Weight loss and wrestling training: effects on nutrition, growth, maturation, body composition, and strength

JAMES N. ROEMMICH AND WAYNE E. SINNING
Applied Physiology Research Laboratory, Kent State University, Kent, Ohio 44242

Roemmich, James N., and Wayne E. Sinning. Weight loss and wrestling training: effects on nutrition, growth, maturation, body composition, and strength. *J. Appl. Physiol.* 82(6): 1751–1759, 1997.—Adolescent wrestlers (n = 9, 15.4 yr) and recreationally active control adolescent males (n = 7, 15.7 yr) were measured before, at the end (late season), and 3.5–4 mo after a wrestling season to assess the influence of dietary restriction on growth, maturation, body composition, protein nutrition, and muscular strength. Controls consumed adequate amounts of energy, carbohydrate (CHO), protein, and fat, and demonstrated normal gains in weight, fat mass (FM) and fat-free mass (FFM). Wrestlers consumed a high-CHO (61 ± 2% kcal), low-fat (24 ± 2% kcal) diet during the season but did not consume adequate energy (24.7 ± 3.5 $kcal \cdot kg^{-1} \cdot day^{-1}$) or protein (0.9 $g \cdot kg^{-1} \cdot day^{-1}$). Deficient dietary intake reduced prealbumin levels (26.0 ± 1.9 vs. 20.2 ± 0.9 mg/dl) and slowed the accrual of lean arm and thigh cross-sectional muscle areas (A_{XSECT}, T_{XSECT}, respectively). For wrestlers, dietary deficiency also decreased weight (60.3 ± 3.5 to 58.0 ± 3.3 kg), relative fat (9.9 ± 0.5 to 8.0 ± 0.7%), and FM (6.0 ± 0.5 to 4.7 ± 0.6 kg). Postseason, wrestlers and controls consumed similar diets, and wrestlers had significant increases in prealbumin, A_{XSECT}, and T_{XSECT}. Wrestlers also increased their weight (6.1 ± 0.6 kg), FFM (3.0 ± 0.6 kg), and FM (3.2 ± 0.5 kg) postseason. Rates of bone maturation and segmental growth were not different between the groups. The wrestlers had reductions in elbow and knee strength from preseason to late season but increases postseason. Lean tissue changes were associated with the changes in strength and power (r = 0.72–0.91, $P < 0.001$). After covariance for FFM or limb-specific cross section, few significant changes remained. In conclusion, dietary restriction reduced protein nutrition and muscular performance but produced little effect on linear growth and maturation. Prealbumin levels and the rate of lean tissue accrual were positively related (r = 0.43, $P \leq 0.05$).

adolescence; weight loss; protein nutrition; muscular strength

WEIGHT LOSS through dietary restriction has been speculated to slow the somatic growth (21, 30, 34) of adolescent wrestlers, although there are no reported effects on growth in height. Previous studies of pubescent wrestlers have shown that several skeletal breadths and body girths have decreased incremental growth during the season and increased incremental growth during the postseason (26, 29).

The pubertal accrual of fat-free mass (FFM) may also be slowed during the wrestling season. Longitudinal investigations of body composition across a wrestling season have shown the FFM to be either unchanged (14) or nonsignificantly reduced (7, 27). One investigation reported that the incremental growth in FFM of wrestlers was significantly slower than other recreationally active youth during the wrestling season (26), and several studies have reported an accelerated growth in FFM of wrestlers during the postseason (26, 29). Horswill et al. (12) speculated that a reduction in the protein nutrition status of adolescent wrestlers caused by dietary restriction contributed to the significant reduction in skinfold estimates of FFM. However, no study has used a criterion method of body composition assessment to investigate the relationship between changes in the protein nutrition and FFM of wrestlers or other weight-control athletes.

By impeding the normal adolescent accrual of lean tissue, dietary restriction may affect strength performance. Previous studies have shown significant decreases (7, 16, 26), increases (9, 31), or no change (16, 23) in muscular strength of wrestlers during a sport season. The purpose of the present study was *1*) to relate changes in energy and nutrient intake that occur during an interscholastic wrestling season to changes in growth and maturation and *2*) to examine the interrelationships among changes in protein nutrition, body composition, and arm and leg power of adolescent wrestlers. A companion paper (27) discusses the alterations in growth-related hormones of undernourished wrestlers.

METHODS

Subjects. Wrestlers (n = 9) and recreationally active adolescent males (n = 7) were recruited. The procedures for participation were explained to both the subjects and their parents, and written informed consent was obtained before participation. Procedures were approved by the Kent State University Human Subjects Review Board. To avoid influence of dehydration on body composition, the subjects were tested in mid-November, 1–2 wk before the first wrestling match (preseason). At this time, the wrestlers were training but were not dehydrating to make a specific weight. Subjects were then tested 3.5–4 mo later (late February to mid-March), depending on when the wrestler no longer qualified for tournament competition (late season). At late season, the wrestlers were measured at least 24 h after their last match to allow time for rehydration. Data were also collected 3.5–4 mo after the wrestling season ended (postseason; early June to mid-July). At postseason, the wrestlers were not losing weight or dehydrating. The control subjects were tested at the same time intervals as the wrestlers. On all test dates, all subjects were measured at least 16 h after the last exercise bout.

After an overnight fast, the subjects arrived at the laboratory and emptied their bladders and bowels. A blood sample was withdrawn to measure prealbumin, blood urea nitrogen (BUN), and alkaline phosphatase concentrations. After the hematocrit was measured a minimum of three times, the blood samples were allowed to clot and then centrifuged; serum was removed and stored in cryogenic vials at −135°C. The blood samples used in this study were obtained as part of the serial sampling used for hormonal analyses (27).

Nutrition and bone growth activity. In-season diet records were timed so that the wrestlers had one match during the 7-day diet-recording period. The early-season diet records were completed during the first or second week of December, which coincided with the wrestlers' initial attempt to "make weight" for competition (Fig. 1). The late-season diet records were taken before the wrestlers' last match. Subjects were given a verbal explanation of how to properly record the amounts and types of foods eaten and were shown measuring

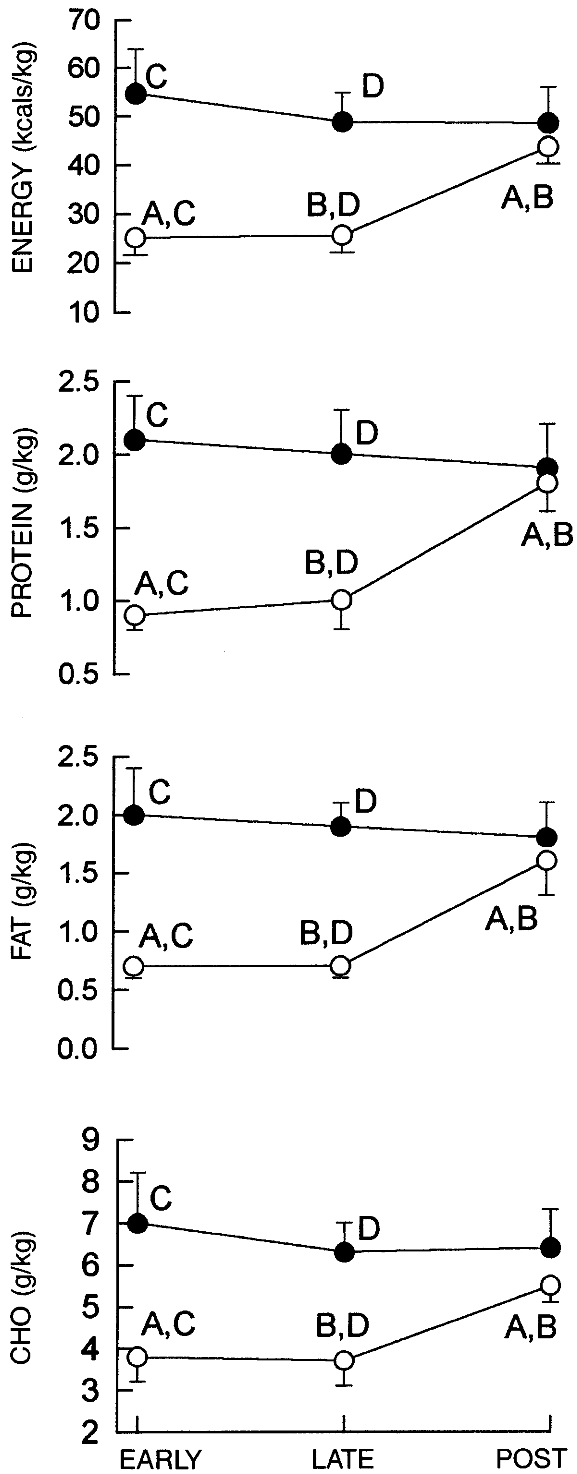

Fig. 1. Relative intake of energy ($kcal \cdot kg^{-1} \cdot day^{-1}$), protein ($g \cdot kg^{-1} \cdot day^{-1}$), fat ($g \cdot kg^{-1} \cdot day^{-1}$), and carbohydrate (CHO; $g \cdot kg^{-1} \cdot day^{-1}$) for the wrestler (●, $n = 9$) and control (○, $n = 7$) groups at times early and late in the season and postseason. Like letters indicate significant difference. Values are means ± SE.

Table 1. *Intraexaminer technical error of measurement and coefficient of variation for anthropometric measures of all 16 subjects*

Measurements	σ_e, cm	CV, %
Lengths		
Stature	0.179	0.107
Shoulder-elbow	0.235	0.679
Elbow-wrist	0.336	1.226
Calf	0.309	0.805
Breadths		
Biacromial	0.432	1.317
Bi-iliac	0.219	0.806
Elbow	0.081	1.174
Girths		
Shoulder	1.273	1.241
Natural waist	0.849	1.197
Flexed midarm	0.298	1.038
Thigh	0.363	0.786
Calf	0.238	0.704

σe, Technical error of measurements; CV, coefficient of variation.

devices from the kitchen and food models to help them visualize a single portion. Diet records were analyzed with the West Nutrition Program (West Publishing, St. Paul, MN). Macronutrients were examined as the percentage of total energy provided and as the amount of nutrient consumed per kilogram body weight per day. Plasma prealbumin was measured by radial immunodiffusion plates (Behring Diagnostics, La Jolla, CA). BUN was assessed by using Sigma kit no. 640-A (Sigma Chemical, St. Louis, MO). Alkaline phosphatase was measured with a photometric assay (no. 245, Sigma Chemical).

Anthropometry and physical maturation. All measures were made by one experienced anthropometrist (J. N. Roemmich). The recommendations of Lohman et al. (19) were followed relative to landmarks and methods. Except for skinfold thicknesses, each variable was measured three times; the median score was used to avoid the effects that an outlying measure might have on the mean score. Skinfold thicknesses were measured until three at each site were within 5% of each other; the mean was then computed. The skeletal lengths included stature, sitting height, and the lower extremity, hand, forearm-hand, elbow-wrist, shoulder-elbow, thigh, and calf lengths. Breadths taken were the biacromial, transverse chest, anterior-posterior chest, bi-iliac, elbow, wrist, knee, and ankle. Circumference measures included the wrist, forearm, flexed midarm, shoulder, chest, natural waist, abdomen, hip, thigh, and calf. Skinfold-thickness sites included the subscapular, triceps, biceps, chest, suprailiac, abdominal, thigh, and midcalf. The flexed lean (muscle plus bone) cross-sectional area of the midarm (A_{XSECT}) was measured as previously described (26). The relaxed lean midthigh cross-sectional area (T_{XSECT}) was computed by using the midthigh girth and midthigh skinfold (26). All anthropometric measurements were taken at the same time of day in each testing period. The reliability of the anthropometrist was assessed by using within-day replicate measures. The technical error of measurement (σe) and a coefficient of variation (CV) were calculated (20) for several important anthropometric measures and are reported in Table 1. The σe and CV are equal to or less than those of other experienced anthropometrists (20).

Normal variations in growth and the small sample size had the potential to produce mean growth rates for the control group that were not representative of adolescent males of this age. Thus the observed pre- to postseason growth increment in height and weight was adjusted to the expected 6-mo increment and compared with tables of incremental growth for 6-mo age intervals. The tables were derived from the Fels study of longitudinal growth of boys living in southern Ohio (4). This represented a proper comparison group because our subjects also lived in Ohio.

Skeletal maturation of the lefthand wrist was assessed by the Fels method (24). The subjects self-assessed their pubertal maturation by standing in a private room with a full-length wall mirror and comparing themselves to drawings of the five standard stages of pubic hair and genital development as described by Tanner (22).

Body composition. Body composition was measured by underwater weighing with the use of the procedures previously described by Sinning (28). Residual volume (RV) was measured on land by nitrogen washout (33) with the subject seated in the same position used during the underwater weighing. The RV measurements were repeated until two trials were within ±50 ml. The equations by Lohman (18), which account for maturation-related changes in the density of the FFM, were used to compute percent body fat (%BF).

Strength and power. Isokinetic peak torque (strength) and power were measured at 60 and 180°/s (Lumex, Cybex Division, Bay Shore, NY) during flexion and extension exercises of the right elbow and knee. During the strength measurements, the axis of rotation of the elbow or knee joint was aligned with the axis of the dynamometer. For elbow flexion and extension, each subject lay supine, and the elbow was stabilized with a 2-in.-wide strap that went around the table and over the arm just proximal to the antecubital crease. For knee flexion and extension, the subjects sat on a chair that was anchored so that it could not move independently. The thigh was stabilized with a 3-in.-wide strap. For both the elbow and the knee, three submaximal warm-up flexions were followed by three maximal flexions, with 1 min of rest between trials. The same procedure was repeated for the extension movement. The peak torque and peak power were averaged over the three trials. Intraclass correlations for the within-day and between-day reliability of these measures were 0.94 or above ($P < 0.05$; Ref. 26).

Physical activity records. For the physical activity records, the length of time spent in activities that were more strenuous than walking was recorded for 1 wk during the sport season and 1 wk during the postseason. Physical activity was expressed as kilocalories per kilogram body weight per week by multiplying the rate of energy expenditure in kilocalories per kilogram body weight per hour by the duration of the activity (1).

Statistics. Data were analyzed for the main effects of group and time and the interaction of group by time with a 2 (group) × 3 (test period) repeated-measures analysis of variance (ANOVA). Incremental changes in weight and FFM were analyzed with a 2 × 2 (group × time) ANOVA. Body weight and dietary intake were analyzed with a 2 (group) × 7 (day) repeated-measures ANOVA to investigate the changes in body weight and nutrient intake during a week leading up to a competition. Analysis of covariance was used to adjust the strength and power data for FFM, A_{XSECT}, and T_{XSECT}. A Newman-Keuls post hoc analysis was used to locate statistical significance when an ANOVA was significant. Simple effects, followed by Newman-Keuls post hoc analyses, were performed to locate significance of the interactions. Pearson product-moment correlations were used to determine associations among strength measures and FFM, A_{XSECT}, and T_{XSECT}. A similar correlation was performed between the late-season prealbumin concentrations and the pre- to late-season change in FFM. For all statistical comparisons, a significance level of $P \leq 0.05$ was chosen.

RESULTS

Physical characteristics. Initially, the groups were not significantly different for any of the physical characteristics listed in Table 2. The relative age (skeletal age − chronological age) remained constant for both groups. The hematocrit did not change for the wrestlers (41.1, 42.8, 42.6%) or controls (43.5, 43.4, 43.5%) at pre-, late, or postseason.

Diet records. The wrestlers' energy and relative nutrient intakes were less than the controls during the sport season but similar to the controls postseason (Fig. 1). The wrestlers consumed a low-fat, high-carbohydrate diet during the sport season and a more typical Western diet postseason (Fig. 2). The percentage of energy from protein was not significantly changed.

The energy intake and body weight were reported daily (Fig. 3) to illustrate how the wrestlers altered their energy intake to make weight. The wrestlers consumed more energy Sunday and Monday than the day before competition (Friday). To cut weight for competition, the wrestlers consumed less energy than the controls on Wednesday, Thursday, and Friday. The controls' body weight (Fig. 3) did not change, whereas the wrestlers' body weight steadily decreased Sunday

Table 2. *Physical characteristics, frequency distribution of preseason genital maturation stage, and body composition data for wrestlers and controls*

Characteristic and Group	Preseason	Late Season	Postseason
Stature, cm			
Wrestler	166.3 ± 2.6	167.2 ± 2.5	168.4 ± 2.4
Control	167.2 ± 3.9	168.7 ± 3.7	168.9 ± 3.6
Age, yr			
Wrestler	15.4 ± 0.3	15.7 ± 0.3	16.0 ± 0.3
Control	15.0 ± 0.4	15.3 ± 0.4	15.6 ± 0.4
Skeletal age, yr			
Wrestler	15.7 ± 0.4	16.0 ± 0.4	16.3 ± 0.4
Control	15.4 ± 0.7	15.8 ± 0.7	16.1 ± 0.7
Genital stage			
Wrestler	III = 1, IV = 6, V = 1		
Control	III = 2, IV = 2, V = 1		
Weight, kg			
Wrestler	60.3 ± 3.5^{a}	58.0 ± 3.5^{a}	64.1 ± 3.6^{a}
Control	53.8 ± 5.1^{b}	55.5 ± 5.1^{b}	56.5 ± 4.9^{b}
Percent fat, %			
Wrestler	9.88 ± 0.53^{a}	8.03 ± 0.66^{a}	12.29 ± 0.84^{a}
Control	10.54 ± 1.37	10.85 ± 0.85	11.53 ± 0.90
Fat mass, kg			
Wrestler	6.00 ± 0.54^{a}	4.72 ± 0.58^{a}	7.95 ± 0.78
Control	6.00 ± 1.17	6.30 ± 0.97	6.66 ± 0.96
Fat-free mass, kg			
Wrestler	54.28 ± 3.11^{a}	53.17 ± 2.98^{b}	56.16 ± 3.07^{b}
Control	47.75 ± 4.14^{c,d}	49.44 ± 4.17^{c}	49.88 ± 4.09^{d}
Lean arm area, cm^2			
Wrestler	66.9 ± 4.4^{a}	66.4 ± 3.9^{b}	75.0 ± 4.6^{a,b}
Control	52.8 ± 6.3^{c}	59.3 ± 7.0^{d}	61.6 ± 6.8^{c,d}
Lean thigh area, cm^2			
Wrestler	172.5 ± 9.9^{a}	160.9 ± 7.8^{a,b}	177.3 ± 4.6^{b}
Control	140.0 ± 11.6^{c}	141.9 ± 9.8	145.4 ± 11.9^{c}

Values are means ± SE. Wrestlers, $n = 9$; controls, $n = 7$. For significant group-by-time interactions, means with same letter, $P < 0.05$.

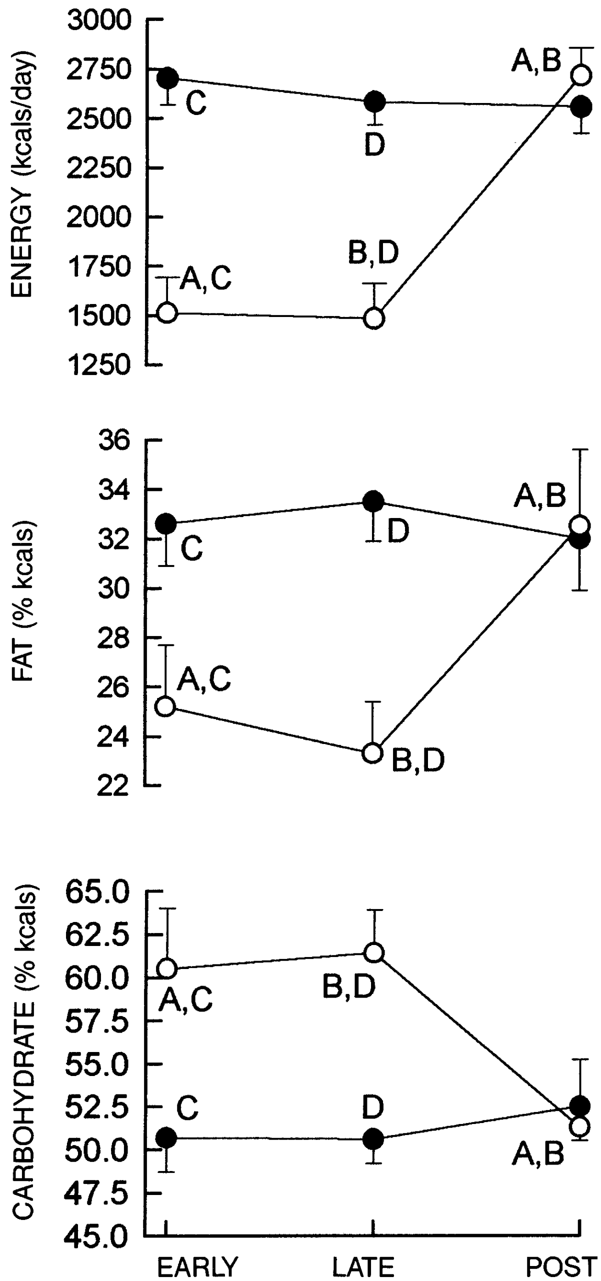

Fig. 2. Energy intake (kcal/day) and %energy from dietary fat and CHO for wrestlers (●, n = 9) and controls (○, n = 7). Like letters indicate significant difference. Values are means ± SE.

through Saturday. All post hoc comparisons between days were significant except the comparison between Tuesday and Sunday. The mean weight lost between Monday and Saturday 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%.

Body composition. Significant group-time interactions were found for changes in weight, %BF, fat mass (FM), and FFM (Table 2). The controls increased their weight and FFM from pre- to postseason but did not change their %BF or FM. The wrestlers lost weight, FM, and %BF from preseason to late season and then gained a significant amount postseason. The in-season decrease in FFM of 1.1 kg was not significant, but the postseason increase (3.0 kg) was significant. The pre- to postseason increase in FFM (1.9 vs. 2.1 kg) was similar for both groups. As expected, the growth increments for weight (−3.72 kg/6 mo, <3rd percentile for age) and FFM (−1.92 kg/6 mo) of the wrestlers were significantly lower during the sport season than the postseason (9.29 kg/6 mo, >97th percentile for age; and 4.49 kg/6 mo, respectively). The controls had sport seasonal and postseasonal weight increments of 3.19 kg/6 mo (63rd percentile for age) and 1.60 kg/6 mo (37th percentile for age) and FFM increments of 2.5 and 0.9 kg/6 mo. The weight increment for the wrestlers from pre- to postseason (2.9 kg/6 mo, 62nd percentile for age) was similar to the controls (2.4 kg/6 mo, 54th percentile for age) (4).

Anthropometrics. The pre- to late-season and late- to postseason corrected height increments of the wrestlers (1.46 ± 0.24 cm/6 mo, 46th percentile for age vs. 1.78 ± 0.41 cm/6 mo, 56th percentile for age) and controls (2.32 ± 0.47 cm/6 mo, 55th percentile vs. 1.81 ± 0.54 cm/6 mo, 57th percentile) did not produce significant main or interaction effects. Both the wrestlers' (1.76 ± 0.32 cm/6 mo, 55th percentile) and the controls' (2.16 ± 0.48 cm/6 mo, 66th percentile) pre- to postseason height increments were within the normal range (4). For the segmental lengths and skeletal breadths, there were many significant time effects, but only shoulder-elbow length and elbow-wrist length had significant interactions (Table 3). For both shoulder-elbow

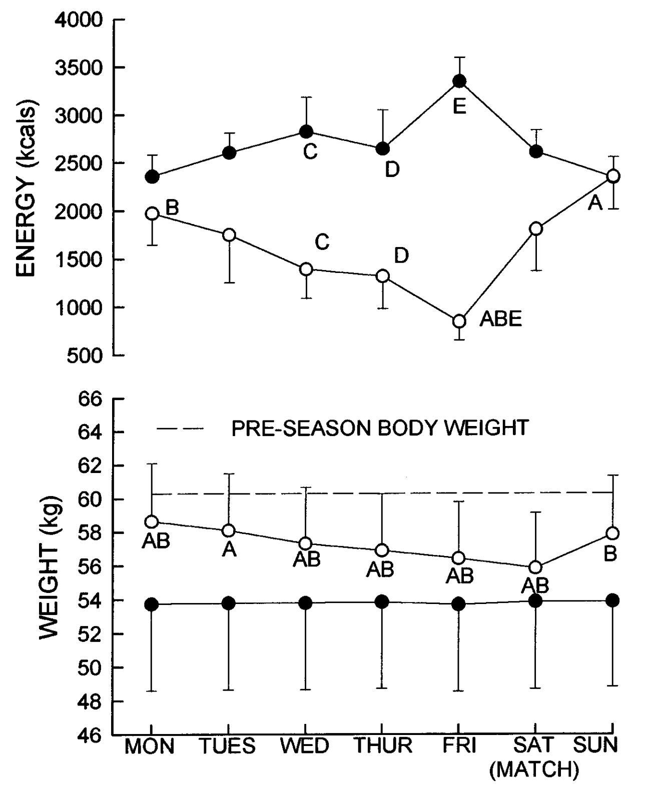

Fig. 3. Daily energy intake (kcal/day) and body weight (kg) for wrestlers (●, n = 9) and controls (○, n = 7) during 1 wk, with weight certification for wrestlers on Saturday. Like letters indicate significant difference. Values are means ± SE.

Table 3. *Segmental lengths and girths for wrestlers and controls*

Variable and Group	Preseason	Late Season	Postseason
	Lengths, cm		
Shoulder-elbow			
Wrestler	34.5 ± 0.6[a]	34.6 ± 0.6	35.0 ± 0.5[a]
Control	34.8 ± 0.7[b,c]	35.2 ± 0.7[b]	35.3 ± 0.6[c]
Elbow-wrist			
Wrestler	27.5 ± 0.7	27.5 ± 0.7	27.7 ± 0.7
Control	27.3 ± 0.6[a,b]	27.7 ± 0.5[a]	27.9 ± 0.6[b]
	Girths, cm		
Flexed arm			
Wrestler	30.1 ± 1.0[a]	29.8 ± 0.9[b]	31.7 ± 0.9[a,b]
Control	26.9 ± 1.8[c]	27.8 ± 1.8	28.4 ± 1.7[c]
Forearm			
Wrestler	26.1 ± 0.7[a]	25.8 ± 0.7[b]	26.9 ± 0.7[a,b]
Control	24.1 ± 1.1[c]	24.6 ± 1.1	24.9 ± 1.0[c]
Wrist			
Wrestler	16.4 ± 0.3[a]	16.1 ± 0.3[a]	16.6 ± 0.3[a]
Control	15.9 ± 0.4[b]	16.0 ± 0.4	16.3 ± 0.3[b]
Thigh			
Wrestler	48.4 ± 1.3[a]	46.7 ± 1.1[a,b]	49.2 ± 1.2[b]
Control	43.2 ± 2.3[c]	44.1 ± 2.4	44.6 ± 3.1[c]
Calf			
Wrestler	34.5 ± 0.9[a]	33.6 ± 0.8[a,b]	34.8 ± 0.7[b]
Control	32.8 ± 1.4	33.2 ± 1.4	33.2 ± 1.3
Shoulder			
Wrestler	105.3 ± 2.3[a]	104.1 ± 2.4[a]	108.3 ± 2.4[a]
Control	99.2 ± 4.5[b]	100.9 ± 4.3	102.0 ± 4.3[b]
Chest			
Wrestler	90.9 ± 2.4[a]	89.9 ± 2.4[a]	92.5 ± 2.4[a]
Control	84.1 ± 3.6[b]	85.0 ± 3.6	85.6 ± 3.4[b]
Natural waist			
Wrestler	71.9 ± 2.1[a]	70.9 ± 2.2[b]	74.7 ± 2.3[a,b]
Control	69.6 ± 2.9	70.6 ± 2.9	69.6 ± 2.7
Abdominal			
Wrestler	73.2 ± 2.3[a]	72.2 ± 2.2[b]	76.4 ± 2.3[a,b]
Control	71.7 ± 2.5	72.6 ± 2.5	72.6 ± 2.5
Hip			
Wrestler	88.4 ± 2.4[a]	86.7 ± 1.8[a]	90.3 ± 2.0[a]
Control	83.0 ± 3.3	84.3 ± 3.3	85.0 ± 3.1

Values are means ± SE in centimeters. Wrestlers, $n = 9$; controls, $n = 7$. For significant group-by-time interactions, means with same letter, $P < 0.05$.

and elbow-wrist length, controls increased over preseason values at both late season and postseason. The wrestlers' shoulder-elbow length increased from pre- to postseason.

Significant group-time interactions were found for all girths (Table 3). For the wrestlers, 6 of the 10 girths measured decreased from preseason to late season. All girths increased from late season to postseason. The groups' pre- to postseason increases in most girths were very similar (within 2–3 mm), but the wrestlers' late season to postseason increases were often more than twice that of the controls.

Protein nutrition. The wrestlers' prealbumin concentrations (Fig. 4) were reduced from preseason to late season and then increased postseason. The prealbumin concentration varied directly with the change in FFM (Fig. 4). The wrestlers' preseason (12.3 ± 0.9 mg/dl), late season (14.3 ± 0.6 mg/dl), and postseason (13.4 ± 0.9 mg/dl) BUN concentrations did not change significantly.

Lean limb cross-sectional areas are commonly used as markers of protein nutrition and are thought to reflect muscle protein reserves (10). The A_{XSECT} and T_{XSECT} (Table 1) of the controls increased significantly from pre- to postseason. Despite training from preseason to late season, the wrestlers A_{XSECT} did not change, whereas the T_{XSECT} decreased. Both increased significantly postseason. The pre- to postseason increases in A_{XSECT} (8.1 vs. 8.8 cm^2) and T_{XSECT} (4.8 vs. 5.4 cm^2) were similar for both groups.

Strength and power. Elbow peak power and torque changes are shown in Table 4. There were no significant changes for the controls, but from preseason to late season the wrestlers' peak torque decreased for elbow flexion (EF) at 60°/s and elbow extension (EE) and EF at 180°/s. The wrestlers' peak arm power decreased from preseason to late season for EE and EF at 180°/s. For the wrestlers, all measures increased significantly postseason. The A_{XSECT} and FFM were directly related to arm strength and power ($r = 0.80$ to 0.90, $P < 0.001$). After covariance for FFM and A_{XSECT}, only the wrestlers' EF torque at 60°/s and EF torque and power at 180°/s remained reduced from preseason to late season and increased postseason.

The peak torque and power produced during knee extension (KE) and flexion (KF) at 60 and 180°/s are shown in Table 5. For all knee strength and power variables, the wrestlers had significant reductions from

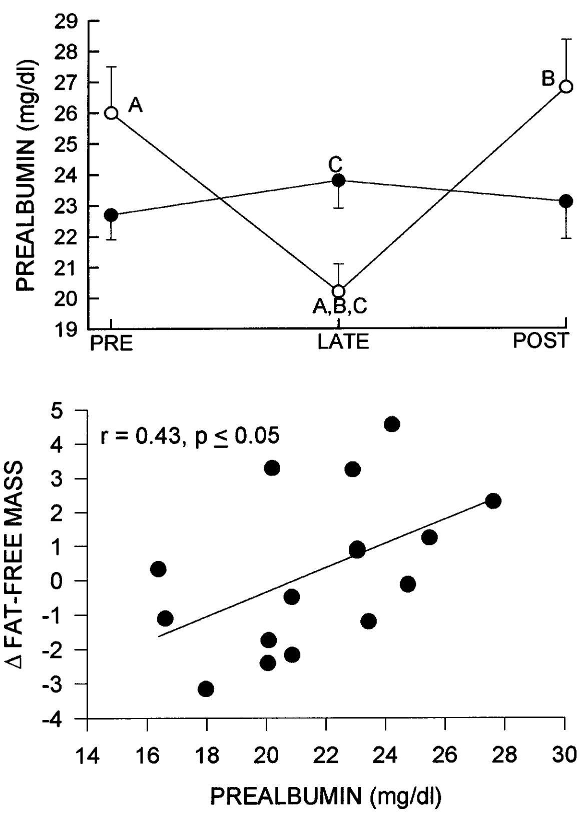

Fig. 4. Serum prealbumin in mg/dl (*top*) and relationship between late-season prealbumin concentration and preseason-to-late season change in fat-free mass (FFM; *bottom*) for wrestlers (●, $n = 9$) and controls (○, $n = 7$). Like letters indicate significant difference. Values are means ± SE.

Table 4. *Arm isokinetic torque and power produced at 60 and 180°/s for wrestlers and controls*

Variable and Group	Preseason	Late Season	Postseason
60°/s			
Extension peak torque, nm			
Wrestler	38.5 ± 2.8[a]	35.8 ± 2.9[b]	42.7 ± 3.0[a,b]
Control	32.9 ± 5.3	35.0 ± 5.3	34.6 ± 4.7
Extension peak power, W			
Wrestler	41.2 ± 3.2[a]	38.9 ± 3.4[b]	46.7 ± 3.3[a,b]
Control	36.4 ± 5.4	37.2 ± 5.5	37.7 ± 5.4
Flexion peak torque, nm			
Wrestler	37.8 ± 3.1[a]	33.3 ± 2.9[a]	44.3 ± 2.5[a]
Control	33.7 ± 5.3	34.4 ± 5.0	36.8 ± 5.1
Flexion peak power, W			
Wrestler	40.2 ± 3.2[a]	37.9 ± 3.9[b]	48.1 ± 2.7[a,b]
Control	37.9 ± 5.1	38.2 ± 5.1	40.2 ± 5.4
180°/s			
Extension peak torque, nm			
Wrestler	33.1 ± 2.4[a]	29.8 ± 3.0[a,b]	35.4 ± 2.4[b]
Control	23.3 ± 3.6	25.9 ± 3.6	25.4 ± 3.8
Extension peak power, W			
Wrestler	111.8 ± 9.4[a]	98.8 ± 10.7[a,b]	119.2 ± 8.5[b]
Control	81.7 ± 10.3	88.7 ± 10.7	91.4 ± 11.2
Flexion peak torque, nm			
Wrestler	30.4 ± 2.3[a]	24.5 ± 2.7[a]	34.3 ± 1.6[a,b]
Control	23.8 ± 3.3	23.7 ± 3.4	24.4 ± 3.8
Flexion peak power, W			
Wrestler	103.2 ± 7.9[a]	83.2 ± 7.3[a,b]	111.5 ± 7.6[b]
Control	86.3 ± 11.0	91.7 ± 10.4	96.0 ± 11.8

Values are means ± SE. Wrestlers, n = 9; controls, n = 7. For significant group-by-time interactions, means with same letter, $P < 0.05$.

preseason to late season and significant increases postseason. Analysis of covariance was computed for KE and KF peak torque and power by using FFM or T_{XSECT} that had high correlations with these measures (r = 0.72 to 0.91, $P < 0.001$). After covarying, no interactions remained significant.

Physical activity. The wrestlers participated in a significantly higher amount of physical activity expressed as kilocalories per kilogram per week during the sport season compared with the postseason (71 vs. 41 $kcal \cdot kg^{-1} \cdot wk^{-1}$). The physical activity of the controls was not significantly changed (25 vs. 36 $kcal \cdot kg^{-1} \cdot wk^{-1}$). Physical activity values for the groups were significantly different during the sport season.

In general, wrestling practice sessions consisted of live wrestling (45–90 min), wrestling drills (20–45 min), calisthenics (10–20 min), instruction (10–20 min), and running (10–25 min). Wrestlers participated in basketball (n = 2, 45–60 min) and running (n = 1, 20 min) on Sunday. No wrestler listed weight training as an activity during the sport season. Five of the controls were Boy Scouts and participated in many outdoor activities. All of the control subjects were recreationally active in sports such as tennis, off-road motorcycling, bicycling, basketball, and baseball.

DISCUSSION

This investigation is novel because it is the only study of adolescent wrestlers to investigate the interactive effects of energy drain on growth and maturation, including bone age. Also, the actual undernutrition of adolescent wrestlers has not been well documented. One investigation (12) reported the energy intake of adolescent wrestlers, but the present study is the only one to estimate both the energy intake and expenditure. In addition, although other studies (7, 12) have investigated the relationship between changes in body composition and strength in adolescent wrestlers, they did not include a nonwrestling control group, did not report alterations in growth or maturation, and in one study (12) the body composition was estimated from skinfolds. In the present study, the subject groups were initially matched for physical characteristics and maturational status. Therefore, a valid comparison can be made regarding the influence of wrestling training and dietary restriction on growth, maturation, and body composition.

Despite participation in 65% more physical activity than the controls during the sport season, the wrestlers' early- and late-season energy intake (Figs. 1 and 2) was roughly 50% of the recommended 48 $kcal \cdot kg^{-1} \cdot day^{-1}$ (8). The wrestlers' postseason energy intake

Table 5. *Knee isokinetic torque and power produced at 60 and 180°/s for wrestlers and controls*

Variable and Group	Preseason	Late Season	Postseason
60°/s			
Extension peak torque, nm			
Wrestler	159.2 ± 11.4[a,c]	134.3 ± 9.4[a,b]	162.0 ± 12.7[b]
Control	116.9 ± 16.3[c]	124.6 ± 16.7	130.6 ± 19.7
Extension peak power, W			
Wrestler	182.2 ± 13.2[a,c]	155.8 ± 9.4[a,b]	184.1 ± 13.9[b]
Control	137.1 ± 20.3[c]	143.1 ± 19.0	151.5 ± 22.3
Flexion peak torque, nm			
Wrestler	89.3 ± 9.9[a]	75.6 ± 8.1[a]	101.4 ± 10.5[a]
Control	75.5 ± 10.6	78.5 ± 10.7	79.3 ± 12.2
Flexion peak power, W			
Wrestler	102.0 ± 11.3[a]	84.2 ± 8.5[a]	116.7 ± 13.0[a]
Control	82.3 ± 12.3	85.9 ± 11.2	89.5 ± 14.3
180°/s			
Extension peak torque, nm			
Wrestler	110.5 ± 7.3[a,c]	94.0 ± 7.2[a,b]	113.6 ± 10.1[b]
Control	84.6 ± 11.8[c]	91.9 ± 12.7	98.7 ± 14.1[c]
Extension peak power, W			
Wrestler	408.5 ± 25.2[a,c]	357.6 ± 28.0[a,b]	411.6 ± 37.9[b]
Control	291.6 ± 25.5[c,d]	313.5 ± 22.5	343.7 ± 24.7[d]
Flexion peak torque, nm			
Wrestler	73.4 ± 6.3[a]	65.1 ± 5.5[a]	82.3 ± 7.1[a]
Control	56.8 ± 10.5[b]	62.4 ± 9.5	68.4 ± 8.5[b]
Flexion peak power, W			
Wrestler	267.1 ± 25.4[a]	233.9 ± 21.0[a]	296.6 ± 29.2[a]
Control	217.5 ± 40.0[b]	233.1 ± 36.0	258.5 ± 36.8[b]

Values are means ± SE. Wrestlers, n = 9; controls, n = 7. For significant group-by-time interactions, means with same letter, $P < 0.05$.

was similar to the controls and close to the recommendation. Horswill et al. (12) also reported deficient in-season and adequate out-of-season energy intakes of adolescent wrestlers (27 vs. 43 kcal $\cdot$ kg^{-1} $\cdot$ day^{-1}, respectively). Thus, despite position statements on weight loss (2, 3), wrestlers continue to lose weight by severe dietary restriction. The mean in-season protein intake was also similar to that reported by Horswill et al. (12) of 0.9 g $\cdot$ kg^{-1} $\cdot$ day^{-1}. The recommended minimum protein intake for this age is 0.97 g $\cdot$ kg^{-1} $\cdot$ day^{-1} (8), but the protein intake may be even more deficient than these data suggest. The protein requirement is higher during physical training (17), periods of reduced energy intake (6), and growth (8), all conditions that were present in the wrestlers.

A unique aspect of this study is the documentation of the change in energy intake and weight during the days leading up to a competition (Fig. 3). In conflict with the common belief that rapid fluctuations occur in weight and energy intake before a match, the wrestlers reduced their weight and energy intake in a linear manner. On no day during the week did the wrestlers consume enough energy to meet the combined requirements of growth, resting metabolic activity, and training, suggesting that they were in a constant state of undernutrition throughout the week. If this week is representative, the entire season would be characterized by graded undernutrition as supported by our prealbumin findings (Fig. 3).

The undernutrition does not appear to slow pubertal maturation (Table 2), as indicated by the wrestlers' slightly advanced bone ages, stable relative ages (bone age − chronological age), and pubertal stages within the normal range (24, 32). Continuing skeletal maturation and a slowing in linear growth could result in a wrestler's not attaining his genetic potential for height. However, as in previous reports, the wrestlers' incremental growth in stature was similar to the controls both during the season and postseason (13, 26), and the alkaline phosphatase activity suggested no change in bone growth metabolism. The skeletal breadths also demonstrated little difference in the rate of bone growth between the wrestlers and controls. Although there was a lack of change in elbow-wrist length of the wrestlers (Table 2), this may have been due to systematic measurement error (Table 1). Also, a significant loss of skinfold thickness from preseason to late season (77.5 ± 5.4 to 61.5 ± 4.2 mm) may have reduced the fat-skin layer over the upper limb landmarks, creating a situation where growth of the bones appeared to slow. The fat-skin layer increased during the postseason (sum of skinfolds = 97.4 ± 4.2 mm). In agreement with previous findings (14, 26), the wrestlers' body girths decreased from preseason to late season and increased from late season to postseason (Table 2). The wrestlers' large postseason increments in girth demonstrate an accelerated growth in soft tissue after the wrestling season.

The mean %BF (10.5%) of the control group was low for recreationally active youth but allowed matching the groups for adiposity. Even though the in-season reduction in FFM was not statistically significant, it may be biologically significant. The FFM increased for the controls and was related to the loss of arm and leg strength in the present and past studies (26). The wrestlers' weight and FFM increased at an accelerated rate during the postseason, as reported previously (26, 29). Alterations in the hydration of the wrestlers had the potential to influence the body composition results. However, the body composition measurements took place when the subjects should have been euhydrated (see METHODS). Furthermore, the hematocrit was not changed for either group.

Horswill et al. (12) speculated that the lack of lean tissue accrual by adolescent wrestlers was due to a reduction in protein nutrition and muscle protein synthesis. Prealbumin (Fig. 4) is a sensitive marker of marginal protein or energy intake in apparently healthy children and serves as a marker of malnutrition before clinical complications are evident (15). The modest relationship (r = 0.43, $P \leq 0.05$) between the late-season prealbumin concentration and the preseason to late-season change in FFM may be limited by prealbumin's being more of an indicator of visceral protein status (5) rather than the entire FFM. Reductions in serum prealbumin concentration are caused by a reduction in its synthesis in the liver (15). Reduced protein synthesis in other tissues, especially muscle tissue, would slow the physical development of the adolescent wrestler (12). Although we have no direct measures of protein synthesis, the wrestlers' mean FFM was 2.0% lower (a nonsignificant change), as in a previous study (26), and the normal adolescent increase in the lean limb cross-section (10) was significantly slowed or reversed from preseason to late season (Table 2). An increase in protein catabolism could also slow lean tissue accrual, but the wrestlers' BUN concentrations were not significantly changed.

After covariance of the muscle performance data for FFM or cross section, only 2 of 26 measures remained significant, suggesting that changes in power are primarily related to changes in lean tissue, as previously reported (7, 16, 26). A change in the wrestlers' strength training regimen or an overtraining effect may have contributed to the change in muscle performance. None of the wrestlers included weight training as a part of his in-season workout, but during the postseason six of the nine wrestlers did weight training 3–4 days a week. The influence of weight training on the muscle mass and strength of wrestlers during the sport season is uncertain.

The reduction in arm and leg strength and power during the wrestling season should be of concern to the wrestler and the coach, as the importance of power for wrestling success has been previously established (25). The reduction in muscular strength and power relative to the loss of lean tissue conflicts with the theory that weight loss allows a participant to gain a competitive edge. However, successful wrestlers have been reported to reduce a greater percentage of their body weight than less successful wrestlers, and many factors other than strength are related to wrestling success (25). Perhaps the most successful wrestlers are those who are able to reduce their weight and still maintain their strength and power by limiting the loss of FFM. Through differences in weight-loss regimens and nutrition, successful wrestlers may also limit losses of muscle glycogen. Investigations of acute weight loss with low-energy, high-carbohydrate diets have demonstrated a maintenance of performance in collegiate wrestlers (11). However, the strength and power reductions in the present study were influenced by a sport season of weight maintenance in less physically mature high school wrestlers.

In conclusion, dietary restriction and wrestling training had little effect on bone growth or maturation. Dietary restriction did produce significant reductions in protein nutritional status, body protein and fat stores, and muscular strength and power. All were quickly reversed during the postseason when the wrestlers decreased their physical activity and increased their energy intake. During the sport season, changes in lean tissue were directly associated with changes in protein nutritional status. The reductions in strength and power during the sport season were primarily associated with the loss of lean tissue. Subsequent studies should measure, by using stable isotopes, the rate of protein synthesis of wrestlers.

We thank the subjects, parents, and wrestling coaches for their participation and cooperation. We thank Dr. Craig Horswill for helpful insights and contributions to the data interpretation and discussion, and we thank Dr. Alan D. Rogol for suggestions during preparation of the manuscript.

This study was supported in part by grants from Ronald McDonald Children's Charities, the Sisler McFawn Foundation, and Gatorade Sport Science Institute.

Address for reprint requests: J. N. Roemmich, Univ. of Virginia Health Sciences Center, Dept. of Pediatrics, Div. of Endocrinology, Box 386, Charlottesville, VA 22908 (E-mail: jr5n@virginia.edu).

Received 26 July 1996; accepted in final form 6 February 1997.

REFERENCES

1. **Ainsworth, B. E., W. L. Haskell, A. S. Leon, D. R. Jacobs, H. J. Montoye, J. F. Sallis, and R. S. Paffenbarger.** Compendium of physical activities: classification of energy costs of human physical activities. *Med. Sci. Sports Exercise* 25: 71–80, 1993.
2. **American College of Sports Medicine.** American College of Sports Medicine position stand on weight loss in wrestlers. *Med. Sci. Sports Exercise* 28: ix-xii, 1996.
3. **American Medical Association.** American Medical Association position paper on wrestling and weight control. *J. Am. Med. Assoc.* 201: 131–133, 1967.
4. **Baumgartner, R. N., A. F. Roche, and J. H. Himes.** Incremental growth tables: supplementary to previously published charts. *Am. J. Clin. Nutr.* 43: 711–722, 1986.
5. **Bistrian, B. R., G. L. Blackburn, N. S. Scrimshaw, and J. P. Flatt.** Cellular immunity in semistarved states in hospitalized adults. *Am. J. Clin. Nutr.* 28: 1148–1155, 1975.
6. **Butterfield, G. E.** Whole-body protein utilization in humans. *Med. Sci. Sports Exercise* 19, *Suppl.* 5: S157–S165, 1987.
7. **Eckerson, J. M., D. J. Housh, T. J. Housh, and G. O. Johnson.** Seasonal changes in body composition, strength, and muscular power in high school wrestlers. *Pediatr. Exercise Sci.* 1: 39–52, 1994.
8. **Food, and Agricultural Organization, World Health Organization, and United Nations University.** *Energy and Protein Requirements.* Geneva, Switzerland: World Health Organization, 1985. (Tech. Rept. Ser. 724)
9. **Freischlag, J.** Weight loss, body composition, and health of high school wrestlers. *Phys. Sports Med.* 12: 121–126, 1984.
10. **Frisancho, A. R.** New norms of upper limb fat and muscle areas for assessment of nutritional status. *Am. J. Clin. Nutr.* 34: 2540–2545, 1981.
11. **Horswill, C. A., R. C. Hickner, J. R. Scott, D. L. Costill, and D. Gould.** Weight loss, dietary carbohydrate modifications, and high intensity physical performance. *Med. Sci. Sports Exercise* 22: 470–476, 1990.
12. **Horswill, C. A., S. H. Park, and J. N. Roemmich.** Changes in protein nutritional status of adolescent wrestlers. *Med. Sci. Sports Exercise* 22: 599–604, 1990.
13. **Housh, T. J., G. O. Johnson, J. Stout J., and D. J. Housh.** Anthropometric growth patterns of high school wrestlers. *Med. Sci. Sports Exercise* 25: 1141–1151, 1993.
14. **Hughes, R. A., T. J. Housh, and G. O. Johnson.** Anthropometric estimations of body composition in wrestlers across a season. *J. Appl. Sport Sci. Res.* 5: 71–76, 1991.
15. **Ingenbleek, Y., H. G. Van Den Schrieck, P. De Nayer, and M. De Visscher.** The role of retinol-binding protein in protein calorie malnutrition. *Metabolism* 24: 633–641, 1975.
16. **Kelly, J. M., B. A. Gorney, and K. K. Kalm.** The effects of a collegiate wrestling season on body composition, cardiovascular fitness, and muscular strength and endurance. *Med. Sci. Sports Exercise* 10: 119–124, 1978.
17. **Lemon, P. W. R.** Nutrition for muscular development of young athletes. In: *Perspectives in Exercise Science and Sports Medicine. Youth, Exercise, and Sport,* edited by G. V. Gisolfi and D. R. Lamb. Indianapolis, IN: Benchmark, 1989, vol. 2, chapt. 9, p. 369–396.
18. **Lohman, T. G.** Assessment of body composition in children. *Pediatr. Exercise Sci.* 1: 19–30, 1989.
19. **Lohman, T. G., A. F. Roche, and R. Martorell.** *Anthropometric Standardization Reference Manual.* Champaign, IL: Human Kinetics, 1988.
20. **Malina, R. M., P. V. V. Hamill, and S. J. Lemeshow.** *Selected Body Measurements of Children 6–11 Years. Series 11, No. 123.* Washington, DC: US Government Printing Office, 1973.
21. **McMurray, R. G., C. R. Proctor, and W. L. Wilson.** Effect of caloric deficit and dietary manipulation on aerobic and anaerobic exercise. *Int. J. Sports Med.* 12: 167–172, 1991.
22. **Morris, N. M., and J. R. Udry.** Validation of a self-administered instrument to assess stage of adolescent development. *J. Youth Adolesc.* 9: 271–280, 1980.
23. **Park, S. H., J. N. Roemmich, and C. A. Horswill.** A season of wrestling and weight loss by adolescent wrestlers: effect on anaerobic arm power. *J. Appl. Sport Sci.* 4: 1–4, 1990.
24. **Roche, A. F., W. C. Chumlea, and D. Thissen.** *Assesssing the Skeletal Maturity of the Hand Wrist: Fels Method.* Springfield, IL: Thomas, 1988.
25. **Roemmich, J. N., and J. P. Frappier.** Physiological determinants of wrestling success in high school athletes. *Pediatr. Exercise Sci.* 5: 134–144, 1993.
26. **Roemmich, J. N., and W. E. Sinning.** Sport-seasonal changes in body composition, growth, power and strength of adolescent wrestlers. *Int. J. Sports Med.* 17: 92–99, 1996.
27. **Roemmich, J. N., and W. E. Sinning.** Weight loss and wrestling training: effects on growth-related hormones. *J. Appl. Physiol.* 82: 1760–1764, 1997.
28. **Sinning, W. E.** Body composition analysis by body densitometry. In: *National Association for Girls' and Women's Sports Research Reports,* edited by M. Adrian and J. Brame. Washington, DC: American Alliance for Health, Physical Education, and Recreation, 1977, vol. 3, p. 138–152.
29. **Sinning, W. E., N. Wilensky, and E. Meyers.** Post-season body composition changes and weight estimation in high-school wres-

tlers. In: *Physical Education, Sports and the Sciences,* edited by J. Broekhoff. Eugene, OR: Microform Publications, 1976, p. 137–153.
30. **Smith, N. J.** Weight control in the athlete. *Clin. Sports Med.* 3: 693–704, 1984.
31. **Song, T. M. K., and K. Cipriano.** Effects of seasonal training on physical and physiological function on elite varsity wrestlers. *J. Sports Med.* 24: 123–130, 1984.
32. **Tanner, J. M., and R. H. Whitehouse.** Longitudinal standards for height, weight, height velocity, weight velocity and stages of puberty. *Arch. Dis. Child.* 51: 170–179, 1976.
33. **Wilmore, J. H.** A simplified method for determination of residual lung volume. *J. Appl. Physiol.* 27: 96–100, 1969.
34. **Williams, M. H.** Exercise effects on children's health. *Sports Sci. Exchange* 4: 1993. (Gatorade Sport Sci. Inst. Ser.)