

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 nomads resident permanently in Phala, Tibet 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 13-69 years of age during the summer and remeasurement of 11 nomads during the winter of 1993 provide no evidence for low summer BMR to compensate for the low summer caloric intake. BMR in 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 this may buffer the summer period of low intake. The pattern of subcutaneous fat accumulation in winter, moreover, may afford slight improvement in physiological cold insulation during the severe winters as a consequence of depositing winter fat on the trunk rather than on the periphery. Thus, the dietary seasonality in Phala is a stress that elicits fluctuation in fat energy stores but not BMR. © 1996 Wiley-Liss, Inc.

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 (Payne and Waterlow, 1971). BMR has become the focus of much scientific attention owing to a 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 peoples living 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 (Benedict, 1932; Dubois and Dubois, 1916). A major review used the nearly 11,000 BMR measurements in the literature to develop predictive equations for males and females throughout the life cycle (Schofield, 1985) and formed the basis for the equations promulgated by the FAO/WHO/UNU (1985) report. Most of the measurements were obtained from Europeans and North Americans. However, that analysis, along with others during the past half-century, revealed

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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, Almeida (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 aboriginals (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, Quenouille 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 Rees (1991) 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 latitudes considered tropical, yet inhabit substantially cooler thermal environments than the surrounding lowlands and may have higher BMRs than predicted on the basis of Euroamerican equations (Gill and Pugh, 1964; Mazess et al., 1969; Picon-Reategui, 1961). Other lines of evidence suggesting that the relationship between BMR and standard independent variables (age, sex, and body size) may vary among populations includes evidence of seasonal variation in BMR corresponding with diet and/or temperature changes (Ferro-Luzzi and Branca, 1993).

This paper reports BMR values in a high altitude (4,850–5,450 m) community in the Tibet 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 4,850–5,450 m at 30° 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 caloric intake by roughly 50–250% (depending on age and sex) during the winter by adding large quantities of meat to the diet. The finding that a substantial proportion of nomads had summer caloric intakes below estimated BMR, 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 caloric intake. Secondly, 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 (4,850–5,450 m) environment on the Northern Plateau of Tibet. The mean annual temperature at a nearby weather station is -2.1°C (Domros and Gongbing, 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 300 people in 50 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 caloric intake in Phala from a low caloric intake during the summer, the time of peak subsistence activity, to a high caloric intake during the winter, a time of light subsistence activity and maximum cold, when 200–500 g of meat/day are added to the diet. Nearly one-half the participants had summer caloric intakes below estimated BMR, while none had winter caloric intakes that low (Beall and Goldstein, 1993). In 1987, the median summer ratios of total caloric intake to predicted BMR (FAO/WHO/UNU, 1985) were 1.0 and 1.6 among girls and boys 5–14 years, respectively, and 0.7 and 1.2 among women and men 15–59 years, respectively. Later that year, the median winter ratios of total caloric intake to predicted BMR rose to 1.9 and 2.3 among girls and boys and to 2.5 and 2.4 among women and men 15+ years of age.

Sample

The study sample consisted of healthy (by self-report), high-altitude native Phala residents 13+ years of age. Every eligible person in four base camps ranging from 4,850 to 5,150 m was invited to participate, and all but one accepted. Forty nomads, 20 males and 20 females 13–69 years, were studied during summer (July and August) 1993. None of the females were pregnant or nursing an infant under 1 year old. Four males and seven females were remeasured during winter (December) 1993. Several factors prevented remeasuring 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, loosening and wrapping heavy fleece robes 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 1993, participants slept in a 2.4 × 2.4 m insulated tent (Hansen Weatherport) ventilated with a 0.3 × 0.3 m window and heated with a single kerosene stove whose stovepipe vented through a pipehole to the outdoors. During December 1993, participants slept in a 3 × 3.9 m storage room of thick 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 heaters 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 = 40). There was no correlation between chamber temperature and summer BMR ($r = .05$, $P > .05$) or between chamber temperature and the difference be-

tween observed and predicted summer BMR ($r = -.01$, $P > .05$). 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 BMR ($r = -.25$, n = 11, $P > .05$) or between chamber temperature and the difference between observed and predicted winter BMR ($r = -.40$, $P > .05$).

At 6:15 a.m., two investigators entered the chamber to conduct tests of BMR 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 200 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 banjo thermister (YSI, Yellow Springs, OH). During the winter, oral temperature was measured with a clinical thermometer.

The volume of air expired at ATPS was measured with a RAM-9200 air flow meter (Rayfield Equipment, Waitsfield, VT) and corrected to STPD using standard equations based on temperature and pressure (Ultimeter model 12+) 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 Processing and Analytical Instruments Division, Pittsburgh, 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, its relative humidity must be taken into account because of the diluting effect of water vapor. The instrument manual provides a nomogram of nominal oxygen content of air vs. relative humidity (Ametek Thermox Instruments Division, Pittsburgh, PA, no date). The average observed oxygen content was 20.68 ± 0.09% (n = 74) compared with the theoretical value of 20.93% for dry room air. The partial pressure of carbon dioxide in the expired air was measured with a Lifespan 100 CO₂ analyzer (Biochem 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 analyzers were powered by electricity passed through a TrippLite line stabilizer/conditioner model LC-1800 powered by a 3500 Watt honda gasoline generator. Dry and wet bulb temperatures were measured using a sling psychrometer (Taylor Sybron, Arden, NC) at the end of the testing period in the morning and at the time of analysis a few hours later (when the animal herds had left camp).

Test reliability was evaluated by comparing first and second night BMR measurements on nine people during the summer and one during the winter. Two people had three summer measurement nights.

Anthropometry was performed according to standard protocols (Cameron et al., 1971; Harrison et al., 1988; Mueller et al., 1989) for height; weight; upper arm, thigh, and calf circumferences; and triceps, biceps, mid-axillary, subscapular, suprailiac, paraumbilical, thigh, and medial calf skinfolds. Body weight was measured with normal clothing and jewelry. The weight of the clothing and jewelry alone was measured later when the individual could change clothes. Reported body weight is measured as total weight less the weight of clothing and jewelry.

Dietary information to confirm the seasonal pattern was obtained by the 24 hr weighed food intake method for several households in the camps where the BMR measurements were obtained in both seasons. Logistical difficulties noted earlier resulted in very small winter samples.

Winter (December) thyroid function was evaluated from fingerstick blood spot samples collected on filter paper (Schleicher and Schuell, no. 903), air dried away from sunlight, and frozen (-23°C) only upon delivery to the laboratory. Blood spot thyroid stimulating hormone (TSH) was measured using a time-resolved fluoroimmunoassay (DELFA neonatal hTSH kit, Wallac Oy) performed as specified by the manufacturer. Concentrations are reported in serum equivalents. Assay sensitivity is $2\ \mu\text{U}/\text{mL}$ (2 SD above the lowest standard of $1\ \mu\text{U}/\text{mL}$); within- and between-assay coefficients of variation each averaged to 10.1% for a medium control (mean $10.2\ \mu\text{U}/\text{mL}$).

Analysis

A total of 56 summer and 18 winter overnight tests were completed. The 51 summer tests (40 first, 9 second, and 2 third nights) and 12 winter tests (11 first and 1 second

nights) are reported. Tests were omitted from analyses for subsequent report of pregnancy (one night), illness at the time of the test (two nights), and an anomalous BMR (one night), and for having a difference $> 20\%$ between the highest and lowest BMRs of the three trials (seven nights).

The respiratory quotient (RQ) was calculated as the ratio of the volumes of expired CO_2 and O_2 . BMR was calculated using a modification of the standard equation for energy expenditure (Weir, 1949) based on the percentage of oxygen in and the volume of expired air, assuming a fixed RQ, 20.93% oxygen content of inspired air, and a coefficient of 4.92. Because carbohydrate proportion in the Phala diet may change from summer to winter with the dietary change, the RQ and the coefficient may also change. Therefore, the energy expenditure equation was applied with a coefficient calculated using the measured RQ. This coefficient was obtained by substituting the measured respiratory quotient into the formula provided by Peters and Van Slyke (1946, p. 9). The actual percentage of oxygen in inspired air was used in the calculation of energy expenditure rather than the assumed 20.93%. The three 10-minute trials were averaged for the analysis. The difference between BMR calculated using all three trials and BMR calculated using just the last two was less than 1%. Predicted BMR based on sex, age, and weight was calculated using WHO equations ((FAO/WHO/UNU, 1985, p. 71).

Results are presented as means and standard deviations in the age categories used for the WHO prediction equations. The statistical analyses excluded the male and female over 60 years of age who are 10 and 13 years, respectively, older than anyone else in the sample. Paired t-tests addressed the null hypotheses of no seasonal differences, no night-to-night variation, and no difference between measured and predicted BMR. A significance level of $P < .05$ was accepted.

RESULTS

Table 1 presents the summer anthropometric and BMR data for 40 Phala males and females in four age groups. The low RQs result in coefficients for the energy equation lower than the usually assumed 4.92. The BMR of males and females average 1% and 7%, respectively, higher than that predicted by the WHO equations. The difference is significant for women (paired $t = 3.6$, $P < .05$).

TABLE 1. Anthropometric dimensions and basal metabolic rate measurements of 40 Phala nomads during July/August 1993

Variable	All ages (<60 yr)	10-17 years	18-29 years	30-59 years	60+ years
Males					
N	19 ¹	7	5	7	1
Age, years	29 ± 16	15 ± 1	23 ± 3	47 ± 9	69
Weight, kg	43 ± 11	31 ± 7	49 ± 6	50 ± 6	48
BMI, kg/m ²	17.7 ± 2.3	15.3 ± 1.4	19.4 ± 0.5	18.9 ± 1.7	19.7
Sum of 4 trunk skinfolds, mm ²	26 ± 9	20 ± 5	31 ± 14	29 ± 7	28
Sum of 4 peripheral skinfolds, mm ²	18 ± 3	17 ± 3	18 ± 3	19 ± 4	17
BMR, kcal/24 hr	1,360 ± 190	1,251 ± 163	1,545 ± 111	1,336 ± 7	1,367
BMR, WHO prediction, kcal/24 hr	1,353 ± 152	1,199 ± 124	1,429 ± 85	1,454 ± 68	1,131
Difference between observed and predicted	6 ± 150	52 ± 98	116 ± 87	-118 ± 143	235
BMR, kcal/24 hr RQ	.84 ± .06	.85 ± .07	.81 ± .07	.86 ± .06	.79
Calculated coefficient for energy expenditure equation	4.85 ± .08	4.86 ± .09	4.81 ± .08	4.87 ± .07	4.79
Females					
N	19 ¹	9	6	4	1
Age, years	25 ± 14	15 ± 1	21 ± 3	51 ± 7	67
Weight, kg	34 ± 7	34 ± 7	39 ± 4	41 ± 5	33
BMI, kg/m ²	17.1 ± 1.9	16.1 ± 1.9	18.2 ± 1.3	17.5 ± 1.9	15
Sum of 4 trunk skinfolds, mm ²	50 ± 24	46 ± 28	63 ± 20	38 ± 15	69
Sum of 4 peripheral skinfolds, mm ²	33 ± 11	32 ± 11	35 ± 9	31 ± 15	—
BMR, kcal/24 hr	1,239 ± 142	1,244 ± 191	1,227 ± 40	1,247 ± 145	561
BMR, WHO prediction, kcal/24 hr	1,136 ± 89	1,162 ± 93	1,064 ± 66	1,185 ± 44	940
Difference between observed and predicted	103 ± 126	82 ± 153	163 ± 58	62 ± 130	-378
BMR, kcal/24 hr RQ	.83 ± .06	.85 ± .07	.81 ± .07	.85 ± .06	.79
Calculated coefficient for energy expenditure equation	4.83 ± .08	4.87 ± .05	4.84 ± .09	4.74 ± .05	4.92

¹This summary and subsequent analyses exclude the two individuals over 60 years of age who are 13 (male) and 10 (female) years older than anyone else in the sample. Mean ± standard deviation.

²Sum of subscapular, midaxillary, paraumbilical, and suprailliac skinfolds.

³Sum of triceps, biceps, thigh, and medial calf skinfolds.

BMR, basal metabolic rate; RQ, respiratory quotient; BMI, body mass index.

Table 2 demonstrates no significant increase in BMR for the 11 nomads remeasured during the winter.

Table 3 reports body composition changes between summer and winter. The insignificant average increase of 1.0 kg in body weight and 0.9 kg/m² in the BMI reflects trunk and not peripheral subcutaneous fat deposition. The sum of four trunk skinfolds increases significantly, while the sum of four peripheral skinfolds does not. The estimated percentage of body fat calculated using the paraumbilical skinfold and equations devel-

oped for a Japanese sample (Nagamine and Suzuki, 1964) increases by an average of 2.3%. Estimated lean body mass (LBM) and the ratio of BMR to LBM do not change. The seasonal change is more pronounced in females than males.

DISCUSSION

There is no evidence for summer metabolic adaptation in BMR among Phala nomads. Current WHO prediction equations are accurate for males and slightly underestimate summer BMR for females in this high-alti-

TABLE 2. Basal metabolic rate of 11 Tibetan nomads during July/August and December 1993

Variable	July/August	December	Change	Paired t value
Weight, kg	39 ± 6	40 ± 4	+1 ± 2	-1.1, ns
BMR, kcal/24 hr, measured	1,253 ± 131	1,212 ± 191	-41 ± 194	-7, ns
BMR, kcal/24 hr, predicted	1,230 ± 124	1,241 ± 101	+11 ± 34	-1.1, ns
Difference between measured and predicted BMR, kcal/24 hr	23 ± 156	-29 ± 174	-52 ± 200	0.9, ns
RQ	.82 ± .07	.89 ± .04	-.07 ± .06	-3.8, P < .05
Calculated coefficient for energy expenditure equation	4.82 ± .09	4.91 ± .05	-.09 ± .08	-3.9, P < .05

BMR, basal metabolic rate; RQ, respiratory quotient; ns, not significant.

TABLE 3. Estimated body composition changes of 11 Phala nomads between July/August and December 1993

Variable	July/August	December	Change	Paired t value	% change
Total sample					
Weight, kg	39.3 ± 5.5	40.3 ± 4.3	+1.0 ± 2.4	-1.4, ns	+3.3 ± 6
BMI kg/m ²	17.3 ± 1.2	17.9 ± 1.3	+0.6 ± 1.1	-1.6, ns	+3.3 ± 6
Sum of 4 trunk skinfolds (mm) ¹	43 ± 23	56 ± 32	+13 ± 11	3.9, P < .05	+30 ± 17
Sum of 4 peripheral skinfolds (mm) ²	28 ± 11.4	32 ± 15	+3 ± 7	-1.6, ns	+11 ± 24
Percent body fat ³	15.3 ± 4.8	17.6 ± 6.5	+2.3 ± 2.7	-2.9, P < .05	+14 ± 14
Body fat mass, kg	6.0 ± 1.7	7.2 ± 2.9	+1.2 ± 1.4	-2.9, P < .05	+18 ± 17
Lean body mass (kg)	33.3 ± 5.6	33.2 ± 3.9	-0.1 ± 2.1	.22, ns	-0.4 ± 6
BMR/LBM (kcal/kg)	38 ± 7	37 ± 9	-1 ± 9	.4, ns	-2 ± 22
Males, N = 4		(15-55)			
Age, years	36 ± 21				
Weight, kg	42.2 ± 8.3	41.1 ± 6.0	-1.0 ± 2.7	0.76, ns	-1.4 ± 7.3
BMI kg/m ²	17.9 ± 1.5	17.6 ± 0.4	-0.3 ± 1.2	0.54, ns	-1.4 ± 7.3
Sum of 4 trunk skinfolds (mm) ¹	27 ± 10	33 ± 13	6 ± 4	-3.4, P < .05	+24 ± 11
Sum of 4 peripheral skinfolds (mm) ²	19 ± 2	18 ± 2	-1 ± 2	0.93, ns	-5 ± 13
Percent body fat ³	10.2 ± 1.8	12.0 ± 3.8	+1.7 ± 2.9	1.21, ns	+16 ± 16
Body fat mass, kg	4.4 ± 1.5	5.1 ± 2.2	0.7 ± 1.0	-1.5, ns	+15 ± 15
Lean body mass (kg)	37.8 ± 7.0	36.1 ± 4.1	-4 ± 5	-1.62, P < .05	-10 ± 14
BMR/LBM (kcal/kg)	34 ± 6	38 ± 9	+4 ± 5	-1.62, ns	+10 ± 14
Females, N = 7		(14-57)			
Age, years	31 ± 19				
Weight, kg	37.6 ± 2.8	39.9 ± 3.4	+2.3 ± 1.4	-4.18, P < .05	+6 ± 3.8
BMI kg/m ²	17.0 ± 1.0	18.1 ± 1.6	+1.0 ± 0.7	-4.17, P < .05	+6 ± 3.8
Sum of 4 trunk skinfolds (mm) ¹	53 ± 23	70 ± 33	17 ± 12	-3.62, P < .05	+32 ± 20
Sum of 4 peripheral skinfolds (mm) ²	34 ± 11	39 ± 12	+6 ± 8	-1.97, ns	+20 ± 25
Percent body fat ³	18.3 ± 2.9	20.8 ± 5.5	+2.5 ± 3.1	-2.14, .05 > P < .10	+13 ± 14
Body fat mass, kg	6.8 ± 1.1	8.4 ± 2.6	+1.5 ± 1.6	-2.49, P < .05	+20 ± 18
Lean body mass (kg)	30.8 ± 2.8	31.5 ± 2.7	+0.8 ± 0.9	-2.35, .05 > P < .10	+3 ± 3
BMR/LBM (kcal/kg)	41 ± 16	37 ± 10	-4 ± 10	0.97, ns	+8 ± 23

¹Sum of subscapular, midaxillary, parasumbilical, and suprailiac skinfolds.

²Sum of triceps, biceps, thigh, and medial calf skinfolds.

³Equation using parasumbilical skinfold (Nagamine and Suzuki, 1964).

BMI, body mass index; BMR, basal metabolic rate; LBM, lean body mass; ns, not significant.

tude, cold-stressed population, and there are no seasonal differences in BMR. The 10 retests indicate that the BMR measured under these field conditions are repeatable (Table

4). There is only an average difference of 21 kcal (2%) between the first and second nights of measurement and no difference in the RQ or energy equation coefficient. Thus, mea-

TABLE 4. Repeatability of basal metabolic rate measurements in Phala nomads (n = 11)

Variable	First night	Second night	Difference	Paired t value
BMR, kcal/24 hr	1,303 ± 172	1,325 ± 270	21 ± 199	-0.3, ns
RQ	0.84 ± .07	0.84 ± .08	0 ± .08	-0.1, ns
Coefficient for energy expenditure equation	4.85 ± .09	4.85 ± 1.0	0 ± .08	-0.2, ns

BMR, basal metabolic rate; RQ, respiratory quotients; ns, not significant.

surement variability is unlikely to be the reason for the absence of seasonal differences in BMR.

Although the winter measurements occurred at a lower average chamber temperature than the summer measurements, internal evidence indicates that this did not elicit a thermoregulatory 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 difference between morning core and periphery temperatures would have been greater in the winter due to vasoconstriction to conserve core heat. However, summer and winter morning oral temperatures did not differ (36.2°C, n = 4 and 36.1°C, n = 11), nor did morning hand temperatures (32.3°C, n = 40 and 32.7°C, n = 11) or morning face temperatures (35.5°C, n = 40 and 33.7°C, n = 11). Therefore, the lower winter chamber temperature probably did not spuriously elevate the winter BMR values.

The possibility that a winter increase in BMR is precluded by hypothyroidism is discounted by TSH measurements. The range of TSH serum equivalent values in blood-spots obtained from 13 adult men and women (including the 11 BMR study participants) during December 1993 was 2.0–8.4 μ U/mL (mean 3.6 ± 1.7 μ U/mL). TSH measures provide a basis for inferring adequate thyroid functioning and iodine sufficiency. Thyroid adequacy is judged by cutoff values for TSH beyond which presumptive hypothyroidism is indicated. The standard published serum value (and the one reported for the present assay) is <10 μ U/mL (Torresani and

Scherz, 1986; WHO, 1993). 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 <8 μ U/mL as indicative of euthyroid status, all but one sample (with a value of 8.4 μ U/mL) are well below the cutoff. Therefore, participants were all sufficiently euthyroid to allow the conclusion that poor thyroid function or frank hypothyroidism likely did not limit the potential for a winter increase in BMR.

Adults have higher BMI and more body fat than children; females have higher sums of trunk and peripheral skinfolds than males (Table 1). Fourteen of the 22 adults 18+ years have a BMI \geq 18.5, six have a BMI in the 17.0–18.5 range, and two have a BMI <17. The latter BMI ranges 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 communities. The values of BMI, percent body fat, fat mass, and body weight are consistent with those reported by Norgan (1994) for rural non-European men and women. Therefore, the adult BMI of the Phala nomads may not represent CED.

The expected seasonal difference in dietary intake and composition existed at the times of the BMR tests. No meat was consumed on any of the 50 person days of summer weighed dietary intake. In contrast, meat was consumed on 13 of the 14 person-days of winter weighed dietary intake (one person did not eat meat for health reasons). Among the 22 BMR 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 BMR study participants for whom winter intake data are available had intakes below their measured BMR. These data are consistent with earlier findings that Phala nomads add meat to their winter diet and that a

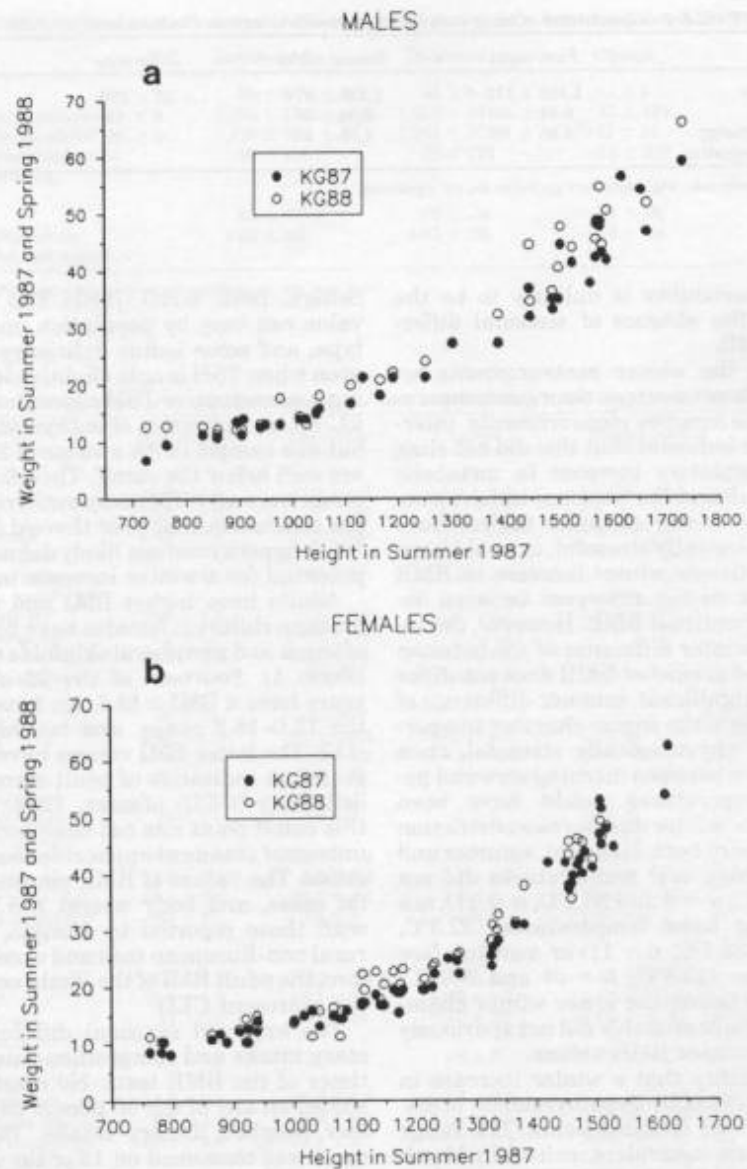


Fig. 1. **a:** Comparison of spring 1988 and summer 1987 weight for height of 47 Phala males <25 years of age. **b:** Comparison of spring 1988 and summer 1987 weight for height of 76 Phala females <25 years of age.

substantial proportion have summer caloric intakes below their BMRs (Beall 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 inferred from the increase in body fat, but not LBM, from summer to early winter. It implies that the period of high calorie intake, beginning in mid-to-late November 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 subsistence activities are highest. The fat is preferentially deposited on the trunk and may improve 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 estimates of fat increase represent 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 (Ferro-Luzzi and Branca, 1993). Evidence that winter weight gain is a recurring pattern in Phala is provided by comparing weights of children and young adults 10–24 years measured during the summer of 1987 and in early spring of 1988. Figures 1A and 1B illustrate heavier weight for height in the spring than summer. The 35 males and 52 females measured in both seasons gained an average of 3 and 2 kg, respectively from the summer through spring 1988.

With respect to the accuracy of WHO prediction equations for BMR in this sample living under altitude and temperature extremes, the data reveal that the BMR of high altitude Tibetans is in the normal to high normal range of the WHO predictions. The finding that the BMR of Phala males is accurately predicted by the WHO equations is consistent with two studies of Andean high-altitude native males that report a BMR about 5% higher than sea level males (Mazess et al., 1969; Picon-Reategui, 1961). Corresponding data for the BMR of high-altitude native females are apparently not available.

In summary, BMR measurements during 74 person-nights of study show no evidence for metabolic adaptation to low summer calo-

ric intakes. Instead, the evidence suggests that Phala nomads adapt by accumulating subcutaneous fat during the winter and losing it during the summer.

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