



[www.aassjournal.com](http://www.aassjournal.com)

ISSN (Online): 2322-4479

ISSN (Print): 2476-4981

**Review Article**

[www.AESAsport.com](http://www.AESAsport.com)

Received: 20/03/2016

Accepted: 10/06/2016

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

<sup>1</sup>Abbass Ghanbari-Niaki\*, <sup>1</sup>Navabeh Zare-Kookandeh

1. Exercise Biochemistry Division, Faculty of Sport Sciences, University of Mazandaran, Baboulsar, Iran.

## 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  $Lipox_{max}/Fat(ox)_{max}$  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

\*. Corresponding Author:

Abbass Ghanbari-Niaki

E-mail: [ghanbara@atu.ac.ir](mailto:ghanbara@atu.ac.ir)

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.

$$\text{Fat oxidation rate (mg/min)} = 1.695 \times \text{oxygen uptake (l/min)} - 1.701 \times \text{carbon dioxide output (l/min)}$$

$$\text{Carbohydrate oxidation rate (mg/min)} = 4.585 \times \text{carbon dioxide output (l/min)} - 3.226 \times \text{oxygen uptake (l/min)}$$

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<sub>max</sub>. 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<sub>2</sub>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<sub>2</sub> and VCO<sub>2</sub>) should be collected using an Gas Analyzer. Test stop if 2 out of the 4 following criteria met. 1) if VO<sub>2</sub> do not increase even when workload increase (< 2 mL·kg<sup>-1</sup>·min<sup>-1</sup> 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<sub>max</sub> with CE protocol currently available.

	Author	year	Exercise mode	subject	Fat <sub>max</sub>	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% VO <sub>2</sub> max untrained 29.4% VO <sub>2</sub> max	trained 0.72 g.min <sup>-1</sup> untrained 0.32 g.min <sup>-1</sup>
2	J Achten et al. (6)	2002	CE	18 moderately trained cyclists	61 ±3 VO <sub>2</sub> max 72 ±2 HRmax	CE <sub>average</sub> : 0.66 ±0.06 g.min <sup>-1</sup> CE: 0.69 ± 0.06 g.min <sup>-1</sup>
3	U Andersson Hall et al. (8)	2015	CE	elite cyclists and triathletes	CON: 55 ± 2 VO <sub>2</sub> max EXER: 62 ± 1 VO <sub>2</sub> max FAST: 62 ± 2 VO <sub>2</sub> max	CON: 0.51 ± 0.04 g.min <sup>-1</sup> EXER: 0.89 ± 0.05 g.min <sup>-1</sup> FAST: 0.69 ± 0.04 g.min <sup>-1</sup> CON : submaximal incremental EXER: two repetitions of 20 min cycling

						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 <sup>-1</sup> FFM <sup>-1</sup> ) 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 <sub>2</sub> peak O (obese ): 42% vo <sub>2</sub> 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 CE 53 VO2peak/ 67 HRmax	
17	S Lanzi et al. (22)	2012	CE	severe obese (SO) men (BMI=40)	Group Fatmax : 52.6 ± 2.5 VO2max Group HIT: 54.4 ± 2.0 VO2max	Group Fatmax: 3.8 ± 0.2 mg.kg <sup>-1</sup> .min <sup>-1</sup> Group HIT: 4.1 ± 0.2 mg.kg <sup>-1</sup> .min <sup>-1</sup>
18	C González - Haro et al. (23)	2011	CE	2 groups of male, well-trained endurance Athletes (short-distance triathletes (ST) and road cyclists (RC))	ST: 52 VO2max RC: 52 VO2max	ST: 0.4 g/min 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: 12 individuals (six boys and six girls) = training and 10 individuals (five boys and five girls) served as controls		Training: Before 135 mgr/min After 235 mgr/min  Control: Before 140 mgr/min After 140 mgr/min
21	L Chu et al. (26)	2011	incremental on mechanically braked cycle ergometer	seven obese boys mean age: 11.4 ± 1.0 year		Control:0.16 ± 0.09 g/min 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. 35, 75% maximal oxygen consumption		Con:0.125 g/min E35:0.28 g/min E70:0.26 g/min
23	K Tolfrey et al. (28)	2010	CE	Twenty-three adolescents (12 girls and 11 boys)	Boys: 39 % VO2peak 61 HR peak Girls: 32 %VO2peak 56% HR peak	Boys: 254 mg/min 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 Women:39 VO2max	
25	JD Coso et al (30).	2010	CE	endurance-trained (TR) (n=10) and untrained (UNTR) subjects exercising (n=10)	TR: achieved at 60% peak oxygen uptake UNTR: at 40% peak oxygen uptake	TR:0.41 ± 0.01 g/min 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 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<sup>-1</sup> and at a gradient of 1% for three min. The speed then increase to 7.5 km·h<sup>-1</sup>. Speed increase by 1 km·h<sup>-1</sup> 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<sub>max</sub> point in CE protocol at % 42 VO<sub>2peak</sub> whereas in Tan *et al.* (2015) study, subjects' s Fat<sub>max</sub> (Twenty-six obese boys) occurred at %43±11 VO<sub>2max</sub> by TM protocol (43). In another study twelve women with T2DM when reached their Fat<sub>max</sub> 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<sub>max</sub> point (44).

As well as in Coso *et al.* (2010) study subjects (endurance-trained ) achieved at 60% peak oxygen uptake at their Fat<sub>max</sub> point with a CE protocol (30) whereas in another study when endurance trained individuals reached their Fat<sub>max</sub> point with a CE protocol , their VO<sub>2max</sub> 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<sub>max</sub> when their VO<sub>2max</sub> 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 VO <sub>2max</sub> non Over Weight : 63 ± 12 VO <sub>2max</sub>	-
2	M Rami et al. (45)	2014	TM	Active male students sedentary male students	Active :40.09±2.58 VO <sub>2max</sub> 56.45±4.33 HR <sub>max</sub> Sedentary: 42.72±3.01 VO <sub>2max</sub> 60.09±3.37 HR <sub>max</sub>	0.29±0.03 g.min <sup>-1</sup> 0.23±0.02 g.min <sup>-1</sup>
3	MC. Venables et al. (39)	2005	TM	300 healthy men and women	48.3 ± 0.9 VO <sub>2max</sub> 61.5 ± 0.6% HR <sub>max</sub>	7.8 _ 0.13 (FFM) <sup>-1</sup> _min <sup>-1</sup>
4	S Takagi et al. (47)	2014	TM	healthy young men	43.2 ± 5.7% VO <sub>2peak</sub>	0.65 ± 0.12 g.min-1
5	M Rami et al. (48)	2012	TM	9 untrained male	42 ± 3 VO <sub>2max</sub> 58±2 HR <sub>max</sub>	0.23 g.min-1
6	NA Crisp et al. (49)	2012	TM	overweight boys (8–12 years)	58±2 VO <sub>2max</sub>	0.44 g.min-1
7	A Mousavian et al. (50)	2013	TM	untrained female university students	Morning: 40.92±6.17 g/m Afternoon: 55.83±3.55 g/m Night: 57.19±3.11 g/m	Morning: 0.30±0.051 Afternoon: 0.45±0.082 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 Afternoon 13.83±57.55 ml/kg/m Night: 10.99±56.96 ml/kg/m	Morning:0.056±0.17 g.min-1 Afternoon: 0.53±0.17 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 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: Control: 41±10 VO <sub>2max</sub> Exercise: 43±11 VO <sub>2max</sub> Lean boys: Control: 52±13 VO <sub>2max</sub> Exercise: 49±19 VO <sub>2max</sub>	Obese boys: Control: 0.41±0.18 g/min Exercise: 0.38±0.13 g/min Lean boys: Control: 0.29±0.12 g/min Exercise: 0.32±0.17 g/min
13	J Wang et al. (55)	2015	A graded treadmill walkingerunning test	Thirty women		Contorl: Rest:0.10 ± 0.04 4km/h: 0.32 ± 0.10 5km/h: 0.18 ± 0.20 Exercise:

						Rest: 0.07 ± 0.03 4km/h: 0.32 ± 0.11 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: 70±1.27 mL/kg/min Healthy: 64±2.61 mL/kg/min	T2D patients: 6.71±0.46 mL/kg/min Healthy: 7.19±0.77 mL/kg/min
15	S Tan et al. (56)	2014	A graded TM	Thirty women (45–59 years)	Exercise : Before: 52 ±6 After: 48 ±8 Control: Before: 52 ± 13 After: 57 ± 10	Exercise : Before: 0.38 ± 0.07 After: 0.45 ± 0.08 Control: Before: 0.40 ± 0.09 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; 25–35% = higher-fat group).	Lower-fat group: 52% VO <sub>2</sub> max higher-fat group: 49% VO <sub>2</sub> max	Lower-fat group: 0.39 6 0.1 g.min <sup>-1</sup> higher-fat group: 0.49 6 0.1 g.min <sup>-1</sup>
17	<a href="#">AE Lima-Silva et al. (58)</a>	2010	incremental TM	18 runners	Low performance: 68.7 VO <sub>2</sub> max Moderate performance: 59.9 VO <sub>2</sub> max	Low performance: 0.27g/min Moderate performance: 0.47 g/min
18	F. Scharhag-Rosenberger et al. (59)	2010	TM	17 sedentary participants	0: 35 ± 6 VO <sub>2</sub> max 6: 44 ± 15 VO <sub>2</sub> max 12: 50 ± 14 VO <sub>2</sub> max	0: 0.26 ± 0.10 g/min 6: 0.27 ± 0.08 g/min 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). incremental test (IncrC) graded test on a treadmill (Incr)	IncrC: 70.7 ± 2.7 VO <sub>2</sub> max  Incr: 65.5 ± 2.6 VO <sub>2</sub> max	IncrC: 0.50 ± 0.03 g/min  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 VO <sub>2</sub> max	0.303 g.min <sup>-1</sup>
2	LAG Freitas et al. (62)	2015	Walking	12 obese women	self-selected exercise intensity 62.0 ± 10.2 VO <sub>2</sub> max imposed exercise intensity 49.2 ± 5.2 VO <sub>2</sub> max	0.372 ± 0.08 0.490 ± 0.1
3	RDS Silveira et al. (63)	2016	running protocols	Sixteen recreational athletes Males (n = 9) Females (n = 7)	-	Fat peak test 1: 0.52 g.min <sup>-1</sup> Fat peak test 2: 0.49 g.min <sup>-1</sup> 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 <sup>-1</sup> GXT: 0.14 g.min <sup>-1</sup>
5	E Makni et al. (65)	2012	six-minute walking distance (6MWD) - cycle ergometer = for fatmax	131 school-aged obese children, 68 boys and 63 girls	-	Boy: 126.5±12.1 ng min <sup>-1</sup> Girl: 120.7±10.0 ng min <sup>-1</sup>

## 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<sub>max</sub> 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<sub>max</sub> 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<sub>max</sub>.
- Fat<sub>max</sub> may have importance role for weight loss programs, and health-related exercise Programs.
- Lipox<sub>max</sub> values are different and can be modifiable by some factors such as gender, puberty, training status, obesity and diabetes.

## ACKNOWLEDGMENT

We wish to thank Dr. R. Fathi (Department of exercise Physiology, University of Mazandaran, Iran), Dr A. Zare Kookandeh (Sahid Rajaei hospital, Iran University of Medical Sciences, Tehran, Iran), Mr A. Shirazi (Department of exercise Physiology, University of Mazandaran, Iran) for helpful comments and guidance.

## REFERENCES

1. Ghanassia E, Brun J, Fedou C, Raynaud E, Mercier J. Substrate oxidation during exercise: type 2 diabetes is associated with a decrease in lipid oxidation and an earlier shift towards carbohydrate utilization. *Diabetes & metabolism*. 2006;32(6):604-10.
2. Brun J, Malatesta D, Sartorio A. Maximal lipid oxidation during exercise: a target for individualizing endurance training in obesity and diabetes? *Journal of endocrinological investigation*. 2012;35(7):686-91.
3. Sahlin K, Sallstedt E, Bishop D, Tonkonogi M. Turning down lipid oxidation during heavy exercise—what is the mechanism. *J Physiol Pharmacol*. 2008;59(Suppl 7):19-30.
4. Starritt EC, Howlett RA, Heigenhauser GJ, Spriet LL. Sensitivity of CPT I to malonyl-CoA in trained and untrained human skeletal muscle. *American Journal of Physiology-Endocrinology And Metabolism*. 2000;278(3):E462-E8.
5. Sakamoto S, Watanabe Y, Akama T, Torii S, Fukubayashi T, Hashimoto T. The study concerning the maximal lipid combustion rate and lipid metabolism in young athletes and outpatients. *Jpn J Clin Sports Med*. 2007;15:236-42.
6. Achten J, Gleeson M, Jeukendrup AE. Determination of the exercise intensity that elicits maximal fat oxidation. *Medicine and science in sports and exercise*. 2002;34(1):92-7.
7. CheneviÈre X, Malatesta D, Peters EM, Borrani F. A mathematical model to describe fat oxidation kinetics during graded exercise. *Medicine and science in sports and exercise*. 2009;41(8):1615-25.
8. Andersson Hall U, Edin F, Pedersen A, Madsen K. Whole-body fat oxidation increases more by prior exercise than overnight fasting in elite endurance athletes. *Applied Physiology, Nutrition, and Metabolism*. 2015;41(4):430-7.
9. Croci I, Hickman II, Wood RE, Borrani F, Macdonald GA, Byrne NM. Fat oxidation over a range of exercise intensities: fitness versus fatness. *Applied Physiology, Nutrition, and Metabolism*. 2014;39(12):1352-9.
10. Støa EM, Nyhus L-K, Claveau Børresen S, Nygaard C, Hovet ÅM, Bratland-Sanda S, et al. Day to day variability in fat oxidation, and the effect after only one day of change in diet composition. 2015.

11. Suk MH, Moon Y-J, Park SW, Park C-Y, Shin YA. Maximal Fat Oxidation Rate during Exercise in Korean Women with Type 2 Diabetes Mellitus. *Diabetes & metabolism journal*. 2015;39(4):328-34.
12. Mohebbi H, Nourshahi M, Ghasemikaram M, Safarimosavi S. Effects of exercise at individual anaerobic threshold and maximal fat oxidation intensities on plasma levels of nesfatin-1 and metabolic health biomarkers. *Journal of physiology and biochemistry*. 2015;71(1):79-88.
13. Iwayama K, Kurihara R, Nabekura Y, Kawabuchi R, Park I, Kobayashi M, et al. Exercise increases 24-h fat oxidation only when it is performed before breakfast. *EBioMedicine*. 2015;2(12):2003-9.
14. Besnier F, Lenclume V, Gérardin P, Fianu A, Martinez J, Naty N, et al. Individualized exercise training at maximal fat oxidation combined with fruit and vegetable-rich diet in overweight or obese women: the LIPOXmax-Réunion randomized controlled trial. *PloS one*. 2015;10(11):e0139246.
15. Jabbour G, O'Loughlin J, Sabiston C, Tremblay A, Mathieu ME. Increased lipid oxidation during exercise in obese pubertal girls: a QUALITY study. *Obesity*. 2014;22(5):E85-E90.
16. Lanzi S, Codecasa F, Cornacchia M, Maestrini S, Salvadori A, Brunani A, et al. Fat oxidation, hormonal and plasma metabolite kinetics during a submaximal incremental test in lean and obese adults. *PloS one*. 2014;9(2):e88707.
17. Croci I, Borrani F, Byrne N, Wood R, Hickman I, Cheneviere X, et al. Reproducibility of Fat max and fat oxidation rates during exercise in recreationally trained males. *PloS one*. 2014;9(6):e97930.
18. Abildgaard J, Pedersen AT, Green CJ, Harder-Lauridsen NM, Solomon TP, Thomsen C, et al. Menopause is associated with decreased whole body fat oxidation during exercise. *American Journal of Physiology-Endocrinology and Metabolism*. 2013;304(11):E1227-E36.
19. Schwindling S, Scharhag-Rosenberger F, Kindermann W, Meyer T. Limited Benefit of Fatmax-Test to Derive Training Prescriptions. *International journal of sports medicine*. 2014;35(04):280-5.
20. Tsujimoto T, Sasai H, Miyashita M, Eto M, So R, Ohkubo H, et al. Effect of weight loss on maximal fat oxidation rate in obese men. *Obesity research & clinical practice*. 2012;6(2):e111-e9.
21. Zakrzewski JK, Tolfrey K. Comparison of fat oxidation over a range of intensities during treadmill and cycling exercise in children. *European journal of applied physiology*. 2012;112(1):163-71.
22. Lanzi S. Effects of 2-wk endurance training in severe obese men: high intensity interval versus Fatmax training.
23. González-Haro C. Maximal fat oxidation rate and cross-over point with respect to lactate thresholds do not have good agreement. *International journal of sports medicine*. 2011;32(05):379-85.
24. Rynders CA, Angadi SS, Weltman NY, Gaesser GA, Weltman A. Oxygen uptake and ratings of perceived exertion at the lactate threshold and maximal fat oxidation rate in untrained adults. *European journal of applied physiology*. 2011;111(9):2063-8.
25. Ounis OB, Elloumi M, Zouhal H, Makni E, Lac G, Tabka Z, et al., editors. Effect of an individualized physical training program on resting cortisol and growth hormone levels and fat oxidation during exercise in obese children. *Annales d'endocrinologie*; 2011: Elsevier.
26. Chu L, Riddell MC, Takken T, Timmons BW. Carbohydrate intake reduces fat oxidation during exercise in obese boys. *European journal of applied physiology*. 2011;111(12):3135-41.
27. Pillard F, Van Wymelbeke V, Garrigue E, Moro C, Crampes F, Guillard J-C, et al. Lipid oxidation in overweight men after exercise and food intake. *Metabolism*. 2010;59(2):267-74.
28. Tolfrey K, Jeukendrup AE, Batterham AM. Group-and individual-level coincidence of the 'Fatmax' and lactate accumulation in adolescents. *European journal of applied physiology*. 2010;109(6):1145-53.
29. Haufe S, Engeli S, Budziarek P, Utz W, Schulz-Menger J, Hermsdorf M, et al. Determinants of exercise-induced fat oxidation in obese women and men. *Hormone and metabolic research*. 2010;42(03):215-21.
30. Del Coso J, Hamouti N, Ortega JF, Mora-Rodriguez R. Aerobic fitness determines whole-body fat oxidation rate during exercise in the heat. *Applied Physiology, Nutrition, and Metabolism*. 2010;35(6):741-8.
31. Bordenave S, Metz L, Flavier S, Lambert K, Ghanassia E, Dupuy A-M, et al. Training-induced improvement in lipid oxidation in type 2 diabetes mellitus is related to alterations in muscle mitochondrial activity. Effect of endurance training in type 2 diabetes. *Diabetes & metabolism*. 2008;34(2):162-8.
32. Achten J, Jeukendrup A. Maximal fat oxidation during exercise in trained men. *International journal of sports medicine*. 2003;24(08):603-8.
33. Friedlander AL, Casazza GA, Horning MA, Buddinger TF, Brooks GA. Effects of exercise intensity and training on lipid metabolism in young women. *American Journal of Physiology-Endocrinology And Metabolism*. 1998;275(5):E853-E63.
34. Friedlander AL, Casazza GA, Horning MA, Huie MJ, Piacentini MF, Trimmer JK, et al. Training-induced alterations of carbohydrate metabolism in women: women respond differently from men. *Journal of applied physiology*. 1998;85(3):1175-86.



35. Brandou F, Savy-Pacaux A, Marie J, Brun J, Mercier J. Comparison of the type of substrate oxidation during exercise between pre and post pubertal markedly obese boys. *International journal of sports medicine*. 2006;27(05):407-14.
36. Riddell MC, Jamnik VK, Iscoe KE, Timmons BW, Gledhill N. Fat oxidation rate and the exercise intensity that elicits maximal fat oxidation decreases with pubertal status in young male subjects. *Journal of applied physiology*. 2008;105(2):742-8.
37. Achten J, Venables MC, Jeukendrup AE. Fat oxidation rates are higher during running compared with cycling over a wide range of intensities. *Metabolism*. 2003;52(6):747-52.
38. González-Haro C, Galilea PA, González-de-Suso JM, Drobnic F, Escanero JF. Maximal lipidic power in high competitive level triathletes and cyclists. *British journal of sports medicine*. 2007;41(1):23-8.
39. Venables MC, Achten J, Jeukendrup AE. Determinants of fat oxidation during exercise in healthy men and women: a cross-sectional study. *Journal of applied physiology*. 2005;98(1):160-7.
40. Perez-Martin A, Dumortier M, Raynaud E, Brun J, Fedou C, Bringer J, et al. Balance of substrate oxidation during submaximal exercise in lean and obese people. 2008.
41. Sardinoux M, Brun J, Lefebvre P, Bringer J, Fabre G, Salsano V, et al. Influence of bariatric surgery on exercise maximal lipid oxidation point in grade 3 obese patients. *Fundamental and Clinical Pharmacology*. 2009;23:57.
42. Brun J-F, Fedou C, Grubka E, Karafiat M, Varlet-Marie E, Mercier J. Moindre utilisation des lipides à l'exercice chez le diabétique de type 1. *Science & Sports*. 2008;23(3):198-200.
43. Tan S, Wang J, Cao L. Exercise training at the intensity of maximal fat oxidation in obese boys. *Applied Physiology, Nutrition, and Metabolism*. 2015;41(1):49-54.
44. Cataldo A, Russo G, Cerasola D, Di Majo D, Giammanco M, Traina M. Relationship between maximal fat oxidation and oxygen uptake: comparison between type 2 diabetes patients and healthy sedentary subjects. *Journal of Biological Research-Bollettino della Società Italiana di Biologia Sperimentale*. 2014;87(1).
45. Rami M, Habibi A, Shakerian S. Comparison between fat max and maximal fat oxidation in active and sedentary males. *Jentashapir Journal of Health Research*. 2014;5(2):53-64.
46. Zakrzewski JK, Tolfrey K. Acute effect of Fatmax exercise on the metabolism in overweight and nonoverweight girls. 2012.
47. Takagi S, Sakamoto S, Midorikawa T, Konishi M, Katsumura T. Determination of the exercise intensity that elicits maximal fat oxidation in short-time testing. *Journal of sports sciences*. 2014;32(2):175-82.
48. Rami M, Habibi A, Shakerian S. Determine Of the Exercise Intensity That Elicits Maximal Fat Oxidation In Untrained Male Students. 2012.
49. Crisp NA, Guelfi KJ, Licari MK, Braham R, Fournier PA. Does exercise duration affect Fatmax in overweight boys? *European journal of applied physiology*. 2012;112(7):2557-64.
50. Mousavian A, Jafarzadeh G, Darvakh H, Valizadeh A. Effect of Circadian Rhythm on Maximal Fat Oxidation mean in untrained female university student during a session of submaximal aerobic exercise. 2013.
51. Darvakh H, Nikbakht M, Shakerian S, Sadat Mousavian A. Effect of Circadian Rhythm on Peak of Maximal Fat Oxidation on Non-Athletic Men. *مجله تحقیقات علوم پزشکی زاهدان*. ۱۱-۸:(۶)۱۶;۲۰۱۴.
52. Konishi M, Takahashi M, Endo N, Numao S, Takagi S, Miyashita M, et al. Effect of one night of sleep deprivation on maximal fat oxidation during graded exercise. *The Journal of Physical Fitness and Sports Medicine*. 2013;2(1):121-6.
53. Iwayama K, Kawabuchi R, Park I, Kurihara R, Kobayashi M, Hibi M, et al. Transient energy deficit induced by exercise increases 24-h fat oxidation in young trained men. *Journal of Applied Physiology*. 2015;118(1):80-5.
54. Robinson SL, Hattersley J, Frost GS, Chambers ES, Wallis GA. Maximal fat oxidation during exercise is positively associated with 24-hour fat oxidation and insulin sensitivity in young, healthy men. *Journal of Applied Physiology*. 2015;118(11):1415-22.
55. Wang J, Tan S, Cao L. Exercise training at the maximal fat oxidation intensity improved health-related physical fitness in overweight middle-aged women. *Journal of Exercise Science & Fitness*. 2015;13(2):111-6.
56. Tan S, Wang J, Cao L, Guo Z, Wang Y. Positive effect of exercise training at maximal fat oxidation intensity on body composition and lipid metabolism in overweight middle-aged women. *Clinical physiology and functional imaging*. 2014.
57. Blaize AN, Potteiger JA, Claytor RP, Noe DA. Body Fat has No Effect on the Maximal Fat Oxidation Rate in Young, Normal, and Overweight Women. *The Journal of Strength & Conditioning Research*. 2014;28(8):2121-6.
58. Lima-Silva AE, Bertuzzi RC, Pires FO, Gagliardi JF, Barros RV, Hammond J, et al. Relationship between training status and maximal fat oxidation rate. *Journal of sports science & medicine*. 2010;9(1):31.

59. Scharhag-Rosenberger F, Meyer T, Walitzek S, Kindermann W. Effects of one year aerobic endurance training on resting metabolic rate and exercise fat oxidation in previously untrained men and women. *International journal of sports medicine*. 2010;31(07):498-504.
60. Chenevière X, Borrani F, Ebenegger V, Gojanovic B, Malatesta D. Effect of a 1-hour single bout of moderate-intensity exercise on fat oxidation kinetics. *Metabolism*. 2009;58(12):1778-86.
61. Ferreira SS, Pereira JL, Alves RC, Redkva PE, Elsangedy HM, Krinski K, et al. Are sedentary women able to self-select a walking intensity that corresponds to maximal fat oxidation (Fatmax). *Journal of Exercise Physiology Online*. 2013;16(2):32-40.
62. Freitas LAG, Ferreira SdS, Freitas RQ, Januário RS, Alves RC, Silva AC, et al. Effect of self-selected and imposed-intensity walking programs on fat oxidation in obese women. *Journal of Exercise Physiology Online*. 2015;18(1):62-70.
63. Silveira RDS, Carlsohn A, Langen G, Mayer F, Scharhag-Rosenberger F. Reliability and day-to-day variability of peak fat oxidation during treadmill ergometry. *Journal of the International Society of Sports Nutrition*. 2016;13(1):1.
64. Alkahtani S. Comparing fat oxidation in an exercise test with moderate-intensity interval training. *Journal of sports science & medicine*. 2014;13(1):51.
65. Makni E, Moalla W, Trabelsi Y, Lac G, Brun J, Tabka Z, et al. Six-minute walking test predicts maximal fat oxidation in obese children. *International Journal of Obesity*. 2012;36(7):908-13.
66. Strasser B, Spreitzer A, Haber P. Fat loss depends on energy deficit only, independently of the method for weight loss. *Annals of Nutrition and Metabolism*. 2007;51(5):428-32.
67. Bouchard C, Tremblay A, Nadeau A, Dussault J, Despres J, Theriault G, et al. Long-term exercise training with constant energy intake. 1: Effect on body composition and selected metabolic variables. *International journal of obesity*. 1990;14(1):57-73.
68. Byrne NM, Meerkkin JD, Laukkanen R, Ross R, Fogelholm M, Hills AP. Weight loss strategies for obese adults: personalized weight management program vs. standard care. *Obesity*. 2006;14(10):1777-88.
69. King NA, Hopkins M, Caudwell P, Stubbs R, Blundell JE. Individual variability following 12 weeks of supervised exercise: identification and characterization of compensation for exercise-induced weight loss. *International Journal of Obesity*. 2008;32(1):177-84.
70. Snyder K, Donnelly J, Jabobsen D, Hertner G, Jakicic J. The effects of long-term, moderate intensity, intermittent exercise on aerobic capacity, body composition, blood lipids, insulin and glucose in overweight females. *International journal of obesity*. 1997;21(12):1180-9.