Weight loss and wrestling training: effects on growth-related hormones

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Roemmich, James N., and Wayne E. Sinning. Weight loss and wrestling training: effects on growth-related hormones. *J. Appl. Physiol.* 82(6): 1760–1764, 1997.—Adolescent wrestlers (n = 9, 15.4 yr) and recreationally active control males (n = 7, 15.7 yr) were measured before, at the end of, and 3.5–4 mo after a competitive wrestling season to assess the influence of dietary restriction on growth-related hormones. Wrestlers had significant elevations preseason to late season for morning serum concentrations (mean of 8 serial samples) of growth hormone (GH; 2.9 ± 0.7 vs. 6.5 ± 1.4 ng/ml) and sex hormone-binding globulin (SHBG; 16.1 ± 2.3 vs. 27.9 ± 6.9 nmol/l) and significant reductions in GH-binding protein (GHBP; 178 ± 19 vs. 109 ± 17 pmol/l), insulin-like growth factor I (IGF-I; 332 ± 30 vs. 267 ± 34 ng/ml), testosterone (T; 4.9 ± 0.4 vs. 3.6 ± 0.4 ng/ml), and free testosterone (Free-T; 22.4 ± 3.6 vs. 15.7 ± 2.8 pg/ml). Wrestlers had significant postseason reductions in GH (3.44 ± 1.30 ng/ml) and SHBG (10.43 ± 4.13 nmol/l) but elevations in GHBP (66.7 ± 23.8 pmol/l), IGF-I (72.9 ± 25.1 ng/ml), T (2.10 ± 0.46 ng/ml), and Free-T (9.76 ± 3.01 pg/ml). Concentrations of luteinizing hormone (LH), estradiol, prolactin, cortisol, insulin, and thyroid hormones did not differ because of exercise-dietary practices of wrestlers. In-season elevations in GH, with concomitant reductions in GHBP and IGF-I, that were reversed during the postseason suggest a reduction in GH receptor number and partial GH resistance during the season. Nonelevated LH with reduced T levels suggests a central hypothalamic-pituitary-gonadal (H-P-G) axis impairment. In conclusion, undernutrition may lead to altered H-P-G and GH-IGF-I axes function in adolescent wrestlers. However, only the wrestlers' late-season Free-T concentrations were outside the normal range, and the hormone axis impairments were quickly reversed. The present data do not address hormonal axis responses to several years of wrestling and weight loss.

growth hormone; growth hormone-binding protein; insulin-like growth factor; insulin-like growth factor-binding protein 3; testosterone

DESPITE CAUTIONS from the medical community (1), adolescent wrestlers continue to reduce their body weight through a combination of dietary restriction and exercise to prepare for athletic competition (27). Repetitive weight loss each week over a 3- to 4-mo wrestling season is associated with chronic weight loss and undernutrition (10, 23, 24).

The undernutrition of adolescent wrestlers has led several investigators to suggest that weight-loss practices of wrestlers may lead to temporary growth suppression (18, 31). Previous studies of pubescent wrestlers have shown that some markers of somatic growth indicate decreased incremental growth during the season and increased incremental (catch-up) growth postseason (23, 24). Others have shown that during the sport season, collegiate (postpubertal) wrestlers have reductions in growth-related hormone concentrations (7, 18, 28). In a companion paper (24), we sought to verify whether the nutritional status of adolescent wrestlers is compromised and whether undernutrition slowed their growth and maturation. Here we discuss the alterations in growth-related hormones of undernourished adolescent wrestlers.

METHODS

Subjects. Wrestlers (n = 9) and recreationally active controls (n = 7) who were in good health and had no known history of endocrine dysfunction were recruited. The subjects were matched a priori for physical characteristics and maturation level. The wrestlers' mean weekly weight loss to make the competitive weight was 2.8 kg or a reduction of 4.8%. The mean weight loss from the preseason weight to make the competitive weight was 4.5 kg or a reduction of 7.4% (24). The procedures for participation were explained to both subjects and their parents, and written informed consent was obtained before participation. Procedures were approved by the Kent State University Human Subjects Review Board.

Subjects were tested in mid-November, 1–2 wk before the first wrestling match (preseason), and 3.5–4 mo later (late February to mid-March), depending on when the wrestler no longer qualified for tournament competition (late season). Data were also collected 3.5–4 mo after the wrestling season ended (postseason; early June to mid-July). The control subjects were tested at the same times as the wrestlers.

Blood collection. After an overnight fast, the subjects arrived at the laboratory and emptied their bladders and bowels. At 0830, a catheter was inserted into a forearm vein. During the entire blood-draw period, the subjects remained in a recumbent position and watched prerecorded situation comedies on a videocassette recorder and television.

After resting for 30 min (at 0900), subjects had blood samples drawn every 20 min for the next 140 min (i.e., sampling at 30, 50, 70, 90, 110, 130, 150, and 170 min) for measurement of growth hormone (GH), prolactin (PRL), cortisol, testosterone (T), free testosterone (Free-T), luteinizing hormone (LH), estradiol, and dehydroepiandrosterone-sulfate (DHEA-S). Additional blood samples were obtained at 30 min to measure the serum osmolality, hematocrit, and hemoglobin, and at 170 min to measure serum concentrations of insulin-like growth factor I (IGF-I), thyroxine (T_4), 3,3′,5-triiodo-L-thyronine (T_3), insulin, GH-binding protein (GHBP), IGF-binding protein 3 (IGFBP3), sex hormone-binding globulin (SHBG), and alkaline phosphatase. The catheter was then removed. After clotting occurred, the blood samples were centrifuged, and the serum samples were partitioned before freezing at −135°C. Serum samples were divided into aliquots and stored in separate cryogenic vials for each assay to eliminate thawing and refreezing for different assays.

Blood biochemistry. Before analysis was done, the serially collected serum hormone samples were pooled by placing an equal aliquot from each of the eight time points into a vial. The pooled sample was then gently mixed and analyzed by immunoassay. GH, cortisol, PRL, and IGF-I (acid-ethanol extracted) were measured by using kits from INCSTAR

(Stillwater, MN), while T, Free-T, LH, estradiol, and DHEA-S were analyzed by using kits from Diagnostic Products (Los Angeles, CA). SHBG was measured by using kits from Wein Laboratories (Succasunna, NJ). Insulin, T_3, and T_4 were measured outside our laboratory (by Dr. Anthony Hackney, University of North Carolina, Chapel Hill, NC) as were growth homone binding protein (GHBP) and IGFBP3 (by Genentech, South San Francisco, CA). Assay reference standards for insulin, LH and PRL were World Health Organization 1st International Reference Preparation (IRP) 66/304, 2nd IRP-human menopausal gonadotropin, and 1st IRP 75/504, respectively. All samples from a given subject for a specific hormone were tested within the same assay. Samples were tested in triplicate, except that those measured outside our laboratory were tested in duplicate. For those hormone analyses completed in our laboratory, a control serum (CON6; Diagnostics Products, Los Angeles, CA) was tested a minimum of five times to determine an intra-assay and interassay (when applicable) coefficient of variation. The intra-assay coefficient of variation ranged from 2.0 to 9.6%, whereas the interassay variation ranged from 7.7 to 12.0%.

Hemoglobin concentrations (Radiometer A/S, Copenhagen, Denmark) and the hematocrit were measured a minimum of three times for each sample. Serum osmolality was determined by freezing point depression (Osmette A automatic osmometer; Precision Systems, Natick MA).

Statistical analysis. Data were analyzed for the main effects of group and time and for the interaction of group by time with a 2 (group) $\times$ 3 (test period) repeated-measures analysis of variance (ANOVA). A Newman-Keuls post hoc analysis was used to locate statistical significance when an ANOVA was significant. A simple effects post hoc analysis was performed on significant interactions. The effects of dietary restriction and wrestling training were shown through significant interaction effects, which is the focus of the analysis. For all statistical comparisons, a significance level of $P \leq 0.05$ was chosen.

RESULTS

Physical characteristics, dietary restriction, and weight loss. These results are detailed in the companion paper (24). During the wrestling season, the wrestlers consumed a high-carbohydrate, low-fat diet that was deficient in total amounts of energy, protein, fat, and carbohydrate. During the postseason, both groups consumed adequate amounts of energy and macronutrients. Several markers of the wrestlers' protein nutritional status (prealbumin concentrations and lean limb cross-sectional areas) demonstrated decreases between early and late season and then increased postseason. Dietary restriction and wrestling training produced little effect on bone growth but resulted in significant reductions in body girths. There was a significant 4.0% decrease in the weight of the wrestlers from preseason to late season, consisting of a significant 2.1% reduction in fat mass (FM) and a nonsignificant 2.0% reduction in fat-free mass (FFM). The incremental growth in weight and FFM of the wrestlers was significantly slower than the controls from preseason to late season and significantly greater than the controls from late season to postseason.

Blood biochemistry. The changes in hemoglobin concentrations from preseason to late season created a significant difference between the groups at late season (Table 1). The wrestlers' mean hemoglobin concentration was significantly increased from late season to postseason. The wrestlers' hematocrit and serum osmolality were not significantly changed (Table 1).

Several hormones had significant interactions. The wrestlers had elevated resting serum concentrations of GH (Fig. 1) from preseason to late season that returned to baseline during the postseason. The wrestlers' GHBP concentrations (a marker of GH receptor number) were reduced from preseason to late season (Fig. 1) and returned to baseline from late season to postseason. Despite the increase in GH in the late season, the wrestlers' IGF-I concentrations were significantly decreased in late season. Changes in IGFBP3 approached significance (group-by-time interaction, $P = 0.07$; Fig. 1).

The wrestlers' T and Free-T concentrations (Fig. 2) decreased from preseason to late season and then increased from late season to postseason. However, the wrestlers' LH concentrations were unchanged and remained in the normal physiological range (Table 1). Serum concentrations of SHBG (Fig. 2) were elevated from preseason to late season but returned to baseline concentrations during the postseason. The wrestlers also had reduced serum concentrations of DHEA-S in the late season, although the wrestlers' concentrations were never below those of the controls (Fig. 2). The wrestlers' mean serum concentrations of other hormones that can modulate hypothalamic-pituitary-testicular activity, including estradiol, prolactin, and cortisol, were not significant for the interaction and remained in normal physiological ranges (Table 1). Serum concentrations of insulin, T_4, and T_3 did not differ between groups or over time (Table 1).

DISCUSSION

The present study is unique as the first to investigate changes in the GH-IGF-I and pituitary-testicular axes (including binding proteins) of adolescent wrestlers over a sport season. The results indicate that dietary restriction while training for wrestling produces a partial GH resistance and a disruption of the pituitary-testicular axis. However, except for Free-T, all of the hormone concentrations remained in the normal physiological range, and we have shown that there is little effect on linear bone growth or pubertal maturation (23, 24).

Wrestlers lose weight through a combination of dietary restriction and dehydration that has the potential to hemoconcentrate the hormones. However, the hematocrit and serum osmolality were not significantly changed, and rather than the increase expected with dehydration, the wrestlers' hemoglobin concentration decreased slightly.

Although the wrestlers' GH concentrations increased and GHBP and IGF-I concentrations decreased in the late season (Fig. 1), the concentrations remained within the normal range (14–16). Previously, McMurray et al. (18) reported a significant increase in GH and reduction in IGF-I concentrations of collegiate wres-

Table 1. *Hematocrit, serum osmolality, and hemoglobin concentration of wrestlers and controls and serum hormone concentrations that did not produce a significant group-by-time interaction effect*

Concentration and Group	Preseason	Late Season	Postseason	Normal Range
Hematocrit, %				
Wrestler	41.1 ± 1.0	42.8 ± 0.9	42.6 ± 0.6	
Control	43.5 ± 0.7	43.4 ± 1.3	43.5 ± 1.3	
Osmolality, mosmol/kg				
Wrestler	277.4 ± 2.4	275.2 ± 2.3	278.3 ± 2.1	
Control	277.0 ± 1.1	275.3 ± 1.0	276.8 ± 1.3	
Hemoglobin, g/dl				
Wrestler	14.6 ± 0.3[a]	14.2 ± 0.3[b,c]	14.9 ± 0.3[b]	
Control	14.7 ± 0.3	15.0 ± 0.4[c]	15.2 ± 0.4	
Luteinizing hormone, mIU/ml				
Wrestler	5.77 ± 0.33	5.56 ± 0.17	6.17 ± 0.39	<2.4–12.5 (12)
Control	5.96 ± 0.66	6.33 ± 0.99	6.51 ± 0.88	
Estradiol, pg/ml				
Wrestler	23.6 ± 1.9	22.5 ± 2.1	24.9 ± 2.4	10–33 (12)
Control	20.0 ± 1.7	19.1 ± 1.2	18.3 ± 1.1	
Prolactin, ng/ml				
Wrestler	6.00 ± 0.37	5.66 ± 0.22	6.38 ± 0.27	4.5–8.0 (19)
Control	5.74 ± 0.37	5.65 ± 0.45	5.54 ± 0.32	
Cortisol, μg/dl				
Wrestler	6.3 ± 0.8	8.4 ± 0.7	8.5 ± 0.9	5–25 (6)
Control	4.8 ± 0.7	5.0 ± 0.6	5.7 ± 0.6	
Insulin, μIU/ml				
Wrestler	23.5 ± 2.9	18.5 ± 3.5	25.9 ± 2.9	0–20 (6)
Control	26.9 ± 4.2	23.0 ± 4.6	18.8 ± 2.7	
3,3′,5-Triiodo-L-thyronine, ng/dl				
Wrestler	140.7 ± 9.2	125.0 ± 11.0	137.0 ± 12.1	70–190 (11)
Control	123.9 ± 6.2	128.3 ± 9.7	134.9 ± 14.9	
Thyroxine, μg/dl				
Wrestler	9.4 ± 1.1	6.5 ± 0.4	8.6 ± 1.3	5–12 (11)
Control	10.5 ± 1.4	8.6 ± 0.9	7.0 ± 0.6	

Values are means ± SE. Refs. are shown in parentheses. For significant group-by-time interaction, means with same letter, $P \leq 0.05$.

tlers. The increased GH concentrations (partial GH resistance) in the present study may have been caused by a reduced negative hypothalamic feedback by IGF-I or a decrease in GHBP concentration. The GHBP concentration, which signifies GH-receptor number (13), is reduced with undernutrition lasting as little as 5 days or as long as an exacerbation of anorexia nervosa (2, 4, 8). The growth effects of GH are enhanced by GHBP and GH secretion would need to increase to account for the reduced GHBP concentration to ensure continuation of normal growth (15).

Most circulating IGF-I is bound to IGFBP3 (25), which inhibits IGF-I action, because IGF/IGFBP3 complexes do not bind to IGF-I receptors (17). Furthermore, IGFBP3 inhibits IGF-I action when present in an excess molar ratio (5). In the present study, IGFBP3 concentrations were not significantly changed (Fig. 1) and remained in the normal range (3). However, as in the present study, others have shown that short- (21) or long-term (4) undernutrition produces a greater percent reduction in IGF-I than in IGFBP3.

The pituitary-gonadal axis was also affected by the dietary restriction (Fig. 2). In the late season, the wrestlers had low-normal T (12) and low Free-T concentrations (6). In previous investigations that utilized single blood samples from collegiate wrestlers (7, 28), reductions in T were also found. Free-T concentrations have not been previously reported in wrestlers.

Albumin and SHBG are plasma proteins that limit the amount of biologically active Free-T (26). Serum albumin concentrations of adolescent wrestlers do not change over a sport season (10). Although the wrestlers' SHBG concentrations increased (Fig. 2), they remained in the normal range (9), and their Free-T/total T ratio was not changed. Reductions in T and Free-T without a change in serum binding indicate an increased clearance or decreased production of T. There is no evidence of chronic changes in the clearance of T in athletes, and the metabolic clearance of T is directly related to Free-T concentrations (29). Thus we conclude that the wrestlers' low T concentrations were caused by a reduction in T production during the season.

As found in previous investigations (7, 28), the wrestlers' LH concentration (Table 1) remained unchanged and in the normal range (12). However, alterations in the pulsatility of LH during sleep, rather than changes in tonic morning LH concentrations, are more likely to affect the stimulation and release of T (30). We did not measure serial nocturnal LH concentrations, but the reduction in morning T concentrations suggests altered LH pulsatility.

Serum PRL, estradiol, and cortisol concentrations (Table 1) were not changed in a manner that would suggest a differential effect of weight loss and wrestling training, and all values remained in the physiological range (12). Using single blood samples, Strauss et al.

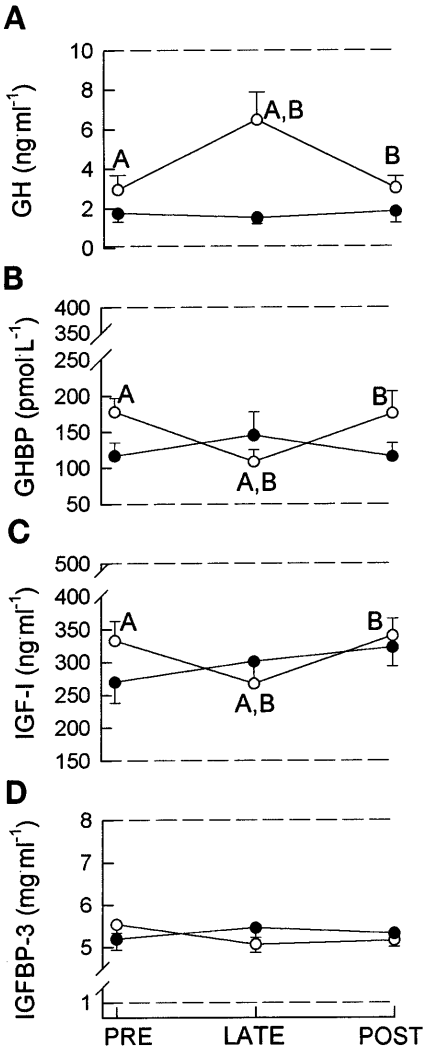

Fig. 1. Concentrations of hormones (means ± SE) included in growth hormone (GH)-insulin-like growth factor I (IGF-I) axis during wrestling season (preseason, late season, and postseason). ●, Wrestlers, $n = 9$; ○, controls, $n = 7$; GHBP, growth hormone-binding protein; IGFBP-3, insulin-like growth factor I-binding protein 3. Like letters indicate $P \leq 0.05$.

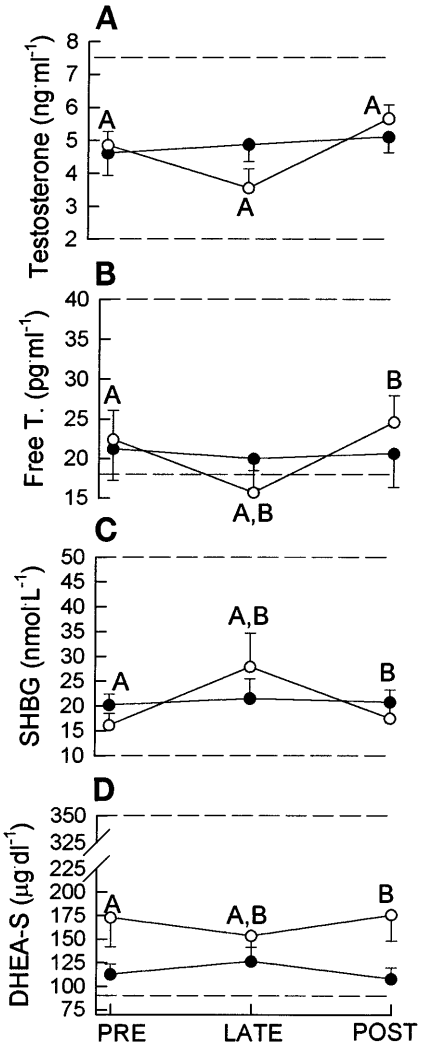

Fig. 2. Concentrations (means ± SE) of testosterone, free testosterone (Free-T), sex hormone-binding globulin (SHBG), and dehydroepiandrosterone-sulfate (DHEA-S) during wrestling season (preseason, late season, and postseason). ●, Wrestlers, $n = 9$; ○, controls, $n = 7$. Like letters indicate $P \leq 0.05$.

(28) and Hackney and Sinning (7) found that the in-season cortisol concentrations of collegiate wrestlers were not significantly elevated compared with postseason concentrations but that in-season PRL concentrations were indeed reduced.

DHEA-S stimulates skeletal and pubertal maturation (20). Although the wrestlers' DHEA-S concentrations were significantly reduced in the late season (Fig. 2), they were not less than those of the controls and remained in the normal range (22). Neither skeletal nor pubertal maturation was affected in the wrestlers.

In conclusion, there were alterations in the wrestlers' GH-IGF-I and pituitary-testicular axes, but only the Free-T concentrations were outside of the normal range. The in-season elevations in GH, with concomitant reductions in GHBP and IGF-I, that were reversed during the postseason suggest a reduction in GH-receptor number and a partial GH resistance during the season. Thus the GH-IGF-I axis is regulated by energy balance through the GH receptor, and the effects are reversible on reduction of the training load (energy expenditure) and increase in energy intake. Nonelevated LH with reduced T levels in the wrestlers suggests a central hypothalamic-pituitary-gonadal axis impairment.

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