

WHERE DOES THE ENERGY TO GALLOP COME FROM?

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Sources of energy in the horses' diet

The foods that feed to our horses are usually complex mixtures of many different types of substances. Horse feeds contain three main energy sources: carbohydrates (i.e. simple sugars or mono-saccharides e.g. glucose and complex sugars or polysaccharides or *chains of simple sugars* e.g. starch and cellulose); fats (fats, oils, lipids); proteins. By far the most common sources of energy used by the body, especially during exercise, are carbohydrates and fats (protein is only usually used as an energy source in extreme circumstances (e.g. illness or starvation)). However, at the level of individual cells within the body (whether these are muscle, brain, liver, heart or kidney, etc) it is not carbohydrate or fat or even protein that is used as the energy source but a compound called adenosine tri-phosphate (ATP). Thus, cells cannot directly use the energy in food as it is eaten. It must be digested and converted into ATP. It will therefore not be surprising to know that the body contains significant stores of ATP. In fact, all living cells within the body have a store of ATP. Cells or tissues (collections of specialised cells) that are effectively dead and therefore do not contain ATP include certain bone cells, hair and the upper layer of skin cells.

There are a number of ways we can think about food being converted to ATP. In the house we turn on a light-switch or a socket and we are using electricity. However, whilst electricity is what makes things work, the electricity itself is made from coal or oil or gas or wind or water. We have to convert the potential energy in these fuels into electricity. You can't make a washing machine run by pouring petrol or oil into it and you can't make a muscle work by pouring cereals into it. So carbohydrates, fats and proteins are the fuels going into the "power station" and ATP is the "electricity" of the body.

Getting energy from ATP

Energy locked up in ATP is released by enzymes (proteins). This process is known as metabolism. Of course, the energy in the food that we or our horse consume can be stored in times of plenty for times of scarcity. Also, whilst feeding ATP is possible and might seem a great way to cut out all those indirect steps of metabolism, it would

not be taken up from the stomach or intestines or be able to cross from the blood into the muscle cells.

Whilst the body stores of ATP are not insignificant, if a horse were to undertake explosive exercise such as running fast for 2-3 seconds, this would use up all the ATP stored within the muscles. This is where other forms of energy stored within the body come into play as these can be used to regenerate ATP.

Regenerating ATP after it has been broken down

For simplicity it is best to only consider carbohydrates and fats. Food from the diet in its complex form is digested into simpler components and used immediately or stored within the body. In plants, the storage form of carbohydrate is starch. Starch is a polysaccharide – simply a chain of many (poly) sugars (saccharide). In animals, the stored form of carbohydrates is glycogen. In simple terms glycogen is chain of many thousands of glucose molecules – i.e. a polysaccharide. The glucose has to be stored in chains as single molecules would be able to “leak” out of cells.

Glycogen as an energy source

The majority of the glycogen stored in a horses’ body, around 90%, is stored within the muscle cells themselves. The remainder, around 10%, is stored within the liver. This is used to maintain the blood glucose level (often referred to as the “blood sugar” level).

The process of getting energy from glycogen to regenerate ATP is relatively rapid and can be accelerated from “standing” within a matter of seconds and can provide significant energy for ATP regeneration in intense exercise lasting for around 3-4 minutes. This source of energy is also used for acceleration during a period of exercise. The breakdown of glycogen to glucose units is triggered by a number of factors, including increases in adrenaline. The glucose is then metabolised by a special linked sequence of chemical reactions catalysed by a number of different enzymes to regenerate ATP. This is the process known as glycolysis and is the pathway whereby lactic acid is formed. This breakdown of glycogen to lactic acid is really the equivalent of rocket-fuel.

The good news about glycolysis is that it can be accelerated immediately and it doesn't have to wait for an increase in breathing and heart rate to deliver oxygen to the muscles. In fact, it's the body's equivalent of 0-60 mph in under 3 seconds. In fact, the 100 metre runner or the acceleration of the racehorse out of the starting stalls or flat out gallops would not be possible without glycolysis. There must be a downside? The problem with glycolysis is that firstly, it's not very efficient. It only produces a small amount of ATP from the potential energy locked in the glucose resulting from the breakdown of glycogen to lactic acid. It's also self-limiting. The body has an in-built safety mechanism – it's called fatigue. Of course we usually view fatigue as an annoyance, especially if it occurs too early! However, fatigue is the body's way of saying "I've had enough". For human athletes, going beyond the pain barrier really means pushing your body beyond the normal point of fatigue and of course this can sometimes have dire consequences in terms of the occurrence of injury.

The precise factor or combination of factors causing fatigue does differ depending on the type of exercise being undertaken and other circumstances, such as climatic conditions (heat, cold), fitness, hydration status, etc. Fatigue can also be defined in different ways. For example, fatigue in a sprinting race may be defined as the point at which the athlete cannot maintain the same speed and begins to slow down, even if this is hardly detectable to those watching. In the case of prolonged exercise, such as a human marathon or equine endurance ride, fatigue may mean a complete inability to continue to exercise at all, even just walking. In the case of short-term, intense exercise fuelled by glycolysis, fatigue occurs due to a combination of different factors, but partly due to the accumulation of lactic acid within the muscle, which in turn dissociates (splits) into lactate and a hydrogen ion. Hydrogen ions lower the muscle pH and make the conditions inside the muscle cell acidic, which in turn slows glycolysis.

Aerobic (oxygen requiring) regeneration of ATP

So glycolysis (anaerobic glycolysis – where no oxygen is used) is good if we want to be fast for a short time. What if we want to exercise for longer? We know that glycolysis is inefficient and self-limiting when it is running flat-out. The option is to run at a lower speed, well below our maximum, and instead of converting the pyruvate to lactic acid (glycolysis), to metabolise the pyruvate to regenerate ATP in

the presence of oxygen. This is referred to as aerobic metabolism and takes place within specialised structures known as mitochondria. The great advantage of mitochondria is that they generate ATP extremely efficiently and produces much more ATP than glycolysis. The end products are water and carbon dioxide, which do not contribute to fatigue and so exercise based on aerobic (in the presence of oxygen) metabolism can be sustained for much longer. The downside is that an adequate delivery of oxygen to the mitochondria must be maintained for oxidative phosphorylation to continue. This involves expending energy to ventilate the lungs and to pump the blood through the lungs and to the muscles. So efficient, but not as fast. This energy pathway is the equivalent to petrol.

Almost all equestrian disciplines rely on a combination of glycolysis (often referred to as anaerobic) and aerobic metabolism to produce ATP. In disciplines involving short, term high-intensity exercise (e.g. Quarter-horse racing), the greater contribution will come from anaerobic energy production. With increasing duration, the contribution will shift more towards aerobic energy production. In many disciplines the underlying exercise may be supported mainly by aerobic sources with the energy for sprinting, acceleration and jumping efforts coming from surges in glycolysis.

The aerobic (oxygen requiring) regeneration of ATP using fat

There is one more fuel source that we have not discussed up to this point – fat. Whereas glycogen and or glucose can be metabolised either anaerobically or through mitochondria (aerobically), fat can only be used to produce ATP within the mitochondria and requires oxygen (i.e. another form of aerobic metabolism). The disadvantages of aerobic metabolism of fat are that large amounts of oxygen are required, it takes maybe 20-30 minutes to get production up to speed and the rate of ATP production is very slow. The advantage of fat is that per gram it contains considerably more potential energy than glucose or glycogen. Exercise is almost never, if ever limited by running out of fat. Using fat is like running a car on diesel – performance is moderate but it's very efficient. Certainly fat may be an important energy source for the racehorse at rest or in light training, but fat is not an important energy source during either flat or National Hunt racing.

Maximising the use of energy stores within the body for high performance

Earlier on, the effect of initial glycogen concentration on the rate of glycogen breakdown during near-maximal exercise and the time to exhaustion in prolonged exercise was highlighted (high initial muscle glycogen concentration = high rate of breakdown or longer time to exhaustion). The muscle glycogen concentration can be dramatically affected by exercise during training. So if you give your racehorse or eventer a short, hard gallop the day before an event or race, it is likely that the muscle glycogen concentration will not have recovered fully by the day of competition. The same applies to prolonged exercise. It would be unwise to do any fast exercise with an endurance horse in the 3-4 days prior to a competition. Whilst it is not possible to glycogen load horses by a combination of diet and exercise as practised by human athletes, reducing the amount and intensity of exercise in the last week before competition should ensure muscle glycogen concentrations at the start of competition are as high as possible.

In general, walking, trotting and slow cantering exercise (heart rates of around 70-140 b.p.m.) will result in significant utilisation of fat. If your horse is overweight and you want to get rid of excess fat, do lots of walking and trotting. If you work your horse hard, it will not “burn-off” the fat. At heart rates around 140-190 b.p.m., the horse will be using a mixture of fat and carbohydrate aerobically at the lower heart rates and aerobic glycogen breakdown at the upper end. Above heart rates of around 200 b.p.m., the horse will get the majority of energy from aerobic glycogen breakdown and with increasing speed, the proportion of energy coming from anaerobic breakdown of glycogen to lactate will increase. Of course, these are generalisations as the fuel sources and the relative importance proportions of aerobic/anaerobic glycogen breakdown will be related to other factors such as breed, age and muscle fibre composition.

Remember, the reason we are interested in optimising the utilisation of fat or aerobic utilisation of glycogen is that in many forms of exercise it is glycogen depletion that is a significant factor in fatigue and performance. If we can use as much fat as possible, then this spares glycogen. If we are exercising our horse at a faster speed which means that we cannot avoid using glycogen, then it is better to try and ensure that the glycogen breakdown is mainly aerobic. Remember that aerobic glycogen

breakdown is more efficient but slower than anaerobic glycogen breakdown. Finally, of course we cannot avoid anaerobic glycogen breakdown if we want to exercise our horse very fast or accelerate. However, this gives us a clue how to minimise unnecessary anaerobic glycogen breakdown to lactate by using an appropriate rising strategy.

In a mile race, the horse can get from start to finish in a number of ways. We can start off slow and try to catch and overtake the other horses, we can go out fast and let them catch us or we can keep changing pace or maintain a steady pace. The last strategy is the one that will result in the most efficient utilisation of glycogen (i.e. at this intensity of exercise, primarily aerobically). Accelerations and decelerations in pace demand anaerobic glycogen breakdown to lactic acid and as this is fast but relatively inefficient, if we ride this way then we run the risk of limiting our horses performance by depletion of glycogen stores.

Thus, in summary, if we maintain a fast steady pace we can optimise utilisation of glycogen. Faster speeds require aerobic utilisation of glycogen and even faster speeds and accelerations require additional breakdown on glycogen to lactate. The difference between aerobic and anaerobic glycogen breakdown are that the switching on and off of anaerobic production is rapid. At a medium speed canter, acceleration to gallop causes a surge in glycogen breakdown to lactate. If the speed is fast enough, lactate will still continue to be produced to supplement aerobic glycogen breakdown. If the pace is slowed back to canter, there is a rapid response and if this intensity does not require anaerobic glycogen breakdown to lactate, then this will be turned off within a matter of seconds. The switch between aerobic metabolism of fat and aerobic metabolism of glycogen is much different situation. If a horse has been exercising at trot for 30-40 min, the rate of ATP regeneration from fat will probably be at its maximum. If the horse accelerates, resulting in an increase in the contributing from glycogen and then slows back to a trot, the return to utilisation of fat at the previous rate may take 10-20 minutes or longer. Therefore to preserve glycogen stores as much as possible in prolonged exercise, particularly in sports such as endurance, it is essential to avoid too many sudden and dramatic changes in pace. Of course it may not be possible to maintain exactly the same pace for say 10 hours or even 10 min, but one should aim for as regular and steady rhythm as possible.

Effect of Diet & Time of Feeding

There is evidence from both human and horse studies that eating a diet high in fat increases the ability to use fat during exercise. In human athletes, a high fat diet has also been shown to have a detrimental effect on the ability to perform moderate to high intensity exercise. This should not be a surprise as of course moderate to high intensity exercise relies on a combination of aerobic and anaerobic glucose and glycogen breakdown. However, it is interesting to note that no human athlete would choose a high fat diet, even a marathon runner consumes a diet rich in mainly carbohydrate with very little fat. Perhaps the only exception are Sumo wrestlers!!!!

However, there is a problem in using the term high-fat diet. If we wanted to feed a person a high fat diet, we could choose to eat foods like cream, chocolate, cheese and corned-beef. We might be able to reach a point where around 75% of our calories were coming from fat. Because we are omnivores, we can tolerate quite wide variations in dietary energy source. A meal for a human athlete during training might consist of around 75% or more carbohydrate. In contrast, the horse being a herbivore with a small-stomach and relying heavily on bacterial fermentation for the digestion of fibre, is much less tolerant of changes in dietary composition. So a normal fat content in a horse diet might be 7-8% and a high fat diet might be considered to be 15-20%. Above this the horse may suffer from digestive disturbance (e.g. diarrhoea, colic). We should therefore not be surprised that the horse has and can only tolerate a relatively low fat diet, that the horse normally has quite a low % bodyfat and that they rely primarily on carbohydrate at rest and during most types of exercise. However, there is evidence that feeding a horse an increased amount of dietary fat (up to around 15%) can improve the utilisation of fat during exercise, provided that the exercise in question is of low enough intensity. Once heart rates increase to above around 180 b.p.m., even a horse that has been fed a high fat diet for many months during training cannot continue to use fat. Fat is high in energy, but the release of the energy is slow. This is why it will only support low-moderate intensity exercise to any appreciable extent.

One of the things to avoid as far as diet is concerned is to start exercise with a high blood glucose. For a human athlete, eating something high in sugar 10-15 min before

exercise would have a negative effect on performance. If exercise is started with a high blood glucose, insulin is released and blood glucose drops. A second effect is that adrenaline will be released, causing a shift towards glycogen utilisation, even during low-intensity exercise. The same is true for horses.

What and when should horses be fed in relation to the start of exercise? If the concentration of free fatty acids (fat) in the blood can be elevated by dietary means (e.g. fasting or feeding hay only), this may cause a shift towards utilisation of fat. However, there appears to be tremendous variation between horses in their ability to use fat during exercise. In one study, the horses that produced the highest amounts of lactate and had the highest proportion of type IIB fibres showed no change in ability to use fat during low-moderate intensity exercise. However, horses with a high proportion of type I and IIA fibres and few IIB fibres did show an increased utilisation of fat.

In most circumstances we would want to avoid starting exercise with an elevated blood glucose concentration for reasons explained previously. One way of achieving this is overnight fasting after a final feed of hay (i.e. no hay or grain on the morning of exercise). Of course we may decide that fasting a horse is not a good option because of the possible risk of gastric ulcers or colic. Feeding hay only has little effect on blood glucose concentration. In contrast, feeding grain only can cause a marked increase in blood glucose concentration for 2-4 hours after feeding. Feeding grain with hay is better than grain alone, provided the grain is given either after or at the same time as the hay and 4-6 hours before the onset of any exercise. However, grain and grain and hay (whether restricted or ad libitum) all increase plasma glucose in the post-feeding period more than hay or fasting and may affect other responses to exercise, including elevated heart rate and or lactate.

Therefore to avoid increasing plasma glucose prior to exercise and considering that fasting may induce anxiety/excitement or colic or gastric ulcers, the most favourable management strategy would be to provide a restricted volume of hay (i.e. normal or reduced volume as opposed to ad libitum access) around 4-6 hours before the start of exercise. During this period the horse should have ad libitum access to water.

How and when horses are warmed-up before a race can also have an important influence on how energy is used. In the horse, moderate (3/4 pace) to intense exercise and excitement (due to the action of adrenaline) causes the spleen to release stored red blood cells into the circulation. The extra red blood cells enable more oxygen to be delivered to the muscles. If a horse were to begin a race having only trotted down to the start, then at the start of the race the red blood cell level in the blood would be lower. Whilst it would increase during the race, the effect would be that the horse would be using less oxygen and relying more on the lactic acid (anaerobic) pathway as a way to regenerate ATP. This would result in poorer performance. The effect on performance would be least for sprint distances and more pronounced for longer races. On the other hand, if the horse is warmed-up to hard by galloping down to fast, then whilst the extra red blood cells would have been released, a significant amount of the muscle glycogen could already have been used before the race started. In addition, this would result in high lactic acid concentrations in the muscle and blood even before the race started and would have a negative effect on performance in the race. So it essential to warm-up at fast canter (not trot, slow-canter or gallop) to avoid using up your energy stores before the race and to make sure that during the race you use the stores more efficiently (with as much oxygen as possible).

Recovery from a race is also important, especially as far as the glycogen stores within the muscle are concerned. After a hard race or even a hard training session (i.e. gallop day) it can take the horse 24-48 hours to restore the glycogen in the muscle to the level it was before the race. The level of glycogen in the muscle is one of the factors that determine how fast the glycogen can be broken down to regenerate ATP. If the level is low the speed of ATP regeneration will be lower. So, whilst there are horses that have run 2 races within 1-2 days, a horse has a better chance of performing well if it were to have at least 2-3 days between races in order to allow the muscle glycogen stores to be replenished.

Summary

Exercise in the horse is almost never, if ever, limited by the body's stores of fat. In contrast, prolonged low-moderate intensity and high-intensity exercise can frequently be limited by muscle glycogen stores. The horse, both at rest and during exercise, relies more on glycogen than we do. The horse's natural diet (grass!) contains very

small amounts of fat. Even the traditional hay/grain diet is low in fats and high fat diets for horses may only result in a total fat intake of 15%. Higher amounts than this are poorly tolerated. Ensuring optimal glycogen stores before exercise and warming-up and riding in a way that does not “waste” glycogen, may help a horse put in a true performance.