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THE GUT DURING EXERCISE

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Introduction

Popularity of the horse for athletic competition, coupled with the tremendous economic importance of the horse, has stimulated increased study of equine exercise physiology. Studies in equine exercise physiology have taken many different avenues, two of the most popular being cardiopulmonary and muscular adaptations to exercise and nutrition of the "equine athlete." Although progress has been made in each area, only recently have studies been conducted which bridge the two fields of study.

In an effort to link diet with exercise performance, many studies have evaluated differences in performance associated with manipulation of various dietary ingredients. Several studies have shown a positive performance response to manipulation of assorted dietary ingredients, fat (vegetable oil) being one of the ingredients receiving a great deal of study. Other researchers have begun to look at not only what we feed athletic horses, but also when we feed these horses prior to exercise. The response of the digestive system is a key factor in determining which ingredients to manipulate and ultimately when to manipulate them. To understand fully how the digestive system can influence exercise performance, one must first appreciate the size and weight of the equine digestive system. Next, one should understand the impact that feeding has on the digestive system, and what impact exercise has on gut function and nutrient digestibility. Finally, this information must be summarized into a series of recommendations relative to what and when to feed horses that are involved in different types of exercise.

The equine digestive system

Anatomically, horses have developed a specialized digestive system which allows them to not only survive, but thrive on high fiber diets (Figure 1). The cecum (C) and colon (D) collectively account for approximately 64% of the empty weight of the horse's digestive system (Meyer *et al*., 1993). These two structures, known as the hindgut, are estimated to hold between 24 - 36 gallons of liquid (Householder *et al*., 1993), and house billions of bacteria and protozoa that ferment plant fiber. The horse's small, one compartment stomach (A) makes up less than 7% of the empty weight of the digestive system (Meyer *et al.*, 1993), and stresses the need for a continual intake of feedstuffs. The small intestine (B) is the single longest and heaviest (empty tissue weight) structure in the horse's digestive system, making up 27.5% of the total gastrointestinal tract weight.

A Stomach
B Small intestine
C Cecum
D Colon

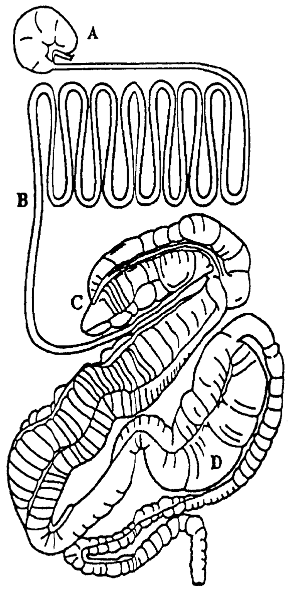

Figure 1. The horse's digestive tract

Taken together, the empty tissue weight of the stomach, small intestine and large fiber fermenting hindgut account for approximately 5% of the body weight of the mature horse. A fed (non-fasted) horse, however, has a fluid capacity within the digestive system of nearly 50 gallons (Householder *et al.*, 1993). After accounting for the weight of the digesta and associated fluid, a much larger percentage of the horse's body weight is associated with the digestive system. This can be appreciated when one considers that a partial fast (24 hours) can result in a 3.5% decrease in body weight for mature physically conditioned ponies (Duren, 1990).

The impact of feeding

One does not have to feed many horses before realizing that horses have a profound cardiovascular response to feeding. The noise associated with rattling buckets in a feed room can send a stable of horses into a pre-feeding frenzy. This phase of feeding is known in the scientific literature as the anticipation/ingestion phase. The anticipation/ingestion phase refers to the period when the animal is aware of an upcoming feeding and continues during ingestion of food. Horses, like many other animal models, respond to the anticipation/ingestion phase of feeding with increased cardiovascular activity. This cardiovascular response generally decreases after the ingestion of food (postprandial phase). In ponies, the cardiovascular response to feeding remains elevated for more than one hour following consumption of a grain meal (Duren, 1990).

Along with cardiovascular changes in response to feeding, changes can also occur in the distribution of blood flow within the body. The distribution of blood flow within the body is controlled by two mechanisms. It is controlled centrally through the nervous system, and locally by the environmental conditions in the immediate vicinity of the blood vessels (Berne and Levy, 1988). Central control of blood flow is mediated by the autonomic nervous system and primarily by the sympathetic nerve fibers (Goodman and Gilman, 1985). Increased sympathetic nerve activity (excitement/panic) causes vasoconstriction in the arterioles of the abdominal viscera, while causing vasodilation of arterioles in skeletal muscle. This scheme shunts blood away from the digestive system to working muscles in an adrenaline driven “flight” response.

Local control of peripheral blood flow appears to be adjusted to the existing metabolic activity of the tissue (Berne and Levy, 1988). According to the metabolic model of tissue blood flow, any intervention that results in an oxygen supply that is inadequate for the requirements of the tissues gives rise to the formation of vasodilator metabolites. These metabolites are released from the tissue and act locally to dilate the arterioles, increasing the flow of blood and the supply of oxygen.

Blood is distributed and redistributed to the various tissues of the body by a combination of central and local control of arteriolar smooth muscle. Duren (1990) reported that in fasted ponies (24 hour fast), 20.4% of cardiac output (blood flow) is distributed to the various tissues of the digestive system, while 79.6% of the blood flow is found in other tissues including skeletal muscle (Figure 2). Once a horse is fed, the amount of blood distributed to the gastrointestinal tract increases (Duren, 1990). This mesenteric hyperemia is confined to the digestive organs actively engaged in digestive functions. Muscle blood flow does not change as a function of feeding in ponies. The net result of feeding in horses is a redistribution of cardiac output (Figure 3) such that 27.4% of blood flow is distributed to the various tissues of the digestive system, while 72.6% of the blood flow is found in non-digestive tissue (Duren, 1990).

Besides changing the distribution of blood flow within the body, feeding has the obvious result of increasing the amount of material in the digestive system. This has a profound impact on the body weight of the animal. Meyer (1987) summarized that for every one kilogram of dry hay intake, approximately 10 kg of water is ingested. Eating hay stimulates saliva production (Meyer, 1987) and an increase in the secretion of digestive juices into the gastrointestinal tract. Much of the fluid in these secretions comes from blood plasma, resulting in a drop in plasma volume (Pagan, 1997). Decreased plasma volume then stimulates a thirst response and horses drink water. Fiber also has the capacity to bind water in the digestive system. This facilitates the holding of water in the hindgut as the amount of fiber in the diet increases. Van Soest (1984) reported that fiber binds water at a rate of 1 - 5 ml/g of fiber. The amount of water ingested with mixed diets (forage + concentrate) is roughly ½ that of all forage diets.

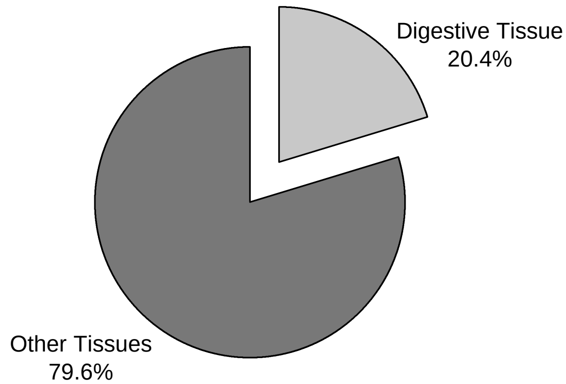

Figure 2. Estimated distribution of cardiac output in fasted ponies at rest.

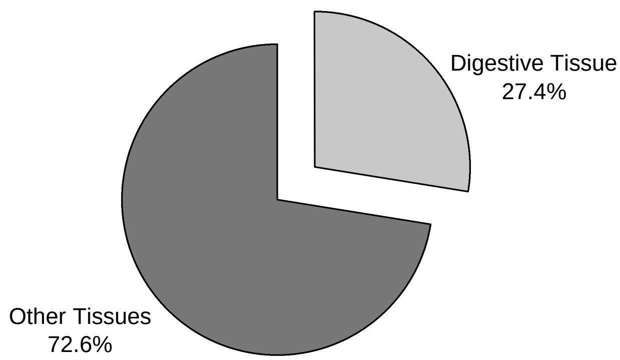

Figure 3. Estimated distribution of cardiac output in fed ponies at rest.

With changes in fluid content of the gut a characteristic of different feeds, the type of diet fed to performance horses can have an impact on body weight during exercise. This can be illustrated by calculating the energy requirement for a given performance horse, then calculating the amount of feed necessary to satisfy this requirement. The amount of feed necessary to maintain energy balance in a performance horse being fed either a 100% forage diet, a 50% forage plus 50% oat diet, or a 45% forage, 45% oat, 10% vegetable oil diet would be different due to the increased energy content of the mixed diets. Kronfeld (1997) calculated that a performance horse would consume 22.2 kg of forage compared to 16.6 kg of mixed feed and 12.9 kg of mixed feed plus vegetable oil to maintain body weight. The fat supplemented diet reduced feed intake by 22%, fecal output (gut fill) by 31% and water requirement by 12 %. Similarly, Pagan *et al.*, (1997) reported that performance horses working at moderate intensity consumed 10% more feed when fed an all forage diet compared with a mixed forage and grain diet. Further, the horses on the all forage diet consumed 33% more water than horses eating the mixed diet. To summarize these research reports, it appears the higher the fiber content of the diet, the greater the fluid content of the digestive system and the more weight carried by the horse.

Exercise and gut function

Limited information exists regarding changes in blood flow distribution during exercise in fed compared with fasted horses. Duren (1990) measured blood flow distribution during exercise in eight fed ponies and eight fasted ponies. The fasted group did not receive feed during the 24 hours preceding data collection. During this 24-hour period, these ponies were housed in a stall containing water and salt, but devoid of bedding material. The fed treatment group was provided free-choice alfalfa hay, water and salt during the 24 hours preceding data collection. In addition, these ponies consumed a pelleted grain concentrate at a rate of 0.7% of body weight 1.4 hours preceding data collection. Each group of ponies was monitored at rest and during 30 minutes of treadmill exercise. The treadmill was positioned at a 7% incline and set at a speed of 28 km/hour such that the ponies reached a heartrate greater than 150 beats/minute. This intensity of exercise is approximately 75% of heart rate maximum.

Blood flow to the digestive tract decreased during exercise in both fasted and fed ponies; however, blood flow was consistently higher throughout exercise in fed ponies (figures 4 and 5).

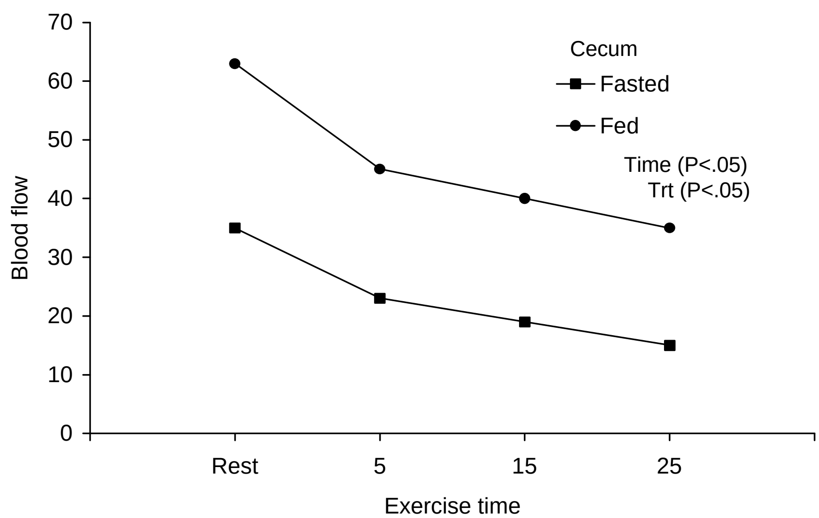

Figure 4. Blood flow (ml/100g tissue/min) to the cecum in fasted and fed ponies at rest and during exericse. SEM for cecum was 5.8

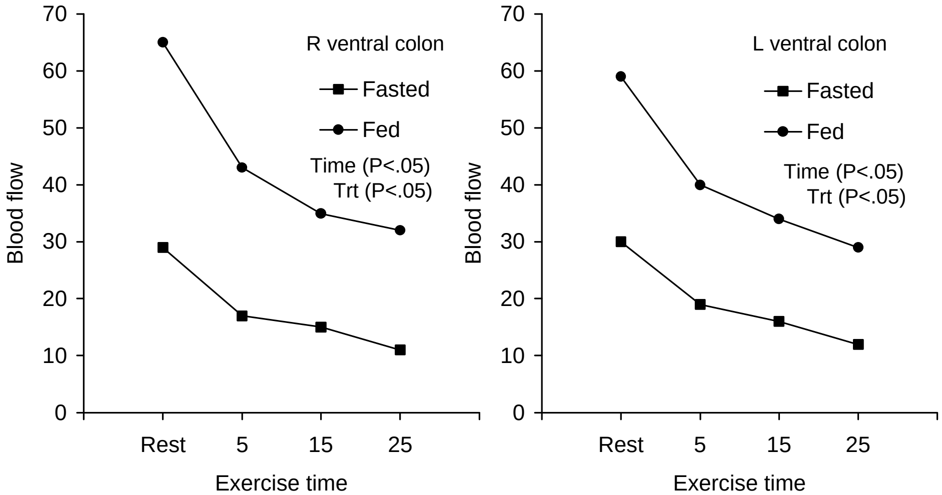

Figure 5. Blood flow (ml/100g tissue/min) to the right ventral colon and left ventral colon in fasted and fed ponies at rest and during exercise. SEM for right ventral colon and left ventral colon were 5.3 and 4.6 respectively

It is speculated that fed ponies had an elevated blood flow at rest, associated with increased digestive tissue oxygen demand, and the increased sympathetic tone produced during exercise was not large enough to totally reverse this hyperemia. As would be expected, blood flow to the locomotor and respiratory muscles increased during exercise in both fed and fasted ponies (Duren, 1990). However, blood flow to both locomotor (figure 6) and respiratory muscles (figure 7) was higher in fed than in fasted ponies.

Duren (1990) speculated that fed ponies worked harder during exercise, as evidenced by increased muscle blood flow, due to increased gut fill associated with feeding. Since the fed ponies exercised at approximately 75% of heart rate maximum, they were able to increase heart rate, cardiac output and stroke volume (figure 8) to deliver an increased amount of blood to both the digestive tract and working muscle.

With the knowledge that blood flow is shunted away from the gastrointestinal tract during exercise, the next logical question may be: what is the effect of exercise on nutrient digestibility? Most digestibility studies in horses have been conducted with idle horses confined to metabolism stalls. The values obtained from these studies are used for all classes of horses including the performance horse. Pagan *et al.*, (1997) reported that exercise resulted in a small but statistically significant decrease in dry matter digestibility. In that study, exercise consisted of walking, trotting and cantering approximately 5 miles/day on an inclined (3^o) treadmill. It is not known if the 1% decrease in dry matter digestibility reported by Pagan is actually biologically significant to the animal, but it does pose some interesting questions:

1) At what level of exercise intensity and duration would one expect to negatively influence nutrient digestibility?

2) Does the term "over training," a situation when the performance and body weight of a horse actually decline during heavy training, represent potential limits in digestive efficiency?

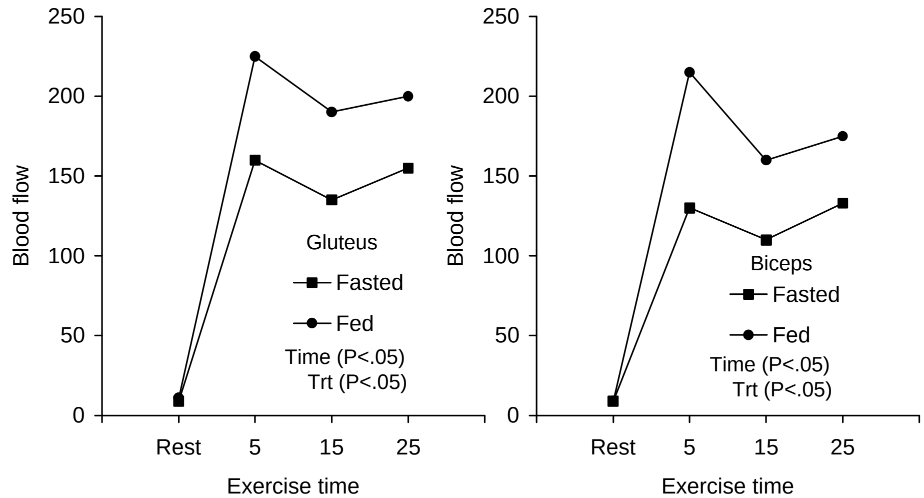

Figure 6. Blood flow (ml/100g tissue/min) to the crural diaphragm and costal diaphragm in fasted and fed ponies at rest and during exercise. SEM for crural diaphragm and costal diaphragm were 16.5 and 21.9 respectively

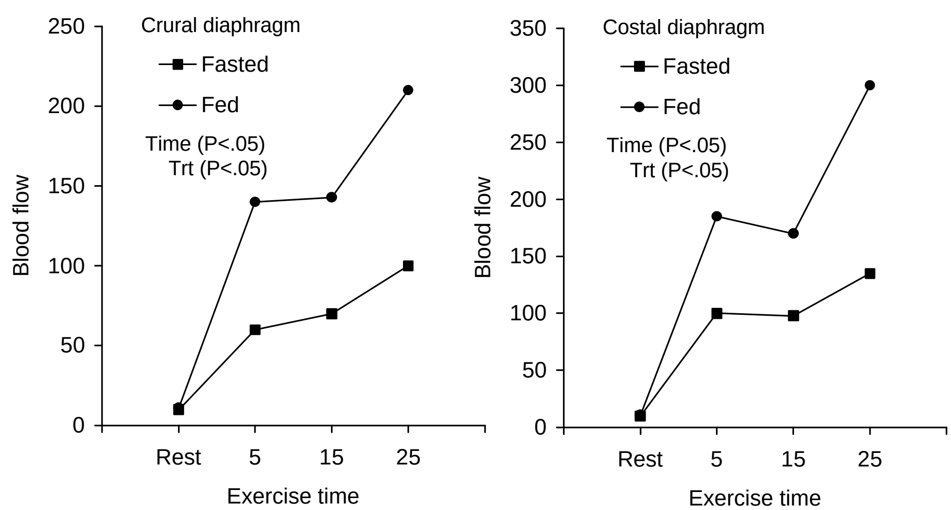

Figure 7. Blood flow (ml/100g tissue/min) to the gluteus medium and biceps femoris in fasted and fed ponies at rest and during exercise. SEM for fluteus medius and biceps femoris were 16.5 and 21.9 respectively

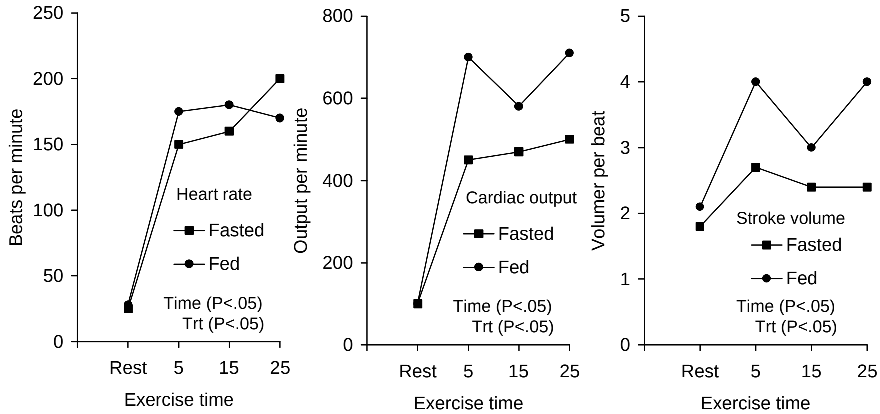

Figure 8. Heart rate (beats/min), cardiac output (9 ml/min/kg) and stroke volume (ml/beat/kg) in fasted and fed ponies at rest and during exercise. SEM

Feeding the performance horse

The preceding pages have detailed: the size and weight of the equine digestive system; changes in the distribution of blood flow associated with feeding; differences in gut fill and water intake associated with different diets and changes in blood flow and nutrient digestibility associated with exercise. From this information, one must attempt to determine the type of diet and the pre-exercise feeding schedule that will allow horses to perform at optimal levels. The following are some guidelines which may help in answering those questions. For the following examples, exercise performance has been classified into the following categories: 1) high intensity, short duration, 2) moderate intensity, medium duration, and 3) low intensity, long duration.

High intensity, short duration exercise

During high intensity, short duration exercise, the horse is working at near heart rate maximum. The horse can only maintain performance, at this level of exertion, for a short period of time (less than 10 minutes). One example of this type of exercise is flat track racing. Due to the short duration of this exercise, it is generally thought that nutrients needed to fuel muscle contraction must be stored in the muscle prior to exercise. Therefore, feeding horses with the intention of “loading” the blood with nutrients to be metabolized during short-term exercise does not appear beneficial. In fact, Stull and Rodiek (1995) and Pagan (1997) reported that grain feeding within four hours prior to submaximal exercise caused large declines in blood glucose during exercise. These declines in blood sugar may be detrimental to exercise performance since glucose is the only fuel metabolized by the central nervous system.

Feeding large fiber meals prior to exercise is not warranted either, since fiber would increase the "dead" weight carried by the horse. Since the speed at which an animal can travel is related to body weight, additional body weight would only serve to slow the animal. Racing officials routinely handicap horses by assigning additional weight to superior runners. If racing officials can potentially change the outcome of a race by assigning as little as 4 lb, what would be the impact of a short-term fast (12 hours) on body weight? Longer periods of fasting would further decrease body weight; potential problems including digestive upset, however, may occur with re-feeding these horses.

FEEDING RECOMMENDATIONS

High intensity, short duration exercise

Hay feeding - eliminate 12 hours prior to exercise
Grain feeding - do not feed within eight hours of exercise
Water - no restrictions

Moderate intensity, medium duration exercise

During moderate intensity, medium duration exercise, the horse is working at a heart rate between 50% and 75% of maximum. Exercise of this intensity may be tolerated for several hours. This type of exercise may include a variety of "show events" in which horses perform in a number of classes throughout the day. Since speed is not the primary concern, the weight (gut fill) of the animal does not appear to be critical. These horses would benefit from small frequent forage meals (partially to eliminate boredom). Grain meals should be avoided within eight hours of performance. This would eliminate large fluctuations in blood glucose associated with feeding and postprandial exercise.

FEEDING RECOMMENDATIONS

Moderate intensity, medium duration exercise

Hay feeding - small frequent meals, avoid large single meals
Grain feeding - eliminate grain within eight hours of exercise
Water - no restrictions

Low intensity, long duration exercise

During low intensity, long duration exercise the horse is typically working at less than 50% of heart rate maximum. At this intensity, exercise can be tolerated all day. Trail riding and some endurance rides are examples of this type of exercise. These horses have increased requirements for water and electrolytes due to the duration of exercise. They would benefit from the water and electrolyte holding characteristics of high fiber diets. The fiber should be of high quality (low degree of lignification) such that fermentation can occur thereby making these nutrients available for absorption. The use of "super" fibers including soybean hulls and beet pulp is warranted due to their high fermentation and water holding capacity. Meals provided during the ride should also maximize forage consumption since forage will stimulate water intake and help maintain hydration. Grain intake should be minimized during the ride in an effort to avoid fluctuations in blood sugar. Dietary fat is recommended to increase the energy density of the diet and to decrease the amount of grain needed in the diet.

FEEDING RECOMMENDATIONS

Low intensity, long duration exercise

Hay feeding - free access to high quality forage (high digestible fiber, low crude protein content)
Grain feeding - eliminate or minimize during day of the ride
Water - no restrictions
Electrolytes - provide pre-ride and early during ride (prior to significant dehydration).

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