Effect of Ramadan fasting on fuel oxidation during exercise in trained male rugby players

E Bouhlel1, Z Salhi2, H Bouhlel1, S Mdella2, A Amamou2, M Zaouali2, J Mercier3, X Bigard4, Z Tabka2, A Zbidi2, RJ Shephard5

SUMMARY

Purpose: The aim of this study was to assess the effect of Ramadan fasting on substrate oxidation in trained athletes during moderate-intensity exercise.

Methods: Nine trained men (age: 19±2 yr, Height: 1.78±0.74 m) were tested on three occasions: during a control period immediately before Ramadan (C), at the end of the first week (Beg-R), and during the fourth week of Ramadan (End-R). On each occasion, they performed submaximal cycle ergometer exercise, with work-rates that were increased progressively (loadings corresponding to 20, 30, 40, 50, 60% of Wmax). Steady-state substrate oxidation was evaluated by indirect calorimetry.

Results: Participants showed significant decreases in body mass and body fat at the end of Ramadan, relative to initial control values (P<0.001). The daily food intake was also reduced during Ramadan (P<0.01). Haemoglobin concentrations and hematocrit were significantly higher at the end-Ramadan, both at rest (P<0.001 and P<0.0001 respectively) and after exercise, (P<0.05 and P<0.01 respectively) compared to control measurements made before Ramadan. At the end of Ramadan, our subjects had increased their fat utilization during exercise. The cross-over was observed at a higher intensity at the End-R (35% vs. 30% of Wmax, P<0.001). For the same power output, the Lipox max was also higher at the End-R, compared to control value (265±38 vs. 199.1±20 mg/min, P<0.001).

Conclusion: Ramadan fasting increases the lipid oxidation of trained athletes during submaximal exercise. The increased fat utilisation may be related to decreases in body mass and body fat content.

Key-words: Fasting · Dehydration · Indirect calorimetry · Metabolic fuels · Moderate exercise.

RESUMÉ


Méthodes : Neuf sujets entraînés (âge : 19 ± 2 ans, taille : 1,78 ± 0,74 m) ont été évalués lors de trois occasions : durant une période contrôle avant le Ramadan (C), à la fin de la 1re semaine du Ramadan (Beg-R) et pendant la 4e semaine du Ramadan (End-R). A chaque visite, les sujets ont réalisé un exercice sous maximal à palier progressif sur ergocycle (charges correspondant à 20, 30, 40, 50, et 60 % de la puissance maximale). L’oxydation des substrats à l’état stable a été évaluée selon la méthode de la calorimétrie indirecte.

Résultats : Les sujets ont montré des diminutions significatives de la masse corporelle et de la masse grasse à la fin du Ramadan par rapport aux valeurs avant le Ramadan (P < 0,001). L’apport alimentaire journalier a été aussi réduit pendant le Ramadan (P < 0,01). Les concentrations d’hémoglobine et l’hématocrite étaient significativement plus élevés à la fin du Ramadan au repos (P < 0,001 et P < 0,0001 respectivement) et après l’exercice, en comparaison avec les valeurs avant le Ramadan (P < 0,05). L’apport alimentaire journalier a été aussi réduit pendant le Ramadan (P < 0,01). Les concentrations d’hémoglobine et l’hématocrite étaient significativement plus élevés à la fin du Ramadan au repos (P < 0,001 et P < 0,0001 respectivement) et après l’exercice, en comparaison avec les valeurs avant le Ramadan (P < 0,05). Les points de croisement métabolique (cross over) et d’oxydation maximale des lipides (Lipox max) étaient significativement plus élevés à la fin du Ramadan (+12 % et +13 % que les valeurs contrôles respectivement, P < 0,05).

Conclusion : Le jeûne du Ramadan augmente l’oxydation des lipides chez les athlètes entraînés lors de l’exercice sous maximal. L’augmentation de l’utilisation des lipides était accompagnée par des diminutions de la masse corporelle et de la masse grasse.

Mots-clés : Jeûne · Déshydratation · Calorimétrie indirecte · Réserves métaboliques · Exercice modéré.
**Introduction**

The impact of Ramadan fasting and dehydration upon athletic training and competitive performance is of growing interest to western sport physicians as the number of observant Muslim competitors increases. During the season of Ramadan, physiological changes may be anticipated from both short-term restrictions of fluid intake and longer-term decreases in food intake and training. In particular, one might anticipate a depletion of both blood glucose and glycogen reserves, and thus an increased utilization of fat and a decreased utilization of carbohydrate during endurance exercise.

Several previous studies have examined the effects of the traditional Ramadan fast (an absence of food and fluid intake between sunrise and sunset) upon resting blood glucose and lipids [1-3]. Larijani et al. [3] found a significant decrease of blood glucose, which was positively correlated with the overall decrease of energy intake during Ramadan. Adlouni et al. [2] also noted significant decreases in serum total cholesterol (7.9%) and triglycerides (30%) during Ramadan, relative to the immediate pre-fast period. There were associated marked increases in high-density lipoprotein cholesterol and decreases in low-density lipoprotein cholesterol [2].

However, other studies found no changes in body composition or blood lipid concentrations [4-7]. Maislos et al. [4] reported that plasma total cholesterol, triglycerides, low-density-lipoprotein cholesterol, and very-low-density-lipoprotein cholesterol all remained unchanged, although they observed a marked increase in plasma high-density-lipoprotein cholesterol at the end of Ramadan fasting. In the study of El Ai et al. [1], neither body mass nor body composition were influenced by Ramadan fasting; nevertheless, under resting conditions, the carbohydrate oxidation of 16 healthy women was decreased, and their fat oxidation was increased.

Mechanisms determining the fasting-associated changes in body composition and metabolism are poorly understood, particularly during exercise. In the study of Ramadan et al. [8], neither body mass nor body fat were significantly influenced by Ramadan fasting; nevertheless, the respiratory exchange ratio (RER) during steady state submaximal exercise decreased, suggesting that there was an increased oxidation of fat.

The two main sources of energy for muscular metabolism are carbohydrate (CHO) and lipids. The lipids are normally the predominant fuel during moderate exercise, but CHO becomes the major energy source during high intensity exercise [9]. Thus, a point of "cross over" between lipid and CHO is reached as the intensity of effort is increased [10-12]. At greater power outputs, CHO becomes the dominant fuel [11-13]. One might anticipate that Ramadan fasting would shift the substrate balance towards a greater use of fatty acids (FA) during moderate exercise, with an associated decrease in body fat stores. However, there have been no previous empirical studies of how Ramadan fasting modifies the cross-over point. Accordingly, the purpose of this study was to assess the influence of Ramadan fasting on the relative balance of fat and carbohydrate metabolism when trained team athletes performed moderate aerobic exercise.

**Materials And Methods**

**Subjects**

Nine trained male rugby players participated in this study (mean ±SD, age: 19±2 yr, height: 1.78±0.74 m). As members of the Tunisian national team, they engaged in five two-hour training sessions each week. None of the group was affected by chronic disease or endocrine disorders. No medical complications arose from the fasting. The physical characteristics of the subjects are summarized in Table I. After receiving a complete verbal description of the protocol, risks and benefits of the study, participants provided written consent to an experimental protocol approved by the Research Ethics Committee of the Faculty of Medicine, University of Sousse, Tunisia. They observed the traditional pattern of Ramadan fasting, abstaining from food and liquids from approximately 01.00 to 17.30 h for each of 29 d.

**Protocol**

Three progressive cycle ergometer tests were carried: one week before Ramadan (C), at the end of the first week of Ramadan (Beg-R), and during the fourth week (End-R). All tests were performed late in the afternoon (14.00 – 16.30 h), to ensure that subjects had been without food and water for a minimum of 12 hours before exercise testing. Subjects were asked to take the last meal at night at about

| Table I. Anthropometric characteristics of subjects. Mean ±SD of data. |
|---|---|---|
| **Before Ramadan (C)** | **Beg-R** | **End-R** |
| Body mass, kg | 80.4±16.6 | 79.6±16.6* | 78.6±17** |
| BMI, kg/m2 | 25.1±4.1 | 24.9±4.0 | 24.5±4.0* |
| Fat mass, % | 16.4±5.5 | 15.9±5.3 | 15.1±5.3** |
| Lean mass, kg | 60.6±7.2 | 59.8±6.8 | 59.5±8 |
| Waist, m | 0.84±0.09 | 0.83±0.09 | 0.83±0.09 |
| Hips, m | 0.88±0.09 | 0.88±0.09 | 0.87±0.09 |
| Waist/hip ratio | 0.94±0.03 | 0.94±0.03 | 0.94±0.02 |

*Difference from before Ramadan fasting, P<0.05.
**Difference from before Ramadan fasting, P<0.001.
1.00 a.m during Ramadan fasting. On control days, subjects take their lunch at about 20 h. At the time of our study, Ramadan extended from October 4th to November 2nd. The laboratory temperature was held between 22-24°C at a relative humidity of 76% during the test period.

Subjects recorded the times, amounts of food eaten and fluid intakes for a week before and during Ramadan fasting. Nutrient intakes were estimated from the dietary records, using the Bilnutt programme (Nutrisoft, Cerelles, France), and values based on the food-composition tables of the National Institute of Statistics of Tunis (1978).

Body mass and height were measured to the nearest 0.2 kg and 5 mm, respectively. Skinfold thicknesses were measured by calibrated Harpenden calipers at four standard sites (biceps, triceps, subscapular and suprailiac). The mean was taken of three recordings at each site, and body density was calculated using the equations of Durnin and Womersley [14] for men aged 20-65 years: Body density = 1.176s – 0.074s (log10 âS), where âS is the sum of the four skinfold readings (in mm), Body fat = (4.95 / D – 4.50) 100 and D is the density as estimated from the skinfold values. The body mass index (BMI) and the waist/hip circumference ratio were also calculated.

Exercise testing

Subjects exercised on an electromagnetically braked cycle ergometer (Ergoline, Bitz, Germany) according to a protocol proposed by Brandou et al [15]. Gas exchange was monitored on a breath-by-breath basis, using a metabolic cart (ZAN 600, Meβgeräte, Germany). The maximal oxygen intake (V̇O₂ max) and maximal aerobic power (Wmax) were estimated using the anthropometric prediction equations of Wasserman et al. [16] for normal and overweight males; these equations take account of age, and physical characteristics as follows:

- for normal weight males: V̇O₂ max = Body mass (kg) x (50.72 – 0.372 x Age);
- for overweight males: V̇O₂ max = (79 x Ht m – 60.7) x (50.72 – 0.372 x Age).

Five of the rugby players had a body mass index (BMI) between 25-29.9, and were thus considered as overweight subjects. These equations take account of age, and physical characteristics as follows:

- for normal weight males: V̇O₂ max = Body mass (kg) x (50.72 – 0.372 x Age);
- for overweight males: V̇O₂ max = (79 x Ht m – 60.7) x (50.72 – 0.372 x Age).

Five of the rugby players had a body mass index (BMI) between 25-29.9, and were thus considered as overweight subjects.

We used the follow equation to calculate Wmax : Wmax = (VO2max –10 (*M) / 10.3 (Wasserman, et al 1986). Where M is the body mass of the subject (kg); 1 watt = 10.3 ml/min.

Heart rate was monitored electrocardiographically throughout exercise testing (ZAN ECG 800, Meßgeräte, Germany). A 3-min rest period was followed by a five-stage progressive submaximal exercise test (20, 30, 40, 50, and 60 % of Wmax), with 6-min of exercise at each work rate [15]. The test concluded with a 4 min active recovery period at 20% of Wmax. Ventilatory parameters (V̇O₂, V̇CO₂, RER, and V̇E) were recorded throughout testing. Carbohydrates (CHO) and lipid oxidation rates were inferred from gas exchange measurements, using the non-protein respiratory quotient technique [17]:

- CHO (mg/mm)=4.585 V̇CO₂ – 3.255 V̇O₂
- Lipids (mg/mm)=-1.7012 V̇CO₂ + 1.6946 V̇O₂

V̇O₂ and V̇CO₂ were determined as the means of measurements made over the last 3 min at each intensity of exercise.

The simplest form of metabolic analysis assumes that when the RER is 0.7, 100% of energy is derived from lipid oxidation, and when the RER rises to 1.0, CHO represents 100% of the oxidized metabolites. We used the RER values to estimate the “cross-over” point for substrate utilisation and the maximal fat oxidation point (“Lipox max”). The “cross-over” point is defined as the power output beyond which CHO usage predominates (i.e, when approximately 70% of energy is derived from CHO and 30% from lipids, [12]); this corresponds to an exercise RER of 0.91.

The “Lipox max” point is the power output at which usage of lipids is maximal.

Plasma volume changes (%) were calculated from hemoglobin and hematocrit readings, using the equations proposed by van Beaumont [18].

Statistical analyses

Values were expressed as mean ±SD. A one-way analysis of variance (ANOVA) was used to compare values during the C, Beg-R and End-R tests. Where appropriate, a Student’s t-test with Bonferroni correction was used to make pair-wise comparisons. Significance was accepted at P<0.05.

Results

Anthropometric data

Body mass, body mass index (BMI) and fat mass values during the final week of Ramadan differed significantly from those observed before Ramadan (C) (P<0.001, table I). Waist and hip circumferences also tended to be reduced, although the latter differences were not statistically significant.

Dietary data

Total daily energy intake was reduced during Ramadan fasting (table II). The diet pattern used by our subjects during Ramadan showed a significantly reduced intake of both proteins (P<0.01) and CHO (P<0.001). However, the total fat intake was significantly increased (P<0.01) during Ramadan compared to the usual diet, especially with respect to saturated and monounsaturated fatty acids (P<0.01 and P<0.05 respectively).
Plasma glucose concentrations, haemoglobin, hematocrit data and plasma volume

Plasma glucose concentrations did not differ between the 3 periods of observation, either at rest or after exercise (table III). Haemoglobin concentrations were significantly increased relative to control values at the end of Ramadan, both at rest and after exercise (P<0.001 and P<0.05 respectively, table III). Hematocrit values were also significantly higher at the end of Ramadan, both at rest and after exercise (P<0.0001 and P<0.01 respectively, table III). Plasma volume was estimated to decrease during Ramadan in the same manner as Hct (P<0.05, table III).

Metabolic data

Figure 1 shows the Respiratory Exchange Ratio (RER) at different intensities of exercise during the three periods of observation. The RER was consistently lower relative to the control period during the third series of measurements (P<0.001).

The cross-over was observed at a greater power output at the End of Ramadan (35 % vs 30 % of Wmax, or 85 W vs 65 W, P<0.001 [figure 2]). For the same power output, the rates of CHO oxidation at the cross-over point were 14.2±0.1, 12.5±0.3, and 14.8±0.2 mg/[watt.min] before, Beg-R and at the end-Ramadan respectively (0.18±0.001, 0.15±0.002 and 0.19±0.002 mg/kg per watt.min respectively; NS).

Table II
Total daily energy intake before Ramadan fasting and during Ramadan. Mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>Before Ramadan</th>
<th>During Ramadan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy, MJ/d</td>
<td>16.85±3.02</td>
<td>12.1±3.75**</td>
</tr>
<tr>
<td>Energy, Kcal/d</td>
<td>4028±722</td>
<td>2890±898**</td>
</tr>
<tr>
<td>Protein, g/d</td>
<td>115.8±19.4</td>
<td>83.7±26.4**</td>
</tr>
<tr>
<td>Protein, % of energy</td>
<td>11.5±0.8</td>
<td>11.7±1.6</td>
</tr>
<tr>
<td>Total fat, g/d</td>
<td>147.7±33.5</td>
<td>144.2±56.3</td>
</tr>
<tr>
<td>Total fat, % of energy</td>
<td>32.8±2.3</td>
<td>44.4±6.6**</td>
</tr>
<tr>
<td>Saturated fatty acids, g/d</td>
<td>31.9±3.7</td>
<td>24.7±3.4**</td>
</tr>
<tr>
<td>Monounsaturated, g/d</td>
<td>50.3±5.1</td>
<td>57.3±5.8*</td>
</tr>
<tr>
<td>Polyunsaturated, g/d</td>
<td>17.8±5.2</td>
<td>17.9±4.4</td>
</tr>
<tr>
<td>Carbohydrates, g/d</td>
<td>559±90.9</td>
<td>314.6±101.6***</td>
</tr>
<tr>
<td>Carbohydrates, % of energy</td>
<td>55.7±2.3</td>
<td>43.9±6.3***</td>
</tr>
<tr>
<td>Fluid intake, l</td>
<td>3.7±0.7</td>
<td>2.6±0.9*</td>
</tr>
</tbody>
</table>

* Significant at P<0.05.
** Significant at P<0.01
*** Significant at P<0.001

Table III
Plasma glucose concentrations (mmol/l), haemoglobin (g/l), hematocrit (%), and plasma volume (delta %) at rest and after submaximal exercise before, at the end of the first week and at the end of Ramadan. Values are mean ±SD.

<table>
<thead>
<tr>
<th></th>
<th>Before Ramadan</th>
<th>Beg-Ramadan</th>
<th>End-Ramadan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, mmol/l</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>4.7±0.1</td>
<td>4.8±0.4</td>
<td>4.8±0.4</td>
</tr>
<tr>
<td>After exercise</td>
<td>4.9±0.7</td>
<td>5.2±0.7</td>
<td>4.9±0.7</td>
</tr>
<tr>
<td>Haemoglobin, g/l</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>144.6±1.2</td>
<td>150.3±1.1</td>
<td>154.3±1.2**</td>
</tr>
<tr>
<td>After exercise</td>
<td>156.1±1.1</td>
<td>150.4±0.9</td>
<td>163.4±1.3*</td>
</tr>
<tr>
<td>Hematocrit, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>39.9±3.2</td>
<td>43.1±4*</td>
<td>43.8±2.9***</td>
</tr>
<tr>
<td>After exercise</td>
<td>44±3.3</td>
<td>45.1±3.6</td>
<td>46.3±3.7**</td>
</tr>
<tr>
<td>Plasma volume (delta %)</td>
<td>-15.5±17.9</td>
<td>-7.8±7.9**</td>
<td>-9.6±5**</td>
</tr>
</tbody>
</table>

* Difference from before Ramadan fasting, P<0.05
** Difference from before Ramadan fasting, P<0.01
*** Difference from before Ramadan fasting, P<0.001
Resting lipid oxidation was higher than the control value at the end of Ramadan (figure 3). The maximal rate of lipid oxidation (Lipox max) peaked at 20% of Wmax (figure 3). For the same power output, the Lipox max was higher at the end of Ramadan compared to the control value. In deed, Lipox max values were 199±20, 218±35 and 265±38 mg/min before, at the Beg-R and at End-R respectively (figure 3). When expressed as mg/[watt.min], values were 3.26±0.06, 3.58±0.07 and 4.34±0.05 respectively (NS).

Comparing values before and at the end of Ramadan, delta body mass was correlated with both delta fat oxidation and delta free mass (r=0.71, P<0.05, and r=0.67, P<0.05 respectively). Delta total energy intake was also correlated with Δ fat mass and Δ fat oxidation (r=0.69, P<0.05, and r=0.83, P<0.001 respectively).

However, perhaps because of the limited number of subjects, delta body mass was not significantly correlated with delta total energy intake, delta fat, or delta CHO oxidation (r=0.47, r=0.18, and r=0.17 respectively). Delta body fat was also not significantly correlated to Δ fat or Δ CHO oxidation (r=0.46 and r=0.38 respectively), and delta total energy intake was not significantly correlated with Δ CHO (r=0.52).

Discussion

This is the first study that has assessed the effects of Ramadan upon the exercise metabolism of athletes. The data show an increase in lipid oxidation during a bout of progressive submaximal exercise, and a decrease of body mass, BMI and body fat over the course of the fast. Our metabolic inferences are based on the technique of indirect calorimetry, often exploited to assess the relative usage of fat and carbohydrates from the early days of biochemistry; this approach has previously been applied to both low [15] and high intensity exercise [19,20,21,22]. Potential sources of error in this approach are few, at least during moderate intensity effort. During high-intensity exercise, increased blood lactate concentrations require use of the bicarbonate buffering system to regulate pH; this in turn augments CO2 production, causing a short-term increase of RER that is unrelated to substrate balance, although some authors maintain that even then, the bicarbonate-derived CO2 distorts RER by as little as 1% [23]. During Ramadan, values could also be influenced by an increased usage of protein, which is assumed constant in our calculations.

The intensities of effort were set using Wasserman’s equations [15]; these approximate values of VO2 max and Wmax could be over- or under-estimated in some subjects, and this would modify the cross-over points as reported in our study. However, this methodological problem is minimized because values for the three observation periods are compared within a given subject.

More significant limitations in our design include the absence of a true control group; conceivably, changes in season, diet or training could have influenced findings independently of Ramadan. Since the effects we observed could arise from either energy reduction by fasting or training, despite reduction in the intensity of the latter, further studies are needed to clarify the relative importance of these factors.

Nevertheless, our data appear to confirm our initial hypotheses. Ramadan fasting is associated with a reduction in body mass, BMI and fat mass, and an increased metabolism of lipids during submaximal exercise. Ramadan et al [8] also found an increased fat utilisation during steady state submaximal exercise at 70 % of VO2 max in seven sedentary and six active subjects.

Our subjects continued to train regularly during Ramadan and training procedures may have played a pivotal role in augmenting fat utilization. Many studies have reported that endurance training increases fat oxidation during submaximal exercise, reducing the individual’s dependence on CHO as an energy source [24,25,26]. In the present study, fat oxidation peaked earlier, at 20% of Wmax. Achten and Jeukendrup [26] reported that fat oxidation seems to peak at exercise intensities between 45 and 65% of VO2max. They pointed out a relatively large inter-individual variation in maximal fat oxidation even within a homogeneous group of subjects [27]. Venables et al. [28] suggested that exercise intensity plays a major role in the regulation of fat oxidation and that body composition, physical activity level, and training status are secondary factors. The interindividual variation in fat oxidation remains largely unexplained [28]. Fat oxidation is lower in high-intensity exercise than in moderate-intensity exercise, in part because of decreased fatty acid delivery to exercising muscles, and in part because of a reduced availability of oxygen in the active tissues. The relative use of adipose and intramuscular triacylglycerols during exercise depends, in

Figure 3
Lipid oxidation during submaximal exercise before Ramadan (control), at the beginning (Beg-R), and at the end (End-R) of Ramadan. * Significantly different from before Ramadan (control compared with end-R), P<0.001.
large part, on the degree of fitness of the subject and the intensity of exercise. At the same absolute intensity of exercise, endurance trained subjects oxidize more fat without increased lipolysis. Training-induced increases in fat oxidation are due primarily to increased oxidation of non-plasma-derived fatty acids, perhaps from intramuscular triacylglycerol stores [29].

In our study, total fat intake was significantly higher during Ramadan than during the preceding control period. Fatty meals have been suggested as a way to increase fat oxidation [26]. This could certainly contribute to the increased fat oxidation observed during submaximal exercise in Ramadan. Horowitz and Klein [29] reported that fat oxidation increased by 22% when the plasma fatty acids concentration was increased from 0.15 to 0.48 mmol/l. However, because the increase of fat oxidation induced by plasma fatty acids remained less than the fat oxidation seen when fasting, the authors suggested that this was not the only mechanism modifying the rate of fat oxidation.

Venables et al. [33] showed that lean body mass, estimated physical activity level, VO2max, sex, and fat mass together accounted for only 34% of the variance in peak fat oxidation rates. Dietary restriction could explain some of the remaining variance. We found that the decrease in total energy intake was correlated with Δ fat mass and Δ fat oxidation (r=0.69, P<0.05, and r=0.83, P<0.001 respectively).

Our study showed also that the rate of CHO oxidation at the cross-over point did not change significantly during Ramadan fasting. (0.18±0.001, 0.15±0.002 and 0.19±0.002 mg/ kg per [watt.min] before, Beg-R and End-R respectively, NS). Aloulou et al. [34] reported a mean value of 0.22±0.001 mg/ kg per [watt.min] (0.16-0.29). High values were observed in subjects with (hypoglycemic) disorders. Ramadan fasting modified metabolism, by increasing the cross-over point and the Lipox max. The change in substrate utilisation seems confirmed by the decrease of body mass, BMI and body fat at the end of Ramadan [35,36]. From the viewpoint of preventive medicine, the data suggest that the month of fasting had a number of positive effects that could contribute to the prevention and/or management of obesity.

The extent of lipid oxidation depends in part on the availability of carbohydrate-derived energy and/or fatty acids reserves. During End-Ramadan fasting, carbohydrate reserves are likely to be reduced, predisposing to preferential use of lipids by the skeletal muscle. However, as in the study of Roky et al. [7], we saw no change in plasma glucose concentrations over the course of Ramadan. Plasma glucose concentration is normally maintained within a narrow range despite wide variations in glucose flux, a homeostatic feat accomplished by hormonal (essentially the insulin hormone), neural (norepinephrine and epinephrine) and substrate glucoregulatory factors (fatty acids limit glucose oxidation). We found a reduction of total daily energy intake, whereas the total fat intake was significantly higher during Ramadan compared to the control period. The higher lipid oxidation during Ramadan could be related to the increased fatty acids intake.
Glycogenolysis and gluconeogenesis may be the predominant sources of glucose after fasting (night fast and 24 h of fasting respectively). After prolonged fasting (40 d), ketones account for an important proportion of the energy used by the skeletal muscle and even the brain [37]. Other factors such as the physical fitness level of the subjects [22], the training effects of moderate aerobic exercise [15,24], and limitations of muscle blood flow by fast-induced dehydration (table II) may play secondary roles in determining increased fat usage in spite of the unchanged plasma glucose concentration. Our subjects consumed an increased proportion of fat in an attempt to accommodate their training programme to two rather than three meals per day.

Fluid intake also decreased during Ramadan, as confirmed by the haematological measurements and the fall in plasma volume. Bigard et al. [36] also showed increases in hematocrit and haemoglobin values and a 7% reduction of plasma volume at the end of Ramadan. Reduced fluid intake leads to other changes, such as a reduction of the urine volume, sodium, potassium and total solute excretion and an increase of urinary osmolality [38,39]. Dehydration could contribute to the reduction of the body mass. In agreement with our study, Swislo et al. [40] found substantial dehydration, with a significant reduction of body mass, and fat mass, but no change of fat-free mass during Ramadan.

Changes in hematocrit and plasma volume may impact substrate metabolism, influencing growth hormone release and lactate response during exercise. We found significant increases of plasma GH concentrations after exercise, but values did not differ between the three conditions (unpublished data). Fasting and dehydration probably have differential effects on GH, food restriction reducing GH release, and dehydration resulting in hemoconcentration with an increase of GH accentuated by exercise.

Achten and Jeukendrup [26] found that decreased fat oxidation rates were linked to both lactate and hydrogen ions. The first substantial rise of lactate concentration was seen at 10.2 ± 0.8 mmol in the euhydrated condition. However, Roy et al. [42] reported that hyponatremia had no effect on rates of whole body lipolysis or total CHO or fat oxidation in 10 males studied during 60 min of cycling exercise at 61% of \( V\text{O}_2\) max.

From the viewpoint of training and athletic performance, the fluid deprivation of Ramadan probably has greater significance than the shift to fat metabolism, and indeed in hot climates fluid lack would make it quite dangerous for an athlete to undertake prolonged aerobic activity. Nevertheless, to the extent that the metabolic shift reflects a reduction of carbohydrate stores, rugby players and other athletes will have a lesser ability to undertake anaerobic activities, whether short sprints or the physical efforts of the scrum.

Further research is needed on these issues, using a larger sample of subjects, measuring fluid intake as well as fluid loss, making observations after the completion of the four-week fast, and if possible recruiting a parallel sample of subjects who choose not to follow the dietary requirements of Ramadan.

Nevertheless, two immediate conclusions can be drawn. Ramadan fasting increases the lipid oxidation of trained athletes both at rest and during submaximal exercise. The increased fat utilisation is accompanied by decreases in body mass and body fat content. Additional studies are needed to delineate the relative contributions of dietary restriction and associated changes in training to the observed metabolic changes.

Acknowledgements – We thank the coach Baya D. and the subjects for their participation in this study. This study was supported by the minister of Scientist Research of Tunisia.

References