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Case Study: Extreme weight making causes relative energy deficiency, dehydration and acute kidney injury in a male mixed martial arts athlete

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Abstract

The aim of the present case study was to quantify the physiological and metabolic impact of extreme weight cutting by an elite male MMA athlete. Throughout an 8-week period, we obtained regular assessments of body composition, resting metabolic rate (RMR), VO_{2peak} and blood clinical chemistry to assess endocrine status, lipid profiles, hydration and kidney function. The athlete adhered to a "phased" weight loss plan consisting of 7 weeks of reduced energy (ranging from 1300 – 1900 kcal.d^{-1}) intake (phase 1), 5 days of water loading with 8 L per day for 4 days followed by 250 ml on day 5 (phase 2), 20 h fasting and dehydration (phase 3) and 32 h of rehydration and refuelling prior to competition (phase 4). Body mass declined by 18.1 % (80.2 to 65.7 kg) corresponding to changes of 4.4, 2.8 and 7.3 kg in phase 1, 2 and 3, respectively. We observed clear indices of relative energy deficiency, as evidenced by reduced RMR (-331 kcal), inability to complete performance tests, alterations to endocrine hormones (testosterone: <3 nmol.L^{-1}) and hypercholesterolemia (>6 mmol.L^{-1}). Moreover, severe dehydration (reducing body mass by 9.3%) in the final 24 hours prior to weigh-in induced hypernatremia (plasma sodium: 148 mmol.L^{-1}) and acute kidney injury (serum creatinine: 177 µmol.L^{-1}). These data therefore support publicised reports of the harmful (and potentially fatal) effects of extreme weight cutting in MMA athletes and represent a call for action to governing bodies to safeguard the welfare of MMA athletes.

Keywords: rapid weight loss, RED-S, testosterone, dehydration

Introduction

Mixed martial arts (MMA) is a full contact combat sport often referred to as cage fighting or ultimate fighting. When compared with other combat sports (Alderman 2004; Davis et al., 2001; Kiningham & Gorenflo, 2001; Kordi et al., 2011; Morton et al., 2010; Oppliger, Steen & Scott, 2003), the magnitude of weight loss reported by MMA athletes (e.g. 10% in the 24 h prior to weigh-in) (Matthews & Nicholas, 2017) has been identified as a cause for concern in both the literature (Crighton, Close & Morton, 2016) and televised media (Ralph, 2017). The sport has experienced two weight-cutting induced fatalities (Barrabi, 2013; Okamoto, 2017) as well as health problems (e.g. kidney failure) and substance abuse (e.g. diuretics) (Beacham, 2017; Drahota, 2017; Hiergesell, 2018; MMA Junkie Staff, 2017). As such, the California State Athletic Commission have recently introduced a 10-point strategic plan to protect against dangers of extreme weight cutting, notably a 10% maximal weight regain allowance following weigh in, introduction of four new weight classes, "check weigh-ins" and regular hydration testing (Okamoto, 2018).

Given the dangers associated with making weight, the aim of the present case study was to quantify the physiological and metabolic impact of extreme weight cutting. We monitored an elite male MMA athlete during an 8-week training camp and obtained regular assessments of body composition (according to Dual-energy X-ray Absorptiometry, DXA), resting metabolic rate (RMR), VO_{2peak} and blood clinical chemistry to assess endocrine status, lipid profiles, hydration and kidney function.

Athlete Overview

A professional male MMA athlete (age: 22 years; body mass: 80.2 kg; height 1.80 m) volunteered to take part after providing informed written consent and permission to publish. The athlete had been competing professionally since age 17 with a professional record of 13 wins and 1 loss from 14 contests. The contest under investigation in this case-study was also a defence of his featherweight championship with an international MMA organisation. The athlete has typically competed 2-4 times per year since age 17 (his first contest was 2012) and his previous professional contests have been at bantamweight (n=7, 61.2 kg, 2012-2014) and featherweight division (n=7, 65.8 kg, 2015-2017). The methods and relative magnitudes of weight loss undertaken in his previous contests were all similar to that reported here though the athlete reported that it was becoming increasingly strenuous to make weight. In addition, on three of his previous professional contests, he failed to make the designated weight target (2 at bantamweight in 2014 and 1 at featherweight in 2016) though all contests still occurred after conceding 20% of his purse. Despite his history of weight-cycling, the potential negative effects of rapid weight loss (RWL) on performance are still likely to exist (Mendes et al. 2013). Prior to commencing the case-study, the athlete had not engaged in structured training (i.e. typical of that associated with “training camps”) for 9 weeks (since that occurring upon completion of training for his last contest). The case-study was approved by the Ethical Committee of Liverpool John Moores University.

Athlete Assessments

The athlete was assessed at regular periods before and after the contest for body composition via skinfold assessment (according to ISAK standards; Stewart & Marfell-Jones, 2011) and DXA (QDR Series Horizon, Hologic Inc., Bedford, MA, USA) using the DXA Best Practice Protocol (Nana et al., 2015). RMR was assessed via indirect calorimetry (GEM Open Circuit Indirect Calorimeter, GEMNutrition Ltd. UK) using the protocol described by Bone and Burke (2017). Peak oxygen uptake (VO_{2peak}) was assessed on a motorised treadmill (h/p/cosmos, Pulsar, Nussdorf-Trainstein, DE) using an online gas analysis system (CPX Ultima Series Medgraphics, MN, USA) and the exercise protocol described by Bartlett et al., (2012). Blood samples were drawn via venepuncture from the antecubital vein and all biochemical analysis was conducted by Royal Liverpool University Hospital as previously described (Wilson et al., 2012).

Overview of Time-Course and Magnitude of Required Weight Loss

The athlete was required to make weight at 65.7 kg from 80.2 kg over an 8-week period. All nutritional and weight loss strategies were devised by the athlete and his coaching team, according to phases described below.

Phase 1: Energy restriction (-8 weeks to -1 week from weigh-in)

The athlete adhered to a "low carbohydrate" diet for the duration of the 8 weeks. At -8 weeks until -4 weeks, the athlete reported consuming daily energy intakes ranges from 1500 – 1900 kcal per day (1.5-2.5 g/kg CHO, 1.6-1.8 g/kg protein, 0.8-1 g/kg fat) and fluid was consumed ad libitum. From -4 weeks to -1 week, energy intake was reduced to 1300-1500 kcal, as occurring by a reduction in protein intake to approximately 1 g/kg body mass. All food was purchased from an external company (Goodness Grill and Juice Bar, Liverpool, UK) who provided pre-packaged meals in known portion sizes and macronutrient intakes. An overview of the athlete's reported energy intake (as reported by the meal preparation company) during phase 1 is presented in Figure 1. From -8 weeks until -4 weeks, protein intake was typically distributed across breakfast, lunch and dinner as three 25-30 g portions comprising animal protein sources such as eggs, fish, chicken, red meat as well as 25-30 g whey protein (Nutrition X, Gloucestershire, UK) after each training session. From -4 weeks until -1 week, daily protein intake was reduced by removal of the whey protein and reducing portion sizes in the main meals. Estimation of energy intake was provided by the meal preparation company. In addition, the research team also performed dietary analysis on 6 occasions (4 days within phase 1 and 2 days within phase 2) to estimate sodium and fibre content (using the Nutritics dietary analysis software). In Phase 1, estimated fibre and sodium intake was 18.4 and 2.9 grams per day respectively. Training in Phase 1 consisted of 2 days of 3 daily sessions, 2 days of 2 daily sessions, 2 days of 1 daily session and 1 full rest day. This equated to 2 strength and conditioning sessions (e.g. weight training), 8 combat specific training sessions (e.g. grappling, striking, boxing, wrestling, MMA specific) and 2 sparring sessions.

Phase 2: Water loading (-1 week to -1 day)

Energy intake was decreased to approximately 1000 kcal per day but protein intake was increased (0.5 g/kg CHO, 1.3 g/kg protein, 0.5 g/kg fat; as reported by the meal preparation company). The athlete also engaged in water loading where 8 L of water was consumed daily over a 4 day period prior to water intake being reduced to 0.25 L until the evening before weigh in (see Figure 1). Urine output was self-reported by the athlete and was measured using a collection bottle. In Phase 2, estimated fibre and sodium intake was 5.6 and 0.3 grams per day, respectively. Such low intakes of CHO (to induce glycogen depletion) and fibre appear commensurate with recent guidelines on acute weight loss methods in combat athletes (Reale et al. 2017b).

Phase 3: Acute weight cut strategy (-1 day to weigh-in)

At 1800 h on the day prior to weigh-in, the athlete commenced a 20 h acute weight cut period where no food or fluid was consumed. The athlete engaged in a series of continuous cycles of sweating at -20 h (1 bath + 1 wrap; 72.3-72. kg), -19 h (3 baths + 3 wraps; 70.4 kg kg), -6 h (3 baths + 3 wraps; 67.9 kg) and -3 h (2 baths + 2 wraps; 67.0 kg). Cycles consisted of being covered in a wax-oil rub (Sweet Sweat, San Pedro, CA) and submerging distally from the neck in hot water baths (20 min) followed by the athlete wrapping himself in layers of blankets and towels (resembling an Egyptian Mummy) (20 min).

Phase 4: Rehydration and refuel strategy (weigh-in to +1 day)

In the 32 h period between the weigh-in and contest, the athlete rehydrated ad libitum and consumed a high carbohydrate diet (15 g/kg CHO, 3.2 g/kg protein, 2.6 g/kg fat; as quantified from dietary recall performed by author one). As such, the athlete's body mass increased to 77.0 kg at 5 hours prior to competition (the last time the athlete recorded his body mass). In Phase 4, estimated fibre and sodium intake was 63.0 and 8.5 grams respectively in total. CHO provided by fluid sources corresponded to 175 grams and 3 Litres (through milk, fruit juices and sports drinks) though no formal assessment was made of additional fluids consumed. The majority of carbohydrate (9 g/kg CHO, 40 g fibre, 5.3 g sodium) was consumed in the period after weigh-in between 2 pm and 11 pm. Approximately 6 g/kg CHO, 23 g fibre, and 3.2 g sodium was consumed on contest day between 9 am and 6 pm. The athlete reported that his last form of energy intake was consumed at 3 hours (2.1 g/kg CHO, 9.2 g fibre, 1.4 g sodium) before the contest (i.e. 6 pm) though fluid intake was consumed ad libitum (and not recorded) up until the beginning of the contest. The athlete's post-weigh-in energy intake and fluid intake appears to agree with recent combat sport recovery guidelines proposed by Reale et al. (2017b) in terms of CHO content post-weigh-in and also the pre-contest meal. Nonetheless, fibre intake could be considered high given the habitual low fibre intake that the athlete was consuming previously.

Phase 5: Ad libitum recovery (+1 day to +2 weeks)

In the 2 weeks after the contest, the athlete resumed his habitual diet and retuned to the laboratory at 2 weeks after weigh-in for final assessments. In this period, the athlete engaged in no formal training or structured physical activity and consumed both food and fluid ad libitum. No form of dietary assessment or estimation of energy intake was made during this period as the athlete did not engage in any assessments during this time.

Physiological and Biochemical Effects of Weight Cutting

On the basis of initial assessment of body composition (see Figure 2A-F), it was apparent the target weight would have to be achieved via a combination of reductions in fat mass (i.e. adipose tissue) and fat free mass (i.e. muscle protein, muscle glycogen stores and water). The athlete reported adhering to daily energy intake of approximately 1300-1900 kcal/d for the first 7 weeks (i.e. phase 1), largely achieved via macronutrients intake of approximately 1.5-2.5, 1.6-1.8, and 0.8-1.0 g/kg of CHO, protein and fat respectively. When considered with previous literature, such data suggest that the combination of strength training and daily protein intake equivalent to 2 X RDA is sufficient to maintain (or increase) fat free mass (see Figure 2B and 2C), even when in an energy deficient state (Pasiakos et al. 2013; Morton et al. 2018; Longland et al., 2016; Wilson et al., 2013; Wilson et al., 2015). Nonetheless, we acknowledge the potential under-reporting associated with the dietary assessment measures utilised here (i.e. self-reporting of daily energy intake from pre-prepared meal packages).

Whilst we also acknowledge our inability to assess energy availability (owing to the lack of assessments of daily energy expenditure and exercise energy expenditure), we observed that the athlete exhibited clear symptoms of the relative energy deficiency in sport syndrome (RED-S) (Mountjoy et al. 2014). In addition to reductions in resting metabolic rate and the inability to complete the maximal oxygen uptake test (see Figure 2G and 2H, respectively), we observed perturbations to endocrine status and hypercholesterolemia (see Figure 3). The observations of reduced testosterone in MMA athletes who also undertook RWL of 10% body mass in a 24 h period was also documented by Coswig et al. (2015). Nonetheless, the present paper reports the time-course of changes to endocrine markers across the entire 8-week period, as opposed to the cross-sectional study of MMA athletes who did or did not partake in RWL associated with making weight. Interestingly, the time-course of changes to both endocrine (e.g. reduced testosterone and IGF-1 etc) and lipid profiles is similar to that observed in US army rangers during an 8 week simulated expedition considered to induce semi-starvation (Friedl et al., 2000).

Despite a body mass loss of 4.4 kg during phase 1, the athlete was still required to lose 9.6 kg in the next 7-days. In phase 2 of the athlete's strategy, he subsequently underwent a 5-day water loading protocol where 8 L was consumed daily for 4 days (corresponding to approximately 100 ml/kg) followed by 250 ml only for 1 day. Such alterations to fluid intake were done so in conjunction with a further reduction in energy intake to 500-1000 kcal/d that was also comprised of low-residue foods. It is, of course, difficult to ascertain the precise contribution of water loading and/or further reductions in energy availability (note that testosterone concentration declined to <3 $nmol.L^{-1}$) in modulating the additional 2.8 kg lost during phase 2. Nonetheless, it is noteworthy that a comparable water loading protocol (100 ml/kg for 3 days followed by 15 ml/kg for 1 day) has recently been confirmed to enhance body mass loss (3.2 v 2.4%) when compared with a matched subject group who consumed a lower daily water intake of 40 ml/kg (Reale et al., 2017a). Interestingly, we report similar magnitudes of change in body mass (i.e. 3.7%), daily urine output (e.g. an increase of 150% from 4 L to 6 L) and plasma sodium concentrations (maintained within the range of 136-140 $mmol.L^{-1}$) to that observed by the previous authors. When taken together, such data suggest that the water-loading protocol reported here and studied under experimental conditions (Reale et al., 2017a) may be an effective method to enhance acute weight loss without causing clinical meaningful changes to blood biochemistry.

The excessive dehydration experienced in phase 3 (i.e. absolute weight loss of 7.3 kg) induced a significant stress response (e.g. 3-fold increases in plasma cortisol to approximately 1500 $nmol.L^{-1}$, see Figure 3B) and is evidenced by the elevations in serum proteins (see Figure 4D), plasma osmolality (see Figure 4H) and sodium concentration to 148 $mmol.L^{-1}$ (see Figure 4G). This absolute and relative magnitude of weight loss (i.e. 10%) has been previously reported in MMA athletes who also engage in RWL in the 1-7 days prior to contest (Coswig et al. 2015). The increases in plasma sodium observed here are near to the severe levels of hypernatremia (>150 mmol.L^{-1}) where mortality may occur, albeit in intensive care patients (Darmon et al., 2010). The relative (almost a 50% increase) and absolute changes (53 µmol.L^{-1}) in serum creatinine levels during this final phase of the weight cut are consistent with acute kidney injury (AKI), defined as magnitudes of increase >26 µmol.L^{-1} (Kellum & Lameire, 2013). Such alterations to kidney function are likely mediated by ischemic injury and hypoperfusion due to intravascular volume depletion. Given the association of AKI with morbidity, mortality and chronic kidney disease (especially when these insults are repetitive) (Chandrasekar et al., 2017; Ishani et al., 2009; Kellum & Lameire, 2013; Rimes-Stigare et al., 2015), our data suggest that MMA athletes may be particularly sensitive to long-term kidney complications. It is noteworthy that several MMA athletes have retired from the sport citing kidney disease as a contributing factor (Thomas, 2013) Additionally, the impact of such extreme dehydration upon cardiac function also remains to be documented, especially when considering that incidences of athletes being hospitalised (Beacham, 2017; Drahota, 2017; Hiergesell, 2018; MMA Junkie Staff, 2017) and fatalities (Barrabi, 2013; Okamoto, 2015) during weight cutting have been attributed to impaired cardiovascular function and cardiac arrest respectively.

Following the 32 h rehydration and refuelling strategy, the athlete gained 10.6 kg in absolute mass. Unfortunately, we were unable to obtain an additional blood sample immediately prior to competition and hence cannot ascertain if the alterations in clinical chemistry discussed above had yet returned to normal. Nonetheless, at 2 weeks after competition resting metabolic rate, markers of endocrine status, lipid profile, hydration status and kidney function all returned towards or within normative ranges. It is noteworthy, that upon final assessment of body composition the athlete presented with an increased body mass (+3.3

kg, 4.2.% increase) and fat free mass (+3.7 kg) when compared to the baseline assessment. Although gains in fat mass during this time (+2.8 kg from weigh-in) did not cause absolute fat mass to increase above baseline (i.e. 9.7 versus 11.7 kg), such rapid changes to body mass and composition are indicative of the hyperphagia that often occurs in response to acute and intensive periods of energy restriction (Dulloo, 2015; Nindl et al., 1997).

Conclusions

In summary, we observed clear signs of relative energy deficiency, as evidenced by reduced metabolic rate, inability to complete performance tests, marked alterations to endocrine hormones and hypercholesterolemia. Additionally, the extreme dehydration experienced in the final 20 hours prior to weigh-in induced hypernatremia and acute kidney injury. Our data therefore support publicised reports of the harmful (and potentially fatal) effects of extreme weight cutting in MMA athletes and represent a call for action to governing bodies to safeguard the welfare of MMA athletes.

Post-Script

The athlete lost this contest by decision after competing in all 5 rounds. He then had 10 months without competition before returning to win in a "come-back" contest with a submission victory in the 2nd round. It is noteworthy that his comeback contest was undertaken in the higher lightweight category (70.3 kg) and the athlete has now made the decision to remain in the light-weight category, 9.1 kg heavier than his debut contest in the bantamweight category.

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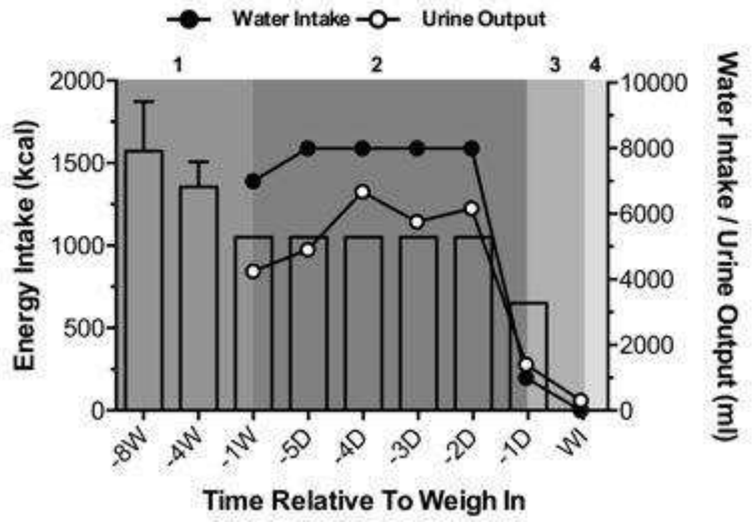

Figure 1. Reported energy intake during the 8 weeks prior to weigh-in (represented by **bars**), and water intake and urine output (represented by **lines**) during the final 7 days (D) prior to weigh-in. Error bars on -8 weeks (W) and -4W represent the mean (SD) of energy intake, as reported by the meal preparation company during the week of assessment.

"Case Study: Extreme Weight Making Causes Relative Energy Deficiency, Dehydration and Acute Kidney Injury in a Male Mixed Martial Arts Athlete" by Kasper AM et al.
International Journal of Sport Nutrition and Exercise Metabolism

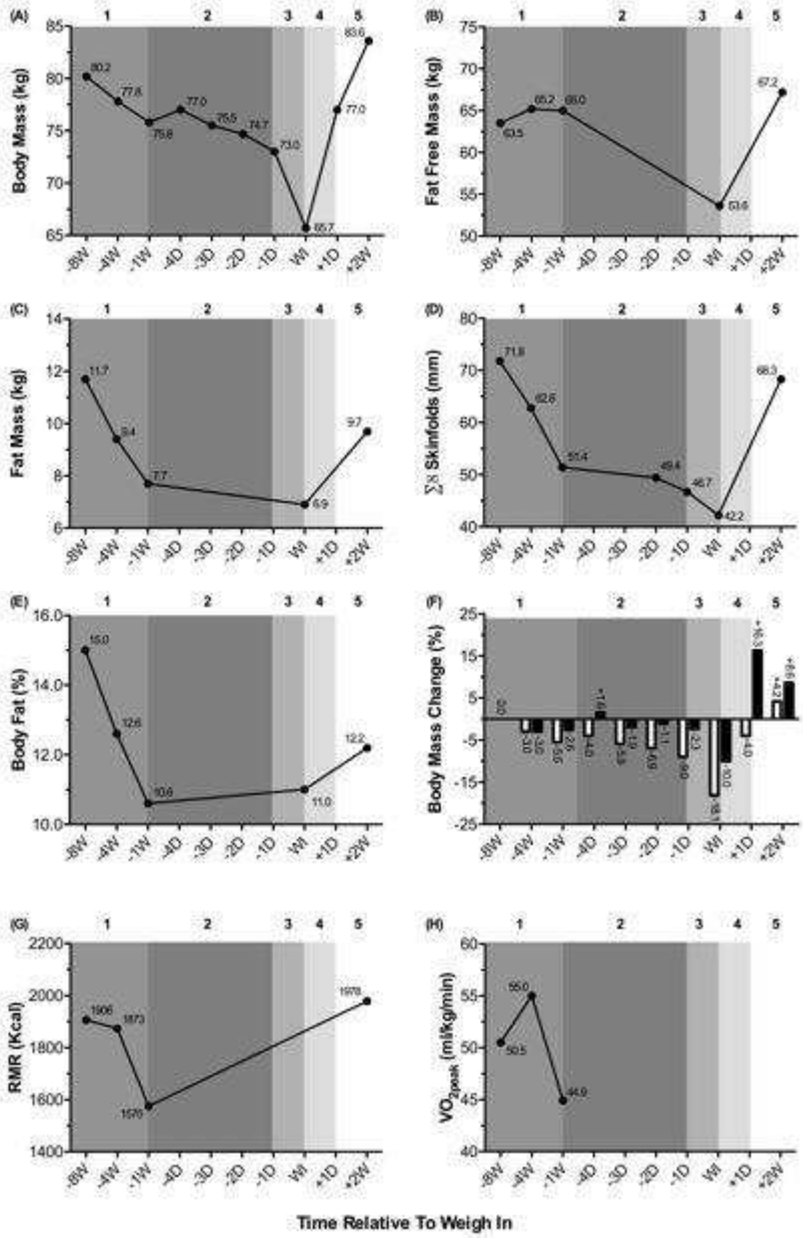

Figure 2. Changes in body mass (**A**) fat free mass (**B**), fat mass (**C**), Σ8 skinfolds (**D**), and percent body fat (**E**) throughout the observational period. Changes in percent body mass (**F**) are also expressed both relative to initial baseline assessment (**White Bars**) and the previous assessment point (**Black Bars**).

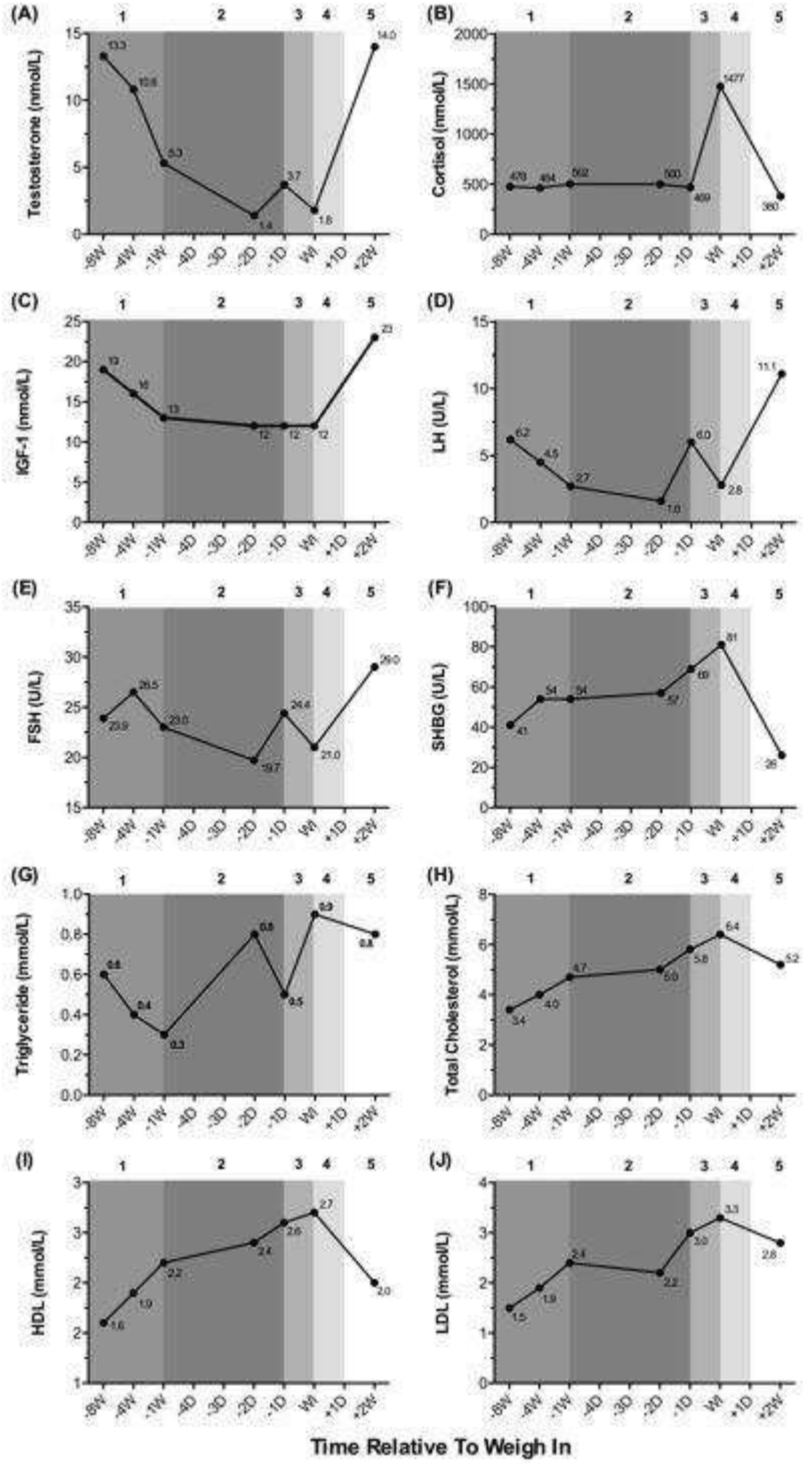

Figure 3. Endocrine and lipid biomarker profile changes: Testosterone (**A**), cortisol (**B**), insulin-like growth factor 1 (IGF-I) (**C**), luteinizing hormone (LH) (**D**), follicle-stimulating hormone (FSH) (**E**), sex hormone binding globulin (SHBG) (**F**), triglyceride (**G**), total cholesterol (**H**), high density lipid (HDL) (**I**), and low density lipid (LDL) (**J**).

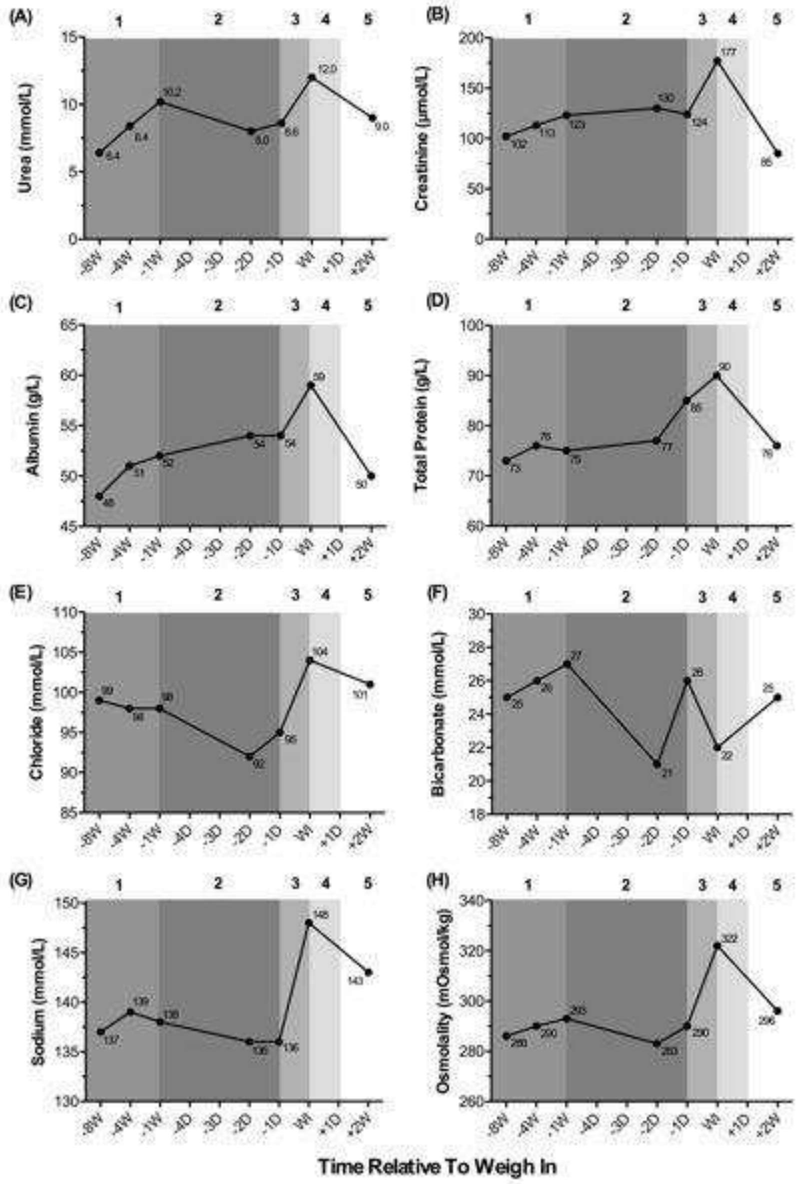

Figure 4. Renal biomarker profile changes: Urea (**A**), creatinine (**B**), albumin (**C**), and total protein (**D**) and electrolyte profile and hydration changes: Chloride (**E**), bicarbonate (**F**), sodium (**G**), and osmolality (**H**).