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Original Research Article

Testosterone, Aging, and Body Composition in Men From Harare, Zimbabwe

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ABSTRACT To examine age-related changes in body composition and testosterone (T) among men in an urban sub-Saharan African population, measures of body composition and salivary T were obtained from 109 males ages 20–78 in Harare, Zimbabwe. Measures included height, weight, suprailiac and triceps skinfold, and percent body fat by bioelectric impedance (BIA). Saliva samples were assayed for T using radioimmunoassay. Average BMI of the overall sample (23.16 (SD = 18.12) kg/m^2 was close to Western populations, while salivary T levels (AM = 196 ± 96 pmol/l; PM = 172 ± 98 pmol/l) were much lower. Both morning (beta = –0.535; $P < 0.001$) and afternoon salivary T declined with age (beta = −0.385; $P < 0.001$). Multiple regression models indicate that PM salivary T (beta = 0.24; $P = 0.025$), was a predictor of fat-free mass, but neither AM nor PM salivary T was related to fat mass or other measures of body composition. In addition, height was significantly related to PM salivary T levels in men under the age of 60. Multivariate regression indicates that PM salivary T is a predictor of fat-free mass when controlled for height and adiposity. These findings suggest that T is related to both lean mass and overall body size among men from a non-Western nonsubsistence population. As such they are consistent with the hypothesis that bioavailable T plays a role in energetic allocation among human males. Am. J. Hum. Biol. 16:704–712, 2004. © 2004 Wiley-Liss, Inc.

The responsiveness of testosterone (T) in human males to energetic status has become a matter of interest to human biologists. Because in most vertebrates reproduction imposes fewer direct physiological costs on males than it does on females, male gonadal function should not be as exquisitely sensitive to energetic status as that of females (Bribiescas, 2001; Campbell and Leslie, 1995). Nonetheless, under evolutionary conditions of energy limitation, male reproductive function may be sensitive to meaningful energetic variation. Both Ellison (2001) and Bribiescas (2001) have argued that male T levels should vary in relation to energy availability as represented by somatic stores, especially of skeletal muscle. Given the long-term cost of maintaining a large body size and the role of T in promoting energetically costly lean tissue (Bhasin, 2003), T responsiveness may be most notable in terms of pubertal growth.

Comparisons of energy-limited subsistence populations provide some support for these theoretical expectations. Most such populations exhibit lower levels of salivary T compared to well-nourished Western samples (Bentley et al., 1993; Bribiescas, 1996; Campbell et al., 2003; Ellison and Panter-Brick, 1996; Ellison et al., 2002; Gray, 2003), suggesting that male reproductive function is sensitive to overall energetic conditions. Age-related differences in salivary T across subsistence populations are most apparent among males age 20–30 (Ellison et al., 2002), suggesting that population differences in salivary T may be more closely tied to the attainment of adult body size, rather than to energetic conditions during adulthood itself.

The relationship of salivary T to anthropometric measures within subsistence populations suggests that T levels may positively reflect current energy status, especially under conditions of low energy availability. Among Tamang males of Nepal, Ellison and Panter-Brick (1996) reported significant positive correlations between T and indicators of energy status such as weight, biceps skinfold, and midarm circumference, but only in winter, a low-nutrition period.

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Campbell et al. (2003) found that salivary T was positively related to measures of fat among nomadic Ariaal men of northern Kenya who were suffering from acute nutritional stress at the timing of sampling.

There have also been reports of a positive T-height relationship in both Western and subsistence populations. Jamison et al. (1993) reported a relationship between salivary T and height in a sample of young adult males in the U.S. Morning salivary T was positively correlated with stature in both Tamang and Kami men of Nepal (Ellison and Panter-Brick, 1996). However, in rural Kavango men salivary T/serum T ratio (but not salivary T alone) was significantly and negatively correlated with stature (Winkler and Christiansen, 1991).

Here we extend the investigation of salivary T and male body composition to a non-Western, nonsubsistence population: urban men in Harare, Zimbabwe. Zimbabwe is a westernizing population with conditions—most importantly, nutrition and pathogen load—that can be characterized as intermediate between previously studied subsistence populations and Western populations. As such, it presents an opportunity to determine the relationship of T to measures of both long-term and short-term energy status in a population with intermediate energetic limitation.

Predictions

1. T levels will be negatively correlated with age. This prediction is in accordance with the large literature on T and aging (Ellison et al., 2002; Harman et al., 2001).
2. T will be positively correlated with measures of height and muscle mass, as indicated by previous human studies (Bhasin et al., 1997; Ellison and Panter-Brick, 1996). Under conditions of moderate energetic limitation, the allocation effects on T should be more visible. This is because trade-offs are more direct when energy is more limited (Stearns, 1992).
3. Salivary T levels among Zimbabwe men will be intermediate between that of Western populations and that of subsistence populations because diet and disease stress is intermediate (Campbell and Leslie, 1995). The slope of age-related decline of T should be commensurately intermediate.

MATERIALS AND METHODS

Study population

Zimbabwe is an unevenly modernizing but poor sub-Saharan African country, which during the study period was not yet undergoing the current regime-driven economic crisis. During 1997, when the study was carried out, the population of Zimbabwe was about 11.6 million (MOHCW, 1997). The major ethnic groups were Shona (77%), Ndebele (18%), and European (<5%) (Palmer and Birch, 1992). The average male life expectancy in Zimbabwe was 52.4 years. The birth rate per 1,000 was 39.1, and the death rate was 12.0. The weight-for-age of all Harare men was comparable to that of U.S. men (MOHCW, 1997).

As in other sub-Saharan African countries, infectious disease is a major problem. Malaria is endemic in Zimbabwe, with a very high prevalence in the wetter lowland areas (MODCW, 1997). Other major infectious diseases are tuberculosis, hepatitis, rabies, cholera, and bilharzia. The prevalence of HIV infection in Zimbabwe is among the highest in sub-Saharan Africa (UNAIDS, 2002).

Subjects

The study was approved by the Institutional Review Board of Harvard University. The participants were recruited from five sites: two factories, a construction site, a government research institute, and an old-age home to obtain a wide age range. The 109 participants ranged in age from 19 to 70. All of the sites, except the old-age home, were located within the city of Harare. It should be noted that the recruitment of employed subjects means that this group is preselected to be at least healthy enough to work, except in the case of the men from the old-age home.

Data collection was carried out during September of 1997 by W. Lukas and B. Campbell. The questionnaires were administered in Shona by research assistants recruited from University of Zimbabwe medical school.

The questionnaires covered three major areas: basic demographic variables, sexual and reproductive histories, and health. Research assistants were trained by B. Campbell and W. Lukas to explain the purpose of the study to participants and to ask survey questions about fertility, health, and behavior in English, Shona, or Ndebele, as required. The questionnaire was modified by conferring with professors, medical students, and nurses at the Obstetrics and Gynecology section of the University of Harare's medical school.

Anthropometric measurements

Measurements of blood pressure, height, weight, percent body fat (bioelectrical impedance analysis), skinfolds (triceps, calf, periumbilical, suprailiac, midaxillary, and subscapular), circumferences (waist, upper arm, and mid-calf) were taken. Skinfolds were taken with standard calipers to the nearest millimeter, weight to the nearest tenth of a kilogram, and body fat to the nearest tenth of a percentage by an electronic scale/body fat monitor (Tanita), circumferences to the nearest tenth of a cm, and height to the nearest cm by a standard anthropometer, following the methods in Lohman et al. (1988). Fat-free mass was calculated by multiplying percent fat-free mass with weight.

Anthropometric formulae

Anthropometric values were computed using the following formulae:

$$\text{Body mass index (BMI)} = \text{weight (kg)}/(\text{height (m)}^2)$$

$$\text{Upper arm muscle plus bone area (MBPA)} = ((\text{arm circumference (cm)}) - (\Pi * \text{triceps sf (cm)})^2)/4\Pi$$

Hormonal measures

Samples of saliva were also collected from the participants. One morning (9–12 AM) and one afternoon (3–4 PM) saliva sample was collected on each of two consecutive days. Participants were given sugarless gum to promote salivation.

The samples were continuously frozen, transported, and stored in the refrigerator in the Anthropology Department of Harvard University. The methods for handling saliva have been described in Ellison (1988). T concentration was determined from the Zimbabwean subjects' saliva with fluoroimmunoassay (FIA) analysis of extracted steroids. FIA assays were performed using DELFIA T assay kits (EG+G Wallac, catalog #A050-101) under the direction of P. Ellison from June to August of 1998.

The interassay coefficient of variation of the controls was 19.78% for the low control and 16.20% for the high control. The manufacturer's estimate of sensitivity is 4 nmol/L (0.01 ng/mL). According to the manufacturer, the kit has a 12% cross-reactivity with dihydrotestosterone. The T values reported are unadjusted for recovery (80–90%). Means were derived from the two AM sample values and from the two PM values from each subject.

Statistical analysis

In order to capture as much of the complexity of the age-related pattern of changes in body composition possible, we chose to model age-related patterns of body composition using Lowess curves, even though this method does not allow for significance testing. On the other hand, because we were comparing age-related declines in salivary T to earlier results, we modeled age-related changes in T using linear regression. We also used linear regression to determine the relationship of salivary T to measures of body composition. All statistical analysis was performed with SPSS for Windows 11 (Chicago, IL). Only individuals with both AM and PM T values were included in the statistical analyses.

RESULTS

Descriptive statistics of anthropometric and endocrine variables are reported in Table 1. The mean age of the Zimbabwean men was 42.18 (SD = 13.75) years. The mean BMI was 23.16 (SD = 18.12) kg/m^2, very similar to that reported for U.S. African-Americans of 23.7 kg/m^2 (Dettwyler, 1992). Average percent body fat was 14.77 (SD = 6.76). Zimbabwean fat-free mass as determined by bioelectrical impedance was 56.59 (SD = 6.91) kg. In comparison, a group of Zimbabwean soldiers had a mean fat-free mass of 60.9 kg prior to a rigorous training program and 57.1 kg after (Sewani-Rusike et al., 2000).

Mean morning (AM) salivary T was 196 (SD = 97) pmol/l and mean afternoon (PM) T was 172 (SD = 98) pmol/l ($t = 3.00$; $P = 0.003$ by paired t-test). In comparison, in the Northern Ache, mean AM T was 192 pmol/l and mean PM was 156 pmol/l (Bribiescas, 1996); in the Lese, mean AM T was 341 pmol/l and mean PM T was 280 pmol/l (Ellison et al., 1989); and in Boston men, mean AM T was 437 pmol/l (Bribiescas, 1997).

TABLE 1. Summary of Zimbabwe anthropometrics and hormone values

	N	Min.	Max.	Mean	SD	Skew	Kurtosis
Age	105	21	78	42.18	13.74	0.422	−0.571
Height, cm	105	148.2	190.5	173.8	7.569	−0.461	0.935
Weight, kg	104	39.1	110.9	66.95	12.83	0.805	1.497
BMI kg/m^2	104	14.90	33.22	22.047	3.383	0.889	0.989
% Body Fat	103	1.5	35.5	14.77	6.756	0.805	0.426
MPBA, cm^2	105	18.34	90.08	41.67	11.04	1.027	2.634
Suprailiac SF	105	2.00	33.00	9.705	6.834	1.674	2.226
FFM, kg	103	37.89	74.25	56.56	6.912	0.142	0.664
AM T, pmol/l	105	15	501	195.9	97.2	0.724	0.354
PM T, pmol/l	105	18	555	171.8	97.5	1.134	1.652

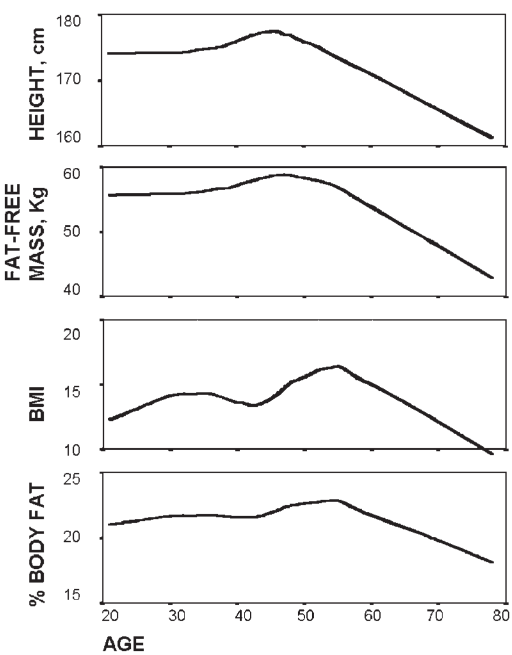

Fig. 1. Age and anthropometric variables. Lines for each variable represent a Lowess fit using 50% of points fit and 3 iterations.

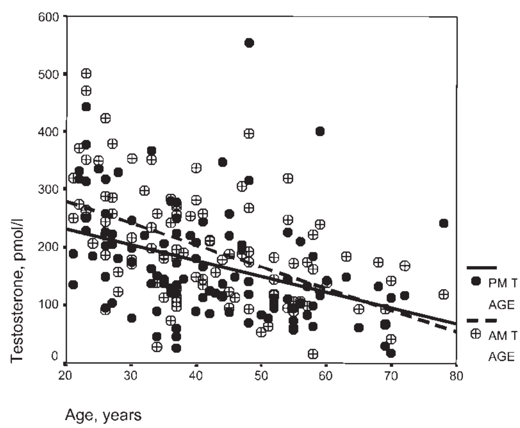

Fig. 2. Decline of AM testosterone and PM testosterone with age. Lines represents best fit linear regression with age. Both AM T and PM T decline significantly with age. AM T(pmol/l) = 353 – 3.7x, beta = –0.534, $P < 0.001$, n = 105; and PM T (pmol/l) = 287 – 2.7x, beta = –0.385, $P < 0.001$, n = 105.

Figure 1 shows the age-related pattern of four anthropometric variables: height, fat-free mass, body fat, and BMI based on Lowess curves for each variable using 50% of points fit and three iterations. The Lowess curves for fat-free mass, body fat, and BMI show similar age-related changes, displaying a gradual rise with a peak in the 50s and steeper decline thereafter.

Height shows a steady age relationship, with decline after the 50s. A linear model of height predicted by age was significant: $R^2 = 0.070$, beta = –0.281, $P = 0.004$.

Figure 2 shows the relationship of AM and PM salivary T with age. Consistent with prediction, both AM (beta = −0.534; $P < 0.001$) and PM (beta = −0.385; $P < 0.001$) measures show a significant decline with age. Such a decline is consistent with numerous studies of both Western (Tenover, 1997) and non-Western men (Bribiescas, 2001; Ellison et al., 2002).

AM T (pmol/l) was predicted by the equation 353 – 3.7x (PM T was predicted by the equation 287 − 2.7x). In comparison, the mean slope of AM T decline in the four other populations is −2.0, while the slope of decline in the U.S. is −3.4. If men over 60 are excluded from the Zimbabwean sample, the slope is even steeper (y = 375 – 4.3x). Closer examination of age groups highlights the steep decline in T. The mean AM T (pmol) of Zimbabwean men 21–29 years old was 285, SD = 105, n = 22; men 30–44 was 197, SD = 77, n = 40; and men 45–60 was 157, SD = 82, n = 34. However, again it must be noted that the non-Zimbabwean populations were assayed with different methods than the Zimbabwean materials.

Table 2 shows the results of various measures of body composition as dependent variables, with salivary T and age as the predictors in linear regression models. Consistent with our prediction, PM T (beta = 0.24; $P = 0.025$) predicted fat-free mass in a linear regression model controlling for age. The relationship between PM T and fat-free mass is depicted in the scatterplot of Figure 3. However, AM T (beta = –0.019; $P = 0.868$) failed to predict fat-free mass. The relationship of PM T to fat-free mass was stronger (overall model adj. $r^2 = 0.09$; age beta = 0.248; $P = 0.024$; PM T beta = 0.342; $P = 0.002$) when men 60 years old and older were excluded from the analysis. Neither AM nor PM T was associated with any other variable that could be indicative of musculoskeletal maintenance, including MPBA, BMI, or total weight.

Table 3 shows regression models predicting fat-free mass, with various anthropometric variables used as predictors in addition to PM T and age. Note that with the addition of height PM T is no longer a significant predictor. However, PM T is once again a significant predictor when body fat ($P < 0.1$) and both body fat and suprailiac skinfold ($P > 0.05$) are added to the regression model, suggesting that T does have an independent effect on lean mass when short-term energetic status is controlled for.

The relationship between PM T and fat-free mass prompted investigation of the relationship between T and height by regression analysis. The relationship between T and height was investigated in men under the age of 60 to eliminate the effects of vertebral compression (White and Folkens, 1991). In men under 60, PM but not AM T was predictive of height ($P = 0.036$), consistent with our prediction.

This relationship between PM T and height in men under 60 is depicted in the scatterplot in Figure 4.

TABLE 2. Testostosterone and anthropometic variables

Dependent variables	N	adj. R^2	beta AMT	beta Age
A. AM testosterone				
AM T and age: independent variables				
Height	104	0.079	0.058	−0.278*
Weight	103	−0.009	0.057	−0.121
BMI	103	−0.016	−0.072	−0.025
% Body Fat	102	−0.015	−0.038	0.043
MPBA	104	−0.015	−0.058	−0.078
Suprailiac SF	104	0.007	−0.178	−0.153
Fat-Free Mass	102	0.007	−0.026	−0.175
B. PM testosterone				
PM T and age: independent variables				
Height	104	0.084	0.162	−0.219*
Weight	103	0.012	0.168	−0.019
BMI	103	−0.015	0.078	0.047
%Body fat	102	−0.014	0.043	0.081
MPBA	104	−0.004	0.123	0.000
Suprailiac SF	104	−0.011	−0.078	−0.090
Fat-free mass	102	0.055	0.240*	−0.061

Note: betas are standardized coefficients. *$P < 0.05$.

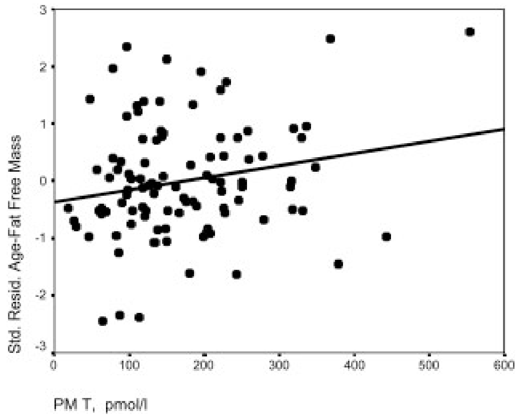

Fig. 3. PM testosterone and standardized residuals of fat-free mass on age in Zimbabwean Men. PM T is significantly positively correlated with standardized residuals of fat-free mass on age. Age-Fat-Free Mass resid = –0.358 –2.1x, beta = 0.201, $P = 0.04$, n = 102.

TABLE 3. Predictors of fat-free mass

Overall regression model				
N	102	102	102	102
Adj. R^2	0.055	0.676	0.875	0.882
Predictors	Std. Co.	Std. Co.	Std. Co.	Std. Co.
PM T	0.240*	0.074	0.072†	0.083*
Age	0.567	0.086	0.034	0.046
Height		0.825**	0.740**	0.727**
% Body fat			0.449**	0.382**
Suprailliac SF				0.083

†$P < 0.1$; *$P < 0.05$; **$P < 0.01$.

DISCUSSION

Contrary to prediction, salivary T levels in Zimbabwean men was not only lower than Western men, but among the lowest levels reported for a non-Western population (Bribiescas, 1996; Ellison et al., 1987). Nor were age-related declines in T intermediate between those of Boston and subsistence populations. PM salivary T was related to both

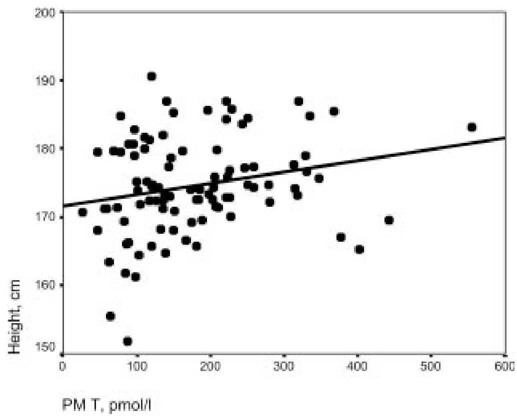

Fig. 4. PM Testosterone and height in Zimbabwean men under 60. PM T is significantly positively correlated with height in men under 60. Height (cm) = 172 – 1.7x beta = 0.230, $P = 0.025$, n = 94.

total lean mass and height in men under 60, suggesting that T may be most directly related to overall body size. However, multiple regression models indicate that salivary T is related to lean mass even when controlled for height and adiposity, suggesting that there is a direct effect of T on muscle mass when overall body size and short-term energy status are taken into account.

Age-related changes in body composition and salivary T

Our results suggest that muscle, fat mass, and BMI remained relatively constant in this sample of urban Zimbabwe men into their 50s and then decline into old age. It should also be noted that these data represent cross-sectional, not true longitudinal, patterns of body composition. Any age-correlated patterns, especially height, may reflect secular trends rather than changes during the aging process.

With the possibility of secular trend in mind, the overall pattern of body composition suggests cumulative positive energy balance until the 50s and then a decline in energy balance after that. While increased muscle and fat mass prior to the 50s suggests the capacity to maintain positive energy balance, in contrast, the decline after the 50s suggests a steep reduction in caloric intake at older ages, which may be related to changes in biological mechanisms underlying appetite (Wilson and Morley, 2003).

These results are generally consistent with studies of Western men (Barlett et al., 1991; Heitmann, 1991), with the exception that Western men tend to have larger increases in fat mass in late middle age (Garn, 1994; Stini, 1994), presumably reflecting a greater cumulative positive energy balance. In addition, we found a decline in height after 50 years of age, which probably reflects both the effects of vertebral compression (White and Folkens, 1991) and a secular trend in growth (Eveleth and Tanner, 1990). Childhood malnutrition has been shown to result in a greater likelihood of lower adult height in Zimbabwe (Alderman et al., 2002).

The age-related decline in salivary T in this sample is consistent with results from the Western populations showing declines in total and free T during aging (Harman et al., 2001; Nahoul and Roger, 1990), as well as declines in salivary T in subsistence populations (Campbell et al., submitted; Ellison et al., 2002). However, contrary to our prediction, the slope of age-related decline in AM salivary T in Zimbabwean men was not intermediate between the U.S. and subsistence populations, but greater than any of the other populations studied: U.S. Lese, Ache, Nepal (Ellison et al., 2002).

Relationship between salivary T and body composition

The positive correlation between PM T and fat-free mass reported here is consistent with earlier findings that salivary T is related to measures of energetic status among men in subsistence populations (Panter-Brick and Ellison, 1996; Campbell et al., submitted). Among males in Nepal, these included weight, biceps skinfold, and arm circumference (Panter-Brick and Ellison, 1996). On the other hand, among the Ariaal of northern Kenya, salivary T was related to both overall body fat and suprailliac skinfolds, but not lean mass (Campbell et al., 2003), contrary to the specific results obtained here. However, the Ariaal results represent the effects of both acute and chronic undernutrition, unlike the condition of the Zimbabwe sample, which appears to be mild undernutrition, based on BMI. It should also be noted that while the relationship between PM T and fat-free mass is significant, it is also very weak (predicting less than 1% of the variance in fat-free mass).

In addition, the positive relationship between PM salivary T and height found in men under 60 is consistent with earlier findings of a relationship between T and height in a sample of men from Nepal (Ellison and Panter-Brick, 1996) and a sample of U.S. males, ages 18–25 (Jamison et al., 1993). Given the restricted age range, variation in height is likely to represent variation in attained adult height. Together, these results indicate that linear growth is related to variation in salivary T across populations.

Interestingly, Campbell et al. (2003) did not find a significant relationship between salivary T and height among a sample of Ariaal males, despite a positive relationship between body fat and salivary T. However, this population included individuals over 60 years of age, potentially biasing the relationship between attained adult height and T exposure due to vertebral compression with age (White and Folkens, 1991).

The finding that salivary T is a predictor of fat-free mass, when controlled for height, percent body fat and suprailliac skinfolds suggests that individual variation in salivary T is directly related to the development and maintenance of muscle mass, independent of long-term growth or short-term energetic status. This is consistent with T's anabolic effects on muscle mass as evidenced by the muscle-enlarging effects of T supplementation in hypogonadal men (Bhasin et al., 1997), improving grip strength in aging men (Tenover, 1994), and enhanced uptake of glucose in muscle cells (Tsai and Sapolsky, 1996). In addition, FTI (free T index) has been related to arm and muscle strength in a longitudinal study of normal aging men (Roy et al., 2002).

It is unclear why we failed to find relationships between both fat-free mass and height and AM salivary T, as we did with PM salivary T. It can be argued that AM salivary T is a better marker of endogenous T production as it is unaffected by events during the day. However, Gray et al. (2004) found a significant relationship between BMI and evening salivary T, but not AM or PM salivary T in a sample of U.S. men, suggesting that PM salivary T may represent a better measure of effective T exposure on somatic tissue, including muscle, than AM salivary T.

Population comparison of testosterone levels

Although the use of different assay techniques and different age ranges precludes direct comparison, our results suggest that compared to previous results for non-Western subsistence populations (Bribiescas, 1996; Ellison et al., 1987), salivary T levels are quite low among men in Zimbabwe. However, a study of total serum T in Zimbabwean soldiers found a mean of 577.24 ng/dL prior to a rigorous training program and 242.25 ng/dL after (Sewani-Rusike et al., 2000). While the latter values are on the low end of the normal Western clinical range of 300–1,000 ng/dL (Krupp, 1995), the pretraining values are safely in the middle of that range.

Several points are of interest in comparing our results with those of Sewani-Rusike et al. (2000). First, the Zimbabwean soldiers used in the Sewani-Rusike et al. study are young men, are presumably better fed than ordinary Zimbabwean men, and thus their serum T levels may be relatively high compared to the general population. On other hand, the men in the current sample cover a wider age range and were primarily selected from factories, meaning that they represent generally healthy individuals. Furthermore, total serum T reflects testicular production of T, while salivary T reflects sex hormone-binding globulin (SHBG) levels as well. SHBG may be influenced by nutritional status; BMI and protein intake are inversely correlated with SHBG (Longcope et al., 2000). Thus, the relatively low salivary T levels in the current study compared to apparently normal total serum T levels found by Sewani-Rusike et al. (2000) may also reflect differences in short-term energetic status and diet between the two groups.

More generally, reduced T levels among males in non-Western populations may result from a number of different factors, including prenatal growth (Cicognani, 2002), current energetic status (Campbell et al., 2003; Ellison and Panter-Brick, 1996), and the energetic costs of infection (Bentley et al., 1993; Campbell and Leslie, 1995). Although a large proportion of Zimbabwean men were mildly underweight, this population does not appear to be under severe nutritional stress, suggesting that nutritional stress is unlikely to be the major cause of low salivary T levels. On the other hand, it is difficult to rule out the possibility of chronic infection, which may also play a role in reducing T levels, directly through endocrine-immune communication (Sun and Risbridger, 1994) as well as indirectly through the effects of infection on energy balance (Bentley et al., 1993; Campbell and Leslie, 1995).

Given the high rates of AIDS in Zimbabwe (UNAIDS, 2002), the possibility that HIV infection has suppressed T levels (Dobs et al., 1988) in this population should also be considered. However, all of the men denied having HIV when we asked them. Of course, it should not be expected that positive HIV status would be readily admitted. Only 10 of the men had BMIs under 18.5, the cutoff for undernutrition according to Ferro-Luzzi et al. (1992), which suggests that HIV-related wasting is hardly evident in this population, if it is occurring at all.

CONCLUSIONS

The current finding that PM salivary T is positively (if weakly) related to lean mass among a sample of Zimbabwe men, as well as height among men under 60, lends additional support to the hypothesis that idea that the level of bioavailable T levels are associated, in part, with the allocation of energy to the somatic component of male reproductive function (Bribescas, 2001; Ellison, 2001). These somatic aspects of reproduction include muscle mass, utilization of fat stores, and increased linear growth during development. In this study involving a population under moderate nutritional stress, the effects of T appear to be related to both muscle mass and linear growth, but not adipose stores. This is consistent with earlier findings among subsistence populations that T is related to measures in a population subject to both acute and chronic nutritional stress (Campbell et al., 2003), and measures of muscle and size among a population characterized by chronic undernutrition (Ellison and Panter-Brick, 1996). Future studies may help reveal in more detail the metabolic mechanisms that link variation in energetic status to salivary T levels.

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