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# Maximal Lipid Oxidation ($Fat_{max}$) in Physical Exercise and Training: A review and Update

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## ABSTRACT

The exercise intensity, at which the maximal fat oxidation (MFO) rate occurs, has been defined as $Fat_{max}$. It has been suggested that the fat oxidation rate during the $Fat_{max}$ intensity is approximately 2-fold greater than at any other intensity although modifiable by several physiological conditions (training, previous exercise or meal). There are a few standardized protocols for estimating of $Fat_{max}$. The most common tests include: Cycle Ergometer (CE) and Treadmill (TM). Reviewing of tables of the study appoint that the extent of weight or fat loss in response to exercise training varies among individuals.

**KEY WORDS:** ***Maximal Fat Oxidation, Fatmax, Cycle Ergometer, Treadmill.***

## INTRODUCTION

The exercise intensity that causes the highest rate of fat oxidation is referred to as the 'maximal fat oxidation rate' ($Fat_{max}$) intensity (1). It is possible to reproduce measurements of $Fat_{max}$ using graded exercise calorimetry (2). This approach can be used to predict the quantity of lipid that will be metabolized during exercise. It has been suggested that the fat oxidation rate during the $Fat_{max}$ intensity is approximately 2-fold greater than at any other intensity (3).

Thus, the $Fat_{max}$ intensity is recommended to maximize the beneficial effects of exercise and weight management.

Below 25% of $VO_{2max}$, fat has been reported to be the major energy supply for the muscle. Above this level, glycogen will rapidly become the predominant fuel, but fat oxidation will still increase until the Lipoxmax/Fat(ox)max is reached. Above this level, it decreases. The reasons for this decrease are not completely understood. Theoretically, lipid supply by lipolysis, lipid entrance in muscle cell, lipid entrance in mitochondria, and mitochondrial fat processing may all be limiting steps. Experiments show that extracellular lipid supply is not limiting, since lipid oxidation decreases even if additional fat is provided to the cell.

Limiting steps seem to be the entrance in mitochondria, governed by CPT-1, which can be inhibited by Malonyl-CoA and lactate (4), and possibly downstream CPT-I other mitochondrial enzymes such as Acyl-CoA synthase and electron transport chain. All these steps are sensitive to the rate of CHO oxidation and thus, a rise in CHO oxidation seems to depress lipid oxidation despite availability of fat and presence of all the enzymes of fat oxidation. Conversely, there is a wide body of evidence that glycogen

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depletion reverses this inhibition and thus increases fat oxidation, as observed during long duration glycogen-depleting exercise.

The maximum fat oxidation rate is defined by genetics, exercise habits, exercise type, degree of obesity and type of obesity (visceral fat or subcutaneous fat). Furthermore, the total fat oxidation rate in terms of exercise (total fat oxidation rate during exercise + post-exercise recovery period) may vary according to exercise intensity, exercise period (length of exercise), meal intake (on an empty stomach or after a meal) and meal content (percentage of fat or carbohydrates in the meal) before the exercise.

Variations in maximum fat oxidation rate, according to the presence of exercise habit and type of exercise, have been reported by the authors (5).

## MATERIALS AND METHODS

### *Measurement of fat oxidation rate*

Formulae for the fat oxidation rate and carbohydrate oxidation rate have been created by experimental means for more than 100 years.

Fat oxidation rate (mg/min) = 1.695 × oxygen uptake (l/ min) − 1.701 × carbon dioxide output (l/min)

Carbohydrate oxidation rate (mg/min) = 4.585 × carbon dioxide output (l/min) − 3.226 × oxygen uptake (l/min)

These formulae can be used to ascertain the fat oxidation rate with a device analysing expired gas, or by entering measurements of oxygen uptake and production of carbon dioxide into the formula.

### *FATMAX test protocol*

There are a few standardized protocols for estimating of Fat$_{max}$. The most common tests include: Cycle Ergometer (CE) and Treadmill (TM)

### *Cycle Ergometer (CE)*

For this protocol all participants should complete a FATMAX test (6) during the preliminary trial to establish maximal oxygen uptake ($VO_2$max). In more detail, the test protocol generally involves a 5 min warm up at 75 W on an electronically braked cycle ergometer. The test started at 95 W, every 3 min the effort increase in incremental steps of 35 W, until voluntary exhaustion reached. During each stage of the test respiratory gas measurements ($VO_2$ and $VCO_2$) should be collected using an Gas Analyzer. Test stop if 2 out of the 4 following criteria met. 1) if VO2 do not increase even when workload increase (< 2 mL· kg-1·min-1 increase from the previous stage) 2) a respiratory exchange ratio (RER) of >1.05 3) a heart rate within 10 beats per min of age predicted maximal heart rate 4) a cadence of 50 rpm cannot be maintained. Heart rate (HR) should record during each stage of the test using a HR monitor (Table 1).

**Table1.** Studies at the Fat$_{max}$ with CE protocol currently available.

| | Author | year | Exercise mode | subject | Fat$_{max}$ | MFO (maximal fat oxidation) rate |
|---|---|---|---|---|---|---|
| 1 | X Chenevie`re et al. (7) | 2009 | CE | 32 healthy volunteers men trained versus an untrained | trained 58.3% VO2max<br>untrained 29.4% VO2max | trained 0.72 g.min-1<br>untrained 0.32 g.min-1 |
| 2 | J Achten et al. (6) | 2002 | CE | 18 moderately trained cyclists | 61 ±3 VO2max<br>72 ±2 HRmax | CE$_{average}$: 0.66 ±0.06 g.min-1<br>CE: 0.69 ± 0.06 g.min-1 |
| 3 | U Andersson Hall et al. (8) | 2015 | CE | elite cyclists and triathletes | CON: 55 ± 2 VO2max<br>EXER: 62 ± 1 VO2max<br>FAST: 62 ± 2 VO2max | CON: 0.51 ± 0.04 g.min-1<br>EXER: 0.89 ± 0.05 g.min-1<br>FAST: 0.69 ± 0.04 g.min-1<br>CON : submaximal incremental<br>EXER: two repetitions of 20 min cycling |

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|---|---|---|---|---|---|---|
| | | | | | | and 10 min rowing) at 75% of VO2max. Fast: overnight fast+ submaximal incremental |
| 4 | I Croci et al. (9) | 2014 | CE | 24 male recreationally trained : high fatness group low fatness group | Low fatness: 46.7 ± 8.6 VO2ma 65.9 ± 4.9 HRmax High fatness: 45.4 ± 7.2 VO2max 62.2 ± 6.4 HRmax | Low fatness: 0.38 ± 0.19 g.min-1 High fatness: 0.42 ± 0.16 g.min-1 |
| 5 | EM Støa et al. (10) | 2015 | CE | 9 healthy moderately trained females | | High Fat: 0.42±0.14 g.min-1 High CHO: 0.29±0.13 g.min-1 |
| 6 | MH Suk et al. (11) | 2015 | CE | T2DM group (12 women) and a control group (12 women). | | T2DM group: 0.39 g/min Control:0.58 g/min |
| 7 | H Mohebbi et al. (12) | 2015 | CE | Nine healthy overweight males | - | - |
| 8 | K Iwayama et al. (13) | 2015 | CE | Ten young healthy men | Fat oxidation was maximal at am | |
| 9 | F Besnier et al. (14) | 2015 | CE | 136 non-diabetic obese | | G1:151.6 ± 36.7 mg/min G2:143.9 ± 38.4 mg/min G3:164.6 ± 50.6 mg/min G1: MFO intensity; G2: 60% of VO2-peak intensity; G3: free moderate-intensity |
| 10 | G Jabbour et al. (15) | 2014 | upright CE | 39 pre-pubertal girls 37 pubertal girls | Lipid contribution (mg $min^1$ $FFM^1$) 25W: 7.6 50W(3min): 5.6 50W(3min): 5.2 50W(3min): 5.5 75W: 1 In OB pubertal group was highest | |
| 11 | S Lanzi et al.(16) | 2014 | CE | Sixteen L and 16 O men | L (lean): 54% $vo_2$peak O( obese ): 42% $vo_2$peak | L (lean): 0.32 g.min-1 O( obese ): 0.42 g.min-1 |
| 12 | I Croci et al. (17) | 2014 | CE | Fifteen healthy, moderately trained male volunteers | | 45 g/min at Wmax57.5% |
| 13 | J Abildgaard et al. (18) | 2013 | CE | Forty-one healthy women [premenopausal (*n* = 19), perimenopausal ( *n* =8), and postmenopausal ( *n* =14)] | | Pre: 0.31 0.03 g/min Post:0.21 0.07 g/min |
| 14 | S Schwindling et al. (19) | 2014 | CE | 16 male cyclists | | endurance trained: 0.32 ± 0.07 g/min highly endurance trained subjects: 0.55 ± 0.22 g/min |
| 15 | Tsujimoto et al. (20) | 2012 | CE | middle-aged obese men | Before weight loose: 34 VO2max after weight loose: 42 VO2max | Before weight loose: 224 mg/min after weight loose: 226.7 mg/min |
| 16 | JK Zakrzewski et al. (21) | 2012 | TM vs CE | 22 early pubertal children (9 girls and 13 boys) | Girl: TM 52 VO2peak / 70 HRmax CE 49 VO2peak / 67 HRmax Boy: TM 64 VO2peak/ 79 | Girl: TM 217 mg/min CE 176 mg/min Boy: TM 262 mg/min CE 191 mg/min |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | HRmax<br>CE 53 VO2peak/ 67 HRmax | |
| 17 | S Lanzi et al. (22) | 2012 | CE | severe obese (SO) men (BMI=40) | Group Fat*max* :<br>52.6 ± 2.5 VO2max<br>Group HIT:<br>54.4 ± 2.0 VO2max | Group Fat*max*:<br>3.8 ± 0.2 mg.kg$^{-1}$.min$^{-1}$<br>Group HIT:<br>4.1 ± 0.2 mg.kg$^{-1}$.min$^{-1}$ |
| 18 | C González - Haro et al. (23) | 2011 | CE | 2 groups of male, well-trained endurance<br>Athletes<br>(short-distance triathletes (ST) and<br>road cyclists (RC) | ST: 52 VO2max<br><br>RC: 52 VO2max | ST: 0.4 g/min<br><br>RC: 0.42 g/min |
| 19 | CA Rynders et al.(24) | 2011 | electronically braked bicycle ergometer | A total of 148 untrained adults | - | - |
| 20 | Ben Ounis et al. (25) | 2011 | CE | 22 obese children:<br>12 individuals (six boys and six girls) = trainig<br>and 10 individuals (five boys and five girls) served as controls | | Training:<br>Before 135 mgr/min<br>After 235 mgr/min<br><br>Control:<br>Before 140 mgr/min<br>After 140 mgr/min |
| 21 | L Chu et al. (26) | 2011 | incremental on mechanically braked cycle<br>ergometer | seven obese boys<br>mean age: 11.4 ± 1.0 year | | Control:0.16 ± 0.09 g/min<br>Carbo:0.07 ± 0.01 g/min |
| 22 | Fabien Pillard et al. (27) | 2010 | CE | Ten healthy, sedentary, overweight men (age, 27.9 ± 5.6 years.<br>35, 75% maximal oxygen consumption | | Con:0.125 g/min<br>E35:0.28 g/min<br>E70:0.26 g/min |
| 23 | K Tolfrey et al. (28) | 2010 | CE | Twenty-three adolescents (12 girls and 11 boys) | Boys:<br>39 % VO2peak<br>61 HR peak<br>Girls:<br>32 %VO2peak<br>56% HR peak | Boys: 254 mg/min<br><br>Girls: 190 mg/min |
| 24 | S. Haufe et al. (29) | 2010 | CE | Obese, otherwise healthy men (n = 38) and women (n = 91) | Men: 37 VO2max<br>Women:39 VO2max | |
| 25 | JD Coso et al (30). | 2010 | CE | endurance-trained (TR) (n=10) and untrained<br>(UNTR) subjects exercising (n=10) | TR: achieved at 60% peak oxygen uptake<br><br>UNTR: at 40% peak oxygen uptake | TR:0.41 ± 0.01 g/min<br><br>UNTR:0.28 ± 0.01 g/min |
| 26 | S Bordenave et al. (31) | 2008 | cycle ergometer | Eleven T2D | - | - |
| 27 | J Achten et al. (32) | 2003 | CE | Enduranced trained (55) | 62.5± 9.8 VO2max<br>73± 6.8%HRmax | - |

***Treadmill (TM)***

A standardized protocol should use for all treadmill FATMAX tests. In more detail, the test can start at 5.0 km·h$^{-1}$ and at a gradient of 1% for three min. The speed then increase to 7.5 km·h$^{-1}$. Speed increase by 1 km·h$^{-1}$ every 3 min until an RER of 1 reached thereafter the speed remain constant and the gradient increase by 1% every 1 min until voluntary exhaustion. Respiratory gas measurements (2 and 2) should collect continuously using a Moxus Modular system. Furthermore, HR should measure throughout the whole test and rating of perceived exertion (RPE) record during each stage (Table 2). The final point of test is similar to the previous protocol (CE).

## RESULTS

Lipoxmax values are different and can be modifiable by some factors such as gender (33, 34), puberty (35, 36), Training status (37-39), Obesity (40, 41) and diabetes (42).

Lanzi *et al.* (2014) used Sixteen L (lean) and 16 O (obese) men for their study (16). They reported that subjects (obese men) reached their $Fat_{max}$ point in CE protocol at % 42 $VO_{2peak}$ whereas in Tan *et al.* (2015) study, subjects' s $Fat_{max}$ (Twenty-six obese boys) occurred at %43±11 $VO_2max$ by TM protocol (43). In another study twelve women with T2DM when reached their $Fat_{max}$ by CE protocol, their MFO rate was about 0.29 g/ min (11) while A Cataldo *et al.* (2014) reported that individuals in their study (Fifteen sedentary T2D patients) showed 6.71±0.46 mL/kg/min (MFO rate) at their $Fat_{max}$ point (44).

As well as in Coso *et al.* (2010) study subjects (endurance-trained ) achieved at 60% peak oxygen uptake at their $Fat_{max}$ point with a CE protocol (30) whereas in another study when endurance trained individuals reached their $Fat_{max}$ point with a CE protocol , their VO2max was about 62.5± 9.8 (32) and also Rami *et al.* (2014) when used a TM protocol for their subjects (Active male students ), they observed that subjects achieved their $Fat_{max}$ when their $VO_{2max}$ was about 40.09±2.58 (45).

**Table2: Studies at the Lipoxmax with TM protocol currently available.**

| | Author | year | Exercise mode | subject | Fatmax | MFO (maximal fat oxidation) rate |
|---|---|---|---|---|---|---|
| 1 | J Zakrzewski et al. (46) | 2012 | TM | 12 OW and 15 NO girls | Over Weight : 52 ± 10 VO2max<br>non Over Weight :63 ±12 VO2max | - |
| 2 | M Rami et al. (45) | 2014 | TM | Active male students<br>sedentary male students | Active :40.09±2.58 VO2max<br>56.45±4.33 HRmax<br>Sedentary: 42.72±3.01 VO2max<br>60.09±3.37 HRmax | 0.29±0.03 $g.min^{-1}$<br>0.23±0.02 $g.min^{-1}$ |
| 3 | MC. Venables et al. (39) | 2005 | TM | 300 healthy men and women | 48.3 ± 0.9 VO2max<br>61.5 ± 0.6% HRmax | 7.8 _ 0.13 $(FFM)^{-1}$ $\_min^{-1}$ |
| 4 | S Takagi et al. (47) | 2014 | TM | healthy young men | 43.2 ± 5.7%VO2peak | 0.65 ± 0.12 g.min-1 |
| 5 | M Rami et al. (48) | 2012 | TM | 9 untrained male | 42 ±3 VO2max<br>58±2 HRmax | 0.23 g.min-1 |
| 6 | NA Crisp et al. (49) | 2012 | TM | overweight boys (8–12 years) | 58±2 VO2max | 0.44 g.min-1 |
| 7 | A Mousavian et al. (50) | 2013 | TM | untrained female university students | Morning: 40.92±6.17 g/m<br>Afternoon: 55.83±3.55 g/m<br>Night: 57.19±3.11 g/m | Morning: 0.30±0.051<br>Afternoon: 0.45±0.082<br>Night: 0.44±0.10 |
| 8 | H Darvakh et al. (51) | 2014 | TM | 4Tnon4T9T-athletes9T male students | Morning: 14.92±41.17 ml/kg/m<br>Afternoon 13.83±57.55 ml/kg/m<br>Night: 10.99±56.96 ml/kg/m | Morning:0.056±0.17 g.min-1<br>Afternoon: 0.53±0.17<br>Night: 0.037±0.26 |
| 9 | M Konishi et al.(52) | 2013 | TM | healthy young males | 18.7 ± 0.8 ml/kg/m | |
| 10 | K Iwayama et al. (53) | 2015 | TM | Nine young male endurance athletes | Maxmal :5.5 kcal/min<br>At 7-7.5 am | |
| 11 | SL Robinson et al. (54) | 2015 | TM | 53 young, healthy men | MFO (g/min) was significantly and positively correlated with 24 h fat oxidation (24 h FO, g/d), | |
| 12 | S Tan et al. (43) | 2015 | TM | Twenty-six obese boys and 20 lean boys | Obese boys:<br>Control: 41±10 VO2max<br>Exercise: 43±11 VO2max<br>Lean boys:<br>Control: 52±13 VO2max<br>Exercise: 49±19 VO2max | Obese boys:<br>Control: 0.41±0.18 g/min<br>Exercise: 0.38±0.13 g/min<br>Lean boys:<br>Control: 0.29±0.12 g/min<br>Exercise: 0.32±0.17 g/min |
| 13 | J Wang et al. (55) | 2015 | A graded treadmill walkingerunning test | Thirty women | | Contorl:<br>Rest:0.10 ± 0.04<br>4km/h: 0.32 ± 0.10<br>5km/h: 0.18 ± 0.20<br>Exercise: |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | Rest: 0.07 ± 0.03<br>4km/h: 0.32 ± 0.11<br>5km/h: 0.28 ± 0.08 |
| 14 | A Cataldo et al. (44) | 2014 | TM | Fifteen sedentary T2D patients (9 males, 6 females) fifteen healthy sedentary subjects | T2D patients:<br>70±1.27 mL/kg/min<br>Healthy:<br>64±2.61 mL/kg/min | T2D patients:<br>6.71±0.46 mL/kg/min<br>Healthy:<br>7.19±0.77 mL/kg/min |
| 15 | S Tan et al. (56) | 2014 | A graded TM | Thirty women (45–59 years | Exercise :<br>Before: 52 ±6<br>After: 48 ±8<br>Control:<br>Before: 52 ± 13<br>After: 57 ± 10 | Exercise :<br>Before: 0.38 ± 0.07<br>After: 0.45 ± 0.08<br>Control:<br>Before: 0.40 ± 0.09<br>After: 0.41 ± 0.09 |
| 16 | AN Blaize et al. (57) | 2014 | TM | Fourteen active, healthy women divided into 2 groups (15–24.9% = lower-fat group;<br>25–35%= higher-fat group). | Lower-fat group: 52% VO2max<br>higher-fat group:49 %VO2max | Lower-fat group: 0.39 6 0.1 g.min-1<br>higher-fat group: 0.49 6 0.1 g.min-1 |
| 17 | AE Lima-Silva et al. (58) | 2010 | incremental TM | 18 runners | Low performance:<br>68.7 VO2max<br>Moderate performance:<br>59.9 VO2max | Low performance:<br>0.27g/min<br>Moderate performance:<br>0.47 g/min |
| 18 | F. Scharhag-Rosenberger et al. (59) | 2010 | TM | 17 sedentary participants | 0: 35 ± 6 VO2max<br>6: 44 ± 15 VO2max<br>12: 50 ± 14 VO2max | 0: 0.26 ± 0.10 g/min<br>6: 0.27 ± 0.08 g/min<br>12: 0.33 ± 0.12 g/min |
| 19 | X Chenevière et al. (60) | 2009 | Incremental TM | Twenty moderately trained subjects (9 men and 11 women).<br>incremental test (IncrC)<br>graded test on a treadmill (Incr) | IncrC: 70.7 ± 2.7 VO2max<br><br>Incr: 65.5 ± 2.6 VO2max | IncrC: 0.50 ± 0.03 g/min<br><br>Incr: 0.40 ± 0.03 g/min |

**Table 3: Studies at the Lipoxmax with other protocol currently available.**

| | **Author** | **year** | **Exercise mode** | **subject** | **Fatmax** | **MFO (maximal fat oxidation) rate** |
|---|---|---|---|---|---|---|
| 1 | S S Ferreira et al. (61) | 2013 | Walking Test | adult women | 51.3 ± 7.2 VO2max | 0.303 g.min-1 |
| 2 | LAG Freitas et al. (62) | 2015 | Walking | 12 obese women | self-selected exercise intensity 62.0 ± 10.2 VO2max<br>imposed exercise intensity<br>49.2 ± 5.2 VO2max | 0.372 ± 0.08<br>0.490 ± 0.1 |
| 3 | RDS Silveira et al. (63) | 2016 | running protocols | Sixteen recreational athletes<br>Males (n = 9)<br>Females (n = 7) | - | Fat peak test 1:0.52 g.min-1<br><br>Fat peak test 2: 0.49 g.min-1<br>48 to 72 h later than test 1 |
| 4 | S Alkahtani et al. (64) | 2014 | The 30-min MIIT involved 5-min repetitions of workloads 20% below and 20% above the MFO intensity. | Twelve sedentary obese males | - | MIIT : 0.17 g.min-1<br>GXT:0.14 g.min-1 |
| 5 | E Makni et al. (65) | 2012 | six-minute walking distance (6MWD)<br>-<br>cycle ergometer = for fatmax | 131 school-aged obese children,<br>68 boys and 63 girls | - | Boy: 126.5±12.1 ng $min^{-1}$<br>Girl: 120.7±10.0 ng $min^{-1}$ |

## CONCLUSION

Nowadays the most important question for population that wants to lose weight is what is the easiest and fastest method to lose the maximum weight. $Fat_{max}$ may be is an efficient exercise intensity for weight loss programs, health-related exercise programs, and endurance training. Several authors assume that ‘‘fat loss depends on energy deficit only, independently of the method for weight loss’’ (66). Studies clearly indicate that is quite possible to lose fat while preserving fat-free mass through regular prolonged exercise of moderate intensity and if energy intake is kept constant at baseline level (67). They also confirm the importance of the individual differences in response to negative energy balance. It is well appointed that the extent of weight or fat loss in response to exercise training varies among individuals (68-70). Future research should investigate an exercise test with which $Fat_{max}$ can be accurately determined, and such a test needs to be validated and tested for reliability.

## APPLICABLE REMARKS

- We have defined the exercise intensity at which maximal fat oxidation is observed as $Fat_{max}$.
- $Fat_{max}$ may have importance role for weight loss programs, and health-related exercise Programs.
- $Lipox_{max}$ values are different and can be modifiable by some factors such as gender, puberty, training status, obesity and diabetes.

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