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Effects of a competitive wrestling season on body composition, endocrine markers, and anaerobic exercise performance in NCAA collegiate wrestlers

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Abstract Few data exist examining the body composition, endocrine, and anaerobic exercise performance changes over a competitive wrestling season. Eighteen NCAA wrestlers were tested for endocrine markers, body composition, hydration, grip strength, and power on four occasions: prior to pre-season training (T1); after pre-season training 3 days prior to the first seasonal meet (T2); mid-season one day prior to a meet (T3); and at the end of the season 2–3 days following the last meet (T4). Body mass, percent body fat (BF %), and fat mass were significantly lower ($P \leq 0.05$) at T2 and T3 compared to T1 but were not different between T1 and T4. Lean body mass was significantly reduced at T2 only. Urine specific gravity was significantly elevated at T3 compared to T1, T2, and T4. Resting cortisol concentrations did not change but resting testosterone concentrations were significantly reduced at T2, T3, and T4. Maximal grip strength was significantly reduced at T2. Vertical jump peak power was significantly reduced at T2, T3, and T4. Wingate peak power was significantly reduced at T2 and T3. However, Wingate average power and total work did not significantly change. Fatigue rate during the Wingate test was significantly improved at T2, T3, and T4 compared to T1. In conclusion, body mass, BF %, and measures of peak force and power were reduced for most of the competitive wrestling season. Competitive wrestling reduces resting total testosterone concentrations throughout the entire season.

Abbreviations

1RM	One repetition-maximum
ANOVA	Analysis of variance
BF %	Body fat percent
BMI	Body mass index
CORT	Cortisol
ELISA	Enzyme-linked immunosorbent assay
HPL	Human performance laboratory
LBM	Lean body mass
NCAA	National Collegiate Athletic Association
T1–T4	Time points 1 through 4
TE	Testosterone
USG	Urinary specific gravity

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Introduction

The physiological demands of an entire competitive wrestling season have received limited investigation. Wrestling is a sport that requires substantial dynamic and

isometric muscular strength, power, and endurance where changes in body composition and hydration status have been shown to affect performance (Horswill 1992). A collegiate wrestler will compete for 7 min starting with a 3-min first period followed by two 2-min periods if the match lasts its entirety imposing substantial metabolic demands, i.e. blood lactates of 16–20 mmol/L (Barbas et al. 2011; Kraemer et al. 2001). During tournaments, multiple matches per day may occur over the course of a few days (Barbas et al. 2011; Kraemer et al. 2001). The competitive season lasts approximately 4 months, e.g. November until the NCAA championships in March. Wrestlers encounter substantial physiologic stress via aerobic and anaerobic training, weight loss, caloric restriction, practice, competition, and potential injury throughout the course of the competitive season.

Regular assessment of body composition and hydration status is critical to wrestling practice. It is customary for collegiate wrestlers to lose body mass during the pre- and in-season periods (Oppliger et al. 1996; Yankanich et al. 1998; Utter et al. 2001). The process of "making weight" has been controversial, especially within days of a major competition. Rapid body mass reduction has been observed in very short periods of time (Oppliger et al. 1996; Yankanich et al. 1998) and wrestlers have been reported to make weight 15–30 times over the course of a season (Lingor and Olson 2010). The pattern of body mass reduction is wrestler-dependent (Yankanich et al. 1998). Methods such as exercise, food and beverage restriction, fasting, excessive perspiration via rubber suits and saunas, laxatives, and diuretics have been used by wrestlers to rapidly reduce body mass (Lingor and Olson 2010; Oppliger et al. 1996). Although the NCAA has implemented its minimal weight program (i.e. determines a wrestlers minimum weight for the season at 5 % body fat) (NCAA 2010) and schedules official pre-competition weigh-ins 1–2 h in advance to enhance safety and alleviate rapid body mass fluctuations, weight loss is an inevitable part of the sport. Because most non-heavyweight wrestlers tend to have low percent body fat initially (Bartok et al. 2004a, b), much of the body mass reduction is in the forms of water, glycogen, and lean tissue mass with a small contribution of subcutaneous fat (Oppliger et al. 1996; Yankanich et al. 1998).

The physiological ramifications of rapid body mass reduction have been of interest to the athletic, medical, and scientific communities. Some studies have shown that rapid body mass reduction (with dehydration) may result in anaerobic performance reductions (Klinzing and Karpowicz 1986; Kraemer et al. 2001; Webster et al. 1990) whereas other studies have reported no such performance reductions with body mass reductions of ≤5 % (Serfass et al. 1984; Singer and Weiss 1968). During tournament competition (with a 6 % initial reduction in body mass),

Kraemer et al. (2001) and Barbas et al. (2011) have shown that grip strength, knee and elbow peak torque, hip/back strength, and sport-specific bear hug strength were significantly reduced compared to baseline measurements while peak power (measured by vertical jump) was maintained (Kraemer et al. 2001) or reduced (Barbas et al. 2011). These data indicate that strength and power may decrease when body mass is greatly reduced in a short period of time.

The physiological stress associated with competitive wrestling, nutrient/fluid restriction, and body mass fluctuations may affect the endocrine system. Two hormones often examined are testosterone and cortisol. Testosterone (TE) is an anabolic hormone known to augment athletic performance while cortisol (CORT) is a catabolic hormone shown to be elevated during times of physiologic stress (Kraemer and Ratamess 2005). Testosterone and CORT concentrations have been shown to reflect the acute and chronic stress of competitive wrestling (Kraemer et al. 2001). Competitive wrestling has been shown to produce acute elevations in total TE and CORT (Barbas et al. 2011; Fry et al. 2011; Kraemer et al. 2001) with the TE response reduced during subsequent matches of tournament wrestling (Barbas et al. 2011; Kraemer et al. 2001). The importance of TE elevations was shown by Fry et al. (2011) who reported the acute TE response to wrestling in winners was significantly greater than the response of those wrestlers who lost their respective matches. Less is known concerning resting TE and CORT concentrations during the course of a competitive season. Studies have shown no changes in resting CORT (Strauss et al. 1985), decreases in total and free TE (Strauss et al. 1985; Roemmich and Sinning 1997b), and a reduced salivary TE/CORT ratio (Passelerque and Lac 1999) with TE reductions significantly related to reduced body fat and mass, and fasting (Strauss et al. 1985; Booth et al. 1993; Karila et al. 2008). However, these studies based seasonal changes on only a few measurement time points, e.g. pre-season compared to post-season (Roemmich and Sinning 1997a, b), mid-season compared to 2 weeks post-season (Strauss et al. 1985), and pre-season compared to a multi-day in-season competition (Passelerque and Lac 1999). Considering the importance of these endocrine biomarkers in assessing the stress of a competitive season, there is a paucity of studies examining a comprehensive evaluation of a wrestling season.

Although wrestlers display a dramatic ability to adapt and rebound to consistent rapid changes in body composition and hydration status, less is known concerning anaerobic strength, power, endocrine, hydration status, and body composition changes over the course of a competitive season. A few studies have addressed this issue in collegiate wrestlers; each examining performance at different time points (Buford et al. 2006; Kelly et al. 1978; Song and

Cipriano 1984; Schmidt et al. 2005; Utter et al. 1998). However, few data are available examining altered physiological profiles of wrestlers over a competitive season. In addition, less is known regarding changes in physiological profiles of wrestlers who start and compete regularly for their team versus those wrestlers who do not regularly start and only wrestle periodically throughout the season. Starters tend to make weight more frequently and may experience more wrestling practice throughout the season. Classifying wrestling status is important for monitoring season-long changes in performance. Therefore, the purpose of the present investigation was to examine body composition, anaerobic power and strength, endocrine, and hydration status changes throughout a competitive season in Division III collegiate wrestlers and to compare the responses of starters and non-starters.

Methods

Experimental design

Division III collegiate wrestlers were tested between 0700 and 0900 h in the morning after an overnight fast (at a standardized time of day) on four occasions: prior to pre-season training; prior to the first meet of the season; mid-season; and at the end of the season. Tests included and followed the same order of blood sampling (for measurement of resting concentrations of testosterone and cortisol) and assessments of body composition (skinfold measurement), urine specific gravity, maximal isometric grip strength, maximal vertical jump force and power, and maximal anaerobic cycling power.

Subjects

Eighteen Division III college wrestlers [age = 19.6 ± 1.2 years; height = 174.7 ± 8.4 cm; body mass index (BMI) = 24.6 ± 2.9 kg/m^2; and wrestling experience = 9.5 ± 3.7 years] from a top-twenty ranked team were examined over the entire wrestling season. Wrestlers were further divided into starters (N = 7; age = 19.9 ± 1.1 years; height = 173.8 ± 7.2 cm; BMI = 25.0 ± 3.6 kg/m^2; and wrestling experience = 11.7 ± 3.7 years) and non-starters (N = 11; age = 19.4 ± 1.2 years; height = 175.3 ± 9.4 cm; BMI = 24.4 ± 2.5 kg/m^2; and wrestling experience = 8.3 ± 3.1 years). The criteria for determining a starter was the wrestler had to have competed in the majority (>70 %) of the matches at their specific weight class in dual meets over the course of the season and have been ranked as one of the top eight wrestlers in their weight class within the conference. These wrestlers had to make weight on a consistent basis. Non-starters were those wrestlers lower in rank that mostly wrestled

in tournaments and occasionally competed in a dual meet due to injury of the primary wrestler, failure of the primary wrestler to make weight, or due to a coach's decision. They also made weight but on an inconsistent basis. Analysis of the wrestling season and training of the wrestlers is presented in the Results section. No subject had any physiological or orthopedic limitations that negatively affected performance as determined by completion of a health history questionnaire, passing a pre-wrestling physical examination from the team physician and communication with the head coach prior to initiating the study. This study was approved by the College's Institutional Review Board and each subject gave written informed consent prior to participation after the risks of the investigation were explained.

Experimental protocol

Subjects reported to the Human Performance Laboratory (HPL) early in the morning between 0700 and 0900 h after an overnight fast at a standardized time of day on four occasions: (1) prior to beginning of the pre-season training period (T1); (2) after pre-season training 3 days prior to the first meet of the season (T2); (3) mid-season 1 day prior to a meet (T3); and (4) end of the season 2–3 days following the last meet and 1 week prior to the National Championships (T4). The wrestlers had refrained from physical activity 24 h prior to T1 testing. However, the wrestlers attended mandatory practice sessions the day before (14–16 h) T2, T3, and T4 testing. Upon arrival to the HPL, subjects sat in a recumbent position for 10 min and subsequently a resting blood sample was obtained. Following blood sampling, subjects provided a urine sample, were weighed on a calibrated physician's scale, and underwent body composition testing consisting of skinfold assessment. During the subsequent performance tests, each subject underwent a general warm-up consisting of 3 min of stationary cycling at 60 rpm, light calisthenics, and 3–4 sets of progressive vertical jumps followed by maximal isometric grip strength, power (vertical jumps on a force platform), and peak anaerobic power (Wingate anaerobic test) assessments in that sequence. Power tests targeting cycling and vertical jump performance were selected because of the high familiarity the wrestlers in the present study had with these modalities of exercise. Because this was an observational study examining Division III collegiate wrestlers over the course of an entire season, a non-wrestling control group was not included. A subgroup of ten subjects were tested on two occasions (separated by 7 days) to determine test–retest reliability for maximal grip strength, peak power during the vertical jump, and peak and mean power obtained during a Wingate test. Test–retest reliability intra-class coefficients were high for the aforementioned performance tests (R = 0.88–0.98).

Blood sampling

Subjects arrived at the HPL early in the morning (with time identical for each wrestler during this time frame over the study) following an overnight fast for blood draws. Each blood sample was obtained from an antecubital arm vein using a 20-gauge disposable needle while the subject remained in a seated position. Blood samples were collected into Vacutainer® tubes. Serum was allowed to clot at room temperature and subsequently centrifuged at $1{,}500 \times g$ for 15 min. The resulting serum was placed into separate 1.8-ml microcentrifuge tubes and frozen at $-80\ ^\circ\mathrm{C}$ for later analyses.

Biochemical analyses

Hematocrit was analyzed in triplicate from whole blood via microcentrifugation (IECmicro-MB centrifuge, Needham, MA, USA) and microcapillary technique. Serum total TE and CORT were determined in duplicate using enzyme-linked immunosorbent assays (ELISA) (Diagnostic Systems Laboratories, Webster, TX, USA). To eliminate inter-assay variance, all samples for a particular assay were thawed once and analyzed in the same assay run. All samples were run in duplicate with a mean intra-assay variance of <2 %.

Urine collection and analysis

Subjects provided a urine sample in a specimen collection cup following blood sampling. Urine samples were immediately analyzed in duplicate for specific gravity (USG) to determine hydration status of the subjects using a hand refractometer (Atago PAL 10-S, Atago, Inc., Tokyo, Japan). Calibration with distilled water occurred before each use. A USG value of 1.020 g/mL was used as criterion for hydration (Bartok et al. 2004a, b).

Body composition

Body composition was assessed via skinfold analysis. Percent body fat was estimated from subcutaneous adipose tissue thickness measurements via a three-site skinfold test. The sites measured were the pectoral, anterior thigh, and abdominal skinfolds using methodology previously described (Jackson and Pollock 1978). Body density was calculated using the equation of Jackson and Pollock (1978) and percent body fat (BF %) was calculated using the equation of Siri (1956). The same research assistant performed all skinfold assessments. Lean body mass (LBM) was calculated using the following equation: Fat mass = body mass × % fat; LBM = body mass − fat mass.

Maximal isometric grip strength testing

Maximal isometric grip strength of both hands was measured using a JAMAR® hand dynamometer (model number 10513404, Clifton, NJ). Subjects gripped the dynamometer with as much force as possible while in a standing position with the elbow fully extended, the proximal radioulnar joint in the midrange position, and with slight wrist extension (Firrell and Crain 1996; Kuzala and Vargo 1992; Ratamess et al. 2007). All subjects were tested at setting II on the grip dynamometer as this has been shown to produce maximal grip strength values in 89 % of the tested population (Firrell and Crain 1996). The best of three trials for each limb was recorded for further analysis. Data are presented as right hand, left hand, and total grip strength (kg) where the right and left values were summed. In addition, the dominant limb (the right limb in all but two subjects) was used for a relative grip strength measure where the peak score was divided by body mass (in kg).

Power assessments

Anaerobic power performance was assessed using a vertical jump and modified Wingate tests. Vertical jump power was assessed using a 3-repetition jump test performed on a force platform (HoLBMan et al. 2009). Following a brief warm-up, subjects stood on a portable force plate (Advanced Medical Technology Inc., Watertown, MA, USA) with hands placed on the hips at all times. Upon cue from a research assistant, each subject performed three consecutive vertical jumps with a standardized counter-movement. The jump with the highest peak power was recorded. The subject was instructed to maximize the height of each jump while minimizing the contact time with the force plate between jumps. Peak power output, force, velocity, and relative power (peak power/body mass in kg) were recorded. Each subject performed 3–5 trials and the best trial (one producing the highest peak power) was used for analysis.

For the modified Wingate anaerobic power test (Lode Excalibur, Groningen, The Netherlands), the subjects pedaled for 1 min at maximal speed against a constant force (1.2 Nm/kg) after a warm-up consisting of 5 min of pedaling at 60 rpm interspersed with three all-out sprints lasting 5 s. The Wingate test was modified to 1-min duration (rather than the conventional 30-s duration) to better assess power endurance specific to wrestling. Peak power, mean power, minimum power, relative power, total work, time to peak power, and fatigue rate were determined. Total work was calculated by multiplying the force and displacement (based on flywheel revolutions per min, distance per revolution, and resistance added to the flywheel) throughout the test. Peak power was calculated at

the highest value attained (work per unit time) over a 3- to 5-s interval, whereas minimum power was the lowest recorded value. Mean power was calculated over the entire test duration. Relative power measures were determined by taking either the peak or mean power value and dividing it by body mass. Fatigue rate was determined by averaging the power loss per second of the test. The modified Wingate test was performed last in the sequence of assessments due to its high fatigability.

Statistical analyses

Standard statistical methods were used to calculate means and standard deviations. A one-way analysis of variance (ANOVA) was used to analyze data for all of the pooled wrestlers. A 2 (group) × 4 (time points) ANOVA with repeated measures was used to analyze data comparing starters versus non-starters. Subsequent Tukey's post hoc tests were utilized to determine temporal differences when significant F ratios were obtained. Pearson-product moment correlation coefficient indices were calculated for evaluating relationships between selected body composition, endocrine, and performance variables. For all statistical tests, a probability level of $P \leq 0.05$ denoted statistical significance.

Results

Descriptive analysis of the wrestling season showed that the team participated in three tournaments, 23 dual meets, the conference championships, and four wrestlers competed in the Division III National Championships during the 2007–2008 wrestling season. Four of the dual meets occurred on the same day (i.e. the team competed against 3–4 different teams). Thus, wrestlers had to make weight approximately 18 times from the beginning of the season through the conference championships. Starters wrestled an average of 34 ± 6 matches (range = 25–43 matches) throughout the season. Seven starters (out of 10 weight classes) completed all phases of the study. Non-starters wrestled an average of 5 ± 7 matches (range = 0–20 matches) throughout the season. All wrestlers regularly attended daily practice sessions and participated in in-season weight training and conditioning in addition to the rigors of competition and corresponding travel schedule. The wrestlers practiced 6–7 days per week for 1.5–2.0 h per session. In addition, wrestlers participated in a 2-day-per-week in-season circuit weight training and conditioning program following practice. This program consisted of performance of 8–12 free weight or machine-based exercises for 10–15 repetitions with minimal rest in between exercises but 1–2 min of rest in between circuits. Practices

consisted of sport-specific technical and competitive practice in addition to conditioning drills targeting muscular endurance and cardiovascular training (to increase maximal aerobic capacity and weight control). While this study focused on the physiological and performance effects of an entire wrestling season, the final n sizes of the two groups of subjects were those who completed the entire season and all testing sessions.

Testosterone and USG data are presented in Figs. 1 and 2. One-way ANOVA revealed total TE was significantly reduced at T2, T3, and T4 compared to T1 in all wrestlers, but no changes were observed for CORT from a baseline value of 260.2 ± 30.4 nmol/L (data not shown) in all wrestlers. For resting TE concentrations, a significant change [$F(3,11) = 5.28$; $P = 0.017$] was observed where TE was significantly reduced at T2, T3, and T4 in starters and non-starters compared to T1. No significant group interaction [$F(3,11) = 0.27$; $P = 0.85$] was observed. No significant change [$F(3,11) = 0.23$; $P = 0.87$] or group interaction [$P(3,11) = 0.54$; $P = 0.67$] was observed for resting CORT concentrations. The resting TE/CORT ratio was significantly reduced from T1 (0.078 ± 0.02) in all wrestlers at T2 (0.068 ± 0.03; 12.9 %), T3 (0.071 ± 0.02; 9.1 %), and T4 (0.64 ± 0.02; 17.9 %) compared to T1. Hematocrit did not change significantly at any time point (data not shown). In addition, no significant correlations were observed between resting hormonal concentrations, body composition measures, or anaerobic strength and power measures at any time point. One-way ANOVA revealed USG was significantly higher at T3 compared to T1 in all wrestlers. A significant difference [$F(3,14) = 4.31$; $P = 0.02$] was observed where starters' USG was higher at T3 compared to T1. No significant differences were observed in non-starters.

Body composition results are presented in Table 1. A significant change in body mass was observed [$F(3, 14) = 6.5$; $P < 0.01$] but there was no significant interaction with group ($P = 0.06$). For all wrestlers combined, body mass was significantly higher at T1 compared to T2 and T3 and higher at T4 compared to T3. In starters, body mass at T1 was significantly greater than T2–T4 and T2 was significantly greater than T3. In non-starters, body mass at T1 was significantly greater than T2 and T2 was less than T3 and T4. Significant changes in BF % were observed [$F(3,14) = 3.7$; $P < 0.04$]. For all wrestlers, BF % was significantly lower at T2 and T3 compared to T1. In starters, BF % was significantly reduced at T2, T3, and T4 compared to T1. In addition, BF % was significantly lower at T3 compared to T2. In non-starters, BF % was only significantly reduced at T2. A significant change in fat mass and a group interaction was observed [$F(3,14) = 5.0$; $P < 0.03$]. For all wrestlers, fat mass significantly decreased at T2 and T3 and significantly
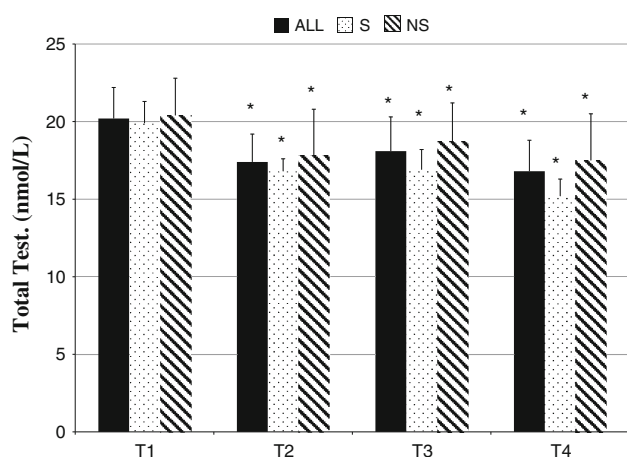
Fig. 1 Resting total testosterone concentrations. *$P \leq 0.05$ from corresponding time point T1. Data shown are mean ± SEM. *ALL* all wrestlers combined, *S* starters, *NS* non-starters
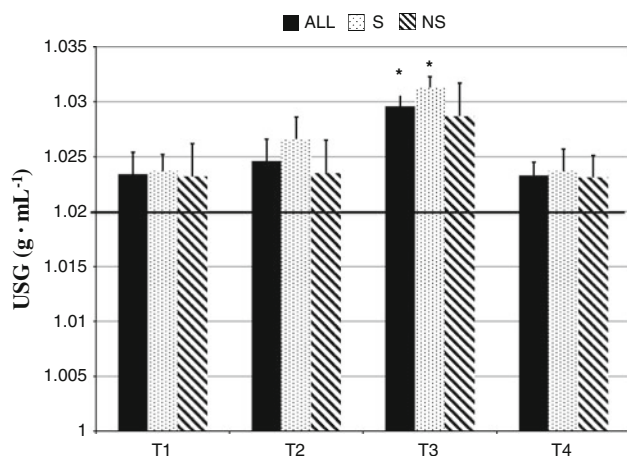
Fig. 2 Urine specific gravity (USG) changes over a wrestling season. *$P \leq 0.05$ from corresponding time point T1. Data shown are mean ± SEM. *ALL* all wrestlers combined, *S* starters, *NS* non-starters. *Bold line* highlights

increased at T4. In starters, fat mass was significantly decreased at T2, T3, and T4 compared to T1 with lowest values observed at T3. In non-starters, fat mass was significantly reduced only at T2 compared to T1. No significant changes or group interactions were observed in LBM. Skinfold analyses indicated that chest skinfolds were significantly reduced at T2, T3, and T4 compared to T1 in all wrestlers combined and starters whereas a significant reduction was only observed at T2 in non-starters. For abdominal skinfolds, significant reductions were observed at T2 and T3 (compared to T1) in all wrestlers, T3 and T4 (compared to T1) in starters, and only at T2 in non-starters. For thigh skinfolds, no significant differences in starters were observed. However, in all wrestlers combined and non-starters significant increases were observed at T4.

Maximal grip strength results are presented in Table 2. One-way ANOVA revealed that the total grip strength (right and left sides combined) for starters and non-starters combined was significantly reduced at T2 only ($P = 0.05$). However, no significant changes [$F_{(3,14)} = 1.39; P = 0.29$] or group interactions [$F_{(3,14)} = 0.50; P = 0.69$] were observed when wrestlers were analyzed as starters versus non-starters. In addition, a trend was observed at T1 where starters' total grip strength approached a statistically significant larger value than non-starters ($P = 0.09$). For right limb maximal grip strength, no significant change [$F_{(3,14)} = 0.88; P = 0.48$] or group interaction [$F_{(3,14)} = 0.34; P = 0.80$] was observed. A trend was observed at T1 where starters' right limb grip strength approached a statistically significant larger value than that of non-starters ($P = 0.09$). For left limb maximal grip strength, no significant change [$F_{(3,14)} = 1.65; P = 0.22$] or group interaction [$F_{(3,14)} = 0.59; P = 0.63$] was observed. One-way ANOVA revealed that left limb maximal grip strength was significantly reduced only at T2 ($P = 0.04$) when all wrestlers were analyzed. No significant changes ($P = 0.67$) or group interactions ($P = 0.59$) were observed for relative grip strength.

Force plate kinetic and kinematic data are presented in Table 3. One-way ANOVA revealed that peak power and peak force were significantly reduced at T2, T3, and T4 compared to T1 in all wrestlers. A significant difference [$F_{(3,14)} = 3.18; P = 0.05$] was observed when comparing peak power in starters and non-starters. Peak power was significantly reduced at T2, T3, and T4 compared to T1 in non-starters. However, no significant differences in peak power were observed in starters. A significant difference [$F_{(3,14)} = 4.49; P = 0.02$] was observed when comparing peak force in starters and non-starters. Peak force was significantly reduced at T2, T3, and T4 compared to T1 in starters. However, no significant differences in peak force were observed in non-starters. No significant differences were observed in peak velocity or relative peak power at any time point.

Wingate anaerobic power performance results are presented in Table 4. One-way ANOVA revealed that peak power was significantly reduced at T2 and T3 compared to T1 but increased at T4 compared to T2 when all wrestlers were analyzed. A significant change in peak power [$F_{(3,14)} = 3.35; P = 0.05$] but not a group interaction [$F_{(3,14)} = 1.77; P = 0.20$] was observed when comparing starters to non-starters. In non-starters, peak power was significantly reduced at T2 and T3 compared to T1 but significantly increased at T4 compared to T2. No significant differences in peak power were observed in starters throughout the season. When combining starters and non-starters, no significant changes in mean power were seen during the course of the season. However, a significant change [$F_{(3,14)} = 3.47; P = 0.04$] was observed where

Table 1 Body composition data

	T1	T2	T3	T4
Body mass (kg)				
Total	76.1 ± 13.9	73.7 ± 13.0[a]	74.2 ± 12.5[a]	75.0 ± 12.1[c]
Starters	77.2 ± 18.5	74.9 ± 17.0[a]	73.6 ± 16.3[a,b]	74.9 ± 15.5[a]
Non-starters	75.5 ± 11.2	73.0 ± 10.8[a]	74.6 ± 10.6[b]	75.1 ± 10.5[b]
Percent fat (%)				
Total	11.3 ± 4.5	10.1 ± 4.7[a]	10.1 ± 4.5[a]	11.3 ± 5.0[b,c]
Starters	11.3 ± 6.0	9.9 ± 6.5[a]	8.7 ± 6.2[a,b]	9.6 ± 6.5[a]
Non-starters	11.3 ± 3.6	10.2 ± 3.6[a]	10.9 ± 3.2	12.2 ± 3.8[b]
Chest skinfold (mm)				
Total	5.6 ± 0.8	4.8 ± 0.5[a]	5.0 ± 1.1[a]	4.9 ± 0.9[a]
Starters	5.8 ± 1.1	4.9 ± 0.7[a]	4.6 ± 0.8[a]	4.6 ± 1.1[a]
Non-starters	5.5 ± 0.6	4.8 ± 0.4[a]	5.2 ± 1.2	5.1 ± 0.7
Ab skinfold (mm)				
Total	22.3 ± 11.9	19.0 ± 12.5[a]	19.2 ± 11.1[a]	20.9 ± 11.9
Starters	22.8 ± 16.0	19.7 ± 17.6	17.6 ± 16.4[a]	17.9 ± 16.1[a]
Non-starters	22.1 ± 9.6	18.6 ± 9.2[a]	20.2 ± 7.1	22.8 ± 8.9
Thigh skinfold (mm)				
Total	12.8 ± 3.4	13.6 ± 4.8	13.7 ± 4.6	15.3 ± 5.5[a,b,c]
Starters	12.4 ± 4.6	12.3 ± 6.2	11.4 ± 5.0	12.6 ± 5.8
Non-starters	13.1 ± 2.6	14.3 ± 3.8	15.1 ± 4.0	16.8 ± 4.9[a,b]
Fat mass (kg)				
Total	9.0 ± 5.5	7.8 ± 5.4[a]	7.9 ± 5.0[a]	8.7 ± 5.3[c]
Starters	9.6 ± 8.1	8.3 ± 8.0[a]	7.2 ± 7.3[a,b]	7.9 ± 7.8[a]
Non-starters	8.7 ± 3.5	7.5 ± 3.4[a]	8.3 ± 3.3	9.2 ± 3.5[b]
LBM (kg)				
Total	67.1 ± 9.5	65.9 ± 9.0	66.3 ± 8.5	66.3 ± 8.2
Starters	67.6 ± 11.1	66.6 ± 9.7	66.4 ± 9.5	67.0 ± 8.7
Non-starters	66.8 ± 9.0	65.5 ± 9.0	66.2 ± 8.3	65.9 ± 8.3

LBM lean body mass

[a] $P \leq 0.05$ from corresponding point T1

[b] $P \leq 0.05$ from corresponding point T2

[c] $P \leq 0.05$ from corresponding point T3

Table 2 Maximal grip strength data

	T1	T2	T3	T4
Grip strength—R + L (kg)				
Total	113.1 ± 25.0	109.7 ± 23.8[b]	110.0 ± 24.9	109.2 ± 22.2
Starters	122.9 ± 26.3[a]	117.0 ± 27.7	115.0 ± 28.5	115.3 ± 26.2
Non-starters	107.0 ± 23.2	105.1 ± 21.1	106.8 ± 23.1	105.4 ± 19.6
Grip strength—R (kg)				
Total	58.0 ± 13.2	56.5 ± 12.5	55.9 ± 12.8	55.1 ± 11.3
Starters	63.3 ± 14.3[a]	60.4 ± 14.9	59.0 ± 14.8	58.6 ± 13.9
Non-starters	54.7 ± 11.9	54.0 ± 10.8	53.9 ± 11.7	53.0 ± 9.3
Grip strength—L (kg)	55.1 ± 12.0	53.2 ± 11.5[a]	54.1 ± 12.3	54.0 ± 11.6
Total				
Starters	59.5 ± 12.3	56.5 ± 12.9	56.0 ± 13.8	56.6 ± 12.5
Non-starters	52.3 ± 11.4	51.1 ± 10.7	53.0 ± 11.8	52.5 ± 11.4
Relative grip strength (kg of strength/kg of body mass)				
Total	0.77 ± 0.19	0.78 ± 0.20	0.77 ± 0.22	0.75 ± 0.20
Starters	0.85 ± 0.24	0.82 ± 0.22	0.81 ± 0.19	0.79 ± 0.17
Non-starters	0.72 ± 0.18	0.74 ± 0.11	0.72 ± 0.11	0.71 ± 0.11

R right, *L* left

[a] $P = 0.09$ between starters and non-starters

[b] $P \leq 0.05$ from corresponding point T1

Table 3 Vertical Jump force plate kinetic and kinematic data

	T1	T2	T3	T4
Peak power (W)				
Total	4,374.4 ± 780.7	3,797.5 ± 822.6[a]	3,815.0 ± 686.1[a]	3,906.5 ± 647.8[a]
Starters	4,407.1 ± 979.5	4,112.2 ± 1,058.0	3,922.8 ± 873.7	3,869.8 ± 631.7
Non-starters	4,353.7 ± 677.8	3,597.4 ± 604.5[a]	3,746.4 ± 573.7[a]	3,929.9 ± 687.2[a]
Peak force (N)				
Total	2,180.0 ± 442.7	2,011.5 ± 379.2[a]	1,917.7 ± 273.6[a]	2,004.0 ± 310.6[a]
Starters	2,442.9 ± 467.1	2,147.7 ± 473.2[a]	1,955.7 ± 295.0[a]	2,105.9 ± 295.0[a]
Non-starters	2,012.7 ± 351.2	1,925.0 ± 298.2	1,893.6 ± 271.2	1,939.3 ± 308.6
Relative peak power (W/kg)				
Total	29.18 ± 7.32	26.09 ± 7.48	26.07 ± 6.85	26.29 ± 6.35
Starters	28.93 ± 6.96	27.81 ± 8.57	27.09 ± 8.07	26.03 ± 5.57
Non-starters	29.33 ± 7.88	25.00 ± 6.91	25.42 ± 6.28	26.46 ± 7.06
Peak velocity (m/s)				
Total	3.10 ± 0.4	2.84 ± 0.3	2.93 ± 0.3	2.90 ± 0.2
Starters	2.96 ± 0.4	2.91 ± 0.4	2.90 ± 0.2	2.83 ± 0.3
Non-starters	3.19 ± 0.4	2.80 ± 0.3	2.96 ± 0.3	2.95 ± 0.2

[a] $P \le 0.05$ from corresponding point T1

mean power was reduced at T2 and T3 compared to T1 in starters. One-way ANOVA revealed fatigue rate was significantly lower at T2, T3, and a trend ($P = 0.09$) was observed at T4 compared to T1 in all wrestlers. However, starter versus non-starter time effect did not reach statistical significance [$F(3,14) = 2.6$; $P = 0.09$]. For all wrestlers, only a trend ($P = 0.06$) for reduction in total work was observed at T2 compared to T1. A significant change in total work [$F(3,14) = 3.3$; $P = 0.05$] was observed when comparing starters to non-starters. No differences were observed in non-starters. However, total work in starters was significantly lower at T2 and T3 compared to T1. Time to peak power, relative peak power, and relative mean power did not significantly differ at any time point.

Discussion

The results of the present study indicated that resting TE concentrations were significantly reduced from T2–T4 compared to T1 with no changes in resting CORT throughout the competitive season. Maximal grip strength (T2), absolute peak power attained during a modified Wingate cycle ergometry (T2 and T3) and vertical jump (T2–T4) were significantly reduced. The reductions were mostly observed in non-starters compared to starters. These reductions occurred as all wrestlers demonstrated significant reductions in body mass and BF % (while LBM was preserved). These data demonstrate the response to a competitive wrestling season is different in starters who competed and made weight regularly versus non-starters.

An important finding was that resting TE concentrations were reduced at T2 (by 13.9 %), T3 (by 10.4 %), and T4 (by 16.8 %) compared to T1 in all wrestlers. Strauss et al. (1985) reported reduced resting TE during the season compared to post season. Passelerque and Lac (1999) reported a reduced salivary TE/CORT ratio in wrestlers during tournament competition compared to pre-season values. Roemmich and Sinning (1997b) reported reductions in TE mid-season (that returned by post-season) in adolescent wrestlers. Significant reductions in body mass (4–5 %) were observed in these studies. Body mass, fasting, and subsequent fluid loss may affect TE concentrations. Karila et al. (2008) reported that 8.2 % loss of body mass (occurring over 2–3 weeks) resulted in a 63 % reduction in TE and 54 % reduction in luteinizing hormone concentrations and the reduction in body mass correlated significantly ($r = 0.53$) with reduced TE. Booth et al. (1993) reported that wrestlers who were fasting had lower TE than wrestlers who did not fast. Our results support previous research showing reduced resting TE concentrations and TE/CORT ratio in wrestlers.

Two unique elements of the present study were the comprehensive measurement time line employed and the resting TE reductions were similar between starters and non-starters. Resting TE reductions occurred over a longer period than previously shown. Previous studies based seasonal hormonal changes on only a few measurement time points, e.g. pre-season compared to post-season (Roemmich and Sinning 1997a, b), mid-season compared to 2 weeks post-season (Strauss et al. 1985), and pre-season compared to a multi-day in-season competition (Passelerque and Lac 1999). We were able to assess hormonal changes during pre-season training, in-season training and competition, 1 day prior to a major dual meet, and at the end of the season. Resting TE reductions took place early

Table 4 Wingate anaerobic power data

	T1	T2	T3	T4
Peak power (W)				
Total	739.9 ± 100.2	667.7 ± 146.4[a]	680.7 ± 138.5[a]	716.3 ± 137.9[b]
Starters	743.3 ± 81.7	707.7 ± 176.6	701.6 ± 167.9	713.0 ± 165.1
Non-starters	737.8 ± 114.2	642.2 ± 126.1[a]	667.4 ± 123.3[a]	718.4 ± 126.3[b]
Mean power (W)				
Total	451.1 ± 70.8	432.3 ± 71.5	445.6 ± 67.8	459.7 ± 71.7[b]
Starters	462.9 ± 58.6	443.4 ± 66.1[a]	444.3 ± 61.9[a]	450.6 ± 61.3
Non-starters	443.3 ± 79.4	425.2 ± 77.0	446.4 ± 74.2	465.5 ± 79.9
Minimum power (W)				
Total	258.6 ± 56.1	269.9 ± 55.1	281.4 ± 61.4	283.6 ± 70.1
Starters	268.9 ± 44.7	270.6 ± 37.5	286.1 ± 44.2	265.1 ± 58.0
Non-starters	252.1 ± 63.5	269.5 ± 65.7	278.4 ± 72.2	294.9 ± 77.2
Time to PP (s)				
Total	7.5 ± 5.4	6.5 ± 3.4	7.3 ± 4.6	6.3 ± 3.3
Starters	9.0 ± 6.5	6.5 ± 2.8	7.3 ± 5.8	7.0 ± 3.6
Non-starters	6.5 ± 4.6	6.5 ± 3.8	7.3 ± 3.9	5.9 ± 3.3
Fatigue rate (W/s)				
Total	9.2 ± 1.3	7.4 ± 2.8[a]	7.5 ± 2.4[a]	7.9 ± 2.7[@]
Starters	9.5 ± 1.1	8.1 ± 3.2	7.7 ± 2.9	8.2 ± 3.2
Non-starters	9.1 ± 1.4	6.9 ± 2.5	7.3 ± 2.2	7.7 ± 2.4
Total work (J)				
Total	27,063.3 ± 4,248.0	25,936.7 ± 4,290.7[#]	26,733.3 ± 4,065.7	27,482.2 ± 4,358.7
Starters	27,771.4 ± 3,513.4	26,605.7 ± 3,963.6[a]	26,657.1 ± 3,717.0[a]	26,925.7 ± 3,717.0
Non-starters	26,612.7 ± 4,764.0	25,510.9 ± 4,621.5	26,781.8 ± 4,453.2	27,836.4 ± 4,863.5
Relative peak power (W/kg)				
Total	9.95 ± 2.04	9.24 ± 2.39	9.37 ± 2.32	9.76 ± 2.40
Starters	10.02 ± 2.35	9.80 ± 3.24	9.85 ± 3.16	9.79 ± 2.92
Non-starters	9.91 ± 1.93	8.88 ± 1.74	9.06 ± 1.70	9.74 ± 2.17
Relative mean power (W/kg)				
Total	6.08 ± 1.42	6.02 ± 1.43	6.17 ± 1.40	6.29 ± 1.50
Starters	6.23 ± 1.46	6.16 ± 1.62	6.24 ± 1.44	6.18 ± 1.33
Non-starters	5.99 ± 1.47	5.93 ± 1.37	6.12 ± 1.44	6.35 ± 1.67

PP peak power

[a] $P \leq 0.05$ from corresponding point T1

[b] $P \leq 0.05$ from corresponding point T2

[@] $P = 0.09$ compared to T1

[#] $P = 0.06$ from T1

and persisted throughout the season. This was the first study to show resting TE suppression was similar between starters and non-starters indicating that TE reductions take place despite a reduced competition schedule. Although non-starters wrestled competitively at a lower frequency than starters, they participated in daily practice and in-season weight training and conditioning and experienced significant reductions in body mass at T2 only. The impact of reduced resting TE remains unclear but may occur as a consequence of body mass reduction, fluid loss, and reduced fluid and kilocalorie intake.

Resting CORT concentrations did not change throughout the season. Cortisol is a catabolic stress hormone that increases lipolysis, increases protein degradation and decreases protein synthesis in muscle cells, and is involved in complex regulation of multiple immune system functions (Fragala et al. 2011). Resting CORT concentrations reflect a long-term training stress (Kraemer and Ratamess 2005). Strauss et al. (1985) and Roemmich and Sinning (1997b) also reported that resting CORT did not change during the season. The lack of change in resting CORT throughout the season has important implications and may suggest that an appropriate balance was maintained by the coaching staff among practice hours, strength training and conditioning, competition, academics, nutrition intake, and body mass reduction methods.

Most studies examined wrestlers pre-, mid-, and post-season or compared mid-season to post-season body composition and performance changes. Kelly et al. (1978) reported no changes in isokinetic strength (with the exception of one measure) and endurance in collegiate wrestlers. Song and Cipriano (1984) reported significant

isometric strength gains despite reductions in LBM in collegiate wrestlers. Utter et al. (1998) showed that Division I wrestlers decreased body and LBM during the season (at mid-season) but were able to maintain isometric clean pull strength and vertical jump power. Utter (2001) reported that wrestlers lost ∼3.0 % of body mass over a season but were able to maintain LBM. Schmidt et al. (2005) reported Division III wrestlers maintained body weight, BF %, and power (vertical jump, power clean, medicine ball put) during the season. However, one-repetition maximum (1RM) bench press and squat were reduced. Buford et al. (2006) reported Division I wrestlers had a ∼7 % reduction in body weight and 28 % reduction in knee extension peak torque compared to post-season despite a relatively constant hydration status. Our results extend these findings but demonstrate the rigors of pre-season training as evidenced by maximal grip strength, Wingate anaerobic power, and vertical jump power reductions observed at T2 compared to T1.

The results showed that the wrestlers' body mass and BF % were highest at T1 and remained significantly lower during the season (with the exception of T4 due primarily to values obtained in non-starters). As a group, wrestlers lost ∼3.2 % of their body mass prior to the first meet and starters lost an additional ∼1.7 % one day prior to a meet during the season (T3). Lingor and Olson (2010) reported that Division III wrestlers lost an average of 5.3 % of body mass and an additional 4.7 % of body mass for each meet. The lower values observed in this investigation may partially reflect changes in NCAA weight reduction procedures (e.g. minimum weight establishment and weigh-ins performed 1–2 h before competition) and subsequently the wrestlers' ability to begin the season at a weight closer to their competition weight classes. In addition, we measured body mass 1 day prior to a meet. Thus, it is likely wrestlers competing in the meet lost additional mass prior to the meet thereby underestimating their pre-competition body mass reduction.

Prior to the NCAA's minimum weight program, wrestlers lost more mass making weight but regained a substantial amount (2–8 kg) prior to weigh-in (Lingor and Olson 2010). Rapid weight loss and dehydration may result in anaerobic performance reductions (Kraemer et al. 2001; Klinzing and Karpowicz 1986; Oppliger et al. 1996; Webster et al. 1990) although this may not be the case with a lower magnitude of body mass loss (Serfass et al. 1984; Singer and Weiss 1968). Wrestling performance is reduced following a mass reduction of 5 % (Klinzing and Karpowicz 1986). During tournament competition (6 % reduction), Kraemer et al. (2001) and Barbas et al. (2011) have shown grip strength, knee and elbow peak torque, hip/back strength, and bear hug strength were reduced. However, vertical jump power was maintained in Kraemer et al.

(2001) but not in Barbas et al. (2011). Our results showed that some measures of strength and power can be compromised in wrestlers despite smaller reductions in body mass.

Percent body fat data were similar to values reported in other studies (e.g. 8.7–12.2 %) (Bartok et al. 2004a, b; Dixon et al. 2005; Schmidt et al. 2005; Serfass et al. 1984; Utter et al. 1998; Utter 2001). However, BF % reductions during the season were lower. Lingor and Olson (2010) reported an average reduction of 2.9 ± 2.1 % in Division III wrestlers compared to the 1.2–2.0 % reduction seen in all wrestlers in the present study. The current findings are consistent with those of Schmidt et al. (2005) who reported an approximate 1.5 % loss of BF % during the season in Division III wrestlers. This may reflect our cohort of wrestlers initiated the season at weights closer to their targeted competition weight class.

Maximal grip strength was reduced only at T2 when all wrestlers were analyzed for the right and left limbs combined. Although mean values at T3 and T4 appeared lower than T1, these values did not reach statistical significance. A trend was observed at T1 where starters' total grip strength approached a statistically significant larger value than that of non-starters. Our data at T3 and T4 partially support Serfass et al. (1984) who reported no significant difference in grip strength following dehydration in wrestlers of 5 % of body mass over a 3-day period. The wrestlers lost ∼3.2 % of their body mass prior to the first meet and starters lost an additional ∼1.7 % one day prior to a meet which is within 5 % weight loss shown. Marttinen et al. (2011) reported no significant change in grip strength following 4 % reduction in body mass. Thus, it appears that wrestlers who weight cycle have the ability to maintain maximal grip strength during periods of weight loss.

Wingate peak anaerobic power performance was significantly reduced at T2 and T3 compared to T1 but increased at T4 compared to T2 when all wrestlers were analyzed. However, no significant differences in peak power were observed in starters supporting the results of Marttinen et al. (2011). However, absolute mean power and total work were reduced at T2 and T3 compared to T1 in starters. It is difficult to compare these data to other studies because we used a modified 1-min Wingate test as opposed to the 30-s maximal test. This was purposely done to assess local muscle endurance to a greater extent. We were unable to show relationships between body mass loss, USG, and Wingate mean power reductions. It appears that other factors such as the rigor of the modified test, changes in training and perhaps overtraining may have contributed as the muscle groups involved in stationary cycling are heavily trained during wrestling practice. This may partially explain why both mean power and total work of non-starters were not significantly affected.

No differences were observed in Wingate relative peak and mean power. Relative peak power values fluctuated between 8.8 and 10.0 W/kg. These findings indicate that collegiate wrestlers have the ability to maintain relative power throughout a season. Our values obtained compared favorably to those reviewed by Horswill (1992) who reported a range of Wingate relative peak power data in collegiate wrestlers of 9.0–12.0 W/kg but are lower than values shown in Division I wrestlers (Marttinen et al. 2011). Fatigue rate was lower at T2, T3, and T4 ($P = 0.09$) in all wrestlers. These data may reflect enhanced local muscular endurance brought about by wrestling training but perhaps may reflect the wrestlers' lack of ability to achieve as high of a peak power output seen at T1.

Unique to the present study was the assessment of power during a vertical jump protocol on a force plate. Most studies used other assessments with the exception of Utter et al. (2002) who used force plate data during a jump to evaluate an elite freestyle wrestler. Peak vertical jump power and peak force were significantly reduced at T2, T3, and T4 compared to T1 in all wrestlers. Peak force was significantly reduced at T2, T3, and T4 compared to T1 in starters. However, no significant differences in peak force were observed in non-starters. Although it is conceivable to speculate that a reduction in body mass could reduce force applied to the ground during a vertical jump, no significant relationships between body mass, body mass loss, and peak vertical jump power were observed. The reduced peak power was due mostly to reduced force application to the ground as no significant differences were observed in peak velocity at any time point. This may be partially explained by wrestling practice that typically emphasizes speed during technical maneuvers.

Reductions in strength and power may result from a multitude of factors. Dehydration (at least 4–5 % of body mass) has been shown to decrease muscle strength and power in some (Webster et al. 1990) but not all studies (Marttinen et al. 2011). It has been postulated that wrestlers demonstrate a remarkable ability to adapt and rebound from rapid weight loss and may be most affected by large reductions in body fluids (Buford et al. 2006; Marttinen et al. 2011). Injuries may also play a role. Yard et al. (2008) reported that college wrestlers experienced injuries at a rate of 7.25 injuries per 1000 athlete exposures, strains and sprains accounted for nearly half of all injuries, the most injured areas were the knee, shoulder, head/face, and trunk, and nearly 43 % of injured wrestlers returned to practice within 1 week following the injury. Minor pain is characteristic of the rigors of competitive wrestling and many wrestlers are not completely pain-free until the end of the season. Last, a change in resistance training or overtraining could play a role (Roemmich and Sinning 1997a). Wrestlers followed a periodized training program where they peaked

for strength and power prior to pre-season practice. During pre- and in-season periods the wrestlers followed a circuit training program aimed at targeting local muscle endurance enhancement. It is possible that the lack of heavy lifting could have contributed to a maximal strength and power detraining effect. Buford et al. (2006) proposed that in-season high-volume circuit training workouts may be too stressful for wrestlers given the rigors of practice and competition. Utter et al. (1998) reported that Division I wrestlers were able to maintain strength and power during the wrestling season despite losing 6 % body mass and 2.9 % LBM and they attributed it, in part, to a successful in-season resistance training program.

References

Barbas I, Fatouros IG, Douroudos II, Chatzinikolaou A, Michailidis Y, Draganidis D, Jamurtas AZ, Nikolaidis MG, Parotsidis C, Theodorou AA, Katrabasas I, Margonis K, Papassotiriou I, Taxildaris K (2011) Physiological and performance adaptations of elite Greco-Roman wrestlers during a one-day tournament. Eur J Appl Physiol 111:1421–1436

Bartok C, Scholler DA, Clark RR, Sullivan JC, Landry GL (2004a) The effect of dehydration on wrestling minimum weight assessment. Med Sci Sports Exerc 36:160–167

Bartok C, Schoeller DA, Sullivan JC, Clark RR, Landry GL (2004b) Hydration testing in collegiate wrestlers undergoing hypertonic dehydration. Med Sci Sports Exerc 36:510–517

Booth A, Mazur AC, Dabbs JM (1993) Endogenous testosterone and competition: the effect of "fasting". Steroids 58:348–350

Buford TW, Rossi SJ, Smith DB, O'Brien MS, Pickering C (2006) The effects of a competitive wrestling season on body weight, hydration, and muscular performance in collegiate wrestlers. J Strength Cond Res 20:689–692

Dixon CB, Deitrick RW, Pierce JR, Cutrufello PT, Drapeau LL (2005) Evaluation of the BOD POD and leg-to-leg bioelectrical impedance analysis for estimating percent body fat in National Collegiate Athletic Association Division III collegiate wrestlers. J Strength Cond Res 19:85–91

Firrell JC, Crain GM (1996) Which setting of the dynamometer provides maximal grip strength? J Hand Surg 21:397–401

Fragala MS, Kraemer WJ, Denegar CR, Maresh CM, Mastro AM, Volek JS (2011) Neuroendocrine-immune interactions and responses to exercise. Sports Med 41:621–639

Fry AC, Schilling BK, Fleck SJ, Kraemer WJ (2011) Relationships between competitive wrestling success and neuroendocrines responses. J Strength Cond Res 25:40–45

HoLBMan JR, Ratamess NA, Kang J, Rashti SL, Faigenbaum AD (2009) Effect of Betaine supplementation on power performance and fatigue. J Int Soc Sports Nutr 6:1–10

Horswill CA (1992) Applied physiology of amateur wrestling. Sports Med 14:114–143

Jackson A, Pollock M (1978) Generalized equations for predicting body density of men. Br J Nutr 40:497–504

Karila TA, Sarkkinen P, Marttinen M, Seppala T, Mero A, Tallroth K (2008) Rapid weight loss decreases serum testosterone. Int J Sports Med 29:872–877

Kelly JM, Gorney BA, Kalm KK (1978) The effects of a collegiate wrestling season on body composition, cardiovascular fitness and muscular strength and endurance. Med Sci Sports 10:119–124

Klinzing JE, Karpowicz W (1986) The effects of rapid weight loss and rehydration on a wrestling performance test. J Sports Med 26:149–156

Kraemer WJ, Ratamess NA (2005) Hormonal responses and adaptations to resistance exercise and training. Sports Med 35:339–361

Kraemer WJ, Fry AC, Rubin MR, Triplett-McBride T, Gordon SE, Koziris LP, Lynch JM, Volek JS, Meuffels DE, Newton RU, Fleck SJ (2001) Physiological and performance responses to tournament wrestling. Med Sci Sports Exerc 33:1367–1378

Kuzala EA, Vargo MC (1992) The relationship between elbow position and grip strength. Am J Occup Ther 46:509–512

Lingor RJ, Olson A (2010) Fluid and diet patterns associated with weight cycling and changes in body composition assessed by continuous monitoring throughout a college wrestling season. J Strength Cond Res 24:1763–1772

Marttinen RHJ, Judelson DA, Wiersma LD, Coburn JW (2011) Effects of self-selected mass loss on performance and mood in collegiate wrestlers. J Strength Cond Res 25:1010–1015

NCAA: Memorandum: NCAA Wrestling Weight Management Program for 2010–2011, pp 1–34. 20 Aug 2010

Oppliger RA, Case HS, Horswill CA, Landry GL, Shelter AC (1996) American College of Sports Medicine position stand: Weight loss in wrestlers. Med Sci Sports Exerc 28:ix–xii

Passelerque P, Lac G (1999) Saliva cortisol, testosterone and T/C ratio variations during a wrestling competition and during the post-competitive recovery period. Int J Sports Med 20:109–113

Ratamess NA, Faigenbaum AD, Mangine GT, HoLBMan JR, Kang J (2007) Acute muscular strength assessment using free weight bars of different thickness. J Strength Cond Res 21:240–244

Roemmich JN, Sinning WE (1997a) Weight loss and wrestling training: effects on nutrition, growth, maturation, body composition, and strength. J Appl Physiol 82:1751–1759

Roemmich JN, Sinning WE (1997b) Weight loss and wrestling training: effects on growth-related hormones. J Appl Physiol 82:1760–1764

Schmidt WD, Piencikowski CL, Vandervest RE (2005) Effects of a competitive wrestling season on body composition, strength, and power in National Collegiate Athletic Association Division III college wrestlers. J Strength Cond Res 19:505–508

Serfass RC, Stull GA, Alexander JF, Ewing JL (1984) The effects of rapid weight loss and attempted rehydration on strength and endurance of the handgripping muscles in college wrestlers. Res Q Exerc Sport 55:46–52

Singer RN, Weiss SA (1968) Effects of weight reduction on selected anthropometric, physical, and performance measures of wrestlers. Res Q 39:361–369

Siri WE (1956) Gross composition of the body. In: Lawrence JH, Tobias CA (eds) Advances in biological and medical physics, IV. Academic Press, New York

Song TM, Cipriano K (1984) Effects of seasonal training on physical and physiological function on elite varsity wrestlers. J Sports Med 24:123–130

Strauss RH, Lanese RR, Malarkey WB (1985) Weight loss in amateur wrestlers and its effect on serum testosterone levels. JAMA 254:3337–3338

Utter AC (2001) The new National Collegiate Athletic Association wrestling weight certification program and sport-seasonal changes in body composition of college wrestlers. J Strength Cond Res 15:296–301

Utter AC, Stone M, O'Bryant H, Summinski R, Ward B (1998) Sport-seasonal changes in body composition, strength, and power of college wrestlers. J Strength Cond Res 12:266–271

Utter AC, Scott JR, Oppliger RA et al (2001) A comparison of leg-to-leg bioelectrical impedance and skinfolds in assessing body fat in collegiate wrestlers. J Strength Cond Res 15:157–160

Utter AC, O'Bryant HS, Haff GG, Trone GA (2002) Physiological profile of an elite freestyle wrestler preparing for competition: a case study. J Strength Cond Res 16:308–315

Webster S, Rutt R, Weltman A (1990) Physiological effects of a weight loss regimen practiced by college wrestlers. Med Sci Sports Exerc 22:229–234

Yankanich J, Kenny WL, Fleck SJ, Kraemer WJ (1998) Precompetition weight loss and changes in vascular fluid volume in NCAA Division I college wrestlers. J Strength Cond Res 12:138–145

Yard EE, Collins CL, Dick RW, Comstock RD (2008) An epidemiologic comparison of high school and college wrestling injuries. Am J Sports Med 36:57–64