APMB - Atti della Accademia Peloritana dei Pericolanti
Classe di Scienze Medico Biologiche
Vol. 112(1) 2024

ISSN 1828-6550

DOI: 10.13129 / 1828-6550 / APMB.112.1.2024.SD2

Scholarly Dialog SD 2 (1-9)

Fundamentals of muscle training of the horse: New paradigms for sports medicine specialists

José Luis López Rivero

Department of Comparative Anatomy and Pathological Anatomy and Toxicology, Faculty of Veterinary Sciences, University of Cordoba, Spain.

Abstract

As the main purpose of training is to modulate the muscular physiology according to the functional demands of each sporting discipline, it seems reasonable that those who in practice direct the training of the horse should know the fundamentals of these adaptations. Thus, it is very important to be clear that today's horse has developed innately and through selective breeding over generations outstanding muscular qualities within the animal kingdom, which are difficult to improve in practice. Thanks to studies carried out over the last 3-4 decades we now have certainty about the muscular changes we can expect in response to certain types of training methods and how these adaptations improve athletic performance. Of practical interest are the muscle genomics studies conducted in the last decade, which allow us to examine candidate genes for targeted selection and early prediction of performance, and to objectively monitor the practical training of these super-athletes. With all this, the equine sports medicine veterinarian now has an arsenal of scientific knowledge and state-of-the-art techniques to compete for the practical training of equine athletes, which is no longer largely empirical, as is unfortunately still the case today.

Key words: Skeletal muscle; physical training; muscle conditioning; muscle genomic; equine exercise physiology.

Introducing Member: Adriana Ferlazzo
Corresponding Author: J.L.Lopez Rivero - an1lorij@uco.es

Introduction

Training, together with its natural history as a herbivore and selective breeding over centuries of evolution, is one of the three pillars that support the modern horse, a species with more than seven hundred thousand years of survival.

The principal goal of athletic training is to modulate muscle anatomy and physiology, as the mechanical energy for exercise is generated within the locomotor muscles.

The specific objectives of athletic training are: first, to develop the basic athletic aptitudes: endurance or aerobic capacity, speed or anaerobic capacity and strength or power; second, to improve specific abilities of each discipline: sprinting, endurance, jumping, dressage, polo, carriage, etc.; and third, to ensure that all parts of the athlete's body adapt to the competition to improve performance. And all this to reduce the incidence of musculoskeletal injuries.

Despite the extensive evidence-based literature available, horse training remains largely empirical. In my opinion, there are three potential reasons for this: 1st because there is much controversy and contradictory results in the literature, especially in the early studies on this subject; 2nd because there is a lack of well-regulated studies that have compared different training protocols in the horse; and 3rd, because those who guide the horse's training in practice (trainers, riders, owners, sport technicians) do not sufficiently understand the basics of muscular response to training in this animal. During 40 years of intensive research, the analysis of muscle biopsies has unlocked many of the secrets of muscle response to training. The sequencing of the equine genome in 2009 has rapidly energized this progress over the last decade, in which we have learned that specific genetic polymorphisms are functionally associated with certain muscle characteristics, significantly modulating muscle response to training in the horse. The integration of these new genomic analyses with conventional analyses opens new horizons for monitoring the practical training of equine athletes.

Equine muscle has great potential to adapt to training and these changes have implications for athletic performance. Comparative analysis of the available studies provides practical information on two essential aspects:

what can be modified in the equine muscle by training, i.e., what muscle adaptations occur in response to different training approaches and what are their physiological consequences; and

How can these changes be achieved, i.e., what type and magnitude of training stimuli are required to induce these muscle changes?

For this goal we need some preliminary concepts and considerations about equine muscle physiology during exercise. It is also of practical interest to understand the basis of two potential problems related with equine training, namely overtraining and detraining.

Home basic concepts and principles

Muscle training is the general term used to improve or maintain equine athletic performance and/or to reduce the incidence of exercise-induced musculoskeletal injuries. On the other hand, muscle conditioning is a narrower term meaning improving athletic performance through objectively quantified muscle changes.

A basic principle of training is that a single training session leads to fatigue followed by an immediate adaptive response (supercompensation). When training sessions are repeated regularly with gradually increasing workloads, the peaks of supercompensation reached after each session (adaptation) become greater, leading to a net increase in performance. But when training is too vigorous and/or when rest periods between sessions are too short, an overall decrease in performance occurs.

When applying the overload principle in practice, it must be understood that a minimum time is needed for these adaptations to occur. In general, greatest adaptations occur within the first 6-8 weeks. There is also an upper limit to these adaptations, which in the horse, as a rule, is in-between 12 and 16 weeks. When the workload is prolonged or intensified beyond this period there is little chance of further beneficial effects, but the risk of overtraining and musculoskeletal injury is increased.

Another basic principle of training is that of individuality, referring especially to the work intensity or stress level or speed of exercise during each training session. The adjustment of this intensity to the individual horse can be done with heart rate or blood lactate measurements during standardized exercise tests under field conditions.

Overview of equine muscle physiology

The extraordinary athletic abilities of today's horse in attributes of speed, endurance and strength are due, in large part, to numerous muscular adaptations consisting of an extreme development of its musculature and a speed of contraction and metabolic capabilities beyond what is expected for an animal of comparable body size.

Because the larger a muscle is, the more powerful it is, muscle mass is relevant to athletic performance. Unlike other mammals, more than half of the horse's body weight is skeletal muscle, and there are important differences between breeds.

The myostatin gene has been studied in the last decade in the athletic horse for its involvement in the regulation of muscle mass. This protein, produced in skeletal muscle, inhibits muscle development by down-regulating myoblasts. We now know that a specific polymorphism of this gene is significantly associated with muscle mass and optimal running distance in Thoroughbred horses. Homozygous C/C horses have a sprinter morphotype (more muscular and smaller in stature) and perform better in short races, while horses with the T/T genotype have an endurance morphotype (less muscular and leaner) and perform better in long distance races.

The capacity for different types of exercise is because there are different types of fibers. Myosin is the molecular motor of muscle contraction and is responsible for this diversity. The horse expresses three myosin isoforms called I, IIA and IIX. The differential distribution at the cellular level of these isoforms determines the three types of muscle fibers we see in this histochemical myofibrillar ATPase stain: I (black), IIA (white) and IIX (intermediate). The speed of contraction increases significantly in the order I > IIA > IIX.

The fast twitch equine muscle fibers (IIA and IIX) have a faster contraction speed than expected based on the large body size of this species. This implies a shorter duration of hoof contact with the ground, which translates into a lower energy cost and greater locomotor efficiency, due to an increase in the frequency of stride.

The percentages of each muscle fiber type vary significantly between breeds with different athletic abilities, and between individuals within the same breed.

The myostatin gene polymorphism also shows a functionally relevant association with muscle fiber type percentages. Horses with the "sprint" variant (C allele) of this polymorphism have more fast myosin and less slow myosin than horses with the alternative T allele, linked to endurance.

The two main routes for regenerating ATP during muscle contraction are glycolysis and oxidative phosphorylation. Glycolysis breaks down blood glucose or muscle glycogen to pyruvate. In the absence of oxygen (anaerobic glycolysis), pyruvate is converted to lactate in the cytosol, but in the presence of oxygen (aerobic glycolysis) pyruvate enters the mitochondria and is converted to acetyl-coenzyme A, which proceeds to oxidative phosphorylation. Thus, acetyl-coenzyme A, derived from pyruvate or beta-oxidation of fats, is the substrate for mitochondrial oxidative phosphorylation. Aerobic routes are more efficient than anaerobic routes, but slower. For each molecule of glucose, anaerobic glycolysis yields only 2 ATP, whereas aerobic glycolysis produces 39 molecules.

Metabolic differences between fibre types play an important role in equine muscle physiology. There is an inverse coupling between the aerobic and anaerobic capacities of equine muscle fibres. Thus, fibres with the highest aerobic capacity (type I) have the lowest anaerobic capacity, and vice versa: fast fibres IIX have the highest anaerobic capacity but the lowest aerobic capacity. This is why slow-oxidative fibres are predominantly involved in low intensity but prolonged exercise, whereas fast-glycolytic fibres are involved in short, intense exercise.

The mitochondrial content of horse muscles represents 7% of the fibrillar area, which is higher than that described in smaller species, such as humans (where it represents 4%) or similar sized species such as cows (3%).

As the mitochondrial content of the muscles is proportional to the maximum oxygen consumption capacity, the VO2max value of the horse is twice that of the best human athlete of Olympic class and 2.7 times higher than that described in cattle.

There is an association between a polymorphism in the myostatin gene and equine muscle mitochondrial content. Compared to the C/C genotype (sprinter profile) the mitochondria content and the overall aerobic capacity significantly higher in horses with the T/T genotype (endurance profile).

Substrate utilization depends on the intensity and duration of exercise. The more intense the exercise, the greater the relative contribution of carbohydrates. And the longer the exercise, the greater the utilization of fats.

Equine muscles contain higher glycogen stores compared to other species, especially in the fast fibres. But glycogen repletion after exercise is an inherently slow process in the horse, which can take up to 72 hours.

Muscle glycogen is a limiting factor in muscle contraction during prolonged submaximal exercise, which occurs below 85% of maximal oxygen consumption capacity. Its depletion is the main cause of fatigue in these exercises, as oxidative phosphorylation is inefficient without a continuous source of pyruvate.

In intense exercise, above 85% of maximal oxygen consumption capacity, the main cause of muscle fatigue is local acidosis associated with intracellular lactate accumulation. When muscle pH falls below 6.5 muscle contraction is disturbed.

To counteract this acidosis, the horse has a very efficient mechanism to evacuate lactate from the fast fibres and transport it as a substrate to the slow fibres for oxidation. This bypass is carried out by two membrane transporters called MCT1 and MCT4.

From a biochemical point of view, the main goal of equine muscle conditioning is to improve performance through a twofold objective: to increase aerobic and/or anaerobic capacities; and to mitigate the two main causes of muscle fatigue during submaximal (glycogen depletion) and supramaximal (muscle acidosis) exercise. Muscle adaptations to training.

What can be modified in the muscle by training and what is its functional significance?

Depending on multiple factors, the adaptive response of equine muscle to training can take several forms:

First, a quantitative response, in which muscle fibres increase in size (hypertrophy) but retain their structural, physiological, and biochemical properties.

Second, a qualitative response or remodeling, in which the myofibres do not change in size, but acquire marked contractile and metabolic differences (e.g., a transformation between fibre types); and Third, a mixed response, of remodeling with discrete or substantial hypertrophy, which is the most common form in practice.

Potentially, training can produce numerous adaptations of muscle fibres in the horse, occurring at three main levels: morphological, contractile, and metabolic. But it must be understood that, although many of these adaptations occur in parallel, they are never simultaneous.

The main morphological adaptations include increases in cell size, mitochondrial density, number of capillaries and number of nuclei.

Among the most common contractile adaptations of myofibres are an IIX to IIA fibre-type transformation, and an IIA to I fibre-type transformation during very prolonged endurance training. Some training increases the intrinsic velocity of muscle fibre types without fibre type conversion. But the real significance of the IIX to IIA fibre transformation is that a greater number of fast twitch motor units are recruited during intense exercise, an adaptation that promotes endurance, strength, and speed.

Aerobic metabolic adaptations are very common and are expressed by an increase in the activities of muscle enzymes representative of aerobic metabolism, an increase in glucose and fatty acid transporters, and an increase in intramuscular glycogen stores.

Certain training programs also produce adaptations in anaerobic metabolism, expressed by an increase in the activities of enzymes representative of glycolysis, and of lactate transporters across the membrane, as well as in the buffering capacity of the muscle.

All these training-induced muscle changes are caused by alterations in the rates of regulation (inhibition or expression) of the genes encoding these proteins.

As an example, for practical application, recent studies have shown that the polymorphism of the myostatin gene significantly mediates the muscle response to training in the horse. Compared to the T/T genotype (endurance fitness), the C/C genotype (speed fitness) of this polymorphism favors a greater development of muscle mass in response to training, and this effect is due to a lower expression of myostatin in horses with the C/C genotype. In contrast, the IIX: IIA fibril transformation, which is expressed by the ratio between the percentage of IIA and IIX fibres, is higher in horses with the T/T genotype (endurance fitness) than in horses with the C/C genotype (speed fitness). In other words, the inhibition of the IIX gene induced by training is greater in horses with the T/T genotype than in horses with the C/C genotype. These results indicate the high practical value of genotyping this polymorphism to objectively monitor the training of athletic horses.

It seems clear that the set of muscular adaptations in response to training has important physiological consequences.

The increase in size and intrinsic speed of contraction of the muscle fibres produces a muscle with greater peak strength and explosive power, two qualities necessary for many disciplines, such as jumping, dressage and sprinting.

Endurance during prolonged submaximal exercise, on the other hand, is improved by a muscle with a higher aerobic capacity and a slower and more oxidative fibre profile. The adaptations in aerobic metabolism are reflected in an increase in maximal oxygen consumption capacity and a delay in the onset of fatigue due to glycogen depletion.

The adaptations of anaerobic metabolism also favor an improvement in net anaerobic capacity at the muscular level, delaying the onset of fatigue due to the accumulation of muscular lactate during supramaximal exercise. It seems clear that these adaptations favor speed fitness in athletic horses.

Specific training programs

Muscle conditioning programs in athletic horses should focus on developing the muscular properties that optimize the balance between endurance, strength, and speed. They should then focus on developing and maintaining the muscular characteristics directly related to each discipline. As there is an upper limit to muscle adaptations to training, we must recognize the signs of overtraining, as this condition reduces performance.

When designing a training program, two groups of factors that influence the muscle adaptive response must be considered:

First, the basal state of the muscle, referring to the breed, age, sex, physical condition, and sporting history of each horse. It seems reasonable that the training of a Thoroughbred and an Arabian horse should be different. It is also to be expected that the magnitude of the adaptations will be greater in a young, inactive horse, with abundant type IIX fibres and low oxidative capacity, than in a mature, active horse, with abundant slow, oxidative fibres.

And secondly, the characteristics of the stimulus, i.e., the training parameters, which are usually defined by these 5 variables: nature or type of exercise, intensity, duration, frequency, and total length of the exercises applied in each training session. The type of exercise conditions the muscular response to training. Different types of exercise have been used to evaluate this response. It is also clear that exercise intensity is more important than duration for developing improvements in speed and strength attributes, while exercise duration is more important for developing endurance attributes. In any case, it seems that it is the sum of these two parameters, together with frequency, which determine the total volume of the workload that has the greatest impact on the development of muscular adaptations.

The aim of training to optimize the three basic athletic qualities (endurance, strength and speed) has serious limitations, as the development of strength and speed is not easy to achieve in practice. The very high percentage of type IIX fibres in the horse (near 50% in the gluteus medius muscle of a Thoroughbred) is related with this limitation, as these fibres are only recruited with maximum intensity exercises that carry serious risks of causing musculoskeletal injuries. In practice, some resources that have been implemented to overcome this difficulty are to gallop horses on sloping ground (5-10%).

By comparing the results of different studies that have described the muscular adaptations induced by well-defined training in terms of intensity, duration, and length, we can know what stimuli are needed to develop the horse's physical capacities (endurance, strength and/or speed).

For example, to develop endurance, only submaximal intensity exercises (between 30 and 60% of maximal aerobic capacity) and long duration (45 to 120 min/session) are needed for periods of 6 to 8 months.

When the aim is to simultaneously improve endurance and strength, training should be designed based on higher intensity exercises (between 80 and 100% of VO2max) and moderate duration (15-60 min/session) for 3 to 5 months.

But if the objective is to increase these 3 capacities, gallops of supra-maximal intensity (100-165% of VO2max) and short duration (over distances between 1600 and 3600 m) are required, applied at least twice a week for 3-4 months.

Overtraining is defined as the unexplained loss of performance that occurs over the course of a prolonged training program (usually more than 16-20 weeks) with excessive overload and little recovery time.

The only functional cause that has been found for this syndrome is an endocrine dysfunction of the hypothalamic-pituitary-adrenal axis.

Overtraining syndrome can be recognized by a range of clinical signs including chronic fatigue, excessive post-exercise heart rate and blood lactate values, discomfort on training, with anxiety and behavioral disturbances, and loss of appetite and weight loss. The problem is serious, because overtrained animals rarely return to their previous performance levels, so prevention is essential.

Conclusion

In conclusion, as the main purpose of training is to modulate the muscular physiology according to the functional demands of each sporting discipline, it seems reasonable that those who in practice direct the training of the horse should know the fundamentals of these adaptations. Thus, it is very important to be clear that today's horse has developed innately and through selective breeding over generations superior muscular qualities within the animal kingdom, which are difficult to improve in practice through training.

Thanks to studies over the last three decades, we now know the expected muscle changes in response to certain types of training and how these adaptations improve athletic performance.

Of practical interest are the muscle genomics studies carried out in the last decade, which make it possible to examine candidate genes for targeted selection and early prediction of performance, and to objectively monitor the practical training of these super-athletes.

As a result, the equine sports medicine veterinarian now has a whole arsenal of scientific knowledge and state-of-the-art techniques at his disposal to help ensure that the practical training of equine athletes is no longer largely empirical, as is unfortunately still the case today.

Acknowledgements

The Author acknowledges Professors Adriana Ferlazzo and Pietro Medica for their support and invitation

Ethical disclosures

The Author declares absence of conflict of interest

The power point presentation of this Scholarly Dialog is available at:

https://view.genial.ly/655247893fa4420011ec3b37 last access February 10, 2024

References

1. Birch, H.L., Brama, P.A.J., Firth, E.C., Goodship., A.E., Rivero, J.L., van Weeren, P.R. (2013). The response of musculoskeletal tissues to exercise. In: Equine locomotion, 2nd edn. Chapter 13. W. Back, H. Clayton, (Eds.) Saunders Elsevier, Edinburgh, pp. 305-341.

2. Harris, P.A., Rivero, J.L. (2013). Exercise-associated muscle disorders. In: Equine applied and clinical nutrition: health, welfare and performance. R.J. Geor, P.A. Harris, M. Coenen (Eds). Chapter 31. Saunders Elsevier, Edinburgh, pp. 521-535.

3. Hill, A. (1950). The dimensions of animals and their muscular dynamics. Scientific Progress 38, 209-230.

Hill, E.W., Gu, J., Eivers, S.S., Fonseca, R.G., McGivney, B.A., Govindarajan, P., Orr, N., Katz, L.M., MacHugh, D.E. (2010). A sequence polymorphism in MSTN predicts sprinting ability and racing stamina in thoroughbred horses. PLoS One 5, e8645. doi.org/10.1371/journal.pone.0008645.

4. McGivney, B.A., McGettigan, P.A., Browne, J.A., Evans, A.C., Fonseca, R.G., Loftus, B.J., Lohan, A.,

MacHugh, D.E., Murphy, B.A., Katz, L.M., Hill, E.W. (2010). Characterization of the equine skeletal muscle transcriptome identifies novel functional responses to exercise training. BMC Genomics 11, 398. doi.org/10.1186/1471-2164-11-398.
5. Miyata, H., Itoh, R., Sato, F., Takebe, N., Hada, T., Tozaki, T. (2018). Effect of Myostatin SNP on muscle fiber properties in male Thoroughbred horses during training period. J Physiol Sci. 68, 639–646. DOI: 10.1007/s12576-017-0575-3.
6. Rivero, J.L., Piercy, R.J. (2004). Muscle physiology: responses to exercise and training. In: Equine sports medicine and surgery: basic and clinical sciences of the equine athletes, 1st edition. Chapter 5. K.W. Hinchcliff, A.J. Kaneps, R.J. Geor, (Eds.). Saunders Elsevier, Edinburgh, pp. 45-76.
7. Rivero, J.L., Piercy, R.J. (2008). Muscle physiology: responses to exercise and training. In: Equine exercise physiology: the science of exercise in the athletic horse, 1st edition. Chapter 2.1. K.W. Hinchcliff, A.J. Kaneps, R.J. Geor, (Eds.). Saunders Elsevier, Edinburgh, pp. 30-80.
8. Rivero, J.L., Boffi, F. (2007). Aparato musculoesquelético. En: Fisiología del ejercicio en equinos. Capítulo 2. F. Boffi, (Ed). Intermédica Editorial, Buenos Aires, pp. 15-40.
9. Rivero, J.L., Piercy, R.J. (2014). Muscle physiology: responses to exercise and training. In: Equine sports medicine and surgery: basic and clinical sciences of the equine athletes, 2nd edition. Chapter 6. K.W. Hinchcliff, A.J. Kaneps, R.J. Geor (Eds.). Saunders Elsevier, Edinburgh, pp. 69-108.
10. Rivero, J.L., Hill, E. (2016). Skeletal muscle adaptations and muscle genomics of performance horses. Vet J. 209, 5-13. doi: 10.1016/j.tvjl.2015.11.019.
Rooney, M.F., Porter, R.K., Katz, L.M., Hill, E.W. (2017). Skeletal muscle mitochondrial bioenergetics and associations with myostatin genotypes in the Thoroughbred horse. PLoS One 12(11), e0186247. doi: 10.1371/journal.pone.0186247.

Received December 6, 2023, revised and accepted December 17 ,2023, published un line March 18, 2023