



FOCUS ON
HEALTH

Dietetics and Nutrition

Self-study CPD activity

Activity Reference Number
K4(26) 2027

Topic

Exercise and Fat Metabolism

Article(s)

Exercise and Fat Metabolism

Profession(s)

Dietitian

Supplementary Dietitian

Nutritionist

Supplementary Nutritionist

This activity is approved for **THREE (3)** 3 Continuing Education Units (CEU's)

Exercise and Fat Metabolism

Solutions to a Long-Standing Conundrum

by Eric Leslie, M.S., ACSM-EP; Christine Mermier, Ph.D., ACSM-CEP; and Len Kravitz, Ph.D., CSCS

Apply It!

- Several types of exercise promote fat burning, which provides flexibility in exercise prescription to achieve benefits in fat metabolism.
- Individualized exercise prescription, with any type of exercise, promotes exercise adherence and optimizes the training-related benefits in fat metabolism.

Key words: Fat Oxidation, Mitochondria, Obesity, High-Intensity Interval Exercise, Adipocyte

INTRODUCTION

Fat is the body's largest energy reservoir with significantly more available energy for satisfying physiologic needs than carbohydrate (glucose/glycogen) (1). This characteristic makes fat metabolism an essential fuel for satisfying total body energy needs. An inability to satisfactorily metabolize fat for energy may increase the likelihood of sustaining an undesirably high level of body fat with an increased risk of obesity and related health sequelae (2). Regular exercise, however, is likely to be health promoting by enabling greater fat metabolism that lowers the risk of obesity. An important feature of regular exercise is that it improves the capacity to burn fat, which lowers the need to burn carbohydrate as a fuel and results in enhanced exercise capacity and endurance. These exercise-induced adaptations reduce the risk of obesity and increase a person's functional exercise capacity. An up-to-date understanding of fat metabolism physiology and how exercise bolsters fat burning will help fitness professionals develop effective exercise programs that promote optimal health for their clients.

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FAT METABOLISM 101: UNDERSTANDING FAT METABOLISM IN THE BODY

Approximately 50% of body fat is stored subcutaneously (*i.e.*, beneath the skin), which provides a source of fuel for skeletal muscles and provides a temperature control “blanket” around the body. Most of the remaining body fat (*i.e.*, visceral fat) surrounds the organs to help maintain their temperature and also provides a source of energy for body tissues. The primary storage of adipocytes (*i.e.*, fat cells) is in the form of triglycerides that consist of three fatty acids attached to a glycerol backbone. These fatty acids are metabolized based on the energy demands of the body, such as during exercise. For example, relatively lower exercise intensities facilitate lower energy demands that have a higher proportionate fat contribution for satisfying energy demands. Alternatively, essential fatty acids, obtained through the diet, have additional benefits for the body in addition to energy production. For example, omega-3 fatty acids found in fish, nuts, seeds, and plant oils are one type of essential fatty acids that have strong anti-inflammatory effects. Humans also have stores of intramuscular triglyceride that are a convenient fuel source easily available to mitochondria, where adenosine triphosphate (ATP) is produced and is the main source of energy in

Type I (*i.e.*, slow twitch) skeletal muscle. Therefore, these smaller intramuscular triglyceride stores are metabolized first, before using triglyceride from general adipose tissue stores that require fatty acid delivery to skeletal muscle through circulation. Triglyceride stores also are influenced by cardiometabolic health because obese individuals have noticeably larger intramuscular triglyceride stores and a reduced capacity to metabolize these triglycerides during exercise, as compared with nonobese individuals (3).

Hormone Regulation of Fat Metabolism

Hormones regulate fat metabolism depending on the body's energy demands. Greater energy demands during exercise increase epinephrine release from the adrenal glands to facilitate lipolysis (*i.e.*, the breakdown of triglycerides) (4). Lipolysis separates fatty acids from the glycerol backbone and allows the now free fatty acids to be transported through the blood, bound to the transport protein albumin, to the skeletal muscle to be metabolized for energy (illustrated in Figure 1). This is in contrast to conditions of greater energy supply than demand, such as when eating a meal, that promotes insulin release by the pancreas to promote fatty acid uptake from the blood for either triglyceride synthesis or breakdown for energy production, depending on the energy demand.

ATP Production from Fatty Acids

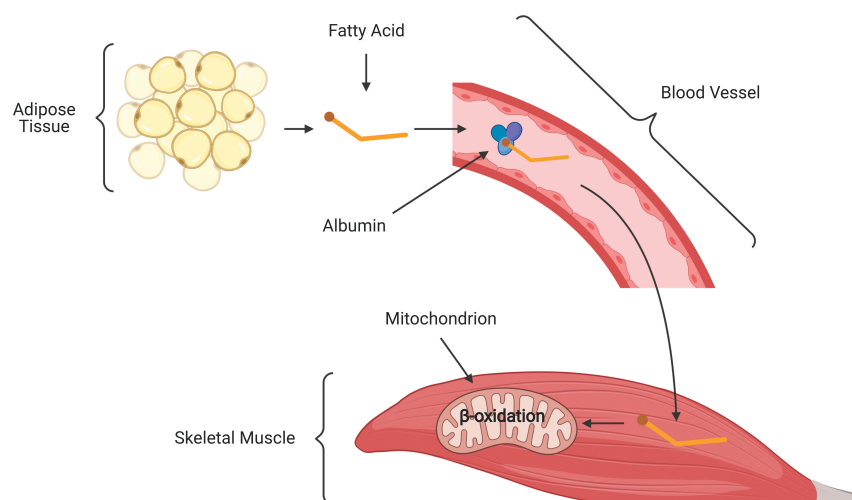
Once inside the muscle cell, fatty acids are transported to the mitochondria (*i.e.*, energy factory of the cell) to be broken down, two-carbon subunits at a time, in a process called β (beta)-oxidation. These two-carbon subunits are used to power the tricarboxylic acid (TCA) cycle that supplies the hydrogen ions and electrons needed for oxidative phosphorylation, the primary process that produces ATP (4,5).

EXERCISE AND FAT METABOLISM: HOW EXERCISE PROMOTES FAT BURNING

Fatty acids have a large molecular size when compared with glucose. This increases the number of metabolic reactions and the time it takes to fully break down a fatty acid for ATP production. For example, palmitate is the most common fatty acid in the body, and it has 16 carbons. Therefore, palmitate needs to be broken down into two-carbon subunits through eight cycles of β -oxidation. In comparison, a glucose molecule only has six carbons and is broken down into two pyruvate molecules through one cycle of glycolysis. With one additional reaction after entering the mitochondria, these pyruvates are subsequently converted into the same, two-carbon subunits as produced through β -oxidation. Although there is greater ATP production from fat metabolism, ATPs are not synthesized until the two carbon subunits from β -oxidation enter the TCA cycle and subsequently oxidative phosphorylation. Glucose metabolism, however, produces a few ATP in glycolysis before the two-carbon subunit entering the TCA Cycle. Therefore, glucose has greater flexibility as a fuel source by producing ATP in both anaerobic and aerobic metabolic processes. This flexibility helps glucose metabolism to supply the metabolic demand during workouts of increasing intensity that require high maintenance of readily available ATP. Consequently, fat metabolism contributes to energy production the most during relatively low-intensity exercise, whereas the proportionate reliance on glucose metabolism increases with greater exercise intensities. Exercise intensity is, however, relative to an individual's fitness level. The same absolute workload will be a lower, relative exercise intensity for someone with higher fitness that promotes a greater contribution of fat metabolism for ATP production.

Exercise itself also affects the activity of enzymes involved in fat metabolism. Intramuscular hormone-sensitive lipase is an

Figure 1. A fatty acid's journey from adipose tissue to skeletal muscle FFA, free fatty acid. Adapted from Purdom et al. (4). Created with Biorender.com.



EXERCISE AND FAT METABOLISM

enzyme involved in the lipolysis of triglyceride stored within muscle. Intramuscular hormone-sensitive lipase activity increases during the first hour of submaximal exercise but then lowers toward preexercise levels due to depletion of intramuscular triglyceride (4). Fat metabolism during exercise is maintained thereafter by the lipolysis of the larger triglyceride stores within adipose tissue.

Understanding Fat Oxidation, Maximal Fat Oxidation, and Exercise

The energy molecule ATP is primarily produced by fat metabolism in an aerobic metabolic process referred to as fat oxidation, which is the breakdown of fatty acids. The rate of fat oxidation may be estimated from a percentage of maximal aerobic capacity or $\dot{V}O_{2\max}$. Fat oxidation contributes more than 90% of energy expenditure at exercise intensities that elicit 25% $\dot{V}O_{2\max}$ (4), which is considered a very low intensity. Maximal fat oxidation occurs at the higher thresholds of steady state exercise, between 60% and 65% $\dot{V}O_{2\max}$, and varies due to sex and training status (4). Beyond ~65% $\dot{V}O_{2\max}$, maximal fat oxidation is limited because of the reduced fatty acid transport into the mitochondria for β -oxidation (4). Intramuscular triglycerides generally supply the fatty acids used for fat oxidation for up to 2 hours of continuous exercise (4). However, individuals with higher fitness have a greater storage capacity for and ability to metabolize intramuscular triglyceride. This delays the need for lipolysis in adipose tissue for energy production in the working muscle. Beyond 2 hours, fat oxidation is maintained by lipolysis of triglyceride and free fatty acid delivery through the circulation to skeletal muscle.

WHAT ARE THE PERILS OF SICK FAT?

Obese individuals, defined as those with a BMI $\geq 30 \text{ kg}\cdot\text{m}^{-2}$ (2), are more likely to have fat that contains abnormally large adipocytes. Obesity also causes greater oxidative stress: defined as a disturbance in the balance between the production of reactive oxygen species (free radicals) and antioxidant defenses (2). These enlarged adipocytes release several proinflammatory compounds and are often called sick fat (2). The inflammation related to sick fat makes lipolysis more difficult and the adipocytes dysfunctional. This sick fat dysfunction causes excess storage of unmetabolized fatty acids from the circulation, abnormally increasing subcutaneous and visceral adipose tissue as well as intramuscular triglyceride. This is in contrast to increased storage of intramuscular triglyceride with endurance training, which is considered a positive adaptation that increases the contribution of fat as a fuel source at a given exercise intensity (6). Carbohydrate metabolism increases to compensate for insufficient fat metabolism and to meet the energy demand of exercise. This increases metabolic acidosis, from the anaerobic portions of carbohydrate metabolism (*i.e.*, glycolysis) in the absence of oxygen, due to protons released from ATP breakdown. This elicits muscle burning sensations and raises an individual's perceived exertion of workouts. The collective consequences of oxidative stress and inflammation from obesity can cause a

dangerous, downward spiral in health without an appropriate exercise intervention.

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SIX EVIDENCE-BASED EXERCISE PROGRAMS THAT BOOST FAT METABOLISM AND CALORIE BURNING

Regular, well-tolerated and appropriate exercise improves fat metabolism and contributes to multifaceted therapeutic efforts that combat obesity. Figure 2 illustrates the comparisons between the effects of exercise and sick fat, caused by obesity, on fat metabolism. Here are six exercise programs that have been shown to bolster fat metabolism for greater efficiency in fuel use and exercise capacity. Considerations for effects on total caloric expenditure, which may be used to assess the effects of each exercise program for weight management, also are discussed. These programs vary based on exercise mode, duration, and intensity. Fitness professionals are encouraged to incorporate and individualize each of these workouts based on client goals, fitness levels, and time constraints.

Low-Intensity Endurance Training

Low-intensity endurance training refers to aerobic-based exercise, such as walking, running, cycling, and swimming, performed at intensities that elicit $<50\%$ $\dot{V}O_{2\max}$ (*i.e.*, a light subjective RPE) for 20 to 60 minutes. Low-intensity endurance training is a particularly desirable option for those who are traditionally inactive, have lower fitness levels, or who suffer from clinical limitations (*e.g.*, arthritis, chronic pain). Interestingly, 8 weeks of low-intensity cycling that elicited 50% $\dot{V}O_{2\max}$ (1 hour of cycling per exercise session completed four times per week) improved fat oxidation by ~30% in overweight (*i.e.*, those with a BMI of 25–29.9 $\text{kg}\cdot\text{m}^{-2}$) and obese adults (7). Although there was no change in total caloric expenditure, these results show that low-intensity endurance training, one of the most accessible forms of exercise, increases the



proportion of fat oxidation for energy production in overweight and obese adults.

Moderate-Intensity Continuous Training

Moderate-intensity continuous training (MICT) refers to continuous, aerobic-based training performed at or near the threshold of maximal fat oxidation, ~60% $\dot{V}O_{2max}$ (8). In the talk test, MICT is endurance training where most individuals can

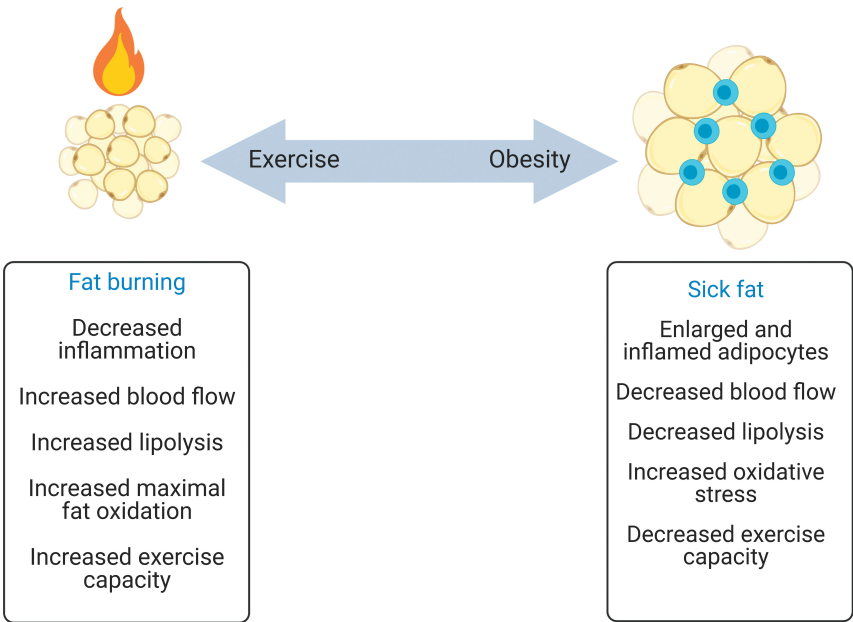
maintain a conversation (but not sing) during exercise. MICT is performed at the threshold where the increased respiratory rate at any intensity above MICT prevents an individual from saying more than a few words with each breath.

MICT triples the amount of fatty acids in circulation and improves fatty acid transport into skeletal muscle mitochondria for oxidation (4). Uniquely, a 40-minute session of MICT performed three times a week for 12 weeks led to a 10% increase in fat oxidation and a 12% increase in $\dot{V}O_{2max}$, despite any overall changes in energy expenditure (8). These great outcomes show not only improved fatty acid availability for energy metabolism but also a near linear relationship between improved fitness and fat oxidation with MICT.

High-Intensity Interval Training

High-intensity interval training (HIIT) is currently one of the most popular trends in exercise. A HIIT session traditionally consists of several high-intensity intervals, which elicit a training intensity of >80% maximal heart rate, alternated with active recovery intervals (9). A 6-month (three times per week) HIIT exercise program for obese individuals with four sets of 4-minute intervals at 90% maximal heart rate (*i.e.*, a hard to very hard RPE) interspersed with 3 minutes of active recovery at 70% maximal heart rate (*i.e.*, at light to moderate RPE)

Figure 2. The effects of obesity and exercise on fat. Obesity causes enlargement and inflammation of adipose tissue. Blue circles indicate proinflammatory molecules released in adipose tissue. This contributes to dysfunctional adipocytes or sick fat. These effects along with decreased blood flow reduce fat from adipose tissue as a fuel source, increase oxidative stress, and reduce exercise capacity. Exercise promotes burning fat as a fuel source. Consistent participation in exercise reduces inflammation and increases blood flow to adipose tissue. These effects, along with improved fitness from training, increase maximal fat oxidation that helps to spare carbohydrate metabolism and improve exercise capacity. Adapted from Paley and Johnson (2). Created with Biorender.com.



EXERCISE AND FAT METABOLISM



improved fat oxidation by 38.9% and reduced fat mass by 3.8% (10). These results show substantial benefits in fat metabolism and reductions in body fat with consistent participation in HIIT.

HIIT also has been shown to be effective in reducing inflammation and abdominal fat, and it may improve exercise adherence because it takes less time than traditional endurance training (2). Therefore, HIIT provides a time-efficient alternative to MICT and produces impressive adaptations in fat metabolism.

Low- and High-Volume Resistance Training

Resistance training has been largely encouraged to prevent the age-related loss of bone density as well as muscle mass and strength (*i.e.*, sarcopenia). However, new evidence shows that resistance training also is effective at burning fat. Four months of low-volume resistance training (three sets of 8–12 reps at 70% 1RM for nine upper- and lower-body exercise) increases muscular strength by 41% and decreases percent body fat by 3% (11). Additionally, decreases in waist circumference, which is an indicator of abdominal obesity, occurred in the high-volume exercise group that completed six sets per exercise (11). The researchers concluded that the high-volume exercise group had greater energy expenditure from the increase workload (11), which may have had the added effect of reducing abdominal fat. Fitness professionals may choose to individualize and/or periodize the resistance training volumes for enthusiastic clients.

Peripheral Heart Action Training

Peripheral heart action (PHA) training is a system of resistance training that promotes whole-body blood flow throughout an entire workout (12). This is accomplished by performing an upper body exercise followed immediately by a lower-body exercise with no breaks in between other than the time it takes to begin the next exercise. Exercises should be completed with 15 repetitions at a moderate intensity, such as at 60% of a

one-repetition maximum (or a load that elicits 60% to 80% maximal heart rate) to maintain consistent blood flow (10). A PHA may be structured as a circuit with a recommended three upper body and three lower-body exercises (six total) (12). A 3-month PHA study that included six exercises (completed in this order: bench press, leg extension, latissimus dorsi pull-down, leg curl, shoulder press, and seated heel raise) performed in four circuits, with 1 minute rest between each circuit, showed a 40+ % increase in upper body strength, a 23+ % increase in lower-body strength, and an 8% increase in $\dot{V}O_{2max}$ (12). Although body fat was not measured for this study, these training adaptations show an increase in quality of life through greater whole-body strength and improved fitness that may contribute to enhanced use of fat as fuel source.

Concurrent Training

Concurrent training consists of a combination of both aerobic (endurance or interval) and resistance training within the same exercise session or in different sessions of the same exercise program. A 12-week (3 days per week) concurrent exercise program that included both HIIT (8 seconds of high-intensity cycling followed by 12 seconds of slow pedaling (20 to 30 rpm) for 20 minutes) followed immediately by resistance training (two sets of 8 to 12 repetitions completed for 10 upper- and lower-body exercises) reduced visceral fat mass more than MICT or HIIT alone (8). Because energy expenditure was similar between MICT, HIIT, and concurrent training, the differing effects on reductions in fat mass remain unclear. However, the researchers speculate that concurrent training produced the highest metabolic stress through a combination of high-intensity exercise and larger workload that may have resulted in slight greater postexercise energy expenditure and greater fat loss after the 12-week training program.

Additionally, because the concurrent exercise was time matched with the 40-minute MICT exercise, the concurrent exercise resulted in the most work performed and benefits achieved without increasing the time of each exercise session.

Sidebar 1: Every exercise session contributes to improved fat metabolism

A single exercise session can increase fatty acid levels in circulation for up to 36 hours depending on the duration and the intensity of exercise (5). This allows ample circulation of fatty acids for both fat oxidation and to replenish intramuscular triglyceride (5). These circulating fatty acids also act as signaling molecules to promote translation (*i.e.*, synthesis) of proteins involved in fat metabolism that increase fatty acid availability and oxidation within skeletal muscle (5). And yes, every exercise session contributes to improved fat metabolism.

A single exercise session can increase fatty acid levels in circulation for up to 36 hours depending on the duration and the intensity of exercise. This allows ample circulation of fatty acids for both fat oxidation and to replenish intramuscular triglyceride. These circulating fatty acids also act as signaling molecules, such as when they are transported through transport proteins on the sarcolemma, to transcribe genes that translate proteins involved in fat metabolism.

CONCLUSION

Fat metabolism is an integral and efficient process for energy production. Regular exercise improves the ability to metabolize fat, which increases functional capacity and delays fatigue during higher intensity or longer duration exercise. Exercise also improves fat burning in obese individuals who may have impaired fat metabolism due to inflammatory and circulatory complications associated with the disease. The positive effects from several types of exercise programs allow fitness professionals to design a wide variety of personalized exercise programs for clients seeking to optimize fat metabolism.

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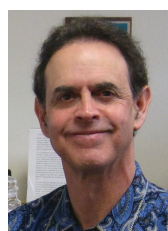
Disclosure: *The authors declare no conflict of interest and do not have any financial disclosures.*



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BRIDGING THE GAP

Fat metabolism is an integral process for energy production that is regulated by energy demand. Obesity causes abnormal fat metabolism that increases the reliance of energy from carbohydrates and makes exercise more difficult due to earlier onset muscle burn caused by metabolic acidosis. Exercise has a range of effects that directly and indirectly improve fat metabolism to promote greater health and fitness.

QUESTIONNAIRE
K4(26)
Exercise and Fat Metabolism

INSTRUCTIONS

- Read through the article and answer the multiple-choice questions provided below.
- **Some questions may have more than one correct answer;** in which case you must mark **all** the correct answers.

Question 1: What is the body's largest energy reservoir?

- A:** Fat
- B:** Protein
- C:** Glucose
- D:** Carbohydrate

Question 2: An important feature of regular exercise is that it improves the capacity to burn fat, which lowers the need to burn carbohydrate as a fuel and results in enhanced exercise capacity and endurance.

- A:** TRUE
- B:** FALSE

Question 3: Subcutaneous body fat provides which if the following? Select all correct options

- A:** Carbohydrate
- B:** A source for muscle repair
- C:** A source of fuel for skeletal muscles
- D:** A temperature control 'blanket' around the body
- E:** None of the above

Question 4: Which of the following is the fat that surrounds organs?

- A:** Superficial fat
- B:** Visceral fat
- C:** Subcutaneous fat
- D:** Deep fat

Question 5: Smaller intramuscular triglyceride stores are metabolized first, before using triglyceride from general adipose tissue stores that require fatty acid delivery to skeletal muscle through circulation.

- A:** TRUE
- B:** FALSE

Question 6: Fat oxidation contributes more than _____% of energy expenditure at exercise intensities that elicit _____% VO₂max?

- A:** 9; 25
- B:** 10; 75
- C:** 90; 25
- D:** 25; 90

Question 7: Maximal fat oxidation occurs at the higher thresholds of steady state exercise, between _____ and _____% VO₂max?

- A:** 60; 65
- B:** 45; 55
- C:** 65; 75
- D:** 85; 95

Question 8: Intramuscular triglycerides generally supply the fatty acids used for fat oxidation for up to _____ of continuous exercise?

- A:** 4 hours
- B:** 1 hour
- C:** 3 hours
- D:** 2 hours

Question 9: Which of the following exercise programs have been shown to bolster fat metabolism for greater efficiency in fuel use and exercise capacity? Select all correct options.

- A:** Low-intensity endurance training
- B:** High-intensity interval training
- C:** High intensity resistance training
- D:** Low- and high-volume resistance training

Question 10: A single exercise session can increase fatty acid levels in circulation for up to _____ hours?

- A:** 36
- B:** 26
- C:** 6
- D:** 3

THE END



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ANSWER SHEET

K4(26)

Exercise and Fat Metabolism

*Time spent on activity						hour		min				
	A	B	C	D	E		A	B	C	D	E	
1						8						
2						9						
3						10						
4						11						
5						12						
6						13						
7						14						
						15						

How relevant was the content of this activity to your scope of practice?			
			
Not at all	Somewhat	Mostly	Extremely

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