Limited Benefit of Fat_max-Test to Derive Training Prescriptions

S. Schwindling, F. Scharhag-Rosenberger, W. Kindermann, T. Meyer

Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany
Heidelberg University Hospital, National Center for Tumor Diseases, Heidelberg, Germany

Key words
fat metabolism
fat oxidation
indirect calorimetry
intensity
cycling
training

Abstract

The intensity that elicits maximal fat oxidation (Fat_max) is recommended for training fat metabolism. However, it remains unclear whether Fat_max leads to the highest fat oxidation rates during prolonged exercise. It was hypothesized that there are no differences in fat oxidation rates among 3 different exercise intensities. Therefore, fat metabolism was compared among 1-h constant load tests at Fat_max a higher and a lower intensity. A cohort of 16 male cyclists (28 ± 6 yrs, BMI: 22.5 ± 1.2 kg/m²; n = 8 with maximal oxygen uptake [VO2max] of 50–60 ml/min/kg [ET]; n = 8 with VO2max>60 ml/min/kg [HET]) completed a maximal incremental cycling test, a submaximal incremental Fat_max-test and, thereafter, three 1-h constant-load tests in randomized order at Fat_max, one exercise stage below (LOW) and one above (HIGH). LOW, Fat_max and HIGH were performed at 52 ± 13, 60 ± 13 and 70 ± 12% VO2max. Heart rate and blood lactate were significantly different (p < 0.001). However, the fat oxidation rate showed no difference (p = 0.61). In conclusion, the fat oxidation rate of endurance trained cyclists shows no difference between 1-h constant load exercise bouts at about 50–70% VO2max. The precision and necessity of Fat_max-tests for controlling the training of fat oxidation are therefore debatable.

Introduction

Enhancing and maximizing fat oxidation is a common training goal in elite and recreational sports. It has been speculated that high fat oxidation rates during exercise might be beneficial for different reasons such as prevention of weight gain for health purposes and carbohydrate sparing during long term endurance competitions such as cycling or running marathons [26]. It is well documented that fat oxidation rises with increasing exercise duration. Prolonged training sessions are therefore performed to enhance fat metabolism [16]. However, the choice of the optimal intensity remains debatable.

When exercise intensity increases, there is a decrease in the relative contribution of fat metabolism. In absolute terms, fat oxidation rates increase from low to moderate intensities and then decline at higher intensities [20]. The exercise intensity that elicits the maximum fat oxidation rate (MFO) has been termed “Fat_max” [1]. Venables and Jeukendrup [24] demonstrated that a continuous training program at Fat_max is superior to a moderate intensity interval training program in increasing fat oxidation rates in obese adults. Therefore, in order to improve MFO, training at Fat_max has been recommended.

To determine Fat_max, incremental exercise tests with long stage durations and small increments in work rate have been used. To determine the validation of such Fat_max tests, an incremental exercise test was compared to 4–6 continuous prolonged exercise tests at constant work rates, corresponding to the work rates of the incremental exercise test [1]. Analysis revealed no significant difference in fat oxidation rate between Fat_max in the Fat_max test and the respective constant load test. Therefore, the authors concluded that Fat_max tests allow valid determination of Fat_max [1]. However, the fat oxidation rates in the constant load test were not compared to each other. Fat oxidation rates are similar over a relatively wide range of exercise intensities around Fat_max. Therefore, there might be no difference in fat oxidation rates during prolonged training sessions at common intensities below or above Fat_max. The necessity of determining Fat_max for training prescription and, consequently, the external validity of Fat_max tests remains debatable.
With the latter considerations in mind, Meyer et al. [15] recently determined Fat max using a sub maximal exercise protocol with 5 stages of 6 min each. To address the external validity of this Fat max-test, the present study examined the relationship between the fat oxidation rates during 3-1 h constant load tests at the intensities of Fat max, one Fat max-test stage below Fat max (LOW) and one stage above Fat max (HIGH). It was hypothesized that there are no differences in fat oxidation rate among the 3 exercise intensities. Furthermore, to consider potential effects of endurance capacity on fat metabolism, 2 subject subgroups of sub-elite endurance trained and highly endurance trained subjects were observed, and it was also hypothesized that while there are no differences of fat metabolism in each subgroup, there is a higher absolute fat metabolism among the highly endurance trained subjects.

### Methods

#### Subjects

16 healthy male cyclists (age: 28 ± 6 yrs, height: 183 ± 7 cm, mass: 75 ± 7 kg, BMI: 22.5 ± 1.2 kg/m²) participated in the study. Half of the subjects were endurance trained (ET, n = 8) with a VO₂ max between 50 and 60 ml/min/kg (age: 31 ± 7 yrs, height: 183 ± 10 cm, mass: 78 ± 10 kg) and the other half was highly endurance trained (HET, n = 8) with a VO₂ max > 60 ml/min/kg (age: 25 ± 3 yrs, height: 183 ± 3 cm, mass: 73 ± 2 kg). Their performance data are given in Table 1. Study design and employed procedures are in accordance with ethical standards and the Declaration of Helsinki. The study was approved by the local ethics committee (Ärztekammer des Saarlandes, Saarbrücken, Germany). Each subject was fully informed about the risks and stresses associated with study participation and gave written informed consent before the start of the study. This study thus meets the ethical standards of the International Journal of Sports Medicine [10].

#### General design

Subjects performed one maximal incremental cycling test, followed by one submaximal Fat max-test and 3 constant-load tests of 1-h duration conducted in randomized order. For each subject, all tests were performed in the morning at the same time. Between the incremental test and the Fat max-test, there was a minimum of 2 days of rest, and between the other tests a minimum of 1 day of rest. All tests were performed within a maximum of 5 weeks. To improve transferability of the results to real life conditions, all tests were performed in a standardized nutritional state. Therefore, to avoid muscle glycogen depletion, the nutrition on the day before each test was carbohydrate-rich, and subjects kept the nutritional intake individually standardized before all tests. The breakfast and the time of breakfast were kept precisely the same for each subject before each test by means of a nutritional recall protocol [11]. Furthermore, subjects avoided intense or long-lasting exercise (>90 min) on the day before each test (controlled by a training diary). In summary, each subject performed all of his tests under individual but equal conditions of training and nutrition. All tests were performed on the same ergometer (Lode Excalibur Supersport, Groningen, Netherlands) with standardized adjustments of saddle and handle bars. Ambulatory gas exchange measurements were constantly conducted during all tests with the same metabolic device (Meta Max II, Cortex, Leipzig, Germany, mixing chamber system).

#### Maximal incremental cycling test

The maximal incremental cycling test was performed to individually derive exercise stages for the Fat max test. It started at 100 or 150 W, depending on body weight and training history. The stage increment was 50 W and the stage duration 3 min. Capillary blood samples were taken from the hyperemic earlobe at rest, at the end of each stage and 1, 3, 5, 7 and 10 min post-exercise to determine blood lactate concentration (bLa, enzymatic-amperometric method, Greiner, Flacht, Germany). From the resulting lactate vs. workload curve, the work rate corresponding to the first increase in bLa was visually derived. Furthermore, the individual anaerobic threshold (IAT) [23] was assessed by means of a computer program (H. Heck, Bochum, Germany). Gas-exchange measurements were carried out continuously throughout the test. The work rate corresponding to a respiratory exchange ratio (RER) of 1.00 was determined as the first work rate with RER ≥1.00 over a minimum of 30 s. VO₂ max was defined as the highest average oxygen uptake over 30 s during the incremental test. Maximal heart rate (HR max, taken from an ECG) and maximal bLa (bLa max) served as criteria for the degree of effort. All subjects met the following requirements for exhaustion: HR max >200 – age and bLa max >8 mmol/L [9].

#### Fat max-test

The Fat max-test consisted of 5 incremental stages with 6 min stage duration to ensure steady states for the gas exchange variables [13,25]. The lowest stage was chosen as the power output corresponding to the first increase in bLa and the highest (fifth) stage represented the work rate at RER=1.00 in the maximal incremental cycling test. The other 3 stages were calculated to reach equal increments in power output for all 5 stages (min-max: 30–50W). This exercise protocol was adopted from previous studies that successfully determined Fat max by a similar procedure in different populations [7,14]. HR was recorded telemetrically (Polar, Kempele, Finland) and evaluated at the end of each stage. Furthermore, capillary blood samples were taken at the end of each stage, and the highest bLa in the test defined as bLa peak. Gas-exchange measurements were carried out continuously throughout the test.

#### Constant-load tests

The three 1-h constant-load tests were conducted in randomized order. The work rate was set equal to Fat max, one exercise stage below Fat max in the Fat max-test (LOW) and one above (HIGH). HR and gas-exchange measurements were carried out.
Lactate measurements were taken at rest and every 15 min during exercise.

Calculation of fat oxidation rates
Calibration of the respiratory gas analysis system was carried out according to the manufacturer’s instructions by means of a 3 l syringe, ambient air (21% O₂, 0.04% CO₂) and a gas of known concentration (12% O₂, 5% CO₂). Absolute rates of fat oxidation were calculated from mean VO₂ and VCO₂ readings for 30 s intervals at the end of each stage in the Fat max-test and for the complete time in the constant load tests by using the formula of Jeukendrup and Wallis [12]: fat oxidation rate [g/min] = 1.695 × VO₂ − 1.701 × VCO₂. Individual Fat max was determined as the stage with the highest fat oxidation rate (MFO).

Statistics
The statistical analyses were performed using the software Statistica 6.1 (StatSoft Inc., Tulsa, OK, USA). Normal distribution of the dependent variables was documented using the Shapiro-Wilks-Test. Except for the fat oxidation rates in the Fat max-test and the fat oxidation rates within the subgroups in the constant load tests, all data were normally distributed. All data are given as means ± standard deviation (SD). The difference of the performance data between the 2 subgroups in the maximal incremental cycling test and at Fat max was tested with a Student’s t-test. The difference of MFO between the 2 subgroups in the Fat max-test was calculated using a Mann-Whitney-U-test. ANOVA for repeated measures served to test for differences among the 3 constant-load tests as well as for differences in fat oxidation rates among Fat max, the exercise stage above and the exercise stage below in the Fat max-test. A 2-way ANOVA (factor 1: group, factor 2: test) was applied to test for differences in the constant load tests between the 2 subgroups. Post-hoc analyses were carried out using Scheffé’s test. Furthermore, a Friedman-ANOVA was used to test the differences in fat metabolism among the 3 constant load-tests for each subgroup. The level of statistical significance was set at an α error of p < 0.05.

Results

Fat max-test
The starting load of the Fat max-test was 141 ± 62 W (min – max: 50–240 W) and the mean increment was 38 ± 7 W (min – max: 30–50 W). The mean HR ranged between 65 ± 10 % on the first and 91 ± 6 % of HR max on the fifth stage. bLa increased exponentially from 1.0 ± 0.3 mmol/l at stage 1 to 5.2 ± 1.8 mmol/l at stage 5, ensuring the submaximal nature of the Fat max-test. Fig. 1 shows the course of HR, VO₂, respiratory exchange ratio (RER) and fat oxidation rate in the Fat max-test. Fat max was derived from this test as the stage with the highest fat oxidation rate (MFO).

Constant-load tests
Table 3 shows the performance and physiological data of the 3 constant load tests. Work rate, exercise intensity, HR and VO₂ were significantly higher in HIGH compared to Fat max (p < 0.001) and Fat max compared to LOW (p < 0.001). bLa was significantly different between HIGH and Fat max (p < 0.001), but not between...
fat oxidation [% of total EE]  29 ± 9  25 ± 7  32 ± 10

Table 2: Performance data at the intensity of maximal fat oxidation rate (Fat max) for all subjects and the subgroups of endurance trained (ET) and highly endurance trained subjects (HET, means ± SD). Asterisks indicate significant differences between ET and HET. IAT: individual anaerobic threshold, VO 2max: maximal oxygen uptake, HR: heart rate, bLa: blood lactate concentration, VO 2: oxygen consumption, RER: respiratory exchange ratio.

### LOW Fat max HIGH

| Exercise stage | 2.6 ± 0.5 | 2.5 ± 0.5 | 2.8 ± 0.5 |
| Work rate [W/kg] | 2.8 ± 0.9 | 2.2 ± 0.7* | 3.3 ± 0.9* |
| Intensity [% IAT] | 78 ± 17 | 72 ± 18 | 83 ± 15 |
| Intensity [% VO 2max] | 60 ± 13 | 55 ± 14 | 64 ± 12 |
| HR [min] | 147 ± 24 | 134 ± 22* | 160 ± 20* |
| MFO [g/min] | 0.44 ± 0.20 | 0.32 ± 0.07* | 0.55 ± 0.22* |


The relative contribution of fat oxidation to total energy expenditure is displayed in Fig. 2b. It was signiﬁcantly higher in LOW compared to HIGH (p<0.01), but no differences were observed between LOW and Fat max (p=0.15) or HIGH and Fat max (p=0.25). Within ET, the relative contribution of fat metabolism was not signiﬁcantly different among the 3 constant load–tests (p=0.31). Within HET, the relative contribution of fat metabolism was signiﬁcantly different between LOW and HIGH (p<0.01), but not between LOW and Fat max (p=0.16) or HIGH and Fat max (p=0.27).

Fig. 2 Fat oxidation rate a and percentage of total energy expenditure (EE) b in the Fat max–test and the 3 constant load tests for all subjects and the subgroups of endurance trained (ET) and highly endurance trained subjects (HET, means ± SD). Diamonds indicate signiﬁcant differences between ET and HET. Asterisks indicate signiﬁcant differences between LOW, Fat max, and HIGH.

Discussion

Although theoretically compelling, it has never been investigated whether Fat max actually leads to the highest fat metabolism rates during prolonged exercise. To clarify this, fat oxidation rates were compared among 3 different 1–h constant load tests: Fat max, LOW and HIGH. Fat metabolism of endurance trained and highly endurance trained cyclists was similar among these exercise bouts between about 50 and 70% of VO 2max, although the
intensities differed significantly in HR, bLa, percentage of VO\textsubscript{2,max} and percentage of IAT. Similarly, close examination of Achten et al.'s [1] results reveals that although the mean Fat\textsubscript{max} intensity was higher than the neighboring intensities, there was rarely a relevant difference between them. These results would suggest that the choice of a particular intensity within the range is not clearly preferable to others when maximal fat oxidation is intended.

In the Fat\textsubscript{max}-Test, fat oxidation rates were significantly different between Fat\textsubscript{max} and the next higher exercise stage and tended to be different among the exercise stages below and above Fat\textsubscript{max}. It might therefore be expected that fat oxidation rate would also differ between the constant load tests performed at the same work rates. However, no differences were observed. The stage duration in the Fat\textsubscript{max} test was set at 6 min to ensure steady states in the gas exchange variables. This is especially important for the RER, which decreases at the onset of exercise due to a transient increase in endogenous CO\textsubscript{2} stores. This phenomenon, which skews the assessment of fat metabolism by means of indirect calorimetry, can last up to approximately 3 min after the onset of exercise [8]. Since the last 30 s of the 6 min exercise stages were evaluated in the present study, disturbances in the determination of fat metabolism can be excluded. Another potential problem of incremental exercise tests is that the substrate oxidation at higher exercise stages might be affected by the previously performed exercise intensities. However, Achten et al. [1] and Rieu et al. [19] demonstrated that this carry-over effect does not affect Fat\textsubscript{max} and the gas exchange parameters needed to calculate Fat\textsubscript{max} in incremental exercise tests, respectively.

Both working groups compared stepwise incremental exercise tests to separate constant load tests of the same duration in the Fat\textsubscript{max} test was set at 6 min to ensure steady states in the gas exchange variables. This is especially important for the RER, which decreases at the onset of exercise due to a transient increase in endogenous CO\textsubscript{2} stores. This phenomenon, which skews the assessment of fat metabolism by means of indirect calorimetry, can last up to approximately 3 min after the onset of exercise [8]. Since the last 30 s of the 6 min exercise stages were evaluated in the present study, disturbances in the determination of fat metabolism can be excluded. Another potential problem of incremental exercise tests is that the substrate oxidation at higher exercise stages might be affected by the previously performed exercise intensities. However, Achten et al. [1] and Rieu et al. [19] demonstrated that this carry-over effect does not affect Fat\textsubscript{max} and the gas exchange parameters needed to calculate Fat\textsubscript{max} in incremental exercise tests, respectively. Both working groups compared stepwise incremental exercise tests to separate constant load tests of the same duration as the stages of the incremental test and did not find relevant differences. Therefore, it appears unlikely that carry-over effects impacted the results of the present study.

During constant load exercise, the calculation of substrate utilization by means of indirect calorimetry is correct as long as there are lactate steady-state conditions [12]. If the lactate steady-state is defined as no more than 1 mmol/l increase in bLa between the 10\textsuperscript{th} and 30\textsuperscript{th} minute of exercise [5], 3 subjects were not in a lactate steady-state in the constant load test at Fat\textsubscript{max} and five were not in a lactate steady state in the HIGH test. In this case, non-metabolic CO\textsubscript{2} comes up through the buffering of hydrogen-ions, affects RER and, therewith, the calculated fat oxidation rate. However, Romijn et al. [20] stated that indirect calorimetry can be used to accurately determine fat and carbohydrate oxidation rates up to exercise intensities of 80–85% VO\textsubscript{2,max}. Similarly, Jeukendrup and Wallis [12] named 75% VO\textsubscript{2,max} as the upper limit for calculations of the fat oxidation rate. The intensity of the HIGH test in the present study averaged 70% VO\textsubscript{2,max}, which is below this threshold and indicates that the calculated fat oxidation rates were presumably correct.

Previous investigations on constant load exercise tests reported decreases in RER over time [6,16]. These increases in fat metabolism are commonly attributed to decreasing glycogen stores and carbohydrate availability, respectively. In the present study, initial glycogen depletion might have driven fat oxidation rates to maximal or nearly maximal levels in all 3 constant load tests. In fact, the fat oxidation rates in the constant load tests were nearly as high as or even higher than MFO assessed in the Fat\textsubscript{max} test. This argues in favor of nearly maximal fat metabolism during all constant load tests and might explain why no differences were observed among these tests while there were differences in fat metabolism among the stages of the Fat\textsubscript{max}-test.

Although fat provides more energy per gram than carbohydrates, fat oxidation requires more oxygen. The energy yield from fat is 5.6 ATP molecules per oxygen molecule used, compared to carbohydrates' yield of 6.3 ATP molecules. Since oxygen delivery is limited, carbohydrates are the preferred substrate during high-intensity exercise. Furthermore, the maximum rate of high-energy phosphate formation from lipid oxidation is too low to match the rate of utilization of high-energy phosphate during higher-intensity exercise [26]. For these reasons, the fat oxidation rate increases from low to moderate exercise intensities to its maximum and then decreases at higher exercise intensities [20]. Within a range of exercise intensities around Fat\textsubscript{max}, where the fat oxidation rate plateaus in the Fat\textsubscript{max} test, differences in energy expenditure during constant load exercise seem to be covered by different carbohydrate oxidation rates.

None of the subjects in the present study performed specific training sessions to improve their fat metabolism. The HET group showed a higher MFO which occurred at a higher work rate compared to the ET group. The relative contribution of fat oxidation to total energy expenditure was not different between the groups. These findings are in accordance with the results of previous studies. For example, Achten and Jeukendrup [4] reported a difference in MFO between subject subgroups of lower and higher VO\textsubscript{2,max} (MFO: 0.48 ± 0.15 vs. 0.56 ± 0.14 g/min).

The maximal fat oxidation rate was significantly correlated with VO\textsubscript{2,max}. It therefore seems that common endurance training, which was reported to be of higher intensity and longer duration in the HET group compared to the ET group, enhances fat metabolism.

Nevertheless, the question of the most effective training intensity to enhance fat metabolism remains open. Venables and Jeukendrup [24] demonstrated in a longitudinal study that continuous endurance training at Fat\textsubscript{max} increases fat oxidation rate, whereas an eucaloric extensive interval training program does not. Their study investigated 8 sedentary, obese males. Similar studies in trained or highly trained athletes have not been published yet. Furthermore, different intensities for continuous endurance training programs have not yet been compared in longitudinal study designs. The present data suggest that continuous training programs of explicitly different intensities (50–70% VO\textsubscript{2,max}) might have similar effects on fat metabolism. However, training studies are needed to prove this assumption.

Compared to low training intensities, high intensities have the advantage of a higher energy expenditure during exercise as well as in the recovery phase [18]. Lower intensities, on the other hand, enable longer training durations, which are associated with an increasing contribution of fat metabolism to energy expenditure [16]. A previous investigation on running 8000 m fast or slow revealed no significant difference in the absolute amount of fat being metabolized (26 ± 2 vs. 20 ± 5 g at about 55 vs. 80% VO\textsubscript{2,max}) [22]. At least in terms of the amount of oxidized fat, the distance covered might therefore be more important than the exercise intensity.

Due to the laboratory conditions in the present study, the variability in fat metabolism was lower than under real-life training conditions. Even under these standardized conditions, there were no differences in fat oxidation among the constant load exercise tests. It can be assumed that a considerably higher variability of fat metabolism occurs in everyday life due to different nutritional intake prior to the training sessions and diurnal vari-
ation, which further reduces the effect of exercise intensity. However, other strategies such as the modification of pre-exercise nutrition [3] or the duration of the training sessions [16] might have a impact on fat metabolism.

In this study, Fat_{max} occurred at 61 % V0_{2max} on average, which is in agreement with other investigations locating Fat_{max} between 60–64 % V0_{2max} [1, 2, 15, 17, 21]. In contrast to most of the other studies, the tests in the present study were not performed in a fasting state. Therefore, the MFO of 0.44 g/min was slightly lower than the previously reported MFO of 0.47–0.60 g/min [1, 2]. Investigating subjects in fasting state results in better internal validity, yet the transferability to real life training conditions is limited. Subjects were therefore tested after a standardized breakfast in the present study.

**Conclusion**

No differences in fat oxidation rates were found between Fat_{max} and 2 neighboring work rates covering about 50–70 % V0_{2max} or 60–90 % of individual anaerobic threshold. These results suggest that the choice of training intensities for constant load training has no relevant influence on the fat oxidation rate and, thus, the workload can be selected on the basis of other criteria. Especially in daily life’s training, the influence of factors other than exercise intensity might be more important for the amount of fat being metabolized (e.g. the pre-exercise nutrition or training duration). Altogether, the necessity of Fat_{max}-tests for selecting the intensity of fat oxidation training is debatable.

**References**