Lipid Profiles of Judo Athletes during Ramadan

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Key words
- islamic fasting
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Abstract

The effect of Ramadan intermittent fasting (RIF) was studied on a battery of blood lipid markers in 15 elite judo athletes during a period when they were maintaining their training load without competing. Nine-to-twelve hours postprandial serum lipid and lipoproteins were measured on five occasions: before, three times during Ramadan, and three weeks post-Ramadan. Dietary data were collected using a 24-hour recall method for three days before, during and after the Ramadan month. Mean energy intake (12.9 MJ/d) remained similar throughout the study as did the macronutrient constituents of the diet. Mean body mass was slightly reduced (2%; $p < 0.01$) by the end of Ramadan due mainly to a 0.65 ± 0.68 kg decrease in body fat ($p < 0.05$). The RIF produced significant changes in some of the blood lipid levels: both HDL-C and LDL-C increased by 0.12 ($p < 0.01$) and $0.20\ \mathrm{mmol \cdot l^{-1}}$ ($p < 0.05$), respectively. During Ramadan, mean non-esterified fatty acid (NEFA) levels decreased from 0.73 to $0.28\ \mathrm{mmol \cdot l^{-1}}$ ($p < 0.01$) during the first week, then increased ($p < 0.05$) to $1.22\ \mathrm{mmol \cdot l^{-1}}$ over the middle of Ramadan and recovered to pre-Ramadan concentrations for the end and the post-Ramadan periods. Apolipoprotein A1 (Apo-A1) levels were significantly elevated at the end ($p < 0.01$) and the post-Ramadan periods ($p < 0.05$). Three weeks after Ramadan, blood levels of glucose, NEFA, Apo-A1, and Apo-B did not return to the values observed before Ramadan. In conclusion, the present results show that the combination of the change in diet pattern during Ramadan, along with intense exercise training, induced a significant decrease in body mass associated with a reduction in body fat and changes in some of the serum lipids and lipoproteins. Nevertheless, all the measured serum parameters remained within normal levels for young and active individuals. The volunteers, in this study, were able to maintain a constant training load during RIF.

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Introduction

During Ramadan, Muslims abstain from food and fluid intake from dawn to sunset for one month and are permitted to eat and drink only during the hours of darkness. There are no nutritional restrictions on the quantity or type of food after breaking the daily fast but in most Muslim countries the diet eaten during Ramadan tends to have a higher sugar and fat, especially saturated fat, content [6,17]. The lifestyle changes during Ramadan concern the timing of meals, the decrease in meal number, the reduction in sleep duration and physical activity during the day [17,39, 44]. Experimental fasting before exercise increases fat utilization and lowers the rate of glycogen depletion during exercise [14]. Ramadan intermittent fasting (RIF) is a different model of acute starvation and dehydration [28], which has also been shown to increase the rates of fat oxidation [17,37] and to cause significant changes in the normal blood lipid profile and body composition [5,39] in sedentary individuals. It has been reported that RIF causes little change in body composition, blood glucose, triglyceride (TG) and total cholesterol (TC) levels, an increase in high density lipoprotein cholesterol (HDL-C) and apolipoprotein A1 (Apo-A1), a decrease in low density lipoprotein cholesterol (LDL-C), and a greater preponderance for fat oxidation [5,41,44].

In normal conditions, several studies in elite athletes have shown that serum lipid concentrations do not differ between athletes and sedentary subjects of similar [36] or different body fat content [22]. Nevertheless, a recent study concluded that the lipid profile parameters were significantly different in two categories of professional elite athletes when compared with a sedentary control population [30]. All studies found in the literature, related to the effect of RIF, concerned sedentary populations, which are not likely to be representative of the elite athletes. However, information concerning the combined influence of intense exercise and RIF is lacking in humans, and to the best of our knowledge, the assessment of fasting effects during Ramadan on the body composition and lipid profile in athletes has not previously been investigated.

Sport training and competition continues to be scheduled during Ramadan, and Muslim elite athletes have to maintain training loads and body mass while undergoing one month of complete RIF. Dietary and fluid restriction may affect plasma and blood volume, muscle glycogen stores, endocrine function and psychological parameters which may affect sports performance [10,18]. Moreover, athletes, coaches, and physicians have a general perception that athletes are susceptible to homeostasis perturbations caused by the RIF. The requirement for energy transfer rates to fuel moderate-to-intense exercise are normally met by carbohydrate utilization from muscle and liver glycogen and circulating blood glucose [9,14]. However, it is not known how individuals undertaking hard physical training adapt metabolically to maintain their training load while the dietary perturbations during Ramadan may cause a change in substrate utilization and a possible dehydration. Normally the circulating lipid levels would affect the rate of fat oxidation at rest and during exercise [14].

The focus of this investigation was, therefore, to identify the changes that could occur in body composition, serum lipids, lipoproteins, and hematological parameters in elite athletes maintaining their usual training load during RIF, which could provide some insight into the possible effects of their perturbations on performance. Our hypothesis was that meal schedule changes during Ramadan and intensive training would affect the body composition and the metabolical parameters in sportive individuals.

Methods

Subjects

Fifteen healthy male elite judo athletes from the national team, who were maintaining their regular training schedule (6 days per week and at least 2 training hours per day), participated in the study. The mean and standard deviation (± SD) of their age, body mass, and body mass index (BMI) were 18 ± 1 years, 68.13 ± 8.2 kg and 22.4 ± 1.8 kg/m^2, respectively. All participants had competitive experience in regional and national tournaments for at least 8 years, and most of them had competed internationally. The subjects were all out of competition but were maintaining their body mass and the internal training load (~ 2100 arbitrary units) throughout the study [21]. All the subjects were nonsmokers and did not consume alcohol.

Before commencing the study, athletes had a physical examination by a physician in the National Center of Medicine and Science in Sports, Tunis, and were assessed as having no medical disorders that might limit their full participation in the investigation. The subjects assured us that they were not taking any medication, supplements, exogenous anabolic-androgenic steroids or any other substances expected to affect hormonal balance during this study. The subjects were informed both orally and in writing about the experimental procedures, the possible risks and benefits of the study, which was approved by the national ethics committee. Each volunteer signed a letter of informed consent before participating in this study.

Experimental design

Ramadan lasted from October 4 to November 3, 2005. During this period, the subjects visited the laboratory and were examined on five occasions. The first session (T0) was performed 4 days before Ramadan. The second (T1), the third (T2), and the fourth sessions (T3) were performed in the first week (7th day, D7), the middle (D16) and the end (D29) of Ramadan, respectively. The fifth session (T4) was performed 21 days after Ramadan. Every examination was carried out over two days. On the first morning, each subject underwent anthropometric measurements and answered a dietary questionnaire. On the second morning, they provided a fasting blood sample for the measurement of serum biochemistry, lipid, apolipoprotein concentrations and hematology. All blood samples were collected in the morning, between 08:00 and 10:00 a.m.

Body composition

At T0, T2, T3, and T4 the body mass (BM) of each subject was measured in the morning at the same time of day along with the percentage of body fat mass (%BFM) that was estimated from four skinfold thicknesses (Harpenden caliper, Lange, Cambridge, MA, USA) using the Durnin and Womersley equation [15]. BM was measured to the nearest 100 g with an electronic balance (Seca Instruments Ltd., Hamburg, Germany), with the subjects wearing only shorts. Standing height was measured to the nearest 0.1 cm using a stadiometer (Holtain Ltd., Crymych, UK). Body mass index (BMI) and fat free mass (FFM) were then calculated. All the anthropometric variables were taken by the same highly experienced investigator.

Dietary intake analysis

Dietary intake of foods and nutrients was assessed at baseline (pre-Ramadan) during a pre-fasting control week, through and after Ramadan by using 24-h hour recall method on each occasion for three days [8], which was completed by interview with the same experienced dietician. Subjects were asked to report in detail all foods and fluids consumed during the preceding 24 hours. For each food item mentioned by the athletes, further information was asked about its type, size, the amount consumed, and the utensils used with 2- and 3-dimensional food models shown to help the interviewee in his estimation.

Dietary records were analyzed for energy intake in Microsoft Access by the use of a food database created in our laboratory with values based mainly on the food composition table published by the National Institute of Statistics of Tunisia in 1978 and on other published data [20]. Energy intake was reported in $MJ \cdot d^{-1}$ and in $kj \cdot d^{-1} \cdot kg^{-1}$. Fat, protein, and carbohydrate intakes were expressed as grams per day and/or grams per kilogram body weight per day and as a percentage of energy intake.

Serum biochemistry lipid and hematological measurements

At each phase of the study, athletes provided venous blood samples in a sitting position from an antecubital vein into plain vacutainer tubes, in the morning at rest. Blood samples (5 ml) were collected from the right arm after at least nine hours following their last meal, and at least twenty-four hours after the last training session. During Ramadan, for the pre-blood sampling

Table 1 Estimated daily dietary intake (mean ± SD) during the three phases of the study. For comparison, French norms for sportsmen are listed [36]

	Pre-Ramadan	During Ramadan	Post-Ramadan	French Norm
Energy intake				
▸ ($MJ \cdot d^{-1}$)	12.5 ± 1.2	13.1 ± 2.0	13.0 ± 1.2	12.5 – 14.6
▸ ($kj \cdot d^{-1} \cdot kg^{-1}$)	183.1 ± 40.6	198.8 ± 36.8	195.2 ± 34.1	
Carbohydrates				
▸ ($g \cdot d^{-1}$)	419 ± 115	430 ± 95	432 ± 74	450
▸ ($g \cdot d^{-1} \cdot kg^{-1}$)	6.2 ± 1.6	6.4 ± 1.45	6.5 ± 1.2	6 – 10
▸ (%)	55.4 ± 6.0	53.2 ± 5.5	55.2 ± 3.2	60 – 65
▸ saccharose ($g \cdot d^{-1}$)	49 ± 14	59 ± 20	49 ± 17	
▸ saccharose (%)	12.8 ± 2.8	14.1 ± 4.4	12.9 ± 7.6	
Fats				
▸ ($g \cdot d^{-1}$)	99 ± 25	114 ± 21	107 ± 17	100
▸ ($g \cdot d^{-1} \cdot kg^{-1}$)	1.4 ± 0.4	1.7 ± 0.4	1.6 ± 0.3	1.5
▸ (%)	29.7 ± 5.8	32.8 ± 4.3	30.02 ± 3.2	< 30
▸ animal fats	51 ± 16	67 ± 11*	53 ± 15	
▸ vegetable fats	41 ± 13	43 ± 10	40 ± 14	
Proteins				
▸ ($g \cdot d^{-1}$)	106 ± 24	107 ± 12.8	111 ± 18	81
▸ ($g \cdot d^{-1} \cdot kg^{-1}$)	1.6 ± 0.4	1.6 ± 0.3	1.7 ± 0.3	
▸ (%)	14.7 ± 2.1	14.0 ± 2.2	14.6 ± 1.2	15 – 20
Water intake (l)	3.46 ± 0.73	3.34 ± 0.81	3.16 ± 0.73	3.5

* Significantly different from the pre-Ramadan phase ($p < 0.05$)

days, subjects ate their dinner no later than 01:00 a.m. in order that they would be at least 9 h fasted before the morning blood sample was collected. After clotting, serum was prepared by immediate centrifugation at 1500 g for 10 min at 4 °C, collected and stored at – 20 °C until subsequent analysis.

Serum lipids (total cholesterol [TC], triglyceride [TG], High-density lipoprotein cholesterol [HDL-C] and low-density lipoprotein cholesterol [LDL-C]), serum apolipoprotein-A1 and apolipoprotein-B (Apo-B), serum total-proteins, albumin (Alb) and uric-acid concentrations were determined on a Konelab 20i automated analyzer (Thermo Electron Corp, Oy, Vantaa, Finland) using the respective kits (Konelab, Vataa, Finland). NEFA concentrations were measured using an enzymatic test kit (Randox Laboratory, Antrim, UK) and was performed by colorimetry. Hemoglobin (Hb) and hematocrit (Hct) were measured by an automated analyzer (MS9-Melet Schloesing Laboratoires, Osny, France) according to the manufacturer's protocol. Changes in Hb concentration and Hct levels were used to estimate changes in plasma volume [13]. Serum cortisol and insulin concentrations were measured by appropriate radioimmunology methods (AxSYM System, Abbott Laboratories, Abbottpark, IL, USA). The ratios TC/HDLC and LDL-C/HDL-C were derived from the respective concentrations.

Statistics

Statistical analysis was performed using the SPSS/PC Statistical Package for Social Science (version 13.0). All data are expressed as mean ± SD. Friedman's two-way ANOVA for repeated measures was used to determine the differences between the phases of the study, with each subject serving as his own control. When a significant χ^2 value was achieved, appropriate Wilcoxon post hoc test procedures with Bonferroni correction were used to locate where the differences lay between T0 (pre-Ramadan measures) and T1 – T4: a global 0.05 alpha level was thus distributed evenly among the k individual comparisons to be done, so that each comparison was tested against a 0.05/k probability level. Pearson correlation coefficients (r) were used to determine the association between calculated percentage changes in plasma volume and lipoprotein and serum proteins variables.

Results

Dietary intake

The values (mean ± SD) of estimated daily dietary intake before, during and three weeks after Ramadan are reported in **Table 1**. No significant differences of total daily energy intake were found between pre-Ramadan, during and after Ramadan. The proportion of total energy expressed as grams per day and/or grams per kilogram body weight per day, from carbohydrates, fat, and protein, was also maintained over the whole period of the investigation. However, the qualitative analysis of fat eaten shows that the amount of animal fats ingested during Ramadan was significantly greater ($p < 0.05$) than that in the pre-Ramadan phase. Total water intake (the sum of the water content of the cooked foods plus ingested drinks) was similar during the three phases of the study (**Table 1**). The energy and macronutrient intake of the elite judoists were similar than what was observed in other studies that have assessed elite-level judoists during weight maintenance periods [10,11,18,19].

Body composition

The mean values (± SD) of body mass, BMI, FM, fat-free mass (FFM) and the % BFM obtained before Ramadan (T0), in the middle of Ramadan (T2), at the end of Ramadan (T3), and three weeks after Ramadan (T4) are listed in **Table 2**. The RIF caused significant decreases in BM ($p < 0.01$), BMI ($p < 0.01$), and body fat (BF) ($p < 0.05$) by the end of Ramadan. There was no difference in body composition parameters between T0, T2, and T4 except for BF which decreased significantly ($p < 0.05$) by the middle of Ramadan and remained statistically lower ($p < 0.01$) three weeks after Ramadan. FFM was maintained throughout the period of the RIF.

Serum lipid and lipoprotein parameters

The values for serum lipid, lipoprotein and apolipoprotein levels measured at T0, T1, T2, T3, and T4 are shown in **Table 3**. Total serum cholesterol concentration tended to be higher during Ramadan and was significantly greater ($p < 0.05$) on T1 and T3.

Table 2 Anthropometric characteristics of the athletes (mean ± SD) at four of the phases of the study

	Pre-Ramadan	Mid-Ramadan	End of Ramadan	Post-Ramadan
Body mass	68.13 ± 8.24	67.51 ± 8.87	66.90 ± 8.62**	67.74 ± 9.04
BMI ($kg \cdot m^{-2}$)	22.35 ± 1.75	22.13 ± 1.92	21.93 ± 1.85**	22.20 ± 1.93
Body fat (%)	11.7 ± 2.5	11.1 ± 2.5*	10.9 ± 2.7*	10.1 ± 2.6**
Fat mass (kg)	8.05 ± 2.54	7.63 ± 2.55*	7.39 ± 2.68*	6.97 ± 2.63**
Fat free mass (kg)	60.08 ± 6.35	59.88 ± 6.98	59.50 ± 6.59	60.77 ± 7.15

* Significantly different from the pre-Ramadan phase ($p < 0.05$); ** significantly different from the pre-Ramadan phase ($p < 0.01$); pre-Ramadan (T0) = 4 days before the beginning of 30 days fasting; mid-Ramadan (T2) = 16 days after starting the fast; end of Ramadan (T3) = 29 days after starting the fast; post-Ramadan (T4) = 21 days after the end of 30 days fasting

Table 3 Serum lipid, lipoprotein and apolipoprotein analysis (mean ± SD)

	T0	T1	T2	T3	T4
TG ($mmol \cdot l^{-1}$)	0.67 ± 0.15	0.58 ± 0.17	0.53 ± 0.08*	0.59 ± 0.15	0.58 ± 0.08
TC ($mmol \cdot l^{-1}$)	3.43 ± 0.26	3.61 ± 0.21*	3.56 ± 0.32	3.72 ± 0.31*	1.35 ± 0.18
NEFA ($mmol \cdot l^{-1}$)	0.73 ± 0.18	0.28 ± 0.08**	1.22 ± 0.24*	0.84 ± 0.26	0.89 ± 0.29
HDL-C ($mmol \cdot l^{-1}$)	1.30 ± 0.31	1.30 ± 0.23	1.32 ± 0.32	1.42 ± 0.28**	1.37 ± 0.28
LDL-C ($mmol \cdot l^{-1}$)	1.81 ± 0.31	1.92 ± 0.36	2.02 ± 0.41*	2.02 ± 0.41*	1.86 ± 0.34
Apo-A1 ($g \cdot l^{-1}$)	1.93 ± 0.42	2.03 ± 0.48	1.68 ± 0.35	2.51 ± 0.44**	2.96 ± 0.58*
Apo-B ($g \cdot l^{-1}$)	0.65 ± 0.10	0.70 ± 0.09	0.70 ± 0.13	0.66 ± 0.12	0.56 ± 0.18*
LDL-C/HDL-C	1.47 ± 0.41	1.54 ± 0.47	1.64 ± 0.62	1.50 ± 0.52	1.45 ± 0.49
TC/HDL-C	2.74 ± 0.54	2.85 ± 0.53	2.83 ± 0.59	2.68 ± 0.64	2.66 ± 0.59

* Significantly different from the pre-Ramadan phase ($p < 0.05$); ** significantly different from the pre-Ramadan phase ($p < 0.01$). Note: TG = triglycerides; TC = total cholesterol; NEFA = non-esterified fatty acids; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; Apo-A1 = apolipoprotein A1; Apo-B = apolipoprotein B; LDL-C/HDL-C = ratio of LDL-C to HDL-C; TC/HDLC = ratio of total cholesterol to high-density lipoprotein cholesterol. T0 = 4 days before the beginning of 30 days fasting; T1 = 7 days after starting the fast; T2 = 16 days after starting the fast; T3 = 29 days after starting the fast; T4 = 21 days after the end of 30 days fasting

Table 4 Serum glucose biochemistry, protein, and haematology analysis (mean ± SD)

	T0	T1	T2	T3	T4
Glu ($mmol \cdot l^{-1}$)	5.49 ± 0.39	5.72 ± 0.33	5.61 ± 0.22	5.55 ± 0.44	4.83 ± 0.33*
Albumin ($g \cdot l^{-1}$)	46.2 ± 1.5	47.0 ± 1.8	45.0 ± 1.5*	47.6 ± 3.7	49.2 ± 4.6*
Protein ($g \cdot l^{-1}$)	77.1 ± 4.4	79.9 ± 4.5*	71.2 ± 3.5**	70.1 ± 4.3**	73.0 ± 0.57*
Uric acid ($\mu mol \cdot l^{-1}$)	267 ± 38	295 ± 46*	304 ± 45**	289 ± 46*	292 ± 36*
Hemoglobin ($g \cdot l^{-1}$)	149 ± 9	152 ± 7	143 ± 9*	153 ± 7	149 ± 9
Hematocrit (%)	43.6 ± 2.2	45.0 ± 1.8*	43.8 ± 2.1	45.2 ± 1.6*	43.1 ± 2.1
ΔPV (%)	0 ± 0	– 3.3 ± 6.5*	4.3 ± 8.2	– 4.4 ± 6.9*	1.1 ± 8.3
Insulin ($U \cdot l^{-1}$)	5.36 ± 1.75	6.93 ± 3.16*	7.23 ± 2.71**	7.08 ± 2.55*	5.57 ± 2.71
Cortisol ($mg \cdot l^{-1}$)	13.4 ± 2.2	9.0 ± 1.9*	9.3 ± 2.3*	10.3 ± 2.1*	10.6 ± 2.6*

* Significantly different from the pre-Ramadan phase ($p < 0.05$); ** significantly different from the pre-Ramadan phase ($p < 0.01$). Note: Glu = glucose; ΔPV (%) = calculated percentage change in plasma volume from pre-Ramadan levels. T0 = 4 days before the beginning of 30 days fasting; T1 = 7 days after starting the fast; T2 = 16 days after starting the fast; T3 = 29 days after starting the fast; T4 = 21 days after the end of 30 days fasting

After Ramadan, TC levels recovered to pre-Ramadan values. Compared with T0, HDL-C increased ($p < 0.01$) at T3 and then returned to pre-Ramadan values. The LDL-C concentrations were higher on both T2 and T3 compared to T0 ($p < 0.05$), before they decreased to approximately T0 values 3 weeks following the RIF. No differences were found in the LDL-C/HDL-C ratio throughout the study. Circulating triglyceride levels were lower at T2 ($p < 0.05$) with respect to T0. NEFA levels initially decreased at T1 ($p < 0.01$), then increased by T2 ($p < 0.05$) before recovering to pre-Ramadan concentrations for the remaining of the study. Circulating Apo-A1 levels increased in the later stages of Ramadan (T3, $p < 0.01$) and were still higher three week after Ramadan (T4) with respect to pre-Ramadan ($p < 0.05$). Finally, Apo-B levels remained relatively stable during Ramadan, but were significantly lower at T4 ($p < 0.05$) compared with T1, T2 and T3.

Serum glucose, seric protein and hematology

Table 4 summarizes the rest of the serum biochemistry and hematology parameters measured during the phases of the study. The glucose concentrations remained relatively stable, and within normal fasting levels, before and throughout Ramadan. Glucose levels, however, were found to be lower at T4 compared with T0 values ($p < 0.05$). Insulin levels increased from T0 until T3 ($p < 0.05$) before returning to pre-Ramadan values at T4. Serum protein concentration increased during the first week of Ramadan ($p < 0.05$), then fell at T2 ($p < 0.01$), T3 ($p < 0.01$), and T4 ($p < 0.05$) to levels below that seen at T0. Likewise, albumin concentrations fell at T2 ($p < 0.05$) then increased progressively by T3 and T4 ($p < 0.05$).

Circulating cortisol concentration decreased at T1 ($p < 0.05$) and remained lower than T0 even three weeks after ending the fast ($p < 0.05$). Uric acid levels increased at T1 ($p < 0.05$) compared

with T0 and remained higher than T0 levels throughout Ramadan and for at least three weeks after Ramadan ($p < 0.05$).
Hemoglobin concentrations decreased at T2 ($p < 0.05$) then recovered at T4, while hematocrit was increased at T1 and T3 ($p < 0.05$). The calculated changes in plasma volume suggested a slight overall fall in plasma volume during Ramadan followed by a return to pre-Ramadan levels at T4.
The changes in serum albumin levels, but not serum protein, during and after Ramadan were weakly but significantly associated with the calculated fluctuations in plasma volume ($r = -0.29$, $p = 0.01$; $r = -0.03$, $p = 0.78$, respectively). There were also significant relationships between the changes in plasma volume and the increase in circulating total cholesterol ($r = -0.22$, $p = 0.05$), HDL-C ($r = -0.38$, $p = 0.001$) and LDL-C ($r = -0.39$, $p = 0.001$).

Discussion

The aim of this study was to determine whether the RIF would affect the body composition, lipid profile, and hematological parameters of elite judo athletes who were maintaining their usual training load. To our knowledge this is the first study to examine the effect of both prolonged intermittent fasting and heavy training in man. The main results emerged from this study were significant decreases in body mass index and body fat. The RIF produced also significant increases in TC, HDL-C, LDL-C, NEFA, Apo-A1, insulin, and uric acid levels and a decrease in TG and cortisol. Three weeks after Ramadan, blood levels of glucose, NEFA, Apo-A1, and Apo-B did not recover to the pre-Ramadan values. This study also showed that the daily athlete's energy intake did not change during Ramadan.
Our method of calculating dietary intake was validated for the estimation of the average nutrient/energy intakes in groups of subjects [8,12]. In the present study, the estimated energy intake of the judoists was similar to the average baseline data previously reported for elite judo athletes [10,11,18,19]. The RIF induced a small but significant decrease in athletes' body mass. The results are in accordance with other studies where fasting individuals lost body mass [1,23,24,33,44]. The decrease in body mass in our subjects appeared not to be related to the changes in the daily energy intake, since dietary records revealed no changes in the daily energy density of the consumed meals (**Table 1**). An increased utilization of fat can explain these finding [17,37]. Indeed, El Ati et al. [17] have shown that Ramadan fasting decreases energy expenditure, and carbohydrate oxidation and increases fat oxidation in sedentary Tunisian women. This shift in substrate metabolism could be explained by the absence of postprandial thermogenesis [24] and a reduction of the sympathetic activity in response to fasting [43]. The additional requirement to meet the energy needs for sustaining an intense training load would further exacerbate the body's ability to regulate high levels of energy production from a limited carbohydrate pool. Concurrently with the change in diet quality and a reduction in meal frequency, the present study's subjects maintained the same training schedule throughout the study period. While we did not determine any changes in substrate metabolism in this study, it is highly probable that the training load along with the alteration in eating times produced at least a similar or greater increase in fat oxidation during Ramadan in our athletes compared with those of sedentary populations [27].
The baseline and overall study lipid levels are all within the normal reference values for our laboratory and in the general population [10] and comparable with those recently reported in judo athletes [10,11,18,19]. The increase in HDL-C that occurred in the fasting state is a common finding shown in other studies investigating the effects of Ramadan fasting in sedentary subjects [2, 39]. However, only a few studies have shown an increase in total cholesterol and LDL-C levels during Ramadan. In the scientific literature we have found only four studies that have shown an increase in total cholesterol and LDL-C during Ramadan [6,23, 38,44] and none of these studies identified the mechanism that produced this response. Filaire et al. [18] showed that 7-d food restriction produced no change in TC, LDL-C, HDL-C concentrations nor in apolipoprotein-A1 and B. The Ramadan fast is a different dietary regimen that may not produce the same results as that of other fasting protocols.
Decreases in blood volume during Ramadan which have been also shown in other fasting studies [28] could explain a part of the increase in the circulating concentrations of TC, HDL-C and LDL-C seen in the present study. However, the correlation coefficients suggest that only about 23 to 39% of the changes in circulating lipoprotein concentration can be ascribed to the alteration in plasma volume that occurred. The most likely explanation of the lipid changes is the effect of both the change in the type of fats consumed and the continuation of training during Ramadan. It is accepted that high dietary saturated fat intake is associated with elevated levels of total and LDL-C [1,31]. Although in the present study we did not examine the type of fats eaten by the subjects during the different phases of the study, it has previously been shown that there is an increase in saturated fat intake during Ramadan in the Tunisian population [6,17]. The estimated increase in animal fat intake seen in our study (**Table 1**) during Ramadan would strongly suggest that more saturated fats were ingested by the subjects during Ramadan than before or after. In addition, the decrease in meal frequency [4] and the substantial lipolysis that accompanied fasting [40,42] could also explain the increase in blood lipid concentrations. The decrease in LDL uptake by the liver could be a second likely mechanism contributing to increased LDL levels [42]. Further studies, which may include measurements of the turnover of radiolabeled LDL-particles, are required to confirm the involvement of this mechanism.
NEFA concentrations decreased over the first week of Ramadan then increased above the levels measured in pre-Ramadan, before recovering to the baseline values. Adaptations to the composition and timing of the diet may be responsible for the perturbations seen in the NEFA concentrations. Indeed, it has been previously shown that the composition of the diet and the duration between food ingestion and the collection of the blood sample can have marked effects on the measured NEFA levels [27]. Another possibility is that the fluctuation in circulating NEFA levels reflects adaptations in fat oxidation during Ramadan [17]. During the first week of Ramadan, there is a rapid shift to a greater reliance on fat utilization to meet energy needs [17], which may cause depletion of the circulating NEFA levels. As the intermittent fast continues, there is a further adaptation to sustain the increase in fat oxidation with higher levels of insulin-activated leptin, promoting concentrations of circulating free fatty acids in excess [26]. In our study, serum insulin concentration increased progressively during the Ramadan month, while fasting serum glucose values remained relatively stable. This suggests that the higher levels of circulating insulin during Ram-

adan may be primarily a response to promote leptin secretion and, hence, stimulate fatty acid release from adipose tissues [26].

Adlouni et al. [1] suggested that the feeding behavior that occurs during Ramadan beneficially affects serum apolipoprotein levels and may contribute to the prevention of coronary heart disease. In their study, Apo-A1 increased by day 29 of Ramadan compared with the pre-Ramadan levels and remained elevated one month after the end of Ramadan. Apo-B levels, however, fluctuated during the fasting month but were lower during the last week of Ramadan and one month after the fast. Our study findings broadly follow this pattern with Apo-A1 levels being higher in the latter stages of Ramadan and post-Ramadan, while Apo-B concentrations were lower following Ramadan. In the present study, the Ramadan diet of our subjects was higher in animal fats and similar in carbohydrate and protein intake compared with their normal diet. This would suggest that the diet composition has relatively little effect on the apolipoprotein levels during RIF and that meal frequency [1] or exercise levels [16, 29, 35, 36] could be more effective in bringing about these changes.

Several studies have reported an increase in blood uric acid concentrations and a decrease in body mass during Ramadan [17, 33, 34]. Subsequently, we could postulate that an increase in protein breakdown, coupled with dehydration while fasting, as observed in the present study, could lead to raised circulating uric acid levels [33]. The effect of maintaining an intense training load throughout one month of the Ramadan fast may sustain increased fat and protein metabolism for significant periods after the fasting period, and be responsible for the delay in recovering uric acid levels after Ramadan. In this context, the training load of our subjects (~2100 AU) was markedly greater than that seen in soccer players (~1900 AU; [25]) using the same RPE-based method for estimating internal training loads of groups of athletes.

The cortisol level was lower in the morning, which confirms earlier findings [3, 7]. When the blood was taken several time a day, this decrease was observed only during daytime and the 24-h level remained unchanged [7], suggesting that the cortisol level and acrophase would be shifted during Ramadan without a decrease in its overall level.

In our experimental model, the circadian rhythms would not influence any of the biochemical investigated parameters since the blood withdrawal was performed at the same time of day, between 09:00 and 10:00 a.m. In Ramadan, the subjects ate their last meal at 01:00 a.m. in order to be at approximately the same duration of fast time as that during the non-RIF phases of the study. The postprandial period duration could, however, influence these values because this period could be shorter during Ramadan.

In conclusion, the present results suggest that the combination of the changes in eating time and frequency during the RIF, along with the continuation of relatively high training load, increases most of the lipid parameters in elite judo athletes and reduces the body mass and body fat. Nevertheless, the athletes were able to keep the same training schedule throughout the period of the study. All the measured serum parameters in our study remained within normal levels for young, healthy active subjects. Further studies are required to examine the mechanisms of metabolic changes during the Ramadan fast and the possible effects of theses changes on athlete's physical performance.

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