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Reproductive maturation in a sample of captive male baboons

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Abstract: Though baboons have been considered an appropriate non-human primate model for studying human reproductive and endocrine development, the overall similarity of reproductive maturation between the two species is unclear. This paper examines the role of testicular and adrenal hormones for pubertal changes in a cross-sectional sample of 21 captive male savanna baboons. Morphometric and hormonal indices demonstrate changes in size and gonadal function, but not adrenal function, during pubertal maturation among baboons. Results also indicate that gonadal, but not adrenal, androgens are related to morphometric variables. We conclude that savanna baboons do not make an appropriate evolutionary model of human pubertal maturation.

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Introduction

The morphological development and socioendocrinology of baboons have been studied extensively [10, 43], surpassed only in number by studies of rhesus macaques. Utilized in studies of both human disease and growth and development, baboons represent a potentially useful non-human primate model of a wide variety of human physiological processes. Baboons have been considered an appropriate non-human primate model for studying human reproductive and endocrine development [19], because unlike rhesus macaques, savanna baboons are non-seasonal breeders that lack circannual rhythms in testosterone levels [11].

Normal human male pubertal development is characterized by a distinct growth spurt in height [7]. Testicular growth begins at the spurt's initiation and ends late in the growth spurt [37], with spermatozoyte maturation evident prior to peak height velocity [41]. Gonadarche is associated with increases in testosterone in human males [37], coinciding with the somatic growth spurt. Estrogen levels also increase and play a key role in the regulation of bone growth underlying the growth spurt [20, 30].

In addition to gonadal maturation, puberty among humans is characterized by increases in adrenal activity, more specifically the production

of dehydroepiandrosterone (DHEA) and its sulfated metabolite, dehydroepiandrosterone-sulfate (DHEA-S), referred to as adrenarche [7, 21]. Whereas gonadal androgens contribute to bone growth and gonadal maturation [9, 38], the role of DHEA and DHEA-S in the pubertal development of boys is not as well established. While both gonadal and adrenal androgens have been found to contribute to height growth in adolescent males [1, 56], DHEA-S has been shown to have an independent effect on growth in muscle and bone [56].

Pubertal development among male baboons is similar to that of humans in terms of increases in testosterone levels, testicular size, body weight, and crown-rump length during pubertal onset [10, 18, 32]. However, beyond the parallels in gonadal maturation and growth, baboons and humans differ. Baboons show no increase in DHEA-S levels during puberty [11, 19]. Furthermore, the role of estradiol in the pubertal maturation of normal males has not been investigated in baboons, though exogenous estrogen has been shown to stimulate somatomedin-C in adult *cynocephalus* ssp. females [17].

In this paper, we look more carefully at the role of testicular and adrenal androgens in the pubertal maturation of savannah baboons. In addition to testosterone, we also measured estradiol as a marker of gonadal function, and measures of adrenal hormones including DHEA-S, DHEA, cortisol, and their ratios are used to determine if there are changes in adrenal function during pubertal development and their potential contribution to pubertal growth. Given the lack of evidence for increased DHEA production in baboons, we hypothesized that gonadal, but not adrenal, androgens would be significantly correlated to measures of somatic growth.

Materials and methods

This cross-sectional survey utilizes 21 hybrid male baboons between 1.7 and 13.2 years of age maintained at the Tulane Regional Primate Research Center, Covington, LA. These animals represent all males over 1.7 years of age in a hybrid breeding colony of approximately 330 savanna baboons (sex ratio of males to females, 1:12) of both Olive (*Papio cynocephalus anubis*) and Yellow (*Papio cynocephalus cynocephalus*) phylogenetic heritage. All animals were housed in a single one-acre outdoor corral, a semi-natural ecological context that accommodates normal physical and social activity [15, 42]. Animals were provisioned with Purina Monkey Chow (Ralston Purina Co., St Louis, MO) daily. Diet was supplemented with fresh fruit weekly and water was available *ad libitum*. Matrilineal data and precise chronological ages were maintained in the Center's computer system.

All measurements took place during the population's biannual health inspection in early December, 1999. In order to minimize inter-observational error, morphometric measurements and hormonal analyses were made by one investigator (MPM) when possible. However, some morphometric measurements ($< 20\%$) were made by another trained investigator. All animals were anesthetized with ketamine hydrochloride (10 mg/kg), a dissociative anesthetic widely used in studies requiring transient animal tranquilization [5, 13]. Ketamine has shown no significant effects on serum androgen levels or production rates [55]. Each animal was examined once, between 07:00 and 09:00 hours, to eliminate any circadian effect. All animals were held in a standardized position with their bodies lying on the left side and arms and legs extended perpendicular to the vertebral axis. The head and muzzle were aligned in the Frankfort plane relative to the torso [15]. Body weight was determined to the nearest 0.1 kg. A Dean fiberglass tape measure was placed parallel to the vertebrate column and measured to the nearest 0.01 cm from the occipital node to the ischeal callosity. The upper arm circumference, a good predictor of lean body mass [46], was measured to the nearest 0.01 cm by wrapping the tape measure around the halfway point between the olecranon and the tip of the scromion.

Tricep skinfold was measured to the nearest millimeter using non-flexible, sliding calipers, periumbilicular (abdominal) skinfold was measured 1 cm below the umbilicus, and the subscapular skinfold was measured 1 cm below the inferior angle of the scapula [15]. Past studies have indicated that abdominal skinfold in male rhesus macaques is significantly correlated with amount of total body fat [28]. Abdominal and hip circumferences were measured to the nearest 0.1 cm at the widest portion along the umbilicus and pelvis, respectively, using a Dean fiberglass tape measure. Abdominal circumference has been demonstrated to be a good predictor of total body fat mass in macaques [29]. A waist/hip ratio was then calculated, which has also been used as a measure of fat distribution in macaques [29].

Both left and right testes were digitally restrained within the scrotum and length and breadth of each testis were measured to the nearest millimeter using the non-flexible, sliding calipers. The epididymis was excluded in all measurements and scrotal skin thickness was not accounted for. Testicular volumes were calculated using the

formula for determining the volume of a prolate spheroid (testicular volume $= \pi LW^2/6$) [24]. Right testicular volume (to the nearest 0.01 cubic centimeter) will be reported because of a single outlier in left testicular volume. Otherwise, the volume of both testes is highly correlated with one another as well as to total testicular volume (0.97) [4, 6]. A testes/body size ratio was calculated as right testicular volume (cubic centimeter) divided by body size (kg). Our method differs from standard references [25, 45], which use testes weight. However, since testes volume is highly related to testes weight [6] this figure does allow comparison of the current results by species.

A blood sample was collected from the femoral vein using a 10-ml SST vacutainer collection tube (Becton Dickinson, Franklin Lakes, NJ) and a 21-gauge needle. These blood samples were collected immediately following tranquilization, limiting gonadal and adrenal hormone concentrations from being significantly influenced by the stress of capture [43]. The sera from the blood collected were aliquoted into two containers and frozen at -40°C until assayed for estradiol, total testosterone, DHEA-S, DHEA, and cortisol using solid-phase RIA procedures (estradiol, testosterone, and DHEA-S: Diagnostic Products Corp, Los Angeles, CA; DHEA and cortisol: Diagnostic Systems Laboratory, Webster, TX). Intra-assay coefficients of variation were less than 6.9% for all assays.

Due to the small sample size ($n = 21$), normal distribution of variables with equal variances across the relatively wide age range cannot be assumed. Thus, the morphometric and hormonal parameters of the four age groups of animals used here were analyzed and compared via non-parametric statistics using Statistica for Windows [48]. The Kruskal–Wallis (KW) one-way analysis of variance by ranks, which accounts for the magnitude of individual observations in regards to one another [31], was used to assess overall significance. To compare individual groups to one another, the Mann–Whitney U-test, a procedure based on the ranks of observations and comparing medians of individual groups, was utilized [34]. For all statistical tests, alpha was set at $P < 0.05$.

Morphological and hormonal variables were then analyzed as functions of age by polynomial regression. Non-parametric multivariate regression modeling procedures were employed to determine the effect of testosterone and DHEA-S on measures of somatic growth. First, Spearman's correlation coefficient (rho or S), which is the non-parametric rank equivalent of Pearson's correlation coefficient [47], was computed via Statistical Analysis System [44]. Secondly, the typical multiple regression analysis, using the standard t-test to test the null hypothesis H_0: $\beta_p = 0$, or the test of significance for the predictor controlling for age, was computed. Lastly, non-parametric rank regression was used to compute the Jaeckel–Hettmansperger–McKean statistic (HM) [26].

Results

Average values

Average hormone and morphometric variables are reported by age groups similar to the previously described stages of growth of male savanna baboons [10, 18, 32]. The age distribution includes pre-pubertal and pubertal males as well as adults up to 13 years.

Age group one: 2–3 years (testes not yet dropped); $n = 6$.
Age group two: 4–5 years (growth spurt); $n = 4$.
Age group three: 6–9 years (continued development/young adulthood); $n = 6$.
Age group four: 10–14 years (prime adulthood); $n = 5$.

Table 1 shows the average values for all hormonal and morphometric measures, based on the four age groups outlined above. Comparison with other studies [4] suggests that the baboons in this study are comparable in terms of morphometric measures to other populations.

Age-related changes – morphology

Figure 1 presents box-plots of the age-related pattern of selected morphometric measures including weight, length, arm circumference, and waist circumference.

Length, as well as all three skinfold measures, shows differences only in the youngest group versus all older age groups. Males 2–3 years of age were significantly shorter and had significantly smaller skinfold measures than any other males studied. However, males 4–5 years of age were not significantly shorter than older males, the probable result of a small sample size. Importantly, this time period of growth encompasses the previously identified pubertal onset growth spurt of yellow baboons [10].

Males 2–3 years of age weighed significantly less than any of the males in the other age groups and males 4–5 years of age also weighed, on average, less than older males. There was no significant difference between any animals 6–14 years of age in terms of weight. Past studies have demonstrated similar patterns in both length and weight growth

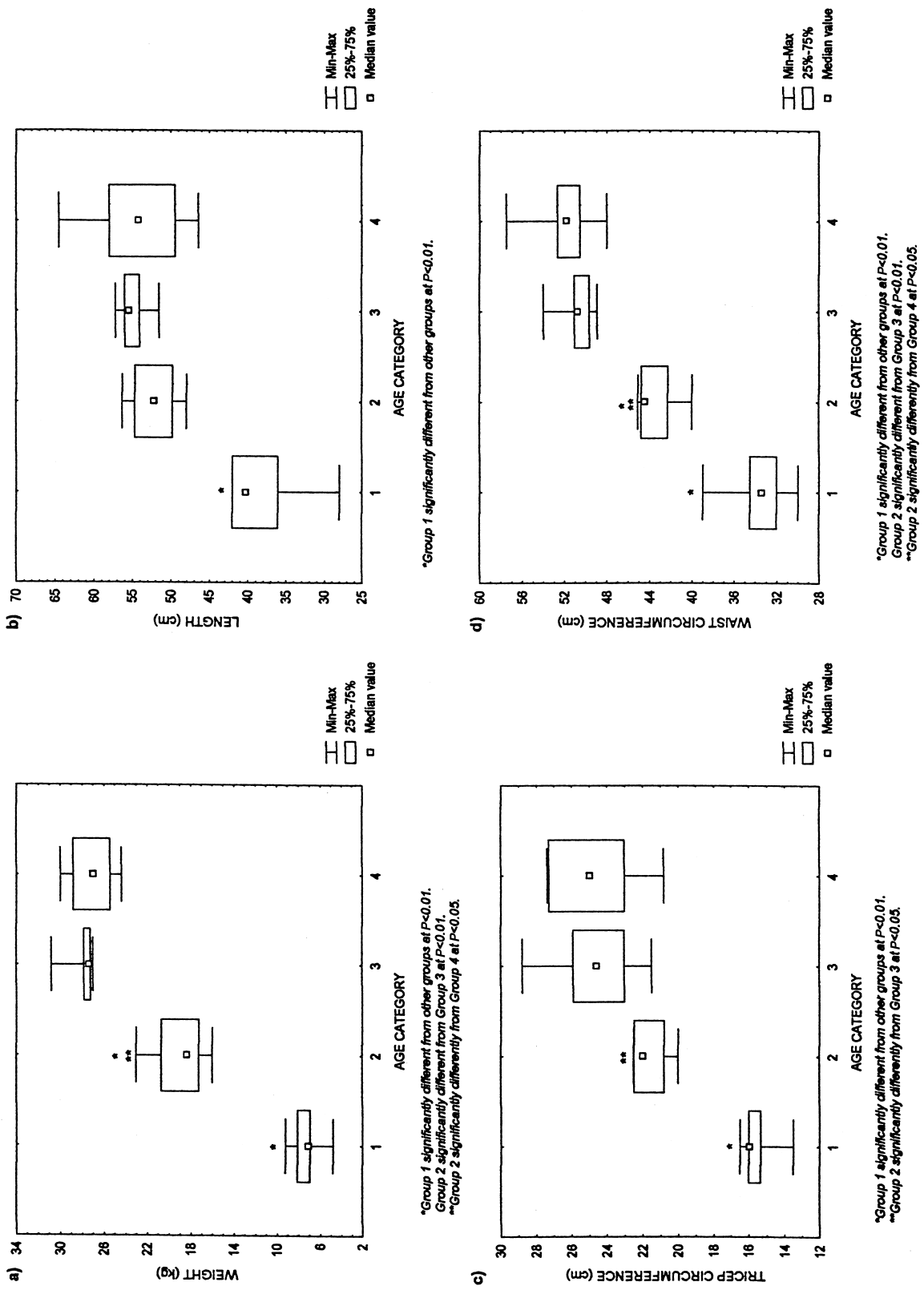

Fig. 1. Median morphometric values for baboons across age groups. (**a**) Weight: Males 2–3 years of age weighed significantly less than any of the males in the other age groups and males 4–5 years of age also weighed, on average, less than older males. (**b**) Length: Only those animals in the youngest age group were, on average, significantly shorter than all older males. (**c**) Tricep circumference: The youngest age group had significantly smaller triceps than all older males and males in the second age group had significantly smaller triceps than males 6–9 years of age. (**d**) Waist circumference: Follows the same pattern as weight, with the youngest age group as well as those animals 4–5 years of age having a significantly smaller waist than all older males.

during the pubertal development of male baboons [18]. Of the three age groups where the testes have dropped, animals in the second age group (4–5 years) demonstrate significantly lower testicular volumes compared to older males in both the third and fourth age groups. There was no significant difference between age groups three and four in terms of testicular volume measurements, suggesting that testicular growth plateaus between 6 and 10 years of age in these animals.

Males in age group one (2–3 years) had significantly smaller tricep circumferences compared to males in the other age groups. Males in the second age group (4–5 years) also had significantly smaller tricep circumferences compared to males 6–9 years of age, but not males 10–14 years of age.

Both hip and waist circumference seem to follow the same pattern as weight in this sample. Hip circumference seems to level off beginning around 8 years of age with no significant difference in hip circumference in age groups three or four. Waist circumference, a good measure of body fat mass [29], seems to increase continually into prime adulthood, but again, the age group comparisons follow the same pattern of significance as they do with respect to hip circumference. Here the pattern includes a dramatic increase through age 5, followed by a leveling out into young adulthood (6–14 years).

Age-related changes – hormones

Figure 2 shows the age-related pattern for the gonadal (testosterone) and adrenal (cortisol, DHEA, and DHEA-S) hormones. Overall, testosterone shows an increase with age with the pre-pubertal animals having the lowest level, with a peak in the second age group (4–5 years), followed by a decline throughout ages 6–14. However, testosterone values are quite variable, which may be due to episodic bursts of testicular activity [12, 23]. In fact, there is no significant difference in testosterone levels in age groups two, three, or four. A box-plot for estradiol is *not* shown because this sample demonstrated little consistent pattern of estradiol with age, due to several values below the limit of detection of the assay.

Among the adrenal hormones, DHEA-S shows a significant decline with age starting with the youngest animals (youngest animals age 1–3 years have significantly higher DHEA-S levels compared to all animals 4 years and older). Regression of individual data points indicates that this decrease is best modeled as an exponential decline. On the other hand, DHEA shows more variability and no significant decline with age (although a trend is present). In addition, cortisol also shows high variability and little consistent change with age, although a non-significant decreasing trend is clearly present.

Table 1. Average morphometric and hormonal values for baboons across age groups[1]

	Age group			
Variable	1 (2–3 yr) n = 6	2 (4–5 yr) n = 4	3 (6–9 yr) n = 6	4 (10–14 yr) n = 5
Age (yr)	2.21 ± 0.56[2]	4.89 ± 0.13[2]	8.44 ± 1.08[2]	11.61 ± 1.22
Weight (kg)	7.22 ± 1.46[2]	18.95 ± 2.93[2]	28.17 ± 1.44	26.76 ± 2.12
Length (cm)	38.11 ± 5.49[2]	52.2 ± 3.44	54.37 ± 2.28	54.96 ± 7.19
Tricep circumference (cm)	15.55 ± 1.07[2]	21.63 ± 1.18[3]	24.88 ± 2.52	24.60 ± 2.83
Tricep skinfold (mm)	1.67 ± 0.52[2]	5.00 ± 2.00	4.83 ± 1.60	4.20 ± 1.10
Subscapular skinfold (mm)	1.67 ± 0.52[2]	9.00 ± 1.63	9.00 ± 1.55	8.20 ± 1.30
Abdominal skinfold (mm)	1.67 ± 0.52[2]	7.25 ± 1.71	11.33 ± 6.15	6.40 ± 1.52
Waist circumference (cm)	33.75 ± 3.03[2]	43.53 ± 2.37[2]	51.07 ± 1.81	52.10 ± 3.50
Hip circumference (cm)	36.47 ± 2.63[2]	50.13 ± 2.12[2]	58.53 ± 3.94	57.42 ± 4.53
Waist/hip ratio	0.93 ± 0.08	0.87 ± 0.00	0.87 ± 0.00	0.91 ± 0.00
Testicular volume (cc)	N/A	2.48 ± 0.76[2]	3.79 ± 0.86	3.96 ± 1.09
Testosterone (ng/ml)	0.02 ± 0.01[2]	5.38 ± 2.93	5.18 ± 2.09	4.64 ± 1.91
Estradiol (pg/ml)	0.41 ± 0.73	0.85 ± 1.05	1.35 ± 2.13	0.74 ± 1.64
DHEA-S[4] (μg/dl)	29.14 ± 12.37[2]	4.52 ± 2.79	4.50 ± 2.43	3.75 ± 4.50
DHEA (ng/ml)	18.95 ± 4.36	15.20 ± 1.78	11.59 ± 6.15	14.91 ± 10.28
Cortisol (μg/ml)	60.03 ± 11.81	44.84 ± 15.15	40.96 ± 10.24	41.06 ± 12.28
DHEA-S/cortisol ratio	0.52 ± 0.33[2]	0.10 ± 0.03	0.11 ± 0.07	0.08 ± 0.10
DHEA-S/DHEA ratio	12.06 ± 3.96[2]	2.39 ± 1.59	3.39 ± 2.48	1.69 ± 1.59

[1] Average group values ± standard deviation.
[2] Significantly different from all *older* age groups at $P<0.05$.
[3] Significantly different from age group three at $P<0.05$.
[4] DHEA-S.

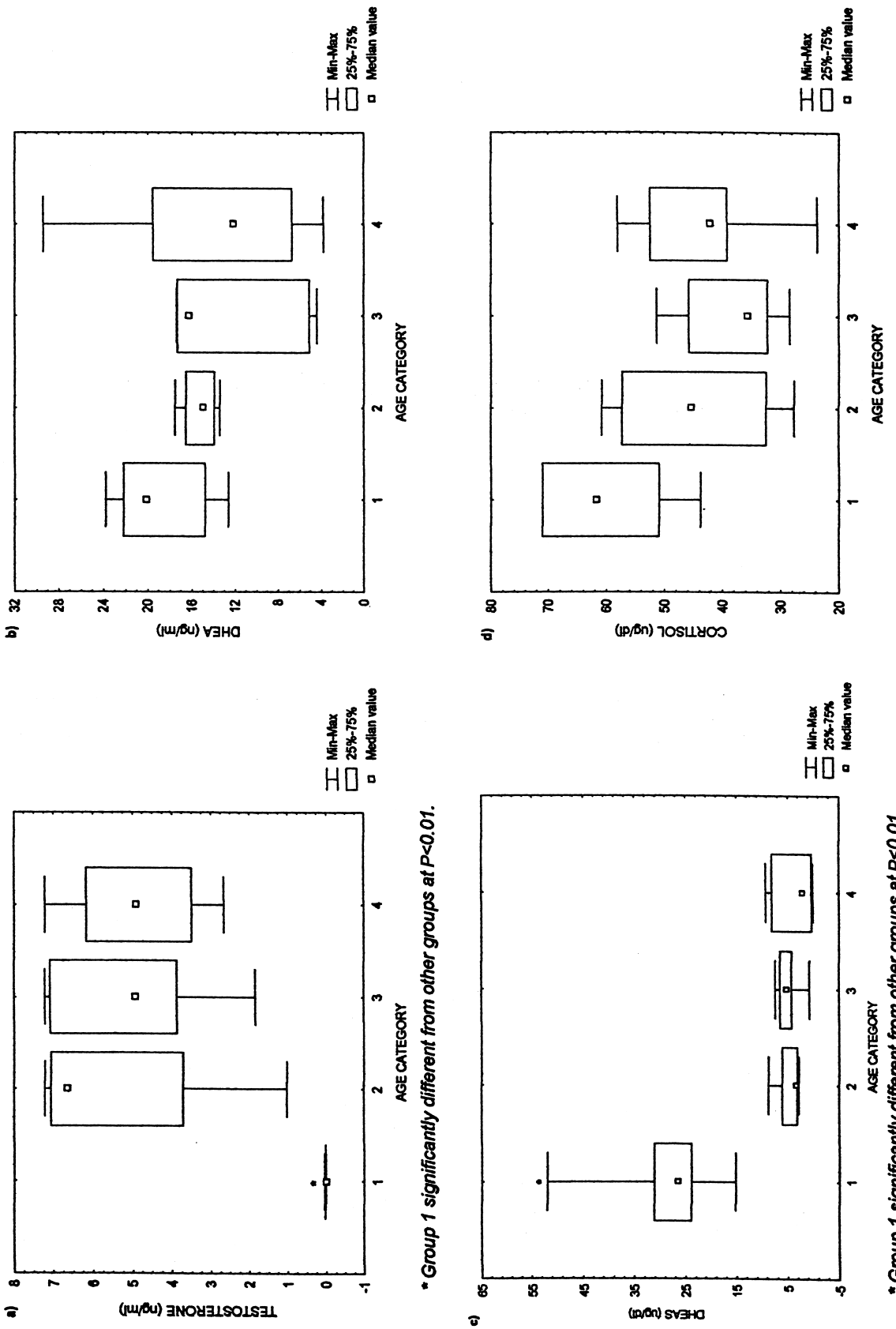

Fig. 2. Median hormonal values for baboons across age groups. (**a**) Testosterone: Only those animals in the first age group had significantly lower testosterone levels than all older males. There seems to be, on average, an initial decline in testosterone levels in the fourth age group, though this is non-significant. (**b**) DHEA: There is no clear pattern of DHEA levels throughout the four age groups. (**c**) DHEA-S: The youngest age group demonstrates significantly higher DHEA-S levels as compared to all older males. (**d**) Cortisol: Like DHEA, cortisol levels are too variable to demonstrate any clear pattern.

Table 2. Hormonal predictors of growth

Predictor: testosterone (n = 21)	
Outcome: weight	
Partial correlation coefficients:	*Rank regression:*
Spearman: S = 0.45, $P = 0.0454$	Predicted weight = 4.84 + 0.824*t + 1.73*age
Pearson: r = 0.41, $P = 0.07$	HM = 4.48, $\sim F_{1,18}$ $P = 0.046$
Outcome: length	
Partial correlation coefficients:	*Rank regression:*
Spearman: S = 0.17, $P = 0.49$	Predicted length = 37.6 + 0.788*t + 1.38*age
Pearson: r = 0.30, $P = 0.21$	HM = 2.73, $\sim F_{1,18}$ $P = 0.12$
Outcome: tricep circumference	
Partial correlation coefficients:	*Rank regression:*
Spearman: S = 0.42, $P = 0.07$	Predicted tricep = 14.97 + 0.562*t + 0.64*age
Pearson: r = 0.43, $P = 0.06$	HM = 3.47, $\sim F_{1,18}$ $P = 0.08$
Predictor: DHEA-S (n = 20)[1]	
Outcome: weight	
Partial correlation coefficients:	*Rank regression:*
Spearman: S = −0.20, $P = 0.40$	Predicted weight = 14.5 − 0.361*D + 1.33*age
Pearson: r = −0.56, $P = 0.02$	HM = 6.91, $\sim F_{1,17}$ $P = 0.02$
Outcome: length	
Partial correlation coefficients:	*Rank regression:*
Spearman: S = 0.28, $P = 0.24$	Predicted length = 45.9 − 0.268*D + 1.08*age
Pearson: r = −0.32, $P = 0.18$	HM = 2.12, $\sim F_{1,17}$ $P = 0.16$
Outcome: tricep circumference	
Partial correlation coefficients:	*Rank regression:*
Spearman: S = −0.27, $P = 0.26$	Predicted tricep = 21.8 − 0.255*D + 0.305*age
Pearson: r = −0.56, $P = 0.01$	HM = 7.05, $\sim F_{1,17}$ $P = 0.02$

[1] A DHEA-S value of 51.7 μg/dl was found to be an outlier and was removed from the analyses.
Abbreviations: t = testosterone; D = DHEA-S.

The following molar ratios of adrenal hormones were calculated for the entire baboon sample: DHEA-S/DHEA, DHEA-S/cortisol, and DHEA/cortisol. Results are presented in Table 2, where average values for each of the four age groups are reported. Both DHEA-S/cortisol and DHEA-S/DHEA significantly decreased from the youngest age group on. Similarly for DHEA-S, only the first age group (ages 1–3 years) demonstrated significantly higher ratio values than the other age groups. Interestingly enough, while DHEA-S/cortisol proved significant, DHEA/cortisol did not. We attribute this to variable DHEA values in a small sample size.

Hormonal predictors of somatic growth

Non-parametric multivariate regression modeling procedures were employed to determine the effect of testosterone and DHEA-S on measures of somatic growth. Table 2 represents the regression of testosterone and DHEA-S in three chosen measures of growth: tricep circumference (a crude measure of muscle mass), length (a measure of total life-time energetic status), and weight (a measure of current energetic status). These three measures of growth were used as outcome measures, while testosterone and DHEA-S were the predictor variables controlling for age.

While the distribution of weight throughout the age range did not demonstrate normal Gaussian distribution (e.g., data points symmetrical about the mean with mean, median, and mode all equal), the distributions of length and tricep circumference appeared to be normal. The scatterplots (not shown) of the three morphometric measures versus testosterone, ignoring age, indicated a cluster of points for the young baboons which had very low testosterone levels, a non-surprising phenomenon given that these animals had not yet undergone sexual development (e.g., testes not yet dropped). The residuals of the predictors, after controlling for age, were also plotted against the morphometric measures. Though all of these relationships appeared basically linear, the usual assumptions of multiple regression analyses could not be met due to a small sample size. Thus, non-parametric rank regression, using Spearman's correlation coefficient and the Jaeckel–Hettmansperger–McKean statistics was employed as discussed earlier.

Testosterone positively predicted a significant amount of variation in weight when controlling for age. Testosterone did not significantly predict length and was a marginal predictor ($P = 0.08$) for

tricep circumference. On the other hand, DHEA-S was a negative and significant predictor of weight and tricep circumference. Like testosterone, DHEA-S did not significantly predict variation in length.

Discussion

The findings presented here demonstrate increases in testosterone and morphometric measures, but not indices of adrenal function, among a sample of pubertal male savannah baboons. In addition, testosterone, but not estradiol or adrenal androgens, was *positively* related to size in this sample of baboons. Thus, while baboon gonadal maturation may be similar to humans, there is no evidence for adrenarche, nor is the relationship found between gonadal maturation and somatic growth in baboons likely to be similar among humans.

Age-related changes

The inherent limitations of using a cross-sectional survey to study growth and development have already been described [10, 32]. Because of the relatively short growth period in non-human primates, as compared to humans, variance in changes pertaining to pubertal growth would inherently be lower [32]. Thus, although cross-sectional surveys of non-human growth do not detect all such changes as accurately as would a longitudinal design, detecting 'false' developmental phenomena are conservatively minimized.

In our results, increases in testosterone, skinfold measurements, and length as well as a decline in DHEA-S are only demonstrable in the pre-pubertal group compared to the other age groups. Increases in weight, arm circumference, and waist and hip circumferences are evident in later age groups as well. Although rates of growth were not measured, these results suggest that *early* pubertal growth in baboons may be focused on increasing stature (length) and may reach a maximum more quickly than does growth in mass (fat and muscle), which seem to continue to increase well into adulthood.

As mentioned above, upper arm circumference is a good predictor of lean body mass [46]. Males in the first age group had significantly smaller tricep circumferences compared to males in the other age groups. In addition, males in the second age group (4–5 years) had significantly smaller tricep circumferences compared to males 6–9 years of age, but not males 10–14 years of age. While the number of points is too small to be definitive, this is suggestive of a pattern of pubertal increase in muscle mass followed by senescent decline.

Adrenarche, or the initiation of androgen production by the adrenal gland, is a debated event in the life history of non-human primates [7], with the exception of chimpanzees [16, 22]. Our results of a progressive DHEA-S decline from infancy through young adulthood in male baboons are similar to earlier results [11, 19]. In addition, while DHEA and cortisol did not show as clear a drop as DHEA-S, both declined with age, providing additional evidence for a lack of adrenarche in this species.

Comparison of the ratios of adrenal hormones across age groups suggests nothing to change this conclusion. Most importantly, we found that the ratio of DHEA-S/cortisol is greatest in the youngest animals and decreases into adulthood (see Table 1). Qualitatively, this age-related change mirrors what is found in humans; DHEA/cortisol ratios peak in early adulthood and then fall progressively until the end of life when the values asymptotically approach zero [49]. DHEA and cortisol have been shown to demonstrate opposing physiological effects; cortisol is a glucocorticoid agonist while DHEA antagonizes this action [8, 27]. It has been speculated that DHEA and cortisol both influence insulin resistance, obesity, and the distribution of body fat [14, 50]. These results suggest that the baboon may be an appropriate model to test some of these hypotheses.

The ratio of DHEA-S/DHEA also varied with age in this baboon sample. This suggests that declines in DHEA-S may represent a change in the enzymatic inter-conversion between DHEA-S and DHEA rather than changes in the adrenal production of DHEA-S *per se*. We can only speculate whether this reflects an increase in sulfation or a decrease in removing the sulfate. However, knowing this difference in ratios may have significance in interpreting future experimental results. Frequently, researchers studying adrenal function only measure DHEA-S as this assay is easier and more readily available. It is often assumed that the level of DHEA-S reflects the level of DHEA, which may be the active steroid [2, 51]. If the ratio of DHEA-S/DHEA changes with age, this assumption may need to be challenged in comparisons across age categories.

Hormonal measures and body composition

The relationships between hormones and morphometric measures reported here are at best tentative given the small sample size. However, the failure of

testosterone to significantly predict length is consistent with previous findings among baboons [12] and contrary to those in humans [37]. This may represent the relatively small degree of pubertal growth in length among baboons as compared to humans [7]. The significant relationship between testosterone and weight, and the significant relationship between testosterone and upper arm muscle mass (though borderline at $P = 0.08$) suggest a possible role of testosterone in other aspects of somatic growth (Table 2). On the other hand, the failure of estradiol to predict length follows from the extremely low levels of estradiol exhibited by the baboons in this sample. These results are in clear contrast with a role for estradiol in determining height in humans [20, 30] and length among rhesus macaques [36], and suggest the possibility of species differences in the role of estradiol in adolescent growth.

In addition to testosterone, DHEA-S has been significantly related with increases in linear growth as well as increases in limb circumference in adolescent male humans [56]. Our finding that DHEA-S was inversely associated with weight and tricep circumference mostly likely represents a non-causal association of a decline in DHEA-S with increases in weight from the youngest animals on, rather than an actual growth suppressing effect of DHEA-S. Nonetheless, the sharp contrast of these results with the growth promoting effects of DHEA-S in humans highlights the hormone's different age-related pattern in the two species.

Implications for humans

Though the body mass growth spurt of humans is no longer considered a uniquely derived morphological feature [32], questions regarding adrenarche and the roles of adrenal androgens in promoting pubertal growth in non-human primates need further investigation. *No* non-human primate species studied to date, with the single exception of chimpanzees, unequivocally demonstrate the characteristics of human adrenarche [16]. In addition, there is consistent evidence for circannual changes in reproductive parameters including testosterone, inhibin, FSH, and spermatogenesis in adult men [33, 35, 39, 40, 52] as well as LH and testosterone in pre-pubertal boys [3]. Thus, attention should be drawn toward investigating great apes such as the chimpanzee that experience adrenarche, and for which there is evidence of seasonality in reproduction in the wild [53, 54] as more appropriate models of human male pubertal maturation.

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