BODY FAT AND SPORTS PERFORMANCE

A SPECIAL REPORT FROM

PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

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AND SPORTS PERFORMANCE

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A CIP catalogue record for this book is available from the British Library.

Printed by: PLP Commercial Printers
Impressions House, 3-7 Mowlem Street, London E2 9HE

Published by P2P Publishing Ltd

Registered office: 33-41 Dallington, London, EC1V 0BB
Tel: 0845 450 6402
Registered number: 06014651

ISBN: 978-1-905096-40-4

Publisher Jonathan A. Pye
Editor Sam Bordiss
Designer The Flying Fish Studios Ltd
Illustrations Viv Mullett

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From the editor

Let me begin by stating, this report on body fat is not a guide on how to lose weight. In fact it is almost, but not quite, the opposite. The term ‘body fat’ will commonly evoke negative images and connotations. In sport, unless you are a sumo wrestler, defensive linebacker or prop forward, excess fat is often discriminated against. Yet there is a lot more to understanding the role of body-fat than meets the eye. This mini-report serves to explain the principles behind body composition, fat storage and fat oxidation, and how they can enhance or hinder sporting performance.

The opening chapter explains what your body composition is, how you can measure it, and what effect changes have on your health and performance. Following this the term ‘fat-burning’ is investigated, focusing on the more appropriate term ‘fat-oxidation’. The middle chapter describes the difficulty in finding the perfect balance between fat levels and running performance. Next, an intriguing article on dietary periodisation is presented, which could enhance fat metabolism for endurance athletes. Finally the relationship between body fat and swimming performance is studied.

Hopefully this report leaves you feeling comfortable and toned for success!

Sam Bordiss
Editor

Body composition and sport – why weight is a poor performance indicator

The bathroom scales might tell you how much is there, but they don't tell you what is there. Knowing your body composition, and more specifically your body fat level, allows you to plan and measure the outcomes of your training and dietary programmes more accurately

Introduction

The human body is composed of many different substances all of which are necessary for us to function. These include water, muscle, bone, organs and fat. But while fat is an essential part of the human body, necessary to provide energy for long-duration athletic endeavours, as well as insulation against cold temperatures and the protection of vital organs, it is often portrayed as an undesirable element that must be eliminated at all costs.

In health terms, too much fat is associated with diabetes and coronary heart disease, while the reduced power-to-weight ratio it produces inevitably leads to impaired athletic performance. A very simple measurement of 'fatness' can be performed to determine whether there's an increased risk of coronary heart disease and other obesity-related illnesses. This is body mass index (BMI), defined by body weight in kilograms divided by the square of height in metres. For example, an 80kg athlete who is 1.78 metres tall would have a BMI of 80 divided by 1.782, or 25.2. Individuals with a BMI over 27 are considered to be at a significantly greater risk of health problems than those under 27.

Conversely, female athletes who have very low BMIs (18 and below) may be at risk of developing irregular menstrual cycles[1]. Those females with low overall body weights may also be at greater risk of developing osteoporosis.

Osteoporosis, a disease characterised by decreased bone strength and a reduction in overall bone mineral content (BMC) is most common in postmenopausal women, but also in those with sedentary lifestyles and those whose diets are calcium deficient. Actual body weight has been shown to be a better indicator of BMC than body composition in women of all ages, with heavier women having higher BMC values[2]. However, measuring body composition can help female athletes achieve a healthy body weight that reduces risk of osteoporosis and irregular menses, but allows optimum performance and reduces the risk of coronary heart disease and diabetes by being over-fat.

Measuring fat

Simply measuring your weight by standing on a set of scales does not allow you to determine whether you have an optimal level of fat in your body for your age, sex and chosen sport. Moreover, athletes who are resistance trained are more likely to have greater amounts of fat-free mass, and therefore be heavier than the non-athletic population, so BMI is not always an accurate tool for sports people.

For example, a recent study of US National Football League (NFL) players compared current players with those of 30 years ago, across a wide range of body composition measurements including height, weight, fat-free mass and BMI[3]. The average BMI for the current defensive linemen was a whopping 34.6, based on an average height of 1.92 metres and weight of 127kg. However, their average body fat percentage was only 18.5, just within healthy limits of the normal population (*see table 1*).

Compare these results with a study of 36 professional and 39 amateur sumo wrestlers, who had an average weight of 117kg, a BMI of 36.5 and a body fat percentage of 26.2, which is defined as clinically obese[4]. Sumo wrestling requires many similar actions to those of playing defensive tackles in the NFL but,

Table 1: body fat percentage scales[5]

	% Fat	
Classification	**Women**	**Men**
Essential fat	11-14	3-5
Athletes	12-22	5-13
Fitness	16-25	12-18
Potential risk	26-31	19-24
Obese	32 and higher	25 and higher

despite a similar BMI, there is a very significant difference in body composition between the two sports.

How does training influence body composition?

If you decide to set a weight target and how much or little of that weight should be fat, what can you do to achieve your goal? The good news is that a combination of diet and training will allow you to change your body composition. The bad news is that it requires a consistent approach and also that any change is not permanent, but can easily be reversed if old habits are revisited.

A lot of sportsmen and women assume they have nothing to worry about; they exercise hard, eat what they want and keep in good shape. However, this approach may be a bit haphazard, because although overall weight may stay the same, body composition can change and could indicate a change in performance. Take wrestling and rugby league over the course of a season, for example, and we can see that body composition is not always a constant measure.

College wrestling in the USA is a seasonal sport running from October to March and consisting of between 20 and 30 matches. Wrestlers are put in weight categories, so body composition is constantly monitored to ensure that the wrestler is not carrying excess fat, which would hinder performance.

In a study of 10 US division III college wrestlers, various body composition measures were taken, pre-, mid- and post season, as well as muscular strength and muscular power tests[7]. Body fat percentage and body weight did not change significantly throughout this study, with the wrestlers having an average weight of 67.5kg and 10.5% body fat midway through the season. Muscular power stayed the same throughout the season, but muscular strength declined slightly.

However, changes in body composition did occur in a study of 52 rugby league players in Australia over their season from April to August, following a pre-season that started in December[8]. Players had their sum of skinfolds measured as well as their maximal aerobic power, and maximal muscular power, at four stages of the year:

- Off season;
- Pre-season;
- Mid-season;
- End of season.

Skinfolds were lowest and aerobic and muscular power highest in pre-season, when the players were training the most. As the season progressed, their sum of skinfolds increased, their aerobic and muscular power declined and, interestingly, their rate of injury increased. Training loads were lightest and match playing times at their highest towards the end of the season.

Body weight and body composition are key factors in college wrestling because wrestlers need to maintain a constant weight in order to enter their fighting categories. By contrast, these factors are not the main focus in rugby league, where any decline in fitness and increase in body fat at the end of the season would occur just at the time when matches become more intense as cup competitions come to their finale, and end of season play-offs and promotion/relegation battles come to a head.

In short, playing the sport of your choice does not ensure that your body composition, or other areas of fitness, remain stable. However, by measuring body composition you can determine whether your levels of fat are remaining constant or are changing, and you can therefore implement an in-season training and diet programme accordingly.

Measuring body fat percentage

Body fat percentage can be determined by several methods, all of which try to measure what percentage of your overall body mass is fat (and what is lean tissue). These methods include:

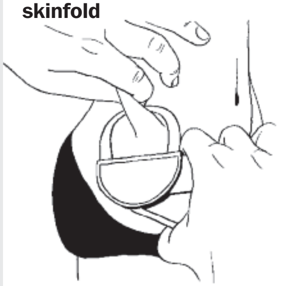
Hydrostatic weighing requires the use of a tank that allows the subject to be measured underwater. A comparison is made between the underwater weight and the dry weight of the subject, taking into account the residual volume of air in the lungs, which affects buoyancy. Because fat is less dense than the other tissues in the body, it floats more easily. The more fat an athlete has, the greater the difference between the dry and wet weights. This is a very accurate measurement, but is time-consuming, labour intensive and not readily available for most populations.

Bioelectrical impedance analysis measures the level of resistance of current through the body. Since water conducts electrical current well, those tissues with higher water levels (muscle) conduct electricity better than those with lower levels (fat). By determining the impedance to electrical current flow, an estimate is made of the percentage of fat in the body. This measurement is quite accurate, but is affected by the level of hydration of the subject, so those subjects who have drunk alcohol, caffeine or have exercised within the previous 12 hours may be dehydrated and not get accurate readings. Females may get different measurements at different points of their menstrual cycle due to water retention[5].

Skinfold callipers are used to measure the levels of subcutaneous fat at different sites around the body. Common sites used are the triceps, biceps, subscapular, suprailiac and the thigh. The tester measures the site by pinching the fat away from the subject's body and then placing the callipers halfway between the base and the apex of the fold. A reading is then taken in millimetres. The sum of these skinfolds is then entered into an equation and a body fat percentage obtained. Consistent measurements of skinfold sums are possible, but this requires the location of the sites on the body to be accurately determined, and properly trained and skilled technicians.

Location for subscapular skinfold

Location for suprailiac skinfold



All three of these methods make certain assumptions in the equations that are used and errors can be made when using these assumptions for different populations. Bone density varies between different ethnic groups and in different age groups of the same ethnic background, so the formulae used in underwater weighing and bioelectrical impedance may not be accurate for non-white subjects, children or the elderly.

Similarly, the equations used to convert the sum of skinfolds to a body fat percentage have mostly been derived from healthy, white, young adult populations. Care has to be taken in applying these equations to overweight, elderly, young and non-white populations[6]

Managing and measuring your body composition

A combination of diet and training can help you control your body composition, but there are many behavioural factors involved, and any behavioural change will be aided by support and education from outside sources such as your family, friends, peers and coaches. A simple resistance training programme of a 75-minute training session, three times a week with diet control has been shown to increase fat-free mass and bone mineral content in obese children[9] in just six weeks. However, changes to your body composition may not be that simple and will depend on your current level of training, how much time you have, and how easy it is for you to change your diet. Whichever route you take, there's no escaping the laws of chemical thermodynamics; for each pound of body fat you want to shed, you'll need to create a 3,500kcal deficit, by increasing your energy output (longer, more frequent or more strenuous training sessions), cutting back your calorie intake, or by a combination of the two.

Measurement strategy

One of the most simple and reliable ways of measuring your body composition is to calculate the sum of your skinfold measurements from four or five sites around your body. You can then compare this with the sum in the future when you remeasure yourself. However, you'll need a pair of skinfold callipers and an assistant who can measure the sites.

The most common sites are the biceps, triceps, subscapular and suprailiac, but the British Olympic Association also recommends that a lower body site such as the front of the thigh also be measured and included[10]. By using the sum of skinfolds, rather than converting to body fat percentage using equations, you can eliminate the errors inherent in the conversion equations but still have a useful measure of your subcutaneous fat levels.

For example, suppose the five sites give you a skinfold total of 45mm. You decide that this corresponds with a low level of fitness and performance and feel that you should lose some fat. You then implement a six- week programme of diet control and an additional 30 minutes of low-intensity cycling twice a week. You retest and find that the sum of skinfolds has dropped to 39mm. You may then decide that your ideal score is somewhere between 35 and 39mm and try to maintain that throughout the year.

A consistent approach to body composition monitoring matched with appropriate training can help prevent a boom and bust cycle of fat gains/losses and performance declines as the season progresses. It will help you to maintain a healthy body composition, and improve your performance in the off season, pre-season and in season.

James Marshall

References

1. *Journal of Sport Sciences 1998; 16(7):629-637*
2. *AHB 29(5):559-565*
3. *Journal of Strength and Conditioning Research 2005; 19(3):485-489*
4. *Annals of Human Biology 1999; 26(2)179-184*
5. *Howley and Franks (1997) Health Fitness Instructor's Handbook, Human Kinetics*
6. *Journal of American Geriatric Society 1997; 45(7):837-843*
7. *JSCR 2005; 19(3):505-508*
8. *JSCR 2005; 19(2):400-408*
9. *JSCR 2005; 19(3):667-672*
10. *JSS 2003; 21(5)369*

Going for the burn

Fat burning is a very popular and often-used term among endurance athletes. But is it really important to burn fat – and, if so, how can it best be achieved? This chapter looks at the latest research

Introduction

The term 'fat burning' refers to the ability to oxidise (or burn) fat, and thus to use fat – instead of carbohydrate – as a fuel. Fat burning is often associated with weight loss, decreases in body fat and increases in lean body mass, all of which can be advantageous for an athlete.

It is known that well-trained endurance athletes have an increased capacity to oxidise fatty acids. This enables them to use fat as a fuel when their carbohydrate stores become limited. In contrast, patients with obesity, insulin resistance and type II diabetes may have an impaired capacity to oxidise fat. As a result, fatty acids may be stored in their muscles and in other tissues. This accumulation of lipid and its metabolites in the muscle may interfere with the insulin-signalling cascade and cause insulin resistance. It is therefore important to understand the factors that regulate fat metabolism, and the ways to increase fat oxidation in patients and athletes.

Fat oxidation during exercise

Fats are stored mostly in (subcutaneous) adipose tissue, but we also have small stores in the muscle itself (intramuscular triglycerides). At the onset of exercise, neuronal (beta-adrenergic) stimulation will increase lipolysis (the breakdown of fats into fatty acids and glycerol) in adipose tissue and muscle. Catecholamines such as adrenaline and noradrenaline may also rise and contribute to the stimulation of lipolysis.

As soon as exercise begins, fatty acids are mobilised. Adipose tissue fatty acids have to be transported from the fat cell to the muscle, be transported across the muscle membrane and then be transported across the mitochondrial membrane for oxidation. The triglycerides stored in muscle undergo similar lipolysis and these fatty acids can be transported into the mitochondria as well. During exercise, a mixture of fatty acids derived from adipocytes and intramuscular stores is used. There is evidence that shows that trained individuals store more intramuscular fat and use this more as a source of energy during exercise[1].

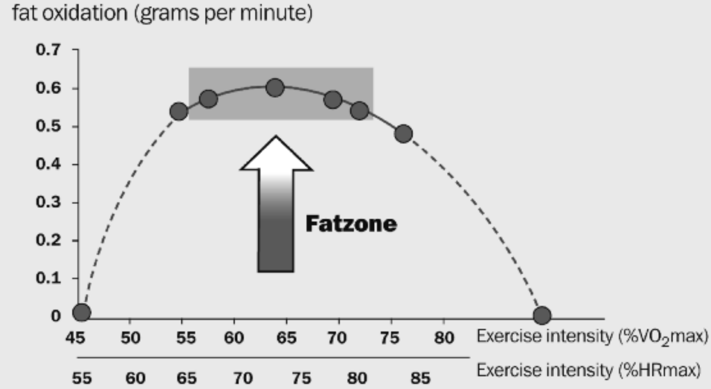
Fat oxidation is regulated at various steps of this process. Lipolysis is affected by many factors but is mostly regulated by hormones (stimulated by catecholamines and inhibited by insulin). The transport of fatty acids is also dependent on blood supply to the adipose and muscle tissues, as well as the uptake of fatty acids into the muscle and into the mitochondria. By inhibiting mobilisation of fatty acids or the transport of these fatty acids, we can reduce fat metabolism. However, are there also ways in which we can stimulate these steps and promote fat metabolism?

Factors affecting fat oxidation

Exercise intensity – One of the most important factors that determines the rate of fat oxidation during exercise is the intensity. Although several studies have described the relationship between exercise intensity and fat oxidation, only recently was this relationship studied over a wide range of intensities[2]. In absolute terms, carbohydrate oxidation increases proportionally with exercise intensity, whereas the rate of fat oxidation initially increases, but decreases again at higher exercise intensities (*see figure 1*). So, although it is often claimed that you have to exercise at low intensities to oxidise fat, this is not necessarily true.

In a series of recent studies, we have defined the exercise intensity at which maximal fat oxidation is observed, called 'Fatmax'. In a group of trained individuals it was found that

Figure 1: Exercise intensity and fat oxidation



Exercise intensity (expressed as %HRmax and %VO_2max) and fat oxidation. Fat oxidation increases from low to moderate exercise intensities, peaks at *Fatmax,* and decreases as the exercise intensity increases further. The grey area represents the Fatzone: a range of exercise intensities where fat oxidation is high.

exercise at moderate intensity (62-63% of VO_2max or 70-75% of HRmax) was the optimal intensity for fat oxidation, whereas it was around 50% of VO_2max for less trained individuals[2,3].

However, the inter-individual variation is very large. A trained person may have his or her maximal fat oxidation at 70%VO_2max or 45%VO_2max, and the only way to really find out is to perform one of these Fatmax tests in the laboratory. However, in reality, the exact intensity at which fat oxidation peaks may not be that important, because within 5-10% of this intensity (or 10-15 beats per minute), fat oxidation will be similarly high, and only when the intensity is 20% or so higher will fat oxidation drop rapidly (*see figure 1*).

This exercise intensity (Fatmax) or 'zone' may have importance for weight-loss programmes, health-related exercise programmes, and endurance training. However, very little research has been done. Recently we used this intensity in a training study with obese individuals. Compared with interval training, their fat oxidation (and insulin sensitivity) improved more after four weeks steady-state exercise (three times per week) at an intensity that equalled their individual Fatmax[4].

Dietary effects – The other important factor is diet. A diet high in carbohydrate will suppress fat oxidation, and a diet low in carbohydrate will result in high fat oxidation rates. Ingesting carbohydrate in the hours before exercise will raise insulin and subsequently suppress fat oxidation by up to 35%[5] or thereabouts. This effect of insulin on fat oxidation may last as long as six to eight hours after a meal, and this means that the highest fat oxidation rates can be achieved after an overnight fast.

Endurance athletes have often used exercise without breakfast as a way to increase the fat-oxidative capacity of the muscle. Recently, a study was performed at the University of Leuven in Belgium, in which scientists investigated the effect of a six-week endurance training programme carried out for three days per week, each session lasting one to two hours[6]. The participants trained in either the fasted or carbohydrate-fed state.

When training was conducted in the fasted state, the researchers observed a decrease in muscle glycogen use, while the activity of various proteins involved in fat metabolism was increased. However, fat oxidation during exercise was the same in the two groups. It is possible, though, that there are small but significant changes in fat metabolism after fasted training; but, in this study, changes in fat oxidation might have been masked by the fact that these subjects received carbohydrate during their experimental trials. It must also be noted that training after an overnight fast may reduce your exercise capacity and may therefore only be suitable for low- to moderate- intensity exercise sessions. The efficacy of such training for weight reduction is also not known.

Duration of exercise – It has long been established that oxidation becomes increasingly important as exercise progresses. During ultra-endurance exercise, fat oxidation can reach peaks of 1 gram per minute, although (as noted in Dietary effects) fat oxidation may be reduced if carbohydrate is ingested before or during exercise. In terms of weight loss, the duration of exercise may be one of the key factors as it is also the most effective way to increase energy expenditure.

Mode of exercise – The exercise modality also has an effect on fat oxidation. Fat oxidation has been shown to be higher for a given oxygen uptake during walking and running, compared with cycling(7). The reason for this is not known, but it has been suggested that it is related to the greater power output per muscle fibre in cycling compared to that in running.

Gender differences – Although some studies in the literature have found no gender differences in metabolism, the majority of studies now indicate higher rates of fat oxidation in women. In a study that compared 150 men and 150 women over a wide range of exercise intensities, it was shown that the women had higher rates of fat oxidation over the entire range of intensities, and that their fat oxidation peaked at a slightly higher intensity(8). The differences, however, are small and may not be of any physiological significance.

Nutrition supplements

There are many nutrition supplements on the market that claim to increase fat oxidation. These supplements include caffeine, carnitine, hydroxycitric acid (HCA), chromium, conjugated linoleic acid (CLA), guarana, citrus aurantium, Asian ginseng, cayenne pepper, coleus forskholii, glucomannan, green tea, psyllium and pyruvate. With few exceptions, there is little evidence that these supplements, which are marketed as fat burners, actually increase fat oxidation during exercise (*see table 1*).

One of the few exceptions however may be green tea extracts. We recently found that green tea extracts increased fat oxidation during exercise by about 20%(4). The mechanisms of this are not well understood but it is likely that the active ingredient in green tea, called epigallocatechin gallate (EGCG – a powerful polyphenol with antioxidant properties) inhibits

Table 1: Nutrition supplements and the scientific evidence that the supplement increases fat metabolism

Nutrition supplement	Evidence	Fat-burning properties or claims
Caffeine	●●●○○	Caffeine stimulates lipolysis and the mobilisation of FAs. These actions might occur indirectly, by increasing the circulating catecholamine levels; or directly, by antagonising receptors that normally inhibit hormone-sensitive lipase and FA oxidation. In some, but not all, conditions this can result in increased fat oxidation.
Carnitine	○○○○○	Carnitine is essential for fat oxidation, as it is needed to transport fatty acids into the mitochondria. Studies have shown, however, that carnitine supplementation may not result in increased muscle carnitine supplementation and therefore it is not surprising that no effects on fat oxidation have been found. Nevertheless, it is one of the supplements aggressively marketed as a fat burner.
Chromium	○○○○○	Chromium was a very popular supplement a few years ago and was associated with insulin sensitivity and fat burning. There is no evidence that chromium has any effect on fat metabolism.
Guarana	●●○○○	The active constituent of guarana, guaranine, is nearly identical to caffeine and is likely to have similar properties. Compared with caffeine, there has been far less research on guaranine.
Ginseng (Asian or Panax)	○○○○○	Asian ginseng (Panax ginseng) has been a part of Chinese medicine for over 2,000 years, and was traditionally used to improve mental and physical vitality. However, evidence for its fat-burning properties is lacking.
Green tea	●●●○○	The active constituents in green tea are the polyphenols, particularly the catechin epigallocatechin gallate (EGCG). However, green tea also contains caffeine. A recent study found that after taking green tea extract, fat oxidation during exercise rose by about 20%.
Hydroxycitric acid (HCA)	○○○○○	HCA is a derivative of citric acid that is found in a variety of tropical plants. There is no evidence that it has any effect on fat metabolism.
Tyrosine	○○○○○	L-tyrosine is a nonessential amino acid that serves as a precursor to catecholamines. The assumption is that more tyrosine results in chronically elevated catecholamine concentrations and increased lipolysis. However, there is no evidence to support this.

The scientific evidence is indicated with ●●●●● meaning very strong evidence and ○○○○○ limited to no evidence the enzyme catechol O-methyltransferase (COMT), which is responsible for the breakdown of noradrenaline. This in turn may result in higher concentrations of noradrenaline and stimulation of lipolysis, making more fatty acids available for oxidation.

Environment – Environmental conditions can also influence the type of fuel used. It is known that exercise in a hot environment will increase glycogen use and reduce fat oxidation, and something similar can be observed at high altitude. Similarly, when it is extremely cold, and especially when shivering, carbohydrate metabolism appears to be stimulated at the expense of fat metabolism.

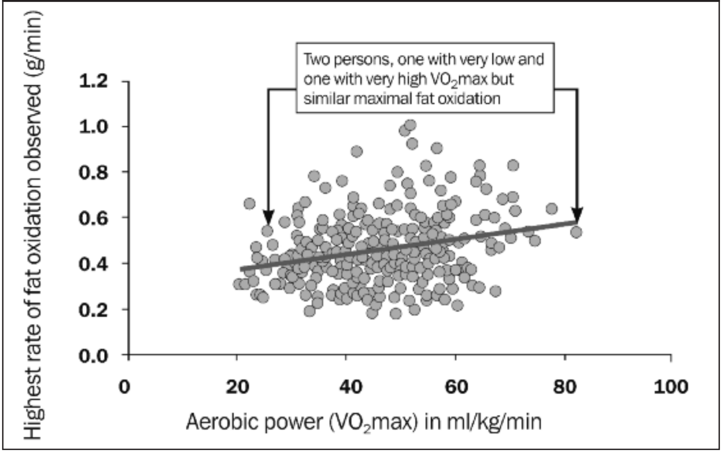
Exercise training

At present, the only proven way to increase fat oxidation during exercise is to perform regular physical activity. Exercise training will up-regulate the enzymes of the fat oxidation pathways, increase mitochondrial mass, increase blood flow, *etc*., all of which will enable higher rates of fat oxidation.

Research has shown that as little as four weeks of regular exercise (three times per week for 30-60 minutes) can increase fat oxidation rates and cause favourable enzymatic changes(10). However, too little information is available to draw any conclusions about the optimal training programme to achieve these effects.

In one study we investigated maximal rates of fat oxidation in 300 subjects with varying fitness levels. In this study, we had obese and sedentary individuals, as well as professional cyclists(9). VO_2max ranged from 20.9 to 82.4ml/kg/min. Interestingly, although there was a correlation between maximal fat oxidation and maximal oxygen uptake, at an individual level, fitness cannot be used to predict fat oxidation. What this means is that there are some obese individuals that have similar fat oxidation rates to professional cyclists (*see figure 2*)! The large inter-individual variation is related to factors such as diet and gender, but remains in large part unexplained.

Figure 2: Maximal fat oxidation as a function of aerobic power (VO_2max). Data from[9].



Weight loss exercise programmes

Fat burning is often associated with weight loss, decreases in body fat and increases in lean body mass. However, it must be noted that such changes in body weight and body composition can only be achieved with a negative energy balance: you have to eat fewer calories than you expend, independent of the fuels you use! The optimal exercise type, intensity, and duration for weight loss are still unclear. Current recommendations are mostly focused on increasing energy expenditure and increasing exercise volumes. Finding the optimal intensity for fat oxidation might aid in losing weight (fat loss) and in weight maintenance, but evidence for this is currently lacking.

It is also important to realise that the amount of fat oxidised during exercise is only small. Fat oxidation rates are on average 0.5 grams per min at the optimal exercise intensity. So in order to oxidise 1kg of fat mass, more than 33 hours of exercise is required! Walking or running exercise around 50-65% of VO_2max seems to be an optimal intensity to oxidise fat. The duration of exercise, however, plays a crucial role, with an increasing importance of fat oxidation with longer exercise. Of course, this also has the potential to increase daily energy expenditure. If exercise is the only intervention used, the main goal is usually to increase energy expenditure and reduce body fat. When combined with a diet programme, however, it is mainly used to counteract the decrease in fat oxidation often seen after weight loss[11].

Summary

Higher fat oxidation rates during exercise are generally reflective of good training status, whereas low fat oxidation rates might be related to obesity and insulin resistance. On average, fat oxidation peaks at moderate intensities of 50-65%VO_2max, depending on the training status of the individuals[2,8], increases with increasing exercise duration, but is suppressed by carbohydrate intake. The vast majority of nutrition supplements do not have the desired effects. Currently, the only highly effective way to increase fat oxidation is through exercise training, although it is still unclear what the best training regimen is to get the largest improvements. Finally, it is important to note that there is a very large inter-individual variation in fat oxidation that is only partly explained by the factors mentioned above. This means that although the factors mentioned above can influence fat oxidation, they cannot predict fat oxidation rates in an individual.

Asker Jeukendrup

References

1. *J Appl Physiol 60: 562-567, 1986*
2. *Int J Sports Med 24: 603-608, 2003*
3. *Int J Sports Med 26 Suppl 1: S28-37, 2005*
4. *Am J Clin Nutr 87: 778-784, 2008*
5. *J Sports Sci 21: 1017-1024, 2003*
6. *J Appl Physiol 104: 1045-1055, 2008*
7. *Metabolism 52: 747-752, 2003*
8. *J Appl Physiol 98: 160-167, 2005*
9. *Nutrition 20: 678-688, 2004*
10. *J Appl Physiol 56: 831-838, 1984*
11. *Int J Obes Relat Metab Disord 17 Suppl 3: S32-36; discussion S41-32, 1993*

Running and body fat – walking the tightrope of optimum performance

All runners know that excess body fat can hinder running performance. However, the relationship between running performance, dietary intake and fat levels is not quite as straightforward as it seems

Introduction

Although it's immediately apparent that there are substantial differences in physical characteristics between sprinters and long distance runners, elite runners at all distances come in a variety of shapes and sizes, and there are perhaps too many exceptions to make all but the broadest generalisations. Generally speaking though, sprinters have powerfully developed musculature of the upper body and of the legs, while distance runners have low body mass, with smaller muscles and extremely low body fat levels.

The one outstanding anthropometric characteristic of successful competitors in all running events is a low body fat content. The textbooks tell us that the body fat stores account for about 15-18% of total body weight in normal young men, and in young women the figure is about 25-30%.

'Normal', of course, is changing, and those ranges should be qualified as being normal for healthy people. Most of this fat is not necessary for energy supply and is simply extra weight that has to be carried throughout the race. This is not to say that people carrying extra fat cannot complete a marathon – they just can't do it in a fast time.

Our fat stores are important and the fat cells play many key roles. As well as acting as a reserve of energy that can be called upon at times of need, fat is important in the structure of tissues, in hormone metabolism, and in providing a cushion that protects other tissues.

An excess of body fat, however, serves no useful function for the endurance athlete. It can help the sumo wrestlers, and perhaps may not even be a disadvantage for the shot putter, but not the runner. Extra fat adds to the weight that has to be carried, and thus increases the energy cost of running. Even in an event as long as the marathon, the total amount of fat that is needed for energy supply does not exceed about 200g for the average runner.

A very lean male 60kg runner with 5% body fat will have 3kg of fat; a typical elite 55kg female runner with 15% body fat will have more than 8kg of body fat. Non-elite runners will commonly have at least twice this amount, and many runners further down the field will be carrying 20kg or more of fat.

Although not all of this is available for use as a metabolic fuel, the amount of stored fat is greatly in excess of that which is necessary for immediate energy production. Within limits, reducing this will lead to improvements in performance, but if the loss is too sudden or too severe, then performance and health may both suffer.

It is probably not sensible for men to let their body fat levels go below about 5% and for women below about 10-15%. There's good evidence that the immune system is impaired when body fat stores are too low(1). A reduced ability to fight infections means more interruptions to training and more chance of being sick on race day.

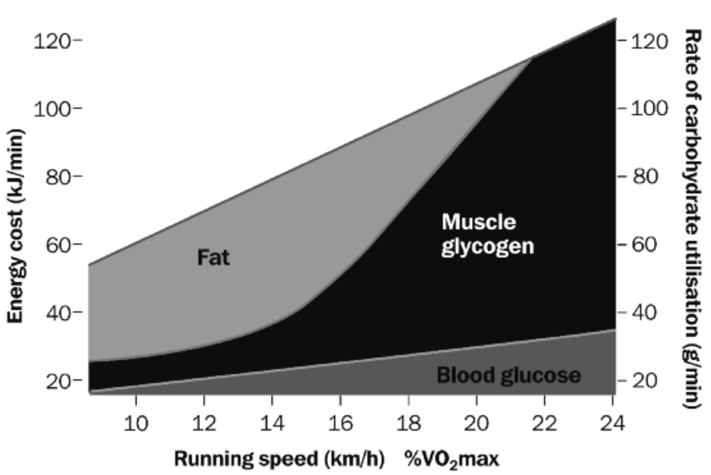
‘Fat typically contributes about half of the total energy cost of a long run’

For female athletes, there are some very immediate consequences of a low body fat level, including especially a fall in circulating oestrogen levels(2). This in turn can lead to a loss of bone mass, causing problems for women in later life through an increased risk of bone fracture. Equally, though, performance will suffer if the body fat level is too high, so staying healthy and performing at peak level is a real challenge.

Fat typically contributes about half of the total energy cost of a long run (this is very approximate, and will depend on speed, fitness, diet and other factors). The graph below shows that at low running speeds, the total energy demand is low and most of the energy supply is met by oxidation of fat, with only a small contribution from carbohydrate in the form of muscle glycogen and blood glucose (which is continuously being replaced by glucose released from the liver).

As speed increases, the energy cost increases more or less in a straight line, but the relative contribution from fat begins to decrease, with muscle glycogen becoming the most important fuel. The problem with running slowly to reduce body fat levels is that it takes a long time, because the rate of energy expenditure is too low. Run too fast, and you burn only carbohydrate, leaving the fat stores more or less untouched.

Contribution of fuel sources as a function of running speed



The left-hand vertical axis shows total energy expenditure in kilojoules per minute (kJ/min); the red shaded area at the bottom represents the contribution of blood glucose to energy supply level; the pink and black shaded areas show the relative contributions from fat and muscle glycogen respectively to energy demand.

Importance of fat

To get an idea of the importance of fat, you can try the following sums. For simplicity, we'll assume that:

- The energy cost of running is about 1 kilocalorie per kilogram body mass per kilometre;
- The energy available from fat oxidation is 9 kilocalories per gram;
- About half of the energy used in a run will come from fat (this amount will actually be greater at low speeds and for fitter runners, and will also be higher if the run is completed after fasting overnight as opposed to just after a high carbohydrate meal).

Example 1

If you weigh 50kg, the total amount of energy you will use in a 10km run is 50x10 = 500kcals. If all of the energy were to come from fat, this would use 500/9 = 56 grams of fat. Half of this is 28 grams fat (almost exactly one ounce in old units).

Example 2

If you weigh 80kg the total energy cost of running a marathon (42.2km) is 80x42.2 = 3,376kcals. If all of the energy were to come from fat, this would use 3,376/9 = 375 grams. Half of this is 188 grams or around 7oz.

Three things emerge from this:

1. The amount of fat you need for even a marathon is small compared to the amount stored; a 70kg runner with 20% body fat has 14kg of stored fat. A 60kg runner with 30% fat has 18kg.
2. Even though the amounts of fat used may seem small, regular running will nibble away at the fat stores – good news if your aim is to use exercise to control or reduce your body fat levels. A runner who uses 28 grams three times per week will lose about 3.5kg of fat over the course of a year. The results are not immediate but, if you persist, the cumulative results are impressive.

3. Running speed does not figure in the equation. If you run for 40 minutes, you might do 5km or you might do 10km.

Body fat and performance

In a study of a group of runners with very different levels of training status and athletic ability, scientists observed a significant relationship between body fat levels and the best time that these runners could achieve over a distance of 2 miles(3). Although these results indicated that leaner individuals seem to perform better in races at this distance, some complicating factors have to be taken into account.

The relationship between body fat and race time may at least in part be explained by an association between the amount of training carried out and the body composition. It would hardly be surprising if those who trained hardest ran fastest, and it would also not surprise most runners to learn that those who train hardest also have the lowest fat levels. Indeed, body fat content does tend to decrease as the volume of training increases, as we found out some years ago when we studied a group of local runners in Aberdeen(4).

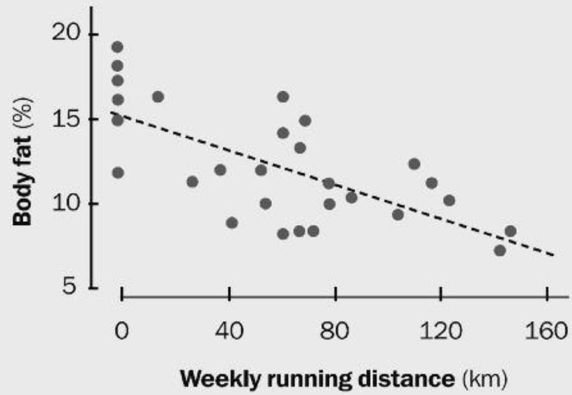
Strategies for controlling weight and body fat while maintaining training

- Pay attention to the portion sizes you consume at meals to ensure that overeating does not occur due to habit;
- Use well chosen snacks between meals to maintain fuel levels for training sessions or to avoid excessive hunger, but avoid snacking for entertainment, for comfort or just to keep others company. Snacks can often be organised by saving part of a meal for a later occasion, rather than by eating extra food;
- Use low-fat – or at least reduced-fat – strategies in choosing foods and while cooking or preparing meals;
- Make meals and snacks more ‘filling’ by including plenty of salads and vegetables, by taking higher-fibre options when these are available, and by including low-glycaemic forms of carbohydrate;
- Keeping a food diary in which you write down everything you eat and drink for a week will help to identify the difference between your ideal eating plan and your actual intake. Many people are unaware of the habits that sabotage their eating goals.

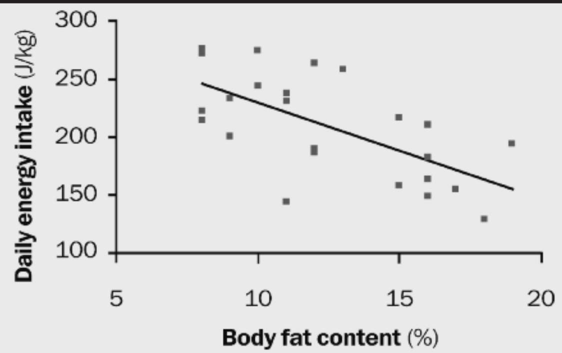
We recruited a group of runners who had been running for at least two years, and asked some sedentary colleagues to act as a control group. All had maintained the same body weight for at least two months before we measured them, and all had had a constant level of physical activity over that time. We measured body fat levels and also got a record of the weight of all food and drink consumed over a one-week period.

As you can see from the following graphs, the runners covering the greatest distance in training had the lowest body fat levels. They also ate more food than those who did less running.

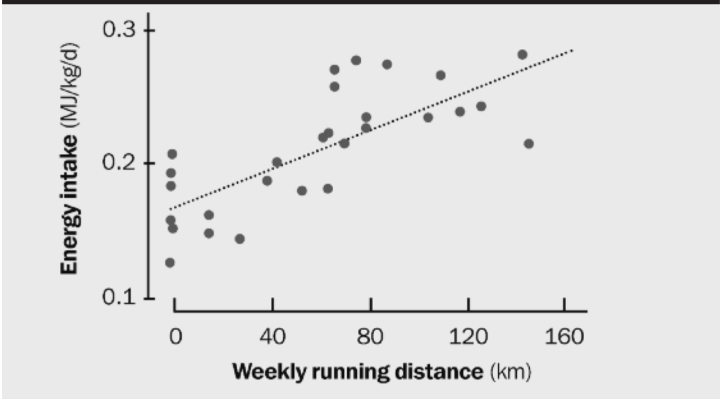
Relationship between body fat and weekly running distance



Relationship between calorie intake and body fat



Relationship between energy intake and weekly running distance



There are, of course, some people who do not fit the line as well as others, but there are many factors that explain this variability. We would expect the people who eat more to be fatter, but no! The subjects who did most running had the lowest levels of body fat, even though they did eat more. Thus, we can separate food intake from body fatness if we add exercise to the equation.

Fat levels in elite runners

Skinfold thickness estimates of body composition in 114 male runners at the 1968 US Olympic Trial race gave an average fat content of 7.5% of body weight, which was less than half that of a physically active but not highly trained group[5]. Since then, similar measurements have been made on various groups of runners, and the findings are fairly consistent.

The low body fat content of female distance runners is particularly striking; values of less than 10-15% are commonly reported among elite performers, but are seldom seen in healthy women outside sport. The occasional exceptions to the generalisation that a low body fat content is a pre-requisite for success are most likely to occur in women's ultra-distance running, and some recent world record holders at ultra-distances have been reported to have a high (in excess of 30%) body fat content. However, this probably reflects the under-developed state of women's long distance running; as more women take part, the level of performance can be expected to rise rapidly, and the elite performers are likely to conform to the model of their male counterparts and of successful women competitors at shorter distances.

Although there's an intimate link between body fat levels and running performance, it's important to remember that reducing fat levels will not automatically guarantee success and may even be counter-productive. If you reduce fat by a combination of training and restricting diet, you are walking a fine tightrope. While a reduction in body fat may well boost running performance, cut down food intake too drastically and not only will training quality suffer, but the risk of illness and injury also increases dramatically.

Ron Maughan

References

1. Journal of Sports Science 2004; 22:115-125

2. Journal of Sports Science 2004; 22;1-14

3. Journal of Sports Medicine 1986; 26:258-262

4. Proceedings of the Nutrition Society 1990; 49:27A

5. Medicine and Science in Sports 1970; 2:93-95

Dietary periodisation – can you enhance performance by burning more fat?

Many athletes are familiar with the concept of training 'periodisation', where training volume and intensity are deliberately structured in distinct phases in order to peak for a specific event, while allowing adequate recovery. In recent years, however, 'dietary periodisation' has been proposed for endurance athletes as a way of enhancing fat metabolism and conserving precious muscle glycogen. But does it work?

Introduction

Although it sounds exotic, if you participate in an endurance sport such as running or cycling, dietary periodisation is something that you've probably already practised without realising. Think about your last long-distance event. Did you manipulate your dietary patterns away from normal in the days leading up to that event, for example by increasing your carbohydrate? If you did, you were practising a simple form of dietary periodisation.

Dietary periodisation tends to mean different things to different people, but in general terms involves departing from the normal diet in order to bring about a specific metabolic adaptation that might improve performance in a future event. There are a number of examples of the use of dietary periodisation in sport; marathon runners who carbohydrate-load before the big day; boxers and wrestlers who diet down before a contest to make their fighting weight; bodybuilders who follow ultra low-fat and low-sodium diets in order to become 'ripped' before a contest. And in more recent years, a

'If there's not enough carbohydrate being broken down, fat metabolism is also compromised'

new type of dietary periodisation practice has emerged – the manipulation of diet in the run-up to an endurance event to enhance fat oxidation as a source of energy during the event. This periodisation strategy involves altering fat metabolism and for this reason is sometimes known as 'fat adaptation'.

Why periodise using fat adaptation?

Although fat and protein can both serve as fuel sources, it's carbohydrate that provides most of the fuel for intense exercise (see diagram). There are several reasons why carbohydrate is such an important fuel, but one of the most important is that only carbohydrate can supply energy rapidly enough to generate ATP (the energy-releasing molecule used to drive muscular contraction) during vigorous exercise. Although fat is a rich source of energy, the energy it contains cannot be released without the presence of oxygen, so it cannot play any part in fuelling anaerobic (*ie* very vigorous) exercise.

Another reason for the critical importance of carbohydrate is that even when exercise intensity is lower, and more of the energy can be derived from fat, a continual breakdown of carbohydrate is required to allow the efficient oxidation of fat for energy. This is because the fragments of fat molecules formed in the first stage of fat oxidation (acetyl-CoA) can only undergo the second stage of oxidation when combined with a molecule called oxaloacetic acid, the main source of which is from carbohydrate metabolism. If there's not enough carbohydrate being broken down, fat metabolism is also compromised. This explains the saying that 'fat burns in a carbohydrate flame'.

Storage

Carbohydrate then is the fuel of choice for vigorous exercise, but there's a major problem and that's storage. Even well-trained endurance athletes can only store about 400g of muscle carbohydrate (glycogen) and around 100g of liver glycogen. And since carbohydrate supplies 4kcals of energy per gram, this amounts to not much more than 2,000kcals in total – enough to fuel a little over two hours of extremely vigorous exercise.

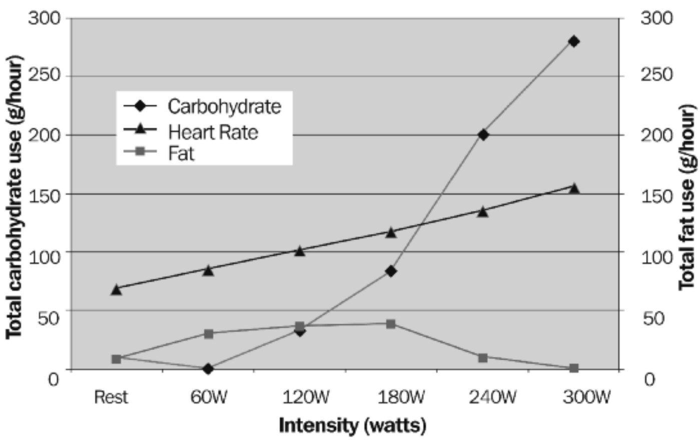
Compare this with fat; a 70kg athlete with a low body fat level of 10% carries 7kg of fat. But since fat supplies 9kcals per gram, this equates to 63,000kcals of available energy. More typically, the average adult stores over 100,000kcals of fat energy and this explains why fat is the preferred source of energy for the body when rapid energy supply is not the priority.

Focusing on fat

The most popular and successful nutritional strategies for prolonging high-intensity endurance exercise have been carbohydrate focused – *ie* maximising glycogen before an event (carbohydrate loading), replenishing carbohydrate during an event (carbohydrate feeding) and replenishing lost carbohydrate immediately after training or competition[1]. However, if carbohydrate was the only source of energy during vigorous exercise, these strategies would still be insufficient to ensure sufficient levels of muscle carbohydrate throughout a long event such as the marathon, and even elite runners would hit a brick wall before crossing the finishing line.

Total metabolic fuel use with increasing exercise intensity

Diagram showing how intensity affects fuel demand; note that at high intensities carbohydrate demand rises steeply, while fat demand falls



Fortunately, well-trained endurance athletes can supply a significant proportion of their energy needs from fat, even at high levels of VO_2max, which means that the rate of depletion of muscle glycogen during an event such as the marathon is slowed, thereby maintaining sufficient stores to complete a marathon without hitting the 'wall'.

If an athlete can increase the proportion of energy derived from fat during vigorous exercise, he or she can conserve stores of glycogen and should be able to maintain high-intensity workloads for longer. This explains the rationale of using ergogenic aids such as caffeine and carnitine to sustain endurance; by helping to mobilise fatty acids and make them more available for oxidation, precious and limited stores of muscle glycogen can be conserved.

Dietary periodisation and fat adaptation

The principle of enhancing fat oxidation rates in order to conserve glycogen, thereby prolonging high-intensity endurance capability, is precisely the goal of dietary periodisation to produce fat adaptation. The theory goes like this: before an important event, consume a high-fat diet for three to seven days followed by a high-carbohydrate diet. During the high-fat period, the body 'adjusts' by increasing the proportion of energy derived from fat – an effect that is sustained for a few days even when the diet switches over to high-carbohydrate. The high-carbohydrate period then helps to ensure that muscle glycogen stores are fully replenished. The net result is muscles topped up with glycogen and an increased fat oxidation rate, which combine to conserve glycogen stores and prolong maximum output during an endurance event. But what's the evidence that this type of dietary periodisation actually works?

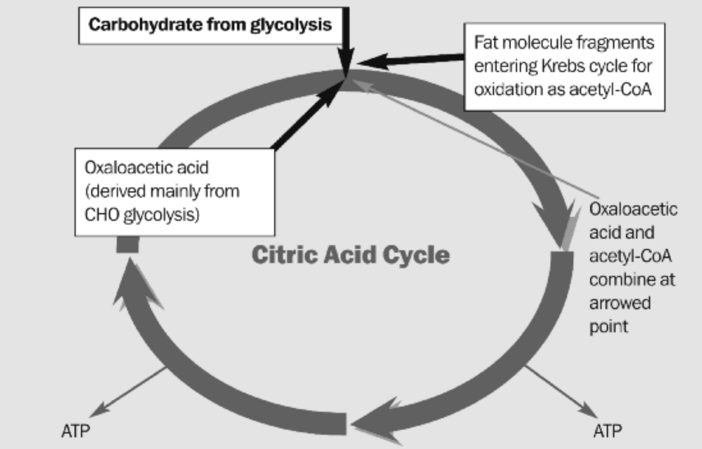
There's certainly no doubt that high-fat diets up-regulate enzymes in the body, resulting in higher rates of fat oxidation. In a study carried out in 2002, scientists studied the effect of either five days of high-fat intake followed by one day of high carbohydrate intake, or six days of high carbohydrate intake on eight endurance-trained athletes (all diets contained the same number of calories)[2]. During the five-day trial period, the subjects continued to train as normal, but on the sixth day (high carbohydrate diet for all subjects), they rested. Both groups then cycled for two hours at 70% VO_2max on day seven, and then performed a time trial lasting approximately 25 minutes. By taking respiratory exchange ratio measurements in both groups of subjects, the researchers found that:

- Fat oxidation before and during the two-hour steady state ride was increased in the high-fat diet group, despite the fact that the subjects had consumed a high-carbohydrate diet the previous day;
- Carbohydrate oxidation in this group was also reduced;
- Time trial results were not significantly different between the two groups (more later).

In the second study the same year, seven endurance athletes underwent a shorter 'fat adaptation' period of just three days[3]. After a consuming a standardised diet on day one, the subjects consumed either a high-carbohydrate or an isocaloric

Fat and the carbohydrate flame

Diagram showing why fat burns in a carbohydrate flame. Molecular fragments of fat (acetyl-CoA) from the early stages of oxidation need to combine with oxaloacetic acid from (mainly) carbohydrate metabolism in order to enter the 'aerobic furnace' of the Citric Acid Cycle and release their energy in the form of ATP



(*ie* containing the same number of calories) high-fat diet for three days. On day five, all the subjects completed a lab training session consisting of a 20-minute warm up at 65% VO_2max, followed by eight five-minute bouts at 86% of VO_2max with one minute recovery in between. After an 18-day period, the groups were switched – *ie* those who had followed the high-fat regime followed a high-carbohydrate diet and vice-versa – and the trial was repeated.

Results showed that after the high-fat diet, the rate of fat oxidation increased from 31 to 61 micromol/kg/min – an increase of almost 100%. However, although the work rate was maintained on the high-fat diet, the perceived rate of exertion increased from an average of 13.8 to 16.0.

How does fat adaptation occur?

Other studies have also confirmed that dietary periodisation consisting of a high-fat diet for a few days does indeed enhance the rate of fat oxidation and even spares carbohydrate reserves[4,5]. So how does fat adaptation occur?

A study on seven male cyclists looked at metabolic changes that occurred after five days of a high-fat diet while training, followed by one day of high-carbohydrate intake, and compared these to six days of isocaloric high-carbohydrate diet[6]. In particular, the researchers were keen to observe the activity of two key enzymes: pyruvate dehydrogenase (PDH – a key enzyme in carbohydrate metabolism) and hormone sensitive lipase (HSL – a key enzyme involved in the breakdown of fat for energy). The results showed the following:

- Compared to the high-carbohydrate diet, the high-fat diet decreased levels of PDH by around 30% and increased HSL levels by around 20%;
- The changes in enzyme levels persisted even after the day of high-carbohydrate feeding to restore muscle glycogen levels to normal;
- During the cycling test on day seven, fat oxidation was increased by around 45%, while carbohydrate oxidation was reduced by around 30%.

The results provide strong evidence that fat adaptation works by up-regulating enzymes involved in fat oxidation while at the same time down-regulating those involved in carbohydrate oxidation. The exact mechanisms for these shifts in enzyme levels are unclear, but there's evidence that a high concentration of dietary fatty acids may directly influence the expression of the genes that code for these enzymes[7].

What are the performance benefits?

So far, so good. We know that fat adaptation does what it says on tin (*ie* increases fat oxidation and conserves muscle glycogen) and how these metabolic changes seem to come about. But what's the evidence it actually improves the performance of endurance athletes? This is where the arguments in favour of this practice come unstuck, because there's little evidence that it confers any real advantage where it counts – on the ground. A number of studies have been carried out comparing the performance of endurance athletes on a normal high-carbohydrate diet with an isocaloric fat adaptation diet followed by carbohydrate replenishment. These include:

- Eight cyclists who followed a five-day fat adaptation regime and who performed no better during a 30-minute time trial than when they followed a normal (high-carbohydrate) diet[6];
- Seven cyclists who followed a five-day fat adaptation regime and who performed no better when asked to complete a 20-minute ride at 80% VO_2max then do a high-intensity 30-minute time trial than on a normal diet[5];
- Seven cyclists who performed no better after following a high-fat adaptation regime for six days then performing a four-hour ride at 65% VO_2max followed by a one-hour time trial, compared to a normal (high-carbohydrate) regime[8].

Fat adaptation may impair performance

On top of this lack of evidence for the performance benefits of fat adaptation has come new research that shows it may

Drawbacks of high-fat diets

Training

Although a dietary period of fat adaptation might sound appealing, it's not all plain sailing. In the studies quoted here, many subjects reported symptoms of lethargy, mild headaches and fatigue during the high-fat treatment. In the studies that incorporated supervised training protocols, many subjects had trouble in completing at least one of their scheduled training sessions, complaining of either an increased perception of effort or difficulty in maintaining the desired training pace. A week of reduced training quality during the fat adaptation period may be a high price to pay for purely theoretical benefits.

Health

Another potential drawback concerns health. High-fat/low-fibre diets are associated with higher levels of blood cholesterol and coronary heart disease as well as cancer, especially of the bowel. While an occasional period of fat adaptation is unlikely to do any harm, regular use of this practice would be hard to recommend on current medical evidence.

even impair performance. A study carried out earlier this year looked at 100km cycling performance and 1km sprint performance in eight well-trained cyclists following a period of fat adaptation[9].

Cyclists completed two trials; a high-carbohydrate diet (68% calories from carbohydrate) and an isocaloric high-fat diet (68% calories from fat). Each trial lasted for six days and was followed by one day of carbohydrate loading. The subjects completed a 100km time trial on day one and a one-hour cycle at 70% VO_2max on days three, five and seven. On day eight, subjects completed another 100km performance time trial followed by a 1km sprint time trial. The results were as follows:

- As expected, the high-fat diet increased blood levels of fatty acids and the fat oxidation rate;
- The 100km time trial performances, perceived rate of exertion, heart rates and electrical activity patterns of the working muscles showed no difference between high-fat and high-carbohydrate conditions;

- The 1km sprint power output after the high-fat diet was significantly reduced.

So here was a carefully crafted study that not only failed (like other studies) to demonstrate any performance benefits of fat adaptation, but also showed a real decline in performance. As Professor Louise Burke, one of the leading authorities in this area of sports nutrition, commented in the same journal, 'Is this study the nail in the coffin for fat adaptation to enhance athletic performance?'

What's going on?

The obvious question is why, when fat adaptation ticks all the right theoretical boxes, does it fail to produce any performance increase or even result in reduced performance? This lack of performance is observed even after glycogen replenishment, when in theory fat adaptation should produce the best of both worlds – more efficient and higher fat utilisation and high levels of muscle glycogen.

The most likely explanation at present involves the metabolic changes in enzyme activity described above[6]. Although fat adaptation increases fat oxidation, thereby conserving stores of carbohydrate, it also seems to reduce the activity of enzymes needed for the release of energy from carbohydrate, such as PDH. In other words, yes you're conserving muscle glycogen, but you're also preventing your body from utilising that glycogen as efficiently as you would normally. And given that the critical importance of carbohydrate is its ability to rapidly generate large amounts of ATP for muscular contraction with or without oxygen, any theoretical benefits from fat adaptation are soon lost.

We've probably not heard the end of fat adaptation as a method of dietary periodisation just yet; there's still the possibility that it could benefit ultra-endurance athletes whose events are three hours and upwards in duration. In such long events, athletes tend to work at lower intensities, so any issues regarding a potentially reduced rate of carbohydrate metabolism may not be so relevant. However, for most endurance athletes, the clear message is to forget about manipulating your fat metabolism and keep taking the carbohydrate – before, during and after training/competition.

Andrew Hamilton

References

1. *Lamb DR and Murray R (eds) (1999) Perspectives in exercise science and sports medicine. Carmel, In.: Cooper. 93-124*
2. *Med Sci Sports Ex 2002; 34:83-91*
3. *Med Sci Sports Ex 2002; 34:449-55*
4. *Br J Nutr 2000; 84:829-38*
5. *J Appl Physiol 2000; 89:2413-2421*
6. *Am J Physiol – Endocrin and Metab 2006; 290:E380-E388*
7. *Am J Clin Nutr 2003; 77: 313-8*
8. *J Appl Physiol 2001; 91: 115-22*
9. *J Appl Physiol Jan 2006; 100(1):7-8*

Should swimmers fight fat for fighting fitness?

Just as in other sports, body composition can play an important role in swimming performance. But what does the latest research say about optimum body composition for swimmers and how best to achieve it?

Introduction

In most sports, achieving optimum body composition is relatively simple and governed by two simple rules. Firstly, lower levels of body fat equate to less 'dead weight' and improved performance; secondly, providing the dietary fundamentals are correct, training for that sport will help to bring about optimum body composition. For swimmers, however, things aren't quite so straightforward.

On land, superfluous body fat acts as a 'dead weight' that blunts acceleration and makes work against gravity (which takes place in any sport that involves running or moving around on foot) more energy demanding for the muscles having to do the work. Since all the propulsive force required to overcome gravity and inertia comes from muscular contraction, having a high power-to-weight ratio (*ie* plenty of lean muscle tissue and a minimum of body fat) makes moving around on land much easier!

In the water, however, things aren't so simple and that's because unlike most other body tissues, body fat is less dense than water (see table 1). In simple terms, a given volume of fatty tissue weighs less than the same volume of lean muscle tissue, because fat is inherently less dense than water, and lean muscle tissue contains much more water than fatty tissue.

Table 1: Relative densities of different body tissue*

Tissue type	Density (kg/m3)
Blood	1,060
Bone	1,810
Bone marrow	1,810
Cartilage	1,100
Eye	1,170
Fat	920
Lens	1,100
Muscle	1,040
Nerve tissue	1,040
Optical nerve	1,040
Skin	1,010
(Water)	(1,000)

Over 1,000kg/m3 is more dense than water, under 1,000kg/m3 is less dense than water** ***Marc André Golombeck, 1999

Applying Archimedes' principle of displacement, a body of lower density than water immersed in water is buoyant (*ie* will rise to the surface), whereas bodies of higher densities than water will sink. It follows therefore that the more body fat a swimmer carries, the more buoyant he or she will be in the water.

Given that swimmers need to stay horizontally aligned on the water's surface for maximum speed through the water, and that they expend energy in doing so, it seems intuitive that, unlike land-based athletes, higher levels of body fat could be advantageous for them.

There's also another reason why higher buoyancy has been regarded as a plus for swimmers; any body moving through water creates 'drag', which acts to slow that body down. For any given body weight, the higher the percentage of body fat, the more buoyant the swimmer will be. This in turns means that less of the body will be under the waterline, which will in turn mean less drag to overcome – *ie* more of the propulsive force can be turned into forward motion. This explains why in days gone by, many swimming coaches considered higher levels of body fat as an asset in their swimmers.

Hydrodynamics and form drag

Like many things in life, however, it's not that simple. While extra buoyancy in the water confers real advantages, piling on pounds of fat can result in slower movement through the water, and that's down to something called 'form drag'.

As anyone who's ever watched a wildlife programme on seals will testify, the transformation of the seal from a fat, lumbering and awkward looking creature on land to the epitome of beauty and grace in the water is amazing to witness. But while seals carry typically about 30-50% body fat[1], it's distributed evenly around the body and in a manner that doesn't impede its extremely efficient hydrodynamics.

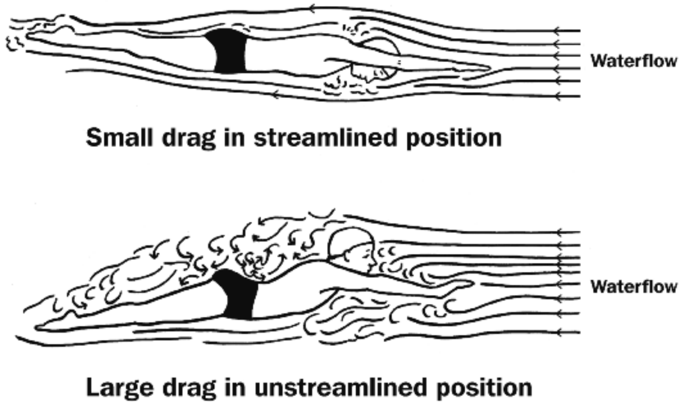
However, when humans carry extra body fat, it's carried unevenly. As a swimmer fattens up in the abdomen, thigh, and buttock areas, movement through the water produces swirling eddy currents around these protruding areas and can slow swimming velocity appreciably – this is form drag, which works against the buoyancy gains.

In the natural world, fast-swimming fish and mammals such as sharks and dolphins all have exceptionally low form drag. A marlin can weigh nearly a tonne yet clock up underwater speeds approaching 50mph! This is largely due to its exceptionally low form drag that results from its almost 'Concorde' shaped frontal profile, combined with powerful musculature. It also explains why boats have slim, smooth hulls with tapered ends rather than hulls that are brick-shaped or with protrusions sticking out.

Form drag is also increased by poor alignment when moving through the water. For example, if your legs begin to drop or your head rises in relation to your trunk, this presents an additional frontal area, which increases form drag (*see figure 1, overleaf*). There's also 'skin drag', which is a frictional drag caused by turbulence as water moves over the skin's surface. However, for the purposes of this discussion, we'll restrict ourselves to considering only those aspects of swimming performance directly related to body composition.

Increasing body fat in swimmers increases buoyancy (aiding performance) but also increases form drag (a hindrance). The

Figure 1: Form drag and alignment in the water



obvious question, therefore, is which exerts a more powerful effect as body fat levels rise? To answer this, scientists at the University of Miami artificially increased body fat levels by 2% or more in a group of 10 male and female swimmers who had been swimming competitively for at least three years[2].

This was achieved by fitting latex pads under a spandex triathlon suit in the same areas where swimmers might be expected to gain body fat – *ie* the abdominal, hip, thigh, chest, back, and buttock areas. Microscopic balloons were also added to the latex so that the pads had the same density as actual body fat. Male swimmers attached a total of 3.3lbs of artificial fat, while females donned an extra 4lbs. Before and after the 'artificial fat gain', each athlete swam 50yd freestyle at maximum effort in a counterbalanced design, swimming twice under each condition (to ensure any differences were due solely to 'fat' changes and not fatigue).

While the artificial fat improved buoyancy, it also slowed the swimmers down considerably, increasing the 50yd time by about 0.8secs or about 0.2secs per additional pound of fat added. In other words, the detrimental effects of increased form drag greatly outweighed any benefits of increased buoyancy.

Does this mean that lower body fat is always beneficial to a swimmer? Not necessarily. As the authors of the above study cautioned, their subjects were chosen to have 25% or less body fat for females and 15% or less for males. However, these are not particularly lean values for athletes; it could be that their buoyancy may have been adequate already with little to gain by adding more. The same might not be true for very lean swimmers, where very low body fat in the lower body can make it harder for them to keep their legs horizontal in order to maintain a streamlined position. Where this is the case, extra buoyancy may help aid a streamlined position, resulting in a net drop in overall drag.

Gender may also be important in this respect. All other things being equal, women tend to carry more body fat than men, and thus will tend to be more buoyant in the water. Moreover, female fat tends to be disproportionately distributed in the lower half of the body, giving a bit more lift to the legs, which in turn reduces form drag.

‘Female fat tends to be disproportionately distributed in the lower half of the body, which reduces form drag’

But while a very lean male swimmer may gain a net advantage by increasing his body fat somewhat, this certainly doesn’t provide a licence to pack on the pounds. That’s because males tend to put on excess body fat in the abdominal region; an expanding waistline shifts their buoyancy forward, which in turn tends to make the legs sink, increasing form drag.

This is easily demonstrated by the fact that most men can swim faster with a float between their legs than without it whereas most women experience little or no improvement when swimming using a leg flotation device.

Optimum body composition

All of this begs the question of what the optimum body composition for efficient swimming is. That’s a tricky one to answer, as it can depend on so many other factors such as body distribution, body shape and the nature of the swimming event.

Emeritus Professor David Costill, a highly respected exercise physiologist and masters swimmer, has suggested that in masters swimming at least, optimum body fat levels range from 10% to 20% for men and from 15% to 25% for women[3].

More recently, however, US researchers at the highly regarded Councilman Research Lab at Indiana University have claimed that body composition may not be particularly relevant in sprint performance and that (in men especially), muscular power is what really counts[4].

By contrast, a fairly recent study on male water polo swimmers suggests just the opposite[5]. In the study, Greek researchers took anthropological and physiological measurements from 19 professional water polo players. These included body composition (using a highly accurate X-ray based technique known as DXA), lactate threshold, the energy cost of swimming, peak oxygen consumption, anaerobic capacity and shoulder strength.

The researchers first set out to determine the polo players' average lactate threshold and found that it occurred at a swimming velocity of about 1.33m per second and at a heart rate of 154bpm. They then measured the average energy cost for swimming at this 'lactate threshold velocity' and discovered that it was in the region of just over 1kJ per metre. When they then looked at how this was affected by body composition, they discovered that the higher body mass indexes (BMI – weight in kilos divided by height in metres squared) of the players were correlated with higher energy costs – *ie* the higher the players' BMIs, the more inefficient they were at moving through the water at lactate threshold pace.

However, a word of caution; higher BMI and percentage of body fat are not the same thing. Although high BMIs are often associated with high levels of body fat, this is not always the case – for example in athletes who are very lean but have large bone structure and who carry large amounts of lean muscle. That said, lower BMIs tend to point toward slimmer, leaner physiques and in this study at least, more efficient movement through the water at higher velocities.

Body composition pressures

Competitive swimmers are often young and therefore impressionable. This makes them vulnerable to pressures to conform to the 'ideal' notion of body composition. These

Box 1: Recommended coaching strategies to minimise 'weight pressures' in swimmers*

- Eliminate weight requirements and weight-related goal setting.
- Avoid group weigh-ins.
- Allow team members to choose team suit whenever possible.
- Educate swimmers about muscle weighing more than fat.
- Encourage swimmers to meet caloric intake needs.
- Discourage team members from making weight-related comments to other swimmers.
- Evaluate your beliefs about weight-performance relationship.
- Monitor swimmers' eating behaviour/body concerns and look for 'at-risk' swimmers.
- Listen to swimmers' concerns about weight and body.
- Encourage 'at-risk' swimmers to keep a food log to ensure adequate caloric intake.
- Be prepared to refer an athlete as needed.

Reel and Gill, 2001[8]

pressures can come not only from their coaches who may have pre-determined (and often unscientific) ideas about what weight/body composition their swimmers should be, but also from the fact that competing in swimsuits in the public arena can add further pressure.

Studies in the 90s reported that swimmers often feel pressure to drop weight[6] and that many coaches of female Olympic swimmers encouraged their swimmers to lose body fat in order to cut times[7]. More generally many swimming coaches routinely advocate about 15% body fat as an upper-end cut-off for elite female swimmers.

However, when double Olympic gold medallist Tiffany Cohen won her 400m and 800m golds at the 1984 Los Angeles Olympics, her body fat was reported at 22%. This is not to say, of course, that 22% is the ideal level of body fat for female swimmers. It merely illustrates that there are no hard and fast rules about what constitutes the optimum percentage of body fat for a particular swimmer because every individual possesses a unique blend of physiological and anthropological characteristics.

In a study of 62 female swimmers from seven US college swim teams, researchers set out to assess the pressures to conform to weight 'norms' experienced by the swimmers[8]. Over half (51.6%) of swimmers agreed with the statement, 'There are weight pressures in swimming.' The most commonly cited pressures were as follows:

- Wearing a revealing swimsuit (45.2%);
- A perception that lower weight helps swim performance (42%);
- Team-mates noticing my weight (16.1%);
- The crowd scrutinising my body (12.9%);
- The belief that the lightest swimmers have a performance advantage (9.7%).

The focus on achieving a headline body composition figure rather than achieving improved swimming performance is not only unhealthy and unproductive, it can signal the start of more serious problems of self-perception, and may result in eating disorders.

Interestingly, although competitive suits are typically one-piece styles, many participants reported that they wore swimsuits two or more sizes smaller than their typical size and some even wore youth sizes in order to prevent drag. This is consistent with the belief that decreased weight and body fat are associated with increased performance. Unfortunately young swimmers then preach the same beliefs when they become coaches themselves. Coaches should therefore approach this issue with caution, and recommendations are given in box 1 below:

Swimming, weight loss and appetite

At this point, you may be wondering what the big deal is? Surely, performing adequate volumes of swimming training will automatically bring about optimum body composition, and produce a fat/weight loss effect if needed? Although this seems intuitively correct (after all, it happens in other sports such as running and cycling), the research in this area suggests otherwise.

One reason is that during swimming, the body's weight is supported by the water. In contrast with running, for example, where each stride involves work against gravity, weight gain in a swimmer does not incur an energy expenditure penalty. If you weigh 70kg and run 10 miles a day, you'll burn up about 1,000kcals per day during training. Gain 7 kilos of body fat and your energy expenditure increases by about 10% – ie, you'll burn about 1,100kcals per run. Put simply, the more weight you carry, the higher the calorie burn and therefore the greater the weight-reducing effect. However, a swimmer who gains a similar amount of body fat will incur virtually no extra energy costs and therefore weight-reducing effect during training.

In a fascinating study, scientists looked at the weight loss/gain effects of walking, cycling and swimming programmes conducted over a three-month period[9]. Each programme began with up to 10 minutes of daily exercise and the length of each workout was increased by five minutes every week, so that participants were averaging 70 minutes day at the end of the programme. The results showed that while the walkers and cyclists lost 17 and 19lbs of weight respectively, those performing the swimming programme actually gained 5lbs despite burning a similar amount of calories!

The researchers surmised that (in addition to the issue of supported body weight) swimming in cold water stimulated the appetites of the swimmers to increase caloric consumption. Further evidence of these two effects can be seen in comparisons of competitive swimmers with runners or cyclists who expend a similar amount of energy when they train; swimmers typically have body fat levels that are significantly higher then runners or cyclists. For example, comparative studies on male athletes competing in the 1964 Tokyo and 1968 Mexico City Olympics showed that the body fat percentage levels of long distance runners and marathoners ranged from 1.4-2.7%, while those for swimmers ranged from 9.0-12.4%[10].

However, a recent Lithuanian study suggests that a structured swimming programme does help reduce body fat[11]. This study actually set out to observe the health effects of a

14-week swimming programme in diabetic and healthy female girls aged 14-19. One of the main findings was that in both groups of subjects, swimming produced significant fat loss of about 2% of body mass compared to the inactive controls.

The cool water environment in which swimmers train appears to play a significant role in explaining why they may struggle to reach optimum levels of body fat. A 2005 study examined the effects of exercising for 45 minutes in neutral (*ie* around ambient body temperature – 37°C) and cold (20°C) water temperatures[12]. After the workout, they were allowed to eat as much food as they wanted.

The researchers discovered that although the men burned a similar number of calories in the cold and neutral water conditions (505 and 517kcals respectively), the calorie intake after exercise in the cold water averaged 877 calories – 44% more than in the neutral temperature water! Although 20°C is colder than most training pool temperatures (27-28°C), the latter water temperature is still cool enough to promote efficient heat loss during swim training and this will help to ameliorate the magnitude of the rise in core temperature that occurs during most exercise modes. This is significant because an exercise-induced rise in core temperature is known to result in appetite suppression both during and immediately after training. You've probably experienced this when starting a training session feeling peckish, only to find that 10-15 minutes into your workout, your appetite has vanished and doesn't return for a while even after training. This effect, however, appears to affect swimmers less.

Conclusions

Unlike most other weight-bearing sports, there's no simple answer as to what constitutes an 'optimum body composition' for swimmers. Both excessively high and low levels of body fat appear to be detrimental to performance, yet striving for the 'perfect' level may not only fail to produce performance gains, but can also lead to unhealthy body image problems and even eating disorders.

Aiming for a ‘perfect’ body composition measurement is probably unproductive; a far better solution is to monitor body composition data (*eg* using skinfold measurements) in a training diary alongside your performance times. There’s a high likelihood that your optimum body composition will be the composition that accompanies your best performance times!

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References

1. *Marine Mammal Science 10 (3), 332–341, 1994*
2. *Journal of Strength and Conditioning Research, 8 (3), pp 149-154, 1994*
3. *www.usms.org/articles/articledisplay.php?a=104, 1994*
4. *Highlights from the USA Swimming Conference on Sports Medicine and Sports Science in September 2003*
5. *J European Appl Physiol, 95 (1), September 2005*
6. *Journal of Health Education, 24 (6), 360-368, 1994*
7. *Physician and Sportsmedicine, 18 (4), 116-122, 1990*
8. *Sport Journal, 4 (2), spring 2001*
9. *Am J Sports Med, 15, 275-279, 1987*
10. *McArdle, Katch and Katch, Exercise Physiology. Lea and Febiger, Philadephia, 1981*
11. *Medicina (Kaunas), 42 (8), 661-666, 2006*
12. *Int J Sport Nutr and Ex Metab, 15 (1) 38-47, 2005*

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