A special report from PEAK PERFORMANCE

The research newsletter on stamina, strength and fitness

CARBO LOADING

for that extra edge

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From the publisher

If legend had recorded that Pheidippides ate a handful of cooked lentils before setting off on his famous run from Marathon to Athens, it might have the first instance in history of carbo loading. Unfortunately, it didn't – at least, not to my knowledge. Anyway, the poor chap is said to have dropped dead at the end of the run, which is not quite the effect athletes hope to achieve by stoking up the carbs. More recently, the modern carbo-loading regime, developed in the 1960s, involved training to exhaustion, followed by eating a diet high in fat and protein for three days (the bleed-out phase) then switching to a very high carbohydrate diet for three days. Experts now agree that the bleed-out phase is unnecessarily extreme and risky and have found that the same effect can be achieved by eating a high-carbohydrate diet (70% carbohydrate) for five days before a competition while tapering training.

This special report on high carbohydrate and carbo-loading has been written by *Peak Performance's* team of specialists, and looks at most aspects of diet that can improve performance – surprisingly, it isn't always a lavish intake of carbohydrate that does the trick. A couple of our articles suggest that sometimes fat can be beneficial, and even phosphate. So the report ranges quite wide in its research and in the practical advice it offers.

I hope you find it useful and stimulating.

Jonathan Pye

CARBO-LOADING RESEARCH

Here's a revolutionary new way to slam 20% more glycogen into your muscles

It used to be so simple. You completed an exhaustive workout and then ate minimal amounts of carbohydrate for three or four days to wipe out your muscle-glycogen stores. Then came the good part: you trained lightly and consumed biscuits, pies, pasta. and potatoes in lavish quantities for three days to super-saturate your leg muscles with carbohydrate. This was the classic 'carbo-loading' strategy developed by top-level Swedish scientists in the late 1960s and early 1970s, a plan which was used by countless endurance cyclists, cross-country skiers, and runners prior to their long-distance races.

But then Dave Costill made things simpler still, In his lab at Ball State University, Costill showed that the initial, three- to four-day, low-carbohydrate, 'depletion' stage was impractical and unnecessary. The famed Indiana scientist suggested that endurance athletes could stay on top of the carbohydrate game simply by reducing their training and eating increased amounts of carbohydrate during the three days before an important, long-distance competition.

The two-hour window

It would have been nice if things stayed that uncomplicated. but scientists gradually discovered that many endurance athletes were not storing enough glycogen in their muscles during periods of vigorous training and were consequently having trouble maintaining their desired training loads. In the late 1980s, one reason for this lack of glycogen storage became apparent: research showed that muscle cells are quite temperamental about when they like to sock away glycogen. For example, muscle fibres usually have little inclination to store glycogen before a meal or during sleep. but they are most willing to pull carbohydrate out of the blood and stockpile it during a fairly brief period: the two hours immediately after a strenuous workout. It seemed that many glycogen-deficient athletes were failing to give their muscles what they needed during this critical two-hour time span.

As a result of that discovery, wise athletes began to 'fuel up' with copious quantities of sports beverages and high-carbohydrate foods, taken in shortly after their workouts had ended. The next step was to figure out exactly how much carbohydrate was actually needed during this muscle prime-time (the two hours after a workout), so that glycogen would be replaced as quickly as possible.

Fortunately, in about 1987 John Ivy, Ph.D. and his colleagues at the University of Texas discovered that eating about two-thirds of a gram of carbohydrate per pound of body weight, once right after a hard workout and a second time two hours later, helped athletes achieve super-high muscle glycogen levels in a short period of time. If you weighed 150 pounds. all you had to do to ensure that the interiors of your muscle cells were 'carbohydrate pantries' was to consume 100 grams of carbohydrate (150 X 2/3) right after your workout and 100 grams two hours later. If your regular meals were also biased toward carbohydrate, you could be fairly certain that your muscle cells would contain enough glycogen to keep you training at a high level.

Supplanting the Ivy

But it's a changing world, and the Ivy strategy now seems almost as outdated as the old Swedish carboloading regimen. In recent research at Ohio State University, scientists have uncovered a scheme which quickly gets at least 20% more carbohydrate into your muscles, compared to the Ivy plan. This 20% boost in carbohydrate should help to ensure greater endurance during subsequent long workouts or races. To put it simply, you'll have a much lower risk of having your performances harmed by low muscle-glycogen levels.

In the Ohio State investigations, 10 fairly fit individuals cycled for 75 minutes at an intensity of 70% VO_2max (80% of maximal heart rate) and then surged through five one-minute sprints at 100% VO_2max (very close to maximal heart rate). To further reduce muscle-glycogen levels, the subjects then completed 10 sets of 10 leg extensions or flexions on a Cybex resistance-training machine.

48 hours after this rugged session, the athletes returned to the laboratory and repeated their cycling efforts (75 minutes of riding, plus five one-minute sprints). Following each of the two workouts, the 10 participants consumed carbohydrate every 15 minutes for four hours. The actual amount of carbohydrate was huge: a total of almost three grams of carbohydrate per pound of body weight, subdivided into 16 equal doses over the four-hour period. This meant that the Ohio State athletes ingested about 30 grams of carbohydrate every 15 minutes.

Although stoking in that much carbohydrate required real effort, the strategy paid off: muscle biopsies revealed that the rate of glycogen storage was at least 20% greater than the storage rate achieved with the old two-snacks-in-two-hours programme and up to 90% greater than traditional carbo-replacement plans.

The reason for the exceptionally advanced glycocen storage in the Ohio State study was simply that the carbohydrate was ingested in 15-minute intervals over four hours, not just in one or two lump sums. The 15-minute pattern insured that blood glucose and insulin levels stayed exceptionally high throughout the entire four hours after exercise. In fact. insulin, a potent booster of glycogen storage, actually increased steadily over the four-hour time period!

An insulin digression

Before going further with this story, we should note that insulin has attracted a bit of notoriety recently. Specifically, ads for various nutritional products sold to athletes suggest that insulin is bad because it reduces the use of fat for energy. While it's true that insulin blocks the release of fat into the blood from fat cells, and it's also true that this would be a bad deal for you if you were running long distances with our being able ingest a sports drink, it's also essential to point out that insulin is a critically important hormone which aggrandises your muscles' stores of carbohydrate. This surplus carbohydrate then allows you to more effectively carry out high-quality interval workouts, long-distance training sessions, and races lasting an hour or more. The bottom line is that you want to have increased blood-insulin levels after a meal (or series of snacks), so that you can stuff as much energy as possible inside your muscle fibres.

The new four-hour strategy is particularly important if you work out more than once a day, if you're a very high-mileage trainer, or if you complete a lot of intense intervals, because these scenarios extensively deplete muscle glycogen. The strategy may also be of value if you're an athlete who carries out a lot of training on hilly terrain, because the Ohio State researchers showed that glycogen storage was reduced by 20% when the post-cycling weight-training work was eccentric in nature. Since hill running emphasises eccentric muscle contractions (actions in which muscles are stretched as they are trying to shorten), normal glycogen storage patterns may be compromised during hill training. Fortunately, the Ohio State strategy is a way to perk up muscle-carbohydrate attendance in athletes who train on rolling terrain.

Wolfing down large amounts of carbohydrate after a workout may seem a bit extreme, but it's a strategy routinely followed by some of the most successful endurance runners in the world - the élite Kenyans. At their rugged, high-altitude camp near Embu, Kenya. where the Kenyan cross country teams complete three demanding workouts per day and run about 140 miles per week, the Kenyans guzzle highly sugared cups of tea and milk almost immediately after each training session and then devour huge platefuls of high-carbohydrate food. They do a great job of preparing their muscles for their next workout, which may follow the preceding training session by just four to six hours.

However, even the world-beating Kenyans don't have the formula exactly right. The Ohio State idea is to graze for four hours or so, converting your bloodstream into a steady river of carbohydrate and insulin and forcing your muscles to work overtime stacking up that carbohydrate as glycogen.

Tips for maximum glycogen storage

If you usually run, cycle, swim, or work out on a stair machine at a moderate intensity for less than about 50 minutes at a time. don't worry too much about the new carbo-loading scheme unless you train more than once a day or tend to eat too little carbohydrate. However, interval and repetition workouts can dramatically deplete glycogen. even when they last less than 50 minutes, so do consider using the strategy after high-intensity sessions, especially if you plan to cycle or go for a long, steady run later in the day.

During all periods of very heavy training and whenever you are significantly increasing your workout duration or total training volume, give the new carbo-loading scheme a try. Also employ the strategy during times when extensive hill training is a priority.

It's easy to figure out how to carbo-load using the Ohio State pattern. Simply multiply your weight in pounds by three. Divide the result by 16 to determine the number of grams of carbohydrate to eat every 15 minutes. Example: Penny weighs 117 pounds. 117 x 3 = 351. 351/16 = 22. 22 grams of carbohydrate should be ingested every 15 minutes.

Since you usually don't think about how many grams of carbohydrate you're actually ingesting, we've made things easier for you by listing food servings which provide about 20-25 grams of carbohydrate:

(1) Two cups of skim milk (2) A little more than half a bagel (3) A two-thirds cup serving of cooked pasta (4) An apple or a banana or a pear (5) Four dates (6) A cup of orange juice (7) One-fifth of a cup of raisins (or two half-ounce packets) (8) An ounce and one-half of corn chips (9) A medium baked potato (10) A slice and a quarter of most breads (11) Two slices of non-fat 'diet' bread (12) A cupcake (13) A muffin (14) A cup

of oatmeal (15) One and one-half cups of Special K cereal (16) One-half cup of cooked rice (17) Three carrots (18) Two-thirds of a cup of cooked lentils (19) A half-cup of cooked kidney or pinto beans (20) A cup of split pea or bean soup

If ingesting 20-25 grams of carbohydrate every 15 minutes for four hours after a tough workout is just too much of a bother, a modified glycogen-storage plan may work almost as well. According to Mike Sherman, Ph.D., one of the Ohio State investigators and an internationally acclaimed expert concerning carbohydrate's role during exercise, taking in 40-50 grams every 30 minutes or 60-75 grams every 45 minutes might yield similar rates of carbohydrate warehousing.

The new carbo-loading scheme requires some planning, and you'll still want to eat some additional carbohydrates during your regular meals, but the effort should add fire to your training and competitive efforts. With extra carbohydrate in your muscles, you'll simply be able to train or compete at a fast pace for longer periods of time.

Jim Bledsoe

ACTION PLAN

Ignore any claims to the contrary – high-carbs are by far the best fuel, as this evidence shows

If you believe some of the sports nutrition articles these days, the popularity of high-carbohydrate eating seems to be on the wane. More and more athletes are crowing that they perform better with fewer carbs and more protein, and even carbohydrate protagonists, perhaps tired from their long efforts to convince the athletic community of carbohydrate's invincibility, appear weak in their praise for carb food.

What's the truth? Has the scientific community really decided that carbohydrate is no longer the gold standard of performance fuel? Can endurance athletes worry less about loading their plates with high-carb nosh?

To answer those questions, it's best to take a careful look at one of the best analyses of the effects of high-carbohydrate fare on endurance performance. This high-powered study, which was carried out several years ago at Loughborough University in the UK by the venerable Clyde Williams and his colleagues, examined the performances of 12 men and six women, all of whom were experienced half-marathon and marathon runners. All 18 runners started the investigation by completing a 30-K (18.64-mile) time trial on a non-inclined treadmill[1].

Following this prolonged ramble, six of the men and three of the women consumed a high-carbohydrate diet for seven days. During this high-carbo week, daily carbohydrate consumption climbed to 566 grams for three days and then dropped back slightly to 452 grams for four days (the runners' 'normal' carbo intake had been 334 grams per day prior to the study). Since each runner weighed about 145 pounds, daily carbohydrate *‘control-group runners experienced exactly the same plunge in running velocity – from 3.8 to 3.4 metres per second – over the last five kilometres’*

consumption rose from 2.3 grams per pound of body weight per day to four grams per pound per day (for three days) and then eased slightly to three grams per pound (for the final four days).

A ‘control’ group, which was composed of the other nine runners (also six men and three women), didn’t increase their carbohydrate consumption but instead wolfed down above-normal quantities of fat and protein during the week following the 30-K trial. As a result, the total number of calories consumed per day were the same in the control and carbohydrate groups during this week.

After the seven days of increased eating, all 18 runners completed a second 30-K run. While control-group runners (those who had eaten more protein and fat) didn’t improve their times at all, eight of the nine high-carb athletes actually ran faster during the second trial, and the average improvement was approximately 2.6 minutes. The big-carb eaters shaved their average 30-K clocking from 137.5 down to 134.9 minutes, a very decent pace of 4.5 minutes per kilometre, which is about 3:09:45 marathon tempo.

That last 5K

As it turned out, the high-carbohydrate eaters fared better primarily because they were able to maintain a faster running pace over *the last five kilometres* of the 30-K run. During the first trial, the final 5K of the 30-K run had been a real trouble spot for both groups of runners. Each group ran at speeds of about 3.8 to 3.9 metres per second (6:58 per mile) for the first 20 to 25K but then slowed to only 3.4 metres per second (7:53 per mile) over the last 5K in the first trial. Bear in mind that this slow-down occurred when the athletes were eating carbs non-voraciously, ie, at a rate of only 2.3 grams of carbohydrate per pound of body weight per day

During the second trial (which followed the seven days of increased eating), control-group runners experienced *exactly the same plunge in running velocity – from 3.8 to 3.4 metres per second – over the last five kilometres*, but the carbo-loaded runners slipped to just 3.64 metres per second (7:22 per mile) as they covered the final 5K. In other words, an increased intake of carbohydrate helped runners maintain their speed during the last, fatiguing portion of the 30-K exertion, while an enhanced ingestion of protein and fat did not. The Loughborough research also demonstrated that a 'normal and routine' diet of 2.3 grams of carbohydrate per pound of body weight per day is linked with dramatic slow-downs in velocity after 20 to 25K during a prolonged bout of running.

More carbs mean longer strides

How did high levels of carb consumption actually produce faster running, especially toward the end of the 30-K effort? As it turned out, the big effect of the carbo-loading was to preserve the runners' *stride lengths*. During the first 30-K trial, when the runners had been eating a miserable 2.3 grams of carbohydrate per pound of body weight per day, stride length fell by about 10 to 20% from the beginning to the end of the run in both groups of runners. During the second trial, stride length dropped by a similar amount in the control runners *but did not decrease significantly* for the carbo-loaded harriers.

As it turned out, the big effect of the carbo-loading was to preserve the runners' stride lengths

Why did poor rates of carbohydrate ingestion shorten the Loughborough runners' strides? Stride length is a function of force production by the leg muscles; the greater the force production, the longer the stride. However, force production declines dramatically as leg-muscle-carbohydrate (glycogen) levels fall too low. Because the high-carb runners had packed their glycogen depots more completely before the beginning of the 30-K run, they had more glycogen available toward the end of the exertion. This reserve of glycogen helped them maintain their stride lengths and thus their power (running speed).

Of course, the carbo-loaded runners also had higher levels of blood glucose – another excellent source of muscle fuel – during the 30-K trial. Blood glucose held steady at about 5 millimoles per litre throughout the exercise for the carbo-loaded runners but fell to 3.5 millimoles/litre after 25 to 30K in the control group.

It is interesting to note that carbohydrate intake in the poorly performing, control group of Loughborough runners settled at 38% of total calories, very close to the 40% level recommended by the 40-30-30 fanatics. Meanwhile, carb ingestion in the better-performing harriers was at about 54% of all calories. Some acute observers of this study have noted that these runners might have performed even better if carb eating had advanced to above 60%.

Any downside?

Were there any negatives associated with the high-carb intakes? Well, blood lactate levels were higher after carbo loading, swelling to about 4.0 mmol/litre, compared to 3.5 during the first trial. However, if you're a regular reader of *Peak Performance*, you'll know that even though high levels of blood lactate are often associated with muscular tiredness, lactate itself does *not* cause fatigue. In fact, in the better-performing runners, the extra lactate was not the result of a sub-par lactate threshold but was simply the consequence of greater carbohydrate eating and a corresponding higher average running pace. Exercising after carbo-loading is one situation in which increased lactate is linked with less rather than more fatigue – and with higher instead of lower performances.

True, you might say that this study is relevant to only very long-distance running (or cycling and swimming). Since the big slow-down in the low-carb group didn't occur until after 20 to 25K of running (ie, after about 90 to 110 minutes), can't we say that high-carb diets are of little relevance to competitors over shorter distances – for example, 10K to 15K for runners?

That's a reasonable question, but bear in mind that as the race distance decreases, the average movement speed – and thus rate of carbohydrate burning – increases. As a result, the athlete whose muscles are poorly supplied with carbohydrate might reach the 'red zone' of glycogen concentration – at which power output falls – after a considerably shorter distance than 20K (or after less than 90 minutes). Read on!

Why the Swedes did even better

The Loughborough research is not the only firm foundation supporting the theory that high-carb eating advances performance. In a classic study carried out over 30 years ago, Swedish scientists found that high-carbohydrate diets improved 30-K running performances *by over 5%*[2].

There were two key reasons for the Swedish success. First, the Swedish race took place over hilly terrain – not on the flat treadmills utilised by the Loughborough runners. Compared to flat-ground running, blasting up and down hills 'burns' carbohydrate at greatly accelerated rates, so runners whose muscle-glycogen levels haven't been maximised by carbo-loading will run out of carbohydrate much more quickly on inclined surfaces compared to level ground, and fatigue will rear its ugly head sooner, increasing the disparity between the carbo-loaded and unloaded runners. In fact, many of the *non-carbo-loaded* Swedes began to slow down appreciably after only 11 kilometres of hilly running.

Second, many of the Swedish subjects were merely physical education students – not experienced runners. In the Swedish study, these *inexperienced* individuals improved 30-K times by almost 8% after carbo-loading, while veteran Swedish harriers improved by only 3%, indicating that carbo-loading is far more important for relatively novice runners. Evidently, veteran runners are better able to mentally 'tough it out' when carbohydrate supplies get low. Alternatively, the leg muscles of seasoned athletes might be more efficient at seizing and storing dietary carbohydrate when it is in short supply. Certainly, experienced runners would be more economical than relative beginners, and their greater efficiency might also help to spare carbohydrate.

You eat a lot, you use a little

As they cruised through their 30-K trials, the runners in the Loughborough study broke down carbohydrate at a rate of 10 grams per kilometre before carbo-loading and 11 grams per kilometre after loading. In other words, carbo-loading led to a

10% boost in the rate of carbohydrate oxidation during running, and a 30-gram overall increase in carbo breakdown during the 30-K run. However, an extra 840 grams of carbohydrate were gulped down during the seven days of loading, so only 3.5% (30/840) of the supplemental carbohydrate was utilised to actually promote superior running. Since the additional 840 grams represented a 50% increase in average carbo intake, it's apparent that athletes who are following a relatively low-carbohydrate diet must upgrade their consumption of carbohydrate by about 50% just to get a 10%-larger carbohydrate 'flame' during a two-hour-plus race and a 2- to 5% improvement in performance. That's not a high rate of return, but most athletes – happy with even a 1% enhancement of race time – are willing to carry out the carbohydrate regimen anyway. Bear in mind that for a 90-minute half-marathoner, a 2-per cent upswing in performance would bring finishing time down to 88:12; a 5% gain would cut the clocking to 85:30, and an 8% change would lead to a somewhat sizzling 82:48.

Although the non-loaded Loughborough runners were clearly at a disadvantage, they might have been able to close the gap on the carbo-feasters merely by sipping sugar-water during the second 30-K trial. After all, blood glucose was almost 50% higher in the carbo-loaded runners near the end of the 30-K efforts, and some of this extra glucose may have been used to promote faster running. If the non-loaded harriers had swilled sports drinks, the absorbed sugar could have sped through the blood to their muscles and provided a boost of power during the tough final kilometres.

The when question again

When is carbo-loading actually helpful? Could it help you run faster in a 10K, for example (or in an event lasting 35 to 40 minutes for cyclists and swimmers)? In the Loughborough study, the benefits of carbos didn't show up until after 25K (or about 110 minutes) of running, but – as we have pointed out – that doesn't mean that 25K or 110 minutes are 'magic thresholds', below which carbo consumption isn't mandatory. In the Swedish study, which still involved 30K of running but took place over hilly terrain, non-carbo-loaded runners began to slow down after just 11K of running, and poorly trained runners slowed down even sooner. Among runners, 10-K pace is generally about 24 seconds per mile faster than 30-K tempo, leading to significantly more rapid rates of glycogen burning. If insufficient carbo intake can cause you to slow down after 11K of a 30-K race, it's easy to think it might produce slowing after seven to eight kilometres of the higher-intensity 10K.

There has been no specific research on the effects of high-carbohydrate diets on 10-K performances, but recent research has shown that carbo-loading can help improve the quality of even shorter-duration efforts. Specifically, in a study carried out at the University of Queensland in Brisbane, Australia, a group of moderately trained male students completely a maximal-intensity interval session consisting of just five 60-second reps of all-out cycling, separated by five-minute recoveries. The students were then divided into three groups: One group followed a high-carbohydrate (83% of total calories) diet, a second group pursued a medium-carbohydrate (58%) plan, and a third group obtained only 12% of energy from carbohydrate (the low-carb group). After 10 days of such eating, all subjects repeated the brief, maximal-intensity interval workout (5 x 60 seconds at max power).

And the result?

Amazingly enough, the high-carbohydrate eaters improved total work performed during the five reps by 5.6%, the medium-carbohydrate students upgraded total work by 2.3%, and the hapless low-carb subjects actually decreased work by 5.4%[3]. High-carb eating was important during an interval workout which consisted of just five minutes of hard work! Thus, it's very likely that carbo-loading can help 10-K runners, too, especially if the 10-K course is not pancake-flat.

Although the studies we've described have employed runners as subjects, high-carbohydrate intake is also important for other endurance athletes – cyclists, swimmers, rowers, kayakers, cross-country skiers, etc. Likewise, non-endurance athletes who rely on intermittent but frequent bursts of high energy – which can deplete muscle glycogen at rapid rates – should think carefully about high-carbohydrate eating. Generally, if you're going to be playing squash or tennis at a high intensity for 45 minutes or more, carbo loading should help reduce fatigue and promote quicker movements toward the ball. Soccer players and wide receivers in American football are also likely to resist fatigue more effectively by consuming ample carbohydrates.

Here are two final tips on carbohydrate consumption:

(1) The old days of carbo-loading, which meant eating whatever you wanted throughout your training cycle and then loading up on carbs during the week before a major competition, are out. A high intake of carbohydrates shouldn't be confined to just the seven days before a competition; it should be a regular habit. The experts tell us that if you are engaged in regular, strenuous training (working out at a decent intensity for an hour or more nearly every day), you should try to consume about four grams of carbohydrate per pound of body weight each day.

However, in practical terms, you shouldn't *rush* to reach this intake level if you are currently eating too few carbs. I was once coaching an excellent endurance athlete who was performing fairly well (although not consistently) but often complained of sore muscles. While he felt that he might be suffering from some sort of serious inflammatory muscle disorder, I suspected the culprit was simply a low-carb diet. An inadequate intake of carbs causes muscles to fatigue too quickly during workouts; as the muscle fibres get tired, they have more difficulty withstanding the eccentric stresses of exercise and are more likely to be damaged, thus inducing soreness.

Sure enough, an analysis of this athlete's diet revealed that he was taking in just 1.5 to 2 grams of carbohydrate per pound of body weight per day, even though one of his weekend workouts lasted for up to four hours! I quickly recommended a change to 4-grams-per-pound eating, and – like a miracle – the soreness went away!

However, there was just one little problem: The athlete also became as fat as a swollen chipmunk. His metabolic rate was low after years of inadequate eating, his ability to store glycogen was probably impaired, and so he began to pack away excessive quantities of fat. A far better move would have been to *gradually* introduce more carbohydrate to his diet, giving his body time to adjust to the new eating plan.

(2) If you haven't been able to eat plentiful amounts of carbohydrate before a competition, don't lose all hope. If your event lasts for an hour or more, you can at least partially compensate for your lack of carbo intake by quaffing a sports drink during your event. A superior sports fluid can be concocted by mixing five tablespoons of sugar, one-third teaspoon of salt, and a little flavouring (artificially sweetened Kool-Aid works okay) with each quart of water. Swill a glass of this beverage shortly before the competition starts, and then ingest three or four healthy swallows every 10 minutes or five to six swallows every 15 minutes during exercise.

Owen Anderson

References

1('The Effect of a High-Carbohydrate Diet on Running Performance during a 30-km Treadmill Time Trial,' European Journal of Applied Physiology, vol. 65, pp. 18-24, 1992).

2 ('Diet, Muscle Glycogen, and Endurance,' Journal of Applied Physiology, vol. 31, pp. 203-206, 1971). This is nearly double the gain made by the Loughborough athletes.

3('The Influence of Dietary Carbohydrate on Performance of Supramaximal Intermittent Exercise,' European Journal of Applied Physiology, vol. 67, pp. 309-314, 1993).

TEAM-SPORT ATHLETES

This new study shows that extra carbohydrate can boost performance in élite team-sport athletes as well

There has been a lot of scientific evidence to show the advantages of high dietary intakes of carbohydrate, but much of this relates to specific one-off performances of volunteers in a laboratory. Little research has been carried out to assess the performance change of elite team-sport athletes caused by additional carbohydrate. A recent study has done just that, combining the scientific assessment of performance in the laboratory with the intensive training carried out by a national squad of athletes.

Researchers at the University of Memphis in the States worked with 14 female members of the US National Field Hockey Team during an intensive training period lasting seven days. A typical training day consisted of two sessions, each of at least two hours, including competitive drills at match intensity. The athletes were paired for position, training specificity and training volume.

One of each pair (Group CHO) ingested a high-carbohydrate concentrated drink (Exceed High Carbohydrate Source) containing lg.kg-1 of carbohydrate four times a day. This provided approximately 1000 calories of extra energy as carbohydrate per day. The other of the paired athletes (Group P) ingested a flavoured and textured water placebo identical in volume to the true supplement. A battery of physiological tests was administered before and during the training week, as well as a test of psychological status after each individual training bout. The aim of the study was to see whether carbohydrate supplements affected these measures in any way.

And what was the result?

First, dietary intake over the seven days was found to differ between the groups. Hardly surprising, perhaps, but it did show that Group CHO were not subconsciously compensating (ie, eating less) for their increased energy intake due to the supplements. Second, psychological analysis of post-exercise fatigue suggested a possible slight reduction for Group CHO compared to Group P. Third, CHO was found to have improved performance of incremental treadmill exercise time to exhaustion over the training period (+3.2%), whereas Group P declined in this measure of aerobic performance (-2.7%). Some observations did not show any differences, either pre- to post-training period, or between groups, such as maximal strength, maximal power and certain cardiopulmonary measures such as ventilatory threshold.

So it appears that some advantages can be obtained from increasing carbohydrate intake during periods of intense training. Maximum training response can be achieved if carbo intake is high. The reason for this proposed by the researchers was the greater and more rapid replenishment of muscle glycogen stores between training bouts. Glycogen stores have, of course, been shown to be directly related to prolonged endurance exercise and repeated bouts of exercise in controlled laboratory experiments.

The investigators in this study admit that if direct measurement of muscle glycogen had taken place, they could have drawn conclusions more confidently. However, it is difficult, not surprisingly, to persuade elite athletes to allow direct muscle tissue samples to be taken. Nevertheless, the theoretical reasoning for the findings in this study seems sound.

The fact that certain measurements showed no improvement over time may be because of the already highly trained nature of the athletes, the fact that certain body systems were not trained specifically, and a period of recovery from the intense training was not allowed. Any tests of fitness for athletes should be carried out after a couple of days of relatively light training, during which the positive adaptations to training stress can occur.

The conclusion

The results of the study add to the existing evidence indicating that a high carbohydrate diet can aid training response and resulting performance. It shows (using scientific evidence) that this can apply to elite competitors in a true-to-life training situation. There are obvious implications for all sports, including team sports, where heavy training and/or match schedules are involved. High carbohydrate diets and supplements should not be the preserve of endurance athletes alone.

However, the proviso of allowing two-to-three hours between a meal and the following exercise still holds. There is now growing scientific evidence for the beneficial effects of a high carbo intake in performances of varied intensity and duration, especially when repeated over a lengthy period of time. The simple message is: whatever your sport, carbohydrate is the key.

Alun Williams

Reference

('Effects of Carbohydrate Supplementation During Intense Training on Dietary Patterns, Psychological Status, and Performance', International Journal of Sport Nutrition, 1995, vol. 5, no 2, pp125-135.)

PRE-COMPETITION CARBS: SPORT BY SPORT

How to get the best out of yourself by putting the best into yourself

Whatever your sport. nutrition should be an integral part of your training and competition strategy. Although the emphasis will vary according to the activity you're involved in. there is a consensus among sports scientists on guidelines that athletes should be aiming for.

The International Conference on Foods. Nutrition and Sports in Lausanne (1991) agreed the following nutrient intakes to be optimum for most sports: 60-70% of calories in the diet from carbohydrates, 12% from protein and the remainder (18-28%) from fat. This in effect means eating a diet far richer in carbohydrate and lower in fat and protein than average.

Later in this article we will go on to consider detailed requirements for different types of sports activity. But first, we'll take a look at the three key ingredients in sports nutrition: carbohydrates, fluid and iron.

The carbohydrate connection

As readers of this special report will know by now, carbohydrate is a crucial fuel for exercise. The body makes its own carbohydrate store, known as glycogen, which is stashed away in the liver and muscles. Glycogen is the body's fuel of choice for any exercise more intense than a gentle jog. This is because it can be broken down to provide energy more quickly than fat (the body's other major energy store). However, the snag with glycogen is that only limited amounts of it can be stored. This means that regular training, as well as competition where activity is at least an hour long, carries the risk of glycogen depletion. Low glycogen stores will mean a more sluggish performance and an increased risk of injury.

Strategies to minimise this problem include carbohydrate loading (see box, and the first article in this report), ensuring that a rich-carbohydrate diet is eaten the whole time during training to avoid burnout; also, consuming carbohydrates during exercise (eg. a cycle ride) or between rounds (eg. a tennis tournament) can cut down on glycogen loss and keep performance boosted.

If you're in regular training, eating lots of carbohydrate-rich foods will encourage your body to store glycogen (see table for carbo contents of various foods). A guideline to aim for is 8-l0g carbohydrate per kg of body weight per day. For an average man (70kg), this would mean aiming for a daily intake of 560-700g; for an average woman (55kg), between 440-550~.

Carbohydrate contents of selected food

Food	Amount	Carbohydrate) (g)
Apple	1 medium	20
Orange	1 medium	20
Banana	1 medium	20
Raisins	1/2 cup	45
Fruit yoghurt	1 cup	35
Muesli	1/2 cup	36
Apple juice	8 H oz	30
Orange juice	8 H oz	25
Baked potato	1 large	55
Baked beans	1 cup	50
Lentils	1 cup (cooked)	40
Spaghetti	1 cup(cooked)	40
Rice	1 cup(cooked)	35

Tips for boosting your carbo intake

The twin strategies are to cut back on fat and to increase carbohydrates:

❋ Base meals around carbohydrate foods – potatoes, pasta. rice, bread
❋ Eat smaller portions of fat-rich foods (eg meat. pies, cheese) and fill up with extra potatoes or bread
❋ Porridge made with water makes a high-carbohydrate start to the day
❋ Drink fruit juice with meals, and a milky drink at bedtime
❋ Cut bread extra-thick for sandwiches
❋ Try carbohydrate-rich snacks that are also low in fat: eg, fresh or dried fruit, water biscuits spread with jam
❋ Choose pasta sauces based on tomatoes or vegetables rather than meat or cheese

Timing your carbo intake

If you need to replenish your glycogen stores quickly (eg, you're training every one or two days) it's best to take advantage of the fact that the body is more likely to make glycogen immediately AFTER exercising – the sooner, the better. Some foods are better than others for this – the best are those with a high 'glycaemic index' (a term which means they will bring about a large surge in blood sugar). Examples of such foods are: bread (white or wholemeal), rice, potatoes, raisins, bananas, glucose, sucrose and honey. If you can't face eating straight after exercising, try a carbo-rich drink instead.

Fluid, the second key ingredient

For many athletes, dehydration is something to watch out for. Even moderate fluid losses can mean operating at less than 80% of your potential, and more significant losses could be dangerous to your health.

To prevent this unhappy state of affairs, the answer is to drink. Water is perfectly adequate for most purposes. However, if you're exercising under particularly hot conditions, and/or you know that you are a champion sweater, you may want to consider one of the commercially formulated sports drinks. Isotonic and hypotonic sports drinks are designed to zap water into your bloodstream as fast as possible, and a number of studies have found that they have a slight edge over plain water. You can make up your own version of a sports drink by adding a pinch of salt and 2-4g glucose per l00mI of water.

To make sure that your fluid balance is well in the black before competing, drink more water than you usually would for the few days beforehand. Don't drink alcohol the night before an event – it will dehydrate you. Before competing, try to drink between 1/2 and 1/4 pint 15 minutes before the start.

Iron, the third key ingredient

Many athletes run the risk of low iron, partly because the stresses of their sport lead to increased losses of iron from the body (runners seem particularly susceptible). A number of studies have found that people in regular training and/or sports activity have low levels of ferritin. a body store of iron. People with low iron stores complain of tiredness and poor recovery from training. If the situation becomes worse, and haemoglobin (the form in which iron is transported around in the blood) levels fall, anaemia could result, with symptoms of severe fatigue, cramps. headaches and shortness of breath.

So what can you do if you suspect you're iron deficient? Iron supplements are available, and taking some for a few days to see if you notice any improvement could help identify if you really are deficient.. However, supplements are commonly associated with side-effects such as nausea and heartburn, so your best bet is to try and boost your iron intake by dietary means. Even if you don't suffer immediate side-effects, you should seek medical advice before taking an iron supplement regularly, because it's also possible to suffer health problems from too much iron!

* Haem iron foods: liver, liver pate, lean steak, chicken (dark meat), fish, oysters, salmon

* Non-haem iron foods: eggs, breakfast cereal (fortified). wholemeal bread, spinach (cooked), lentils/kidney beans

(cooked), tofu, sultanas, dried apricots, almonds, cocoa.

Haem iron is better absorbed by the body than non-haem. However, absorption of non-haem iron is enhanced by vitamin C, so include some raw or lightly cooked vegetables with a meal, or drink fruit juice. Conversely, drinking tea or coffee will make the iron more difficult to absorb.

Tailoring nutrition for specific sports

As a broad generalisation, sports can be divided into activities that are aerobic (eg, endurance events), anaerobic (short, intense bursts of activity, eg, sprinting), and those that are primarily related to strength (eg, weightlifting. throwing). In fact. there will often be a combination of all three elements, but there is usually more emphasis on one of the three.

The endurance athletes priority is to maximise glycogen stores by eating a high-carbohydrate diet both in training and before an event. Carbo loading is advisable, especially for an activity lasting longer than 90 minutes. Care should be taken to avoid dehydration, and this balanced against the possible benefits of taking in extra carbohydrate during the activity. Sports drinks containing maltodextrins enable delivery of some carbohydrate without compromising fluid uptake; on a cool day, however, it could be worth drinking something with a higher concentration of carbohydrate. This will slow down fluid absorption but will spare muscle glycogen. Eating during an endurance event tends to be problematic for runners, but seems to be well tolerated by cyclists.

Sports with an anaerobic content are also performed at their best with muscles well-primed with glycogen. A training diet high in carbohydrate will therefore be beneficial. Carbo loading is not really necessary, however. For anaerobic activities, lactic acid build-up in the muscles is a limiting factor. Some research has shown that sodium bicarbonate taken before events such as a rowing race, 400m swim or 800m run has a positive effect. Some individuals suffer gastrointestinal side-effects, however, so experiment first in training. In recent years. creatine phosphate supplements have shown consistently positive effects on short-term, high-intensity exercise.

Athletes involved in heats or rounds need to ensure that they recover adequately between events. A sweet drink or carbohydrate-rich snack after exercising will pack the glycogen back into the muscles. Similarly, keep topped up with fluids – if rehydration time is at a premium (eg between squash matches) you'd do well to try an isotonic or hypotonic sports drink – and make sure you're well-hydrated at the start of the day.

The common folklore in strength sports is that a high-protein diet is required. The consensus of most sports scientists is that, although the protein needs of strength athletes are slightly higher than the general population, high levels of protein intake are not necessary. In fact, in the quest for protein, many strength athletes end up eating unhealthy high-fat diets. The key issue for bulking up is adequate energy intake alongside a training programme. A high-energy intake from nutritious food will also be high in protein, carbohydrate, vitamins and minerals.

Many studies of strength athletes have reported heavy use of dietary supplements. Favourites include amino acids – arginine and ornithine. for example, are marketed as boosting growth hormone release, mimicking the effect of steroids. There is no proof that the small amounts of amino acids provided by these supplements have any effect at all on growth hormone levels or body condition.

We will now look at some special considerations for swimmers, cyclists, runners, and those involved

Swimming

Optimum body fat for swimmers has become controversial of late. Traditionally, swimmers tend to have more body fat than their counterparts in other sports such as running or cycling. This has always been considered to be an advantage because of the added buoyancy factor. However, recent research has thrown doubt on this accepted wisdom. A study at the University of Georgia found that more fat is not necessarily an advantage. In trials, extra body fat was found to decrease

VO_2max (maximal aerobic capacity). Swimmers trying to lose fat should follow a diet which restricts calories by cutting down on fatty foods. Some popular weight-loss diets advocate cutting down on starchy foods – this is never recommended for an active sportsperson.

Cycling

The long miles and hours of training undertaken by competition cyclists call for a high-energy diet. A dietary study of elite cyclists estimated their average daily calorie intake at over 6000 calories! Its not possible to consume this much at three meals a day, so constant 'grazing' over the day is advised, Take care that snack foods are high in carbohydrates rather than fat-rich.

Distance running

A nutrition-related problem a lot of runners have to contend with is gastrointestinal discomfort – from nausea to trots while on the trot. This seems to be a treat reserved for the distance runner – endurance cyclists don't suffer. It's thought that the problems are caused by the repeated jolting of the gut while running. Some tips that runners have found helpful are:

❋ Try liquid food only for the last meal before a long run or pre-competition
❋ Take care not to become dehydrated while running. Research has found that runners who take on board adequate fluid while running are less likely to suffer from gut problems
❋ Avoid food high in fat or protein before your training runs, as research shows that these are more likely to induce nausea if eaten before exercise
❋ Some athletes find that decreasing the fibre content of their diet before competing improves things.

Power sports

A brief word about making weight (eg, in combat sports, rowing, gymnastics). Drastic strategies such as sweating it out in a sauna, or using diuretics or laxatives, may cause an effective loss of body weight, but your body will have lost water, muscle and glycogen in order to achieve it, This will seriously handicap your performance, and it will be impossible to make good the deficit in the time between weighing-in and competing. The maximum weight loss that can be achieved without affecting fluid and glycogen stores is about 2 lb a week. So ideally, you should be very close to your competition weight two to four days before competing.

Female athletes: special considerations

The two nutritional issues of particular relevance to female athletes are: first, avoiding anaemia, and second, achieving a sensible weight. The daily iron requirement for menstruating women is higher than that for men. There is also a greater likelihood that women athletes will be vegetarian. Although there are vegetarian sources of iron, care must be taken to eat enough of them, and in a context that will enable them to be absorbed well (See section on iron, above).

Females achieving a very low level of body fat can end up with their periods becoming irregular, or even stopping altogether. This carries potential health risks, as studies have shown that female athletes whose periods have stopped have lower levels of minerals (including calcium) in their bones – meaning a higher risk of osteoporosis and stress fracture. Any female athlete with abnormal menstruation should consult her GP, and may need to consider gaining weight. In addition, calcium-rich foods should be consumed, such as dairy products, nuts and seeds, dried fruit and green vegetables.

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CUTTING INJURIES

Eating in a way that keeps your body primed for peak fitness can also reduce your risk of injury

First of all, eating foods that will help to fend off fatigue will minimise injuries arising from tiredness and weakness. Secondly, some of the metabolic processes which can lead to muscle soreness and damage can be counteracted to a degree by dietary factors.

It's old news that keeping your muscles stacked with glycogen can help your endurance capacity. But did you know that a respectable glycogen credit will also make injury less likely? There's evidence linking muscle glycogen depletion with both fatigue and injury. The connection is simple – muscles that are fatigued lose their strength, and thus their ability to protect joints. For example, take that favourite injury, the shin splint. While you're running, you rely on one particular muscle to take proportionately more strain – a strip of sinew that runs down the shin to the inside edge of the foot and pulls the foot inward and upward. During running, this muscle works at least twice as hard as other local muscles, and is therefore most likely to fatigue first. As it gets tired, the risk of shin splints and stress fractures is likely to rise, as does the risk of knee injuries.

There are a number of strategies you can adopt to minimise the chances of this muscle phasing out and landing you with an injury, from specific exercises to selecting your shoes with care. Diet is another crucial factor which you neglect at your peril. Eating to ensure your muscles are packed with glycogen will mean it takes far longer before they run out of fuel and become fatigued. There's direct evidence relating muscle glycogen depletion with muscle fibre damage and sports injuries.

Sports scientists argue that apart from the risk of direct damage to an overworked muscle, fatigue may result in the athlete employing different movement patterns, thereby exposing untrained muscles to an unexpected demand, and making joint injury more likely. For example, researchers found that repetitive overhand throwing fatigues the stabilising muscles surrounding the shoulder, making dislocation more of a risk.

The two causes of muscle fatigue

Fatigue itself is a broad concept, including a number of different components – from mental through the nervous system to the muscle itself. Your diet can help to offset fatigue at the muscular level.

There are two distinct metabolic components of fatigue that develop in the muscles: 1) accumulation of certain metabolites and 2) depletion of other metabolites. The accumulation component includes an increase in the amount of hydrogen ions (eg, as a result of lactate build up). Depletion includes decreasing amounts of fuels found inside the muscle cells – ie, ATP, phosphocreatine and glycogen.

Fatigue may not be the sole cause of injury, but is one of a number of contributing factors. Researchers Worrell and Perrin reviewed the literature on the causes of hamstring strains, and concluded that fatigue was one of several factors that can contribute to this type of injury (J Orthop *Sport Phys Ther* vo1 16, ppl2-18).

The fatigue-injury link

Common sense would suggest that exercising with muscles that are fatigued is likely to damage those muscles. This has been borne out when samples of athletes' muscle fibres have been extracted and inspected under the microscope. Various groups of researchers have examined skeletal muscle tissue taken by biopsy from athletes after endurance exercise. They found deterioration and degeneration in the structures inside the muscle cells, together with significant inflammation in the muscle tissue. Oedema, increase in connective tissue and degeneration of muscle fibre has also been observed after distance running.

This type of muscle damage is not always accompanied by a perception of soreness, unlike damage which occurs after eccentric exercise. 'Eccentric' activity is where your muscles are contracting while simultaneously being stretched. An example of this is running downhill – your thigh muscles are being stretched by the force of gravity at the same time as they are contracting as part of the mechanics of running.

Prolonged exercise and eccentric exercise represent two distinct mechanisms of muscle damage, both of which end up with the same result. Muscle damage due to eccentric exercise appears to have mechanical causes. High tension developed in single muscle fibres during muscle lengthening may bring about the damage. Glycogen depletion is probably not important in injuries sustained as a result of eccentric exercise. But some experts believe that restocking glycogen after this type of exercise may speed up repair.

In comparison, prolonged exercise is associated with a depletion in muscle glycogen stores, which in turn results in a decrease in energy production. The stress of trying to sustain a level of work output which cannot be met by sufficient fuel is thought to contribute to muscle damage. Glycogen, when broken down into its constituent units of glucose, can be used to make ATP.

Who is affected by glycogen-deficient fatigue?

Fatigue experienced in sports performed at low intensities (less than 50% V02 max) is not due to running out of fuel, because at this pace, fat can be used to provide a steady supply of ATP. ATP is the ultimate fuel used by muscles for energy, and can be made at a slow steady pace from fat (glycogen can be used to supply ATP at a faster rate). Most of us carry enough fat to fuel many hours of low- intensity exercise. Fatigue in this scenario is usually a result of a central nervous system component.

In contrast, fatigue in trained athletes exercising at moderate to heavy intensity (SO-75% $V0_2max$), is related to depletion of the glycogen needed to fuel a faster pace. Stores of glycogen stashed away in the muscles and liver will be running low after about 90 minutes of this level of exercise. Blood glucose will start to drop, and to compound this, muscles will be less able to take up what glucose is circulating in the blood, as glucose needs to be conserved for use by the brain. Eventually, there will be a shortfall between the muscle cells' demand for glucose and the amount available. Fatigue and discomfort will set in – and this is when injury is most likely to strike.

At this pace, an unfit individual is less likely to experience fatigue due to depletion of glycogen, and more likely to experience the accumulation component. Lactic acid will start to build up, and force a reduction in pace. As exercise intensity increases to 75-90% $V0_2max$, trained athletes may experience fatigue from a combination of the depletion and accumulation factors – ie, both glycogen depletion and lactic acid build up. Untrained people will be unable to keep up such a pace for very long because of high levels of lactic acid.

Very short supramaximal bursts of activity (greater than 100% $V0_2max$ – eg, in sprinting) are limited by availability of creatine phosphate. This is stored in the muscle cell in limited amounts and is the only substance that can be used to regenerate ATP.

Intermittent exercise, too

Similar to continuous exercise, intermittent exercise results in glycogen depletion. Thus, a footballer alternately sprinting and walking during a match will end up low on glycogen, as will a tennis player at the end of a match.

So, athletes most vulnerable to glycogen depletion-related injury will be those in regular training, who are exercising at moderate intensities for over an hour. Several studies have supported this, finding that prolonged moderate and intermittent exercise coincide with muscle glycogen depletion and are related to injury [1].

For example, a study which investigated injuries in downhill skiers used examination of muscle biopsies. There was a large decline in muscle glycogen content after an entire day of downhill skiing. The investigators concluded that depleted glycogen stores were the reason that more injuries occur toward the end of the day [2].

Another team of researchers examined the association of exercise-induced muscle glycogen depletion and repletion with structural changes in muscle cells. Forty runners completed a marathon and needle muscle biopsies were performed immediately, one week, and one month after the race. They found that the glycogen depletion and repletion pattern immediately after the race and during recovery correlated with the pattern of muscle fibre damage and repair. The researchers concluded that the damage resulted from metabolic stress – ie, the continued demand on the muscle to produce work despite depleted glycogen stores [3].

Although studies tend to focus on specific events, keeping your glycogen level topped up is just as essential in training. It's all too easy to gradually drain your glycogen stores if you're training without eating a diet high enough in carbohydrates.

So how much carb do you need?

As readers of this special report will already be aware, there's a consensus that 8-l0g of carbohydrate per kg of body weight will maintain appropriate glycogen levels during heavy training. For competition itself, carbohydrate loading is a protocol which is only likely to be of benefit for athletes whose event involves continuous moderate exercise for longer than 60 minutes, or whose event requires repeated bouts of high-intensity exercise. A recommended regime is to begin seven days before D-day, gradually tapering your activity while stepping up the proportion of carbohydrate that you eat. For the last three days, your carbo consumption should be around 500-600g/day.

Before exercising, it may be beneficial for endurance competitors to consume a liquid carbohydrate meal one hour beforehand. Most importantly, if you are competing for longer than an hour, if you can take in carbohydrate while exercising, you will delay the onset of fatigue. Glucose polymers (such as maltodextrin) are a good way of taking in carbohydrate while on the move. Ideally, you should aim for a 6-8% solution containing 15-20g of carbohydrate per 7oz of water, and try to drink some every 15 minutes.

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References

1 ('Carbohydrate strategies for injury prevention', Journal of Athletic Training Vol 29, pp244-254)

2 ('Physiological demand in downhill skiing', Phys Sportsmed Vol 5, pp28-37)

3 (Am J Pathol, vol 118, pp33 1 -339)

FAT-CARB RESEARCH

This study looked at the effects of an unusual type of loading on endurance cyclists

In the good old days of carbo-loading, endurance athletes would complete an especially exhausting workout, consume platefuls of fat-laden goodies for three days or so, and then shift to three days of low-fat, high-carbohydrate food in order to maximally boost their muscle-glycogen levels before an important competition.

The three days of fatty foods were fun for athletes who normally followed the strict dictates of healthful, high-carbohydrate eating, and early studies carried out in Sweden indicated that the overall plan could hike glycogen to extraordinary levels and promote superior endurance performances.

Unfortunately, subsequent research showed that the 'depletion' phase of the procedure – the knock-out workout and three days of fat – wasn't really necessary to super-concentrate glycogen. In fact, its main effect seemed to be the production of tired, somewhat cranky athletes. As a result, endurance performers went back to the old humdrum of consistent carbohydrate intake.

Special fat-burning fibres?

However, research carried out recently at the University of Indiana revived the possibility that fat might be fit food for endurance kings. The Indiana investigations suggested that athletes who sup on fat for long periods of time – over a week or so – might convert their muscle cells into special, fat-burning fibres with an increased capacity to conserve glycogen. Capping the fat consumption with a couple of days of high-carbohydrate eating would then lead to extraordinarily high levels of muscle glycogen, because muscle cells, accustomed to using fat to satisfy their energy needs, would simply stockpile the incoming carbohydrate in record amounts. Initial studies with laboratory rats indicated that the prolonged fat plus short-term carbohydrate pattern could bolster endurance in certain situations.

However, the 'fat-first, then-carbo' strategy hadn't been tried out with human subjects – until now. Recently, scientists at the University of Cape Town asked endurance-trained cyclists to consume either their normal diets (less than 30% of total calories from fat) or special high-fat diets (more than 65% of calories from fat) for a period of 10 days. Following the 10 days of normal eating or high-fat dining, the athletes capped muscle glycogen by consuming a high-carbohydrate diet (with more than 75% of calories furnished by carbos) for three days.

After the 13-day dietary manipulations, the athletes cycled for 150 minutes at an intensity of 70% $V0_2max$ and then completed a 20-kilometre time trial as quickly as possible. Compared to the normal diet, the 10-day, high-fat regime speeded performances on the time trial from 30.9 to 29.5 minutes, an 84-second improvement.

Why was high-fat eating better for performance? The high-fat preparation spared muscle glycogen during the 150-minute, pre-trial cycling; 'fat-trained' leg muscles burned glycogen at only half the rate, compared to the muscles of athletes on normal diets. As a result, there was more glycogen left over to spur a spirited sprint during the 20-K time trial.

But take care

So, should you 'fat-load' for 10 days prior to your next endurance competition? Not necessarily! The Cape Town study was carried out in a manner which gave fat-loading a decent chance to beat normal eating; your actual competitions may proceed quite differently. To be more specific, in the Cape Town research the 1 50-minute, pre-trial exertion was completed at a low-enough intensity (just 70% $V0_2max$, or about 80% of maximal heart rate) so that muscles accustomed to a high-fat diet could rely on fat as their primary energy source, saving glycogen for later. You see, muscles will rely primarily on fat for energy only if the actual intensity of exercise is low enough; once intensity rises to a certain level, the muscles have to go with carbohydrate, even if they've been trained to burn fat.

So, in a true competitive situation, even for a prolonged event such as a three-hour marathon, the intensity of exercise is high enough to force muscles to draw heavily from their carbohydrate stores, even if they had been prepared to rely on fat by 10 days of fatty eating.

The bottom line – or actually the 'bottom time' - is about three hours, according to Cape Town researcher Tim Noakes. 'If your competition lasts for longer than three hours, then your average intensity of exercise is modest enough so that fat oxidation becomes important, and you can consider using the pre-race, high-fat eating strategy,' says Noakes. Such eating habits will give your muscle cells a fat fetish, which they can indulge in as you cycle or run at a moderate pace. Your glycogen stores will be more effectively preserved, and you should have less fatigue and an increased ability to push hard at the end of the competition.

So here's the overall picture. If your competition or workout lasts for about three hours or less, don't worry about putting on the high-fat feed bag. For longer efforts, 10 days of fat plus three days of carbos might give you considerably more endurance – and a new PB.

If you complete your race in 2:45 or so, why wouldn't some heavy pre-race fat consumption help you? Well, you'd be teaching your muscles to utilise fat – but then burning primarily carbohydrate during your competition. It would make your muscles schizophrenic, and it wouldn't help your performance. (For more on this subject, see the last article in this special report.)

('Effects of a Low-Carbohydrate, High-Fat Diet Prior to Carbohydrate Loading on Endurance Cycling Performance,' Biochemistry of Exercise Ninth International Conference, p. 32, 1994)

MUSCLE SORENESS

But extra carbohydrate doesn't appear to alleviate muscle pain

Tough workouts promote heightened fitness, but they can also lead to so much muscle soreness that athletes are unable to train effectively during the days after a rigorous session. To promote more consistent training and to limit muscle damage, exercise scientists have searched for ways to prevent excessive post-workout soreness.

One popular anti-soreness recommendation has been for athletes to ingest ample amounts of carbohydrate shortly after a strenuous training session. The idea is that the extra carbohydrate would quickly make its way into muscle cells, providing plenty of fuel to kick-start the repair process which takes place after a workout. The rapid repair would then block muscles from becoming overly inflamed.

Unfortunately, a recent study carried out at California State University suggests that post-workout carbos don't have much effect on muscle pain. In the California research, 20 males started the muscle-soreness ball rolling by completing eight sets of 10 eccentric muscle contractions on bench press, arm curl, and single leg extension machines. (Eccentric contractions, in which muscles are stretched while they are trying to shorten, are noted for inducing soreness. With weight machines, eccentric contractions generally take place as a weight is being lowered.) During the four hours after the workout, subjects consumed either a placebo or a carbohydrate-containing sports drink which provided .4 grams of carbohydrate per kilogram of body weight.

Muscle soreness increased appreciably both 24 and 48 hours after the eccentric workout, but there were no differences between the two groups; the carbohydrate-ingesters did NOT have less muscle pain. Likewise, blood levels of creatine kinase (a muscle enzyme used as a marker of muscle damage) were similar in the two groups.

Why didn't the post-workout carbohydrate limit muscle soreness? The subjects' muscle membranes may have been damaged by the strenuous weight-training sessions, so carbohydrate might have had a rough time even making it across the membranes into the interiors of the muscle cells. However, it's also possible that carbohydrate alone can't cure muscle soreness; it would have been nice if the Cal State researchers had added a third group of athletes to their study – a group which consumed surplus carbohydrate AND protein. The protein might have knitted together damaged muscle areas, while the carbohydrate could have yielded the energy necessary for repair, downplaying overall soreness.

The Cal State study didn't measure 'functional recovery' in the two groups, so it's possible that the carbohydrate group might have been stronger than the placebo group following the eccentric workout, even though soreness levels were similar. The Cal State researchers also used relatively untrained subjects; experienced strength trainers might have been able to use the supplemental carbohydrate more effectively.

It's also important to mention that the Cal State study doesn't mean that post-training carbohydrate is worthless. In fact, other investigations have shown that taking in carbohydrate after workouts speeds glycogen replacement and suitably prepares athletes for training on subsequent days, even if it doesn't dampen soreness.

Reference

(The Effect of Carbohydrate Consumption on Delayed Onset Muscular Soreness and Indices of Damage,' Medicine and Science in Sports and Exercise, vol. 26(5), Supplement, p. S6, 1994)

OTHER FORMS OF LOADING

Can phosphates as well as carbs fuel your exercise?

Phosphates make your bones and teeth as hard as rocks, but they also might help you grind your way to faster workouts and competitive efforts. At least, that's what some sports nutritionists and sports-supplement manufacturers are suggesting. After all, muscles, like bones and teeth, have a large appetite for phosphates. Your muscles use phosphates to make ATP and CP, two high-energy chemicals which provide the energy necessary for muscle contractions. Surplus phosphates also prevent unwanted increases in muscle acidity and may increase the flow of oxygen from your red blood cells into your muscles.

Interest in phosphate supplements for athletes soared some years ago when University of Florida researchers announced that the consumption of about four grams of sodium phosphate per day for three days lowered lactic-acid levels and increased the endurance and aerobic capacity ($V0_2max$) of 10 well-trained distance runners. However, a follow-up study at Brigham Young University wasn't quite as encouraging: when 11 active individuals ingested a commercial phosphate supplement ('Stim-O-Stam'), there were no improvements in $V0_2max$, leg-muscle power, or running performance. Subsequent research at Adelphi University determined that 'phosphate loading' did not hasten competitive cycling times during a five-mile race.

Just to make things interesting, a more recent investigation at Old Dominion University found that consuming four grams of daily sodium phosphate for three consecutive days strengthened cardiac activity, lifted lactate threshold by 10%, hiked $V0_2max$ by 9%, and heightened performance by 8% during a time trial in a group of experienced triathletes.

Now the problems

However, as scientists at the University of New Brunswick have recently pointed out, phosphate research has been plagued by a multitude of problems. For one thing, only seven published studies have actually utilised a 'double-blind, cross-over' research design, in which researchers and subjects were initially unaware of who was taking phosphate, and phosphate- and placebo-ingesting individuals eventually switched their roles. Double-blind, cross-over studies are the 'gold standard' for supplement research, because they limit the possibility of bias on the part of researchers and also help to control for variation between subjects.

Four of these seven top-quality investigations found a performance-enhancing effect with phosphate loading, while three studies showed that phosphate supplementation had no impact on exercise capacity, making phosphate's role as a performance-boosting ('ergogenic') substance somewhat ambiguous. In addition, a total of just 63 subjects took part in the seven research projects, and all 63 were young men in their twenties and early thirties. Thus, it's not clear that the results of the research are actually applicable to older athletes or women.

In addition, only one of the investigations measured blood-phosphate levels before the research actually began, an omission which makes it hard to know how much of the ingested phosphate was actually making it out of the digestive system into the blood (for phosphates to work, they must first be carried to the muscles by the blood). The investigations also showed that exercise itself sometimes lifts blood-phosphate levels more than phosphate supplementation!

Varying doses of phosphates were used, and – strangely enough – the highest dosage was given in one of the three studies which showed no ergogenic effect. Also, a variety of different sources of phosphate were utilised, including neutral buffered sodium phosphate, tribasic sodium phosphate (TSP), mono – and dibasic sodium phosphate, and dibasic calcium phosphate (DCP). Most studies have used TSP, even though TSP has been linked with digestive-system distress and DCP may raise blood-phosphate levels to a greater extent.

Maximal exercise

If phosphate supplements do work, they probably help during maximal – not sub-maximal – exercise. In four of the five investigations which involved high-intensity efforts, phosphate supplementation had some positive effect on exercise capacity, but phosphate failed to aid performance in the two studies which involved only moderate-intensity exertions. It's possible that phosphate loading might help athletes during efforts lasting five minutes or less, while an ergogenic effect during longer-term, lower-intensity exercise seems unlikely.

Phosphate loading is not illegal, and there are no known adverse effects, although chronic phosphate supplementation, combined with a low intake of calcium, could trigger a calcium deficiency. An appropriate amount of phosphate for athletes might be about 4 grams per day – parcelled out into four one-gram doses – for three days before competition, with the last supplement taken two to four hours before competing. However, research on phosphate supplements has yielded such mixed results that, as the New Brunswick scientists noted, 'it is difficult to support phosphate loading as an ergogenic procedure.'

Reference

('Ergogenic Effects of Phosphate Loading: Physiological Fact or Methodological Fiction?' Canadian Journal of Applied Physiology, vol. 19(1),pp. 1-11, 1994)

OTHER FORMS OF LOADING

Endurance athletes may love ice cream, but surely ‘ fat-loading’ is ridiculous... isn’t it?

Recently, six endurance athletes at the State University of New York at Buffalo increased their fat consumption by about 60% for a week – and boosted their performances by over 30%!

It wasn’t a seven-day pizza party which turned the trick, or even a prolonged sojourn at the local ice cream parlour. The athletes’ blubbery diets and improved performances were part of an investigation carried out by a team of researchers at SUNY-Buffalo’s School of Medicine.

The focus on fat’s ability to promote endurance wasn’t exactly new. After all, the first North-Pole explorers needed a 60%-fat diet to sledge-dog their way to the top of the world, and various scientific studies have linked high-fat diets with heightened perseverance during prolonged exercise (see earlier in this special report). In addition, some sports nutritionists have contended that high-fat diets ‘teach’ muscles to metabolise fat during exercise, conserving precious glycogen and giving muscles greater access to the most bountiful source of energy in the body.

In the SUNY-Buffalo inquiry, the six accomplished athletes, all of whom were training more than six hours per week, consumed their normal diets for one week, a high-fat diet for the subsequent week, and a high-carbohydrate diet for one final week. At the end of each week, the athletes participated in an endurance test, which consisted of running as long as possible on a treadmill at an intensity of 75-85% $V0_2max$ (85-92% of maximal heart rate).

The normal diet consumed during the first week contained only 2800 daily calories, about 700 calories less than the athletes really needed, according to the Buffalopian scientists. The normal diet was composed of about 61% carbohydrate, 25% fat, and 14% protein.

During the following week, the high-fat diet crammed about 3500 daily calories into the athletes' bodies, with a composition of just 50% carbohydrate, 38% fat, and 12% protein. Finally, the high-carbohydrate eating also provided 3500 calories per day, with 73% coming from carbos, 15% from fat, and 12% from protein.

What were the results?

We all know that the lofty carbo eating produced the best performances, right? Well, carbo consumption was definitely better than 'normal' eating; the athletes stayed on the treadmills for 76 minutes after a week of carbohydrates, compared to just 69 minutes with their normal fare. However, the best dietary plan of all turned out to be the high-fat protocol ! After a week of increased fat consumption, the athletes ran for over 91 minutes on their treadmills, a 20% advance beyond the carbo plan and a huge 30% improvement over regular eating.

The Buffalo scientists theorised that a fattier diet fostered better performances by increasing the amount of fat stored inside the athletes' leg muscles. These intramuscular bubbles of fat supposedly provided a rich source of fuel during exercise – helping the athletes to run for a more extended period of time. At long last, it appears that sports-active people can savour bountiful bowls of guilt-free ice cream and other high-fat foods – and then set new PBs in their races!

Oops!

Actually, don't start stoking in the high-fat sweets just yet, because it' s likely that other factors were responsible for the fatty-diet advantage. For one thing, the Buffalo athletes had to complete an overnight fast prior to all three of their endurance tests. Without even a whisper of breakfast, the athletes also had to finish a maximum treadmill exercise test before they even started their endurance runs. During this maximal test, the grade of the treadmill increased every three minutes until the athletes were simply too exhausted to continue.

The athletes rested for 30 minutes between the maximum exertion and the actual endurance run (again without ingesting a single morsel of food), but they then faced additional hardship during the first 30 minutes of their endurance effort: the scientists jacked up the treadmills so that the athletes were forced to work at 85% $V0_2$max (90-95% of maximal heart rate) - an intensity which forced the athletes' muscles to rely primarily on carbohydrate, not fat, for energy.

After those tough 30 minutes, the treadmill grade was lowered so that the poor fellows could run at a more moderate 75-80% $V0_2$max, but by then the athletes' leg muscles were probably extremely glycogen-depleted. An overnight fast, abstinence from breakfast, a maximal exercise test, and a 30-minute 'carbo-burner' at 85% $V0_2$max will tend to remove most of the glycogen from anyone's leg muscles!

The bottom line is that the cards were stacked against the athletes after their week of eating carbohydrate. During the high-carbohydrate week, their leg muscles had grown accustomed to utilising carbohydrate as a preferred fuel, but – due to the design of the study – carbohydrate levels were greatly reduced inside their muscles after the first 30 minutes of the endurance test. That threw the advantage over to the fat-eating plan. After a week-long fat orgy, the athletes' muscles were well attuned to the idea of using fat for fuel, so their quads and calves naturally and easily relied on fat when carbo levels dropped, helping the athletes stay on the treadmills longer. The high-fat strategy probably socked more fat away inside the athletes' muscles and converted their blood into a literal river of fat, so the fat-eaters simply had a greater supply of alternative fuel (fat) available when their carbohydrate tanks were drained.

Avoid carbo flame-out

I'd put money on the notion that things would have been far different if the carbohydrate-eaters had taken breakfast on the morning of the endurance tests, avoided the maximal treadmill effort, and started the endurance test at a more moderate pace to avoid carbohydrate flame-out. If the carbo-consumers had also sipped a little sports drink during the endurance test, they probably would have run rings around the fat-eating people, even if the fat-eaters had wolfed down a high-fat breakfast and forced fat into their bodies intravenously.

Let's be realistic. The circumstances which confronted the Buffalo athletes are not the ones you'll face before and during your own competitions. After all, how many competitions force you to fast for 12-16 hours before the race, or participate in a maximal test before the race begins, or start the race far too fast?

High-fat diets might be helpful prior to occasions when you know you'll have to run in a glycogen-depleted state. However, since carbos promote a higher intensity of exercise, compared to fat, competitive athletes should always stack up as much carbohydrate in their muscles as possible – and then keep carbohydrates cascading toward their muscles to prevent glycogen depletion (by taking five to six swallows of sports drink every 15 minutes during an endurance race, for example). Such a strategy will always keep you moving toward the finish line at a faster pace, compared to a plan which forces your muscles to rely primarily on fat. It's also more efficient. Bear in mind that for each litre of oxygen that you consume, carbohydrate yields 7% more energy than fat.

However, that doesn't mean the Buffalo study should be ignored. The fact that the Buffalo athletes' muscles adapted to fat burning after just a week of corpulent eating raises an interesting possibility. What if you could eat in a way that would stimulate your muscles to burn fat efficiently – but also squirrel away lots of carbohydrate? In that case, you'd have the best of both worlds; you would use the abundant carbohydrate to move more quickly and mix just the right amount of fat into your carbohydrate flame, slowing down the carbohydrate-depletion process. There'd be less worry about ingesting the right quantity of carbohydrate during a race and fewer problems if a stomach upset prevented you from consuming a sports drink.

Miller and Lapachet

Enter Wayne Miller, a researcher at Indiana University, and Richard Lapachet, his graduate student. Together they've come up with a neat dietary plan which may super-saturate leg muscles with glycogen and also promote efficient fat utilisation.

In the ingenious Miller-Lapachet research, 48 male rats trained on treadmills for eight weeks. 12 rats consumed a high-carbohydrate diet throughout the entire research period (we'll call these rodents the CC group), 12 rats ingested mainly carbohydrates but switched over to a high-fat diet for the final three days of the study (the CF group), 12 rats feasted on fat throughout the eight-week period (FF), and 12 rodents started out with fat but finished with three days of carbohydrate (FC). At the end of eight weeks, Miller and Lapachet tested the rats for both glycogen storage and endurance capacity.

The clear winners in the glycogen-storage race were the FC rats. Consuming fat for eight weeks and then suddenly switching to carbohydrate for three days produced supramaximal leg-muscle concentrations of carbohydrate. In fact, FC rats had 25-30% more muscle glycogen, compared to CC and FF rodents, and 136% more glycogen than the CF group. Why were CF rats so bad at glycogen storage, even though they had binged on carbohydrate for almost eight weeks? Apparently, the prolonged period of carbo-eating had slanted their muscles toward carbohydrate utilisation. Taking the carbohydrate away – even for only three days – caused their sinews to rapidly use up their glycogen stores, especially since they weren't accustomed to processing fat.

Better endurance

In terms of endurance, the FC rats again won hands down, hustling along on their treadmills for 467 minutes at just-under marathon intensity (85% $V0_2max$). No other exercise group lasted for more than 356 minutes.

Not surprisingly, Miller and Lapachet contend that rat endurance times are optimised when rats adapt to a high-fat diet and then ingest substantial amounts of carbohydrate for a short period of time. Would the same strategy work for humans? 'Human runners who follow a 30% fat diet for several weeks and then switch over to carbohydrates shortly before an important competition should do very well,' says Miller. The idea is that such runners will be great 'fat burners' and will also have ample supplies of high-octane carbohydrate. However, please bear three things in mind:

(1) If the 'high-fat-followed-by-carbo-loading' strategy works, it should only be effective for races longer than an hour or so. In shorter races, the intensity is so high that fat plays only a small role in metabolism, and the race is so brief that glycogen depletion shouldn't be a big problem.

(2) The high-fat diet should be adhered to for only a short period of time (no more than a few weeks). Over longer periods, there would be a risk of gaining unwanted body fat or shifting blood-fat profiles toward an abundance of 'nasty fats' - the LDLs.

(3) In the Miller-Lapachet research, the rodents didn't toss down Ratade (or some other carbohydrate-containing substance) during their competitive efforts. If they had sipped sports drinks, the results might have been different (the CC rodents might have done considerably better). If you take part in long-duration competitions, your best strategy is still to consume lots of carbohydrate during the days before the race, eat a high-carbohydrate breakfast on the morning of the event, and imbibe a sports drink during the competition itself.

Recommendations

So what's the final word? It's not possible to recommend a doughnuts and ice cream diet – if only for a few weeks – just yet. Even though the Miller-Lapachet rats ran best after the fat-followed-by-carbos scheme, things probably work differently in humans, so a well-controlled study with actual male and female athletes is necessary before we can go out on a limb.

If you usually eat lots of carbohydrate and you're convinced that eating more fat might help you, be very wary of regressing to a higher-fat diet for a few days, especially prior to an important competition or a rigorous workout. If you don't follow a fat splurge with at least three days on your usual carbohydrate regimen, the Miller-Lapachet research suggests that you could dramatically increase your risk of glycogen depletion and fatigue.

For now, taking a 'middle ground' on fat intake is advisable. There's no solid evidence that a few weeks of higher fat intake will help you set new PBs, but you shouldn't try to totally eliminate fat from your diet, either. Fat is necessary for the absorption of many vitamins, and a moderate intake of fat can help some endurance athletes who have a tendency to burn far more calories than they ingest.

To increase your chances of performing at your highest level, we continue to recommend a carbohydrate intake of about four grams per pound of body weight per day during vigorous training, with a significant amount of the carbohydrate ingested during the two hours after a workout – when your leg-muscles' carbohydrate 'doors' are open to their fullest extent.

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