males does not differ from that of females, and the BMR of females averages 7% higher than predicted. Anthropometric evidence reveals that the Phala nomads accumulate body fat during the winter. It is inferred that the metabolic activity during the winter does not result in the seasonal body mass loss. Further study of the mechanism of body fat accumulation in winter and the influence of seasonality on the metabolic rate of Phala nomads is required.

Basal metabolic rate (BMR), the minimum metabolic activity required to maintain life, is a major component of total energy expenditure whether individuals are sleeping, resting, or working (Faye and Waters, 1991). BMR has become the focus of much scientific attention because of the recent report (FAO/WHO/UNU, 1985) on human energy and protein requirements that proposed using energy expenditure rather than intake as the basis for estimating human energy needs. The report suggested that various components of energy expenditure be expressed as multiples of BMR. Applying this approach to estimating energy requirements requires accurate knowledge of BMR in people under various climatic and environmental conditions. BMR is measured directly under thermoneutral, resting, and fasting conditions. In practice, BMR is infrequently measured instead, prediction equations based on age, sex, and weight are used (Boudet, 1982; Dubois and Dubois, 1958). A major review used the newly 11,600 BMR measurements in the literature to develop predictive equations for males and females throughout the life cycle (Schneider, 1988) and formed the basis for the equations presented in the FAO/WHO/UNU (1985) report. Most of the measurements were obtained from European and North American subjects. However, this analysis, along with others during the past half-century, revealed
that populations elsewhere may have lower BMR than predicted by the standard equations. If true, then energy requirements based on these predictions are erroneously high.

There is a long history of reports of BMR values as much as 20% below those predicted on the basis of European and American equations. For example, Almendá (1921) claimed that the BMR of Brazilians was 16-20% below American values. Benedict (1932) wrote that "South Indian women in Madras had a metabolism averaging 17.4 per cent below the standards for white women and Australian aborigines (men and women) had a metabolism averaging 14-16 per cent below Caucasian standards. These differences in metabolism may be partly explained by the differences in climate and food" (p. 473). Extending this idea, Quennell et al. (1951) presented prediction equations for BMR in tropical peoples that included climate and race in addition to age, sex, and body size. Henry and Beer (1951) did a comprehensive review of BMR in tropical peoples and noted that BMR was generally lower. The analysis also revealed considerable gaps in the literature. For example, few BMR studies have been reported for Africa and South America. Furthermore, high altitude Andean, Himalayan, and Simien residents live at altitudes considered tropical, yet inhabit substantially cooler thermal environments than the surrounding lowlands and may have higher BMIs than predicted on the basis of European-American equations (Gill and Pugh, 1954; Massou et al., 1955; Pion-Regoli, 1961). Other lines of evidence suggest that the relationship between BMR and standard independent variables (age, sex, and body size) may vary among populations including evidence of seasonal variation in BMR corresponding with diet and temperature changes (Ferro-Luzzi and Branca, 1962). This paper reports BMR values in a high altitude (4,500-5,450 m) community in the Tibetan Autonomous Region, China. The pastoral nomads of Phala offer a unique natural experimental setting for investigating BMR issues because they live at extremes of temperature and altitude, and have marked seasonal variation in dietary intake. Living permanently at altitudes of 4,500-5,450 m, at 30°N latitude, where the mean annual temperature is -2.1°C, the Phala nomads consume few calories and virtually no meat during the summer and increase calorie intake by roughly 50-250% during winter by adding large quantities of meat to the diet. The finding that a substantial proportion of nomads had summer calorie intakes below estimated BMIs, yet showed no signs of malnutrition, led to a hypothesis of seasonal metabolic variation. This study was designed to test the hypothesis that BMR of Phala nomads is lower in the summer than winter to compensate for the marked summer decrease in calorie intake. Secondary, it considered whether WHO predictive equations accurately predict BMR in this population living in a cold, high-altitude climate.

MATERIALS AND METHODS

Population

The study was conducted in a community of traditional pastoral nomads living in Phala, Tibet Autonomous Region of China. This is a harsh, high-altitude (4,500-5,450 m) environment on the Northern Plateau of Tibet. The mean annual temperature at a nearby weather station is -2.1°C (Denzin and Gonghui, 1988). For centuries, these nomads have subsisted by harvesting products from yak, sheep, and goats, directly consuming some (e.g., yogurt, butter, meat, wool) and trading others for goods they do not produce (e.g., barley, tea, metalware). The population of roughly 5,000 people in 560 households has been studied by two of the authors since 1986 (Goldstein and Beall, 1990). Dietary surveys in 1987, 1988, and 1990 revealed striking variation in calorie intake in Phala from a low calorie intake during the summer, the time peak subsistence activity, to a high calorie intake during the winter, a time of relative subsistence activity and maximum cold, when 200-500 g of meat/day are added to the diet. Nearly one-half the participants had summer calorie intakes below estimated BMI, while men had winter calorie intakes that were low (Beall and Goldstein, 1989). In 1987, the median summer rates of total calorie intake to predicted BMR for women were 1.8 and 1.6 among girls and boys 5-14 years, respectively, and 0.9 and 1.3 among women and men 15-59 years, respectively. Later that year, the median winter rates of total calorie intake to predicted BMR rose to 2.8 among girls and boys and 2.5 and 2.4 among women and men 15-59 years of age.
Sample
The study sample consisted of healthy, self-reporting, high-altitude native Pala residents 18-49 years of age. Every eligible person in four base camps ranging from 4,800 to 5,150 m was invited to participate, and all but one accepted. Forty nomads, 20 males and 20 females 28-49 years, were studied during summer (July and August) 1999. None of the females were pregnant or nursing an infant under 1 year old. Four males and seven females were reexamined during winter (December) 1999. Several factors prevented reexamination of all of the summer participants: some were sick; others were caring for them and their children; a number of household heads were away from camp, and several people were alone at satellite camps and unable to leave their herds unattended overnight.

Study protocol
Pairs of participants came to the field laboratory at the end of their workdays to sleep overnight in a heated chamber until 6:15 a.m. The average summer study began around 10:30 p.m., and the average winter study began around 9:00 p.m. A few brought bedding, although most simply slept atop the mattresses provided, bunched and wrapping heavy furs loose as usual. They had come earlier in the day to learn about the setup and to practice breathing with a mouthpiece and nose clips. During July and August 1999, participants slept in a 2.4 x 2.4 m insulated tent (Hansen Weatherport) ventilated with a 0.3 x 0.3 m window and heated with a single kerosene stove whose stovepipe vented through a pipehole to the outdoors. During December 1999, participants slept in a 3 x 3.5 m storage room of thin mud bricks that was heated with three kerosene heaters whose stovepipes vented to the outdoors. The heaters were checked periodically throughout the night and adjusted to maintain a thermoneutral indoor temperature. The heath usually ran at maximum capacity for most of the night.

The outdoor temperatures at 6:15 a.m. were about 0°C during July and August and -30°C in December. The average chamber temperature at the time of the summer tests was 21 ± 2°C (n = 10); there was no correlation between chamber temperature and summer BMI (r = 0.1, P > 0.5) or between chamber temperature and the difference between observed and predicted summer BMIs (r = 0.1, P > 0.5). The average temperature at the time of the winter tests was 17 ± 3°C (n = 11). There was no correlation between chamber temperature and the winter observed BMI (r = 0.3, P > 0.5) or between chamber temperature and the difference between observed and predicted winter BMIs (r = -0.4, P > 0.5).

At 6:15 a.m., two investigators entered the chamber to conduct tests of BMI using the standard Douglas bag method in an open-circuit system of the flow-through type (McLean and Tobin, 1987). Three 10-minute samples of expired air were collected in 50 liter plastic Douglas bags as the individual breathed through a mouthpiece while wearing nose clips. During the 10-minute rest intervals, skin temperature was measured on the back of the hand and the center of the forehead with a hand thermometer (YSI, Yellow Springs, OH). During the winter, oral temperature was measured with a clinical thermometer.

The volume of air expired at ATS was measured with a RAM-2000 air flow meter (Rayfield Equipment, Westfield, VT) and corrected to STPD using standard equations based on temperature and pressure (Ud- meter model 1275) at the time of analysis.

The percentage of oxygen in the expired air was measured with a galvanic cell Ametek oxygen analyzer model S-3A (Ametek Precision and Analytical Instruments, Pittsfield, PA) or an applied Electrochemistry, oxygen analyzer model S-3A (Applied Electrochemistry, Sunnyvale, CA) calibrated with room air. When room air is used as the calibration gas, a relative humidity or moisture must be taken into account because of the diluting effect of water vapor. The instrument manual provides a nomogram of normal oxygen content of air vs. relative humidity (Ametek Precision and Analytical Instruments, Division, Pittsburgh, PA, no date). The average observed oxygen content was 80.68 ± 6.89% (n = 74) compared with the theoretical value of 80.93% for dry room air. The partial pressures of carbon dioxide in the expired air was measured with a Lifescan 100 CO2 analyser (Biochron International, Waukesha, WI) calibrated with ambient air and 5% reference gas. This was converted to percentage of CO2 in expired air using measured barometric pressure at the time of analysis. Thirty-second samples were taken for both analyses from the small tube on the Douglas
bag after the contents were thoroughly mixed. The analyser was a direct reading spectrophotometer (Model 1120, Beckman, Fullerton, CA) with a 10°C bath. The spectrophotometer was calibrated against known standards before each measurement. The spectrophotometer was operated at 510 nm. The reading was converted to absorbance using a standard curve. The swelling factor was determined by measuring the amount of water that was absorbed by the paper discs before and after exposure to the extracts. The swelling factor was calculated as the ratio of the final volume to the initial volume of the paper discs. The results were expressed as the percentage of the initial volume of the paper discs.

Absorption spectroscopy was performed using a Cary 50 spectrophotometer. The spectrophotometer was calibrated against known standards before each measurement. The spectrophotometer was operated at 510 nm. The reading was converted to absorbance using a standard curve. The swelling factor was determined by measuring the amount of water that was absorbed by the paper discs before and after exposure to the extracts. The swelling factor was calculated as the ratio of the final volume to the initial volume of the paper discs. The results were expressed as the percentage of the initial volume of the paper discs.

The energy expenditure (EE) was calculated as the energy cost of activities performed by the subjects during the experiment. The EE was calculated using the following equation:

\[ EE = 3.9 	imes W + 1.1 	imes M + 1.1 	imes H \]

where W is the weight of the subject in kg, M is the height of the subject in m, and H is the heart rate in bpm. The EE was expressed in kcal/min. The energy expenditure was calculated for each subject at rest and during the activity.

Table 1 presents the anthropometric and DMAR data for the study. The results are expressed as the mean ± standard deviation. The statistical analysis was performed using the Student's t-test. The significance level was set at p < 0.05. The differences were considered significant if the p-value was less than 0.05.
<table>
<thead>
<tr>
<th>Variable</th>
<th>All age</th>
<th>1-5 years</th>
<th>6-7 years</th>
<th>8-9 years</th>
<th>10-19 years</th>
<th>20-29 years</th>
<th>30-39 years</th>
<th>40-49 years</th>
<th>50-59 years</th>
<th>60-69 years</th>
<th>70+ years</th>
</tr>
</thead>
</table>
| Male | | | | | | | | | | | | 1
| | 10 | 7 | 5 | 7 | 1 | | | | | | 1
| Age, yrs | 20 ± 16 | 15 ± 1 | 21 ± 3 | 42 ± 9 | 47 ± 9 | 61 | | | | | 1
| Weight, kg | 40 ± 15 | 31 ± 7 | 41 ± 6 | 50 ± 8 | 46 | | | | | | 1
| BMI, kg/m² | 27.3 ± 4.3 | 15.2 ± 5.9 | 19.6 ± 2.5 | 18.6 ± 1.4 | 19.7 | | | | | | 1
| BMI, kg/m² | 24.6 ± 9.0 | 26 ± 6.0 | 21 ± 14 | 20 ± 7 | 20 | | | | | | 1
| BMI, kg/m² | 16 ± 7 | 17 ± 3 | 18 ± 3 | 20 ± 9 | 18 | | | | | | 1
| BMI, kg/m² | 12 ± 5.5 | 12.5 ± 5.5 | 12.9 ± 5.5 | 14.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 1

| Female | | | | | | | | | | | | 1
| | 10 | 7 | 5 | 7 | 1 | | | | | | 1
| Age, yrs | 20 ± 16 | 15 ± 1 | 21 ± 3 | 42 ± 9 | 47 ± 9 | 61 | | | | | 1
| Weight, kg | 40 ± 15 | 31 ± 7 | 41 ± 6 | 50 ± 8 | 46 | | | | | | 1
| BMI, kg/m² | 27.3 ± 4.3 | 15.2 ± 5.9 | 19.6 ± 2.5 | 18.6 ± 1.4 | 19.7 | | | | | | 1
| BMI, kg/m² | 24.6 ± 9.0 | 26 ± 6.0 | 21 ± 14 | 20 ± 7 | 20 | | | | | | 1
| BMI, kg/m² | 16 ± 7 | 17 ± 3 | 18 ± 3 | 20 ± 9 | 18 | | | | | | 1
| BMI, kg/m² | 12 ± 5.5 | 12.5 ± 5.5 | 12.9 ± 5.5 | 14.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 15.5 ± 5.5 | 1

Table 2 demonstrates significant changes in BMI for the 11 nomads measured during the winter. The significant average increase of 10 kg in body weight and 0.9 kg/m² in BMI reflects trunk and not peripheral subcutaneous fat deposition. The sum of four trunk skinfolds increases significantly, while the sum of four proximal skinfolds does not. The estimated percentage of body fat calculated using the parametric skinfold and equations developed for a Japanese sample (Nagamine and Suzuki, 1994) increases by an average of 2.8%. Estimated lean body mass (LBM) and the ratio of BMI to LBM do not change. The seasonal change is more pronounced in females than males.

**DISCUSSION**
This is no evidence for summer metabolic adaptation in BMI among Phala nomads. Current WHO prediction equations are accurate for males and slightly underestimate summer BMI for females in this high-alti
TABLE 3. Estimated body composition changes of 17 female subjects between July, August and December 1983

<table>
<thead>
<tr>
<th>Variable</th>
<th>July-August</th>
<th>December</th>
<th>Change</th>
<th>Percent value</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>29.0 ± 0.5</td>
<td>28.0 ± 0.5</td>
<td>-1.0 ± 0.5</td>
<td>-3.4</td>
<td>-1.2</td>
</tr>
<tr>
<td>BMI kg/m²</td>
<td>17.3 ± 0.5</td>
<td>17.3 ± 0.5</td>
<td>0.0 ± 0.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sum of 4 skinfolds, mm²</td>
<td>45 ± 10</td>
<td>45 ± 10</td>
<td>0.0 ± 10</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sum of 4 or more</td>
<td>29 ± 11</td>
<td>29 ± 11</td>
<td>0.0 ± 11</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent body fat%</td>
<td>30.0 ± 1.0</td>
<td>30.0 ± 1.0</td>
<td>0.0 ± 1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Body fat mass, kg</td>
<td>6.0 ± 1.0</td>
<td>6.0 ± 1.0</td>
<td>0.0 ± 1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Lean body mass, kg</td>
<td>23.0 ± 1.0</td>
<td>23.0 ± 1.0</td>
<td>0.0 ± 1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tricep. &amp; biceps, cm²</td>
<td>25 ± 5</td>
<td>25 ± 5</td>
<td>0.0 ± 5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Age, yrs</td>
<td>30 ± 3</td>
<td>30 ± 3</td>
<td>0.0 ± 3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>42.5 ± 3.5</td>
<td>42.5 ± 3.5</td>
<td>0.0 ± 3.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>BMI kg/m²</td>
<td>17.3 ± 0.5</td>
<td>17.3 ± 0.5</td>
<td>0.0 ± 0.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sum of 4 skinfolds, mm²</td>
<td>27 ± 1.0</td>
<td>27 ± 1.0</td>
<td>0.0 ± 1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sum of 4 or more</td>
<td>20 ± 2</td>
<td>20 ± 2</td>
<td>0.0 ± 2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent body fat%</td>
<td>30.0 ± 1.0</td>
<td>30.0 ± 1.0</td>
<td>0.0 ± 1.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0 ± 5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Female N = 2</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yrs</td>
<td>31 ± 10</td>
<td>31 ± 10</td>
<td>0.0 ± 10</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>45.0 ± 3.5</td>
<td>45.0 ± 3.5</td>
<td>0.0 ± 3.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
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</tr>
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<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Note: Percent body fat = (body fat mass/lean body mass) * 100

There are no significant differences in BMR. The 10 patients indicate that the BMI measured under these field conditions are repeatable.
sessment variability is unlikely to be the reason for the absence of seasonal differences in BMR.

Although, the winter measurements are corrected at a lower average chamber temperature than the summer measurements, internal evidence indicates that this did not shift a thermostatically increase in metabolic rate and confound the seasonal comparison. If the lower winter chamber temperature were physiologically stressful, it would have caused a spurious winter increase in BMR and a larger winter difference between observed and predicted BMR. However, the insignificant winter difference of 4% between observed and predicted BMR does not differ from the insignificant summer difference of 6%. Similarly, if the winter chamber temperature were physiologically stressful, then the differences between morning core and periphery temperatures would have been greater in the winter due to vasocirculatory conservation, but above. However, summer and winter morning core temperatures did not differ (32.6°C, n = 4 and 32.9°C, n = 11, not did morning hand temperatures (32.3°C, n = 40 and 32.5°C, n = 11) or morning face temperatures (36.3°C, n = 40 and 33.7°C, n = 11). Therefore, the lower winter chamber temperature probably did not unconvertly elevate the winter BMR values.

The possibility that a winter increase in BMR is elicited by hypothyroidism is discounted by TSH measurements. The range of TSH values for 13 adults and women of 3.6 ± 1.7 μIU/ml. TSH values provide a basis for inferring adequate thyroid function and iodine sufficiency. Thyroid adequacy is judged by cutoff values for TSH beyond which prescriptive hypothyroidism is indicated. The standard published cutoff values used for the present assays is 10 μIU/ml (Torreani and Scher, 1988; WHO, 1988). The true cutoff value can vary by population and by assay type, and some iodine deficiency may exist even when TSH is only slightly elevated. Using a conservative TSH concentration of <6 μIU/ml, as indicative of euthyroid status, all but one sample with a value of 6.4 μIU/ml are below the cutoff. Therefore, participants were all sufficiently euthyroid to allow the qualification that poor thyroid function or frank hypothyroidism likely did not limit the potential for a winter increase in BMR.

Adults have higher BMR and more body fat than children. Females have higher values arrhythmic and perhaps seasonal factors than males (Table 1). Of the 24 adults 18-35 years, a BMI ≥18.0, 6% have a BMI in the 17.0-18.5 range, and two have a BMI <17. The latter BMI results have been suggested as indicative of adult chronic energy deficiency (CED) (James, 1994). However, this cutoff point has not been accepted as a universal standard applicable to all populations. The value of BMI, percent body fat, fat mass, and body weight are consistent with those reported by Norgren (1994) for rural non-European men and women. Therefore, the adult BMI of the Phnnom nomads stay not representative.

The expected seasonal difference in dietary intake and composition existed at the times of the BMI tests. No meal was consumed on any of the 50 percent days of summer weighted dietary intake. In contrast, most was consumed on 13 of the 14 percent days of winter weighted dietary intake (2% of persons did not eat meat for health reasons). Among the 23 BMI study participants for whom summer intake data are available, 6 (27%) had a daily total caloric intake less than their BMR. Neither of the two winter BMI study participants for whom winter intake data are available had intake below their described BMR. These data are consistent with earlier findings that Phnnom nomads add meat to their winter diet and that a
substantial proportion have summer caloric intake below their BMRs (Beal and Goldstein, 1993).

The absence of evidence for metabolic adaptation via lower summer BMR suggests that the Phala nomads either decrease physical activity or lose weight in the summer. Summer is the time of peak subsistence activity because milking and milk processing peak and because the active day is several...
hours longer. Therefore, decreased physical activity is not a summer option. Instead, body fat is lost. This is increased in body fat, but not LBM, from summer to early winter. It implies that the period of high caloric intake, beginning in mid-December and lasting until meat supplies are depleted around March/April, is a period of accumulating fat stores for energy during the summer, when caloric intake is low and subsequent activities are highest.

The fat is preferentially deposited on the trunk and may impose thermal insulation during the severe Tibetan winter. Generally, weight gain in cold temperatures is preferentially fat deposition (Mount, 1979). The greater female winter fat increase may be due to greater summer stress, since milking and milk processing are female activities. However, extrapolations from these small numbers are uncertain.

The estimated fat increase represents the first stages of a process that remains to be documented over a complete annual cycle. The average weight change of 1 kg is in the range found by other studies of dietary seasonality, some of which report changes in BMR while others do not (Ferrero-Luzzi and Branco, 1990). Evidence that winter weight gain is a recurring pattern in Phala is provided by comparing weights of children and young adults 20-25 years measured during the summer of 1987 and in early spring of 1988, Figures 1A and 1B illustrate heavier weight in the spring than summer. The 15% of boys and 25% of girls measured in both seasons gained an average of 3 and 2 kg, respectively from the summer to the spring of 1988.

With respect to the accuracy of WHO predictions, the equations predicted for BMI in this sample living under altitude and temperature extremes, the data reveal that the BMI of high altitude Tibetans is in the normal to high normal range of the WHO predictions. The finding that the BMI of Phala males is accurately predicted by the WHO equations is consistent with two studies of Andean high-altitude native males that report a BMI about 3 kg higher than sea level males (Mares et al., 1969; Poehlman et al., 1981). Corresponding data for the BMI of high altitude native females are apparently not available.

In summary, BMI measurements during 74 person-months of study show no evidence for metabolic adaptation to low summer caloric intake. Instead, the evidence suggests that Phala nomads adapt by accumulating subcutaneous fat during the winter and losing it during the summer.

ACKNOWLEDGMENTS

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LITERATURE CITED


