Aging and How It Affects the Physiological Response to Exercise in the Horse

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The use of older horses for athletic and/or recreational activities is a common practice, with many animals still actively competing or working even at ages greater than 20 years old. Research involving human athletes shows an age-related reduction in the ability to perform strenuous exercise; however, limited data are available regarding the exercise capacity of aged horses. Advancements in medical care as well as our understanding of nutritional and activity requirements of geriatric horses have led to many horses living well into their 20s and even 30s. Thus, there is an increased demand for a more thorough knowledge of the effects of aging on exercise ability. This review discusses the effects of aging on major physiological systems and the resulting impact on athletic performance.

Key Words: Heart, lungs, insulin-like growth factors, thermoregulation, immune response.

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The number of horses over 20 years of age is increasing every year and many of those animals are still performing various athletic activities well into their 20s.1-5 As with older humans, older horses that remain active continue to perform in athletic events for a variety of reasons including genetics, better health care, and greatly improved nutritional management.1-7 Studies of older humans show that the ability to perform strenuous work decreases with age, with much of the decline in aerobic capacity and anaerobic power attributed to the effects of aging on physiological function.8-14 However, debate in the literature focuses on how much of that decline is due to actual physiological aging versus disease processes related to inactivity.8-11,13,14 Disease and inactivity result in a decline in function that may be preventable and studies of aged humans have shown that both dynamic and resistance exercise training forestalls or even reverses some of the decline in cardiopulmonary performance and muscle function.8-15 This information points out that some of the decline in exercise capacity in older individuals is related to a general decline in physical activity rather than physiological aging.8-11 These facts have led to better exercise prescriptions for the older human athlete that prevent the potentially dangerous effects of excessive work.9-11 The results are new and improved programs to promote fitness for the growing population of older adult human.9,13,16,18,29 Limited data have been published regarding the exercise capacity of the aged horse.2,5,9,11,22-28 The rationale for these studies has been that more horses are living into their 20s.1-3 Nutritional studies have resulted in the development of complete rations specifically tailored to the unique nutritional needs of the older horse.6,7 Other studies have demonstrated that insulin-like growth factor-I (IGF-I) concentrations decline with age in the horse4 and that aging appears to alter metabolic control, immune function, and endocrine function in horses, both at rest and following exercise.2,5,19-28,70 The older horse also undergoes significant changes in body composition, with some older horses exhibiting an obese phenotype and some having a thin old mare appearance.21,22 Importantly, the thin old horses have a smaller muscle mass, a pattern that is also similar in aged humans, whereas the obese older horses tend to have 50% more fat mass than their younger counterparts.21,22 However, like other organ systems, the question remains as to whether this is due to inactivity or aging.21,22 Interestingly, old horses, like old humans, undergo a change in muscle fiber type distribution away from a more aerobic profile that fits with their less active lifestyle and decline in aerobic capacity.21,22 Functional studies have demonstrated that maximal heart rate (HRmax) and maximal aerobic capacity (VO2max) appear to decline with age,2,5,19 an observation similar to the decrease in cardiovascular function seen in humans.9,14 As with old humans, older equine athletes (ie, horses over 20 years) have the ability to continue to perform in athletic events. Unfortunately, many horse owners continue to train their older animals by using exercise training protocols that, while appropriate for a younger or middle aged animal, may not be appropriate for the older equine athlete. The present article will review how aging affects the major physiological systems that would be expected to alter exercise ability.

II. Aging-Induced Changes in Respiratory Function That May Impact Exercise

It is well recognized that factors affecting lung health can have a cumulative effect in the horse.30 Over a lifetime older horses can be exposed to more pathogens and allergens that ultimately can lead to small airway disease.30 Pathologies like hyperreactive airway disease and chronic obstructive pulmonary disease, exercise-induced pulmonary hemorrhage, and so on, tend to be more prevalent in older animals.30 Furthermore, those conditions can negatively impact respiratory function...
during exertion. Unfortunately, we cannot find any published studies of the effects of aging by itself on the respiratory response to exercise in healthy older horses. However, in humans aging appears to have a significant effect on lung function during exercise.

A recent review article suggests that there are multiple alterations in pulmonary function that can limit respiratory capacity in older individuals. Studies reporting flow:volume loops suggest that an expiratory flow limitation occurs at lower work intensities in older individuals. Dempsey and Seals also point out that the elastic recoil of the lung is altered with aging, a change negatively affecting expiratory flow rates. Older humans also have a greater dead space that affects the dead space to tidal volume ratio. All together these age-related changes affect the work of breathing during exertion. Lung hemodynamics are also affected by aging-induced decreases in arteriovenous compliance, a detrimental change that may lead to capillary stress failure. The latter may have implications for the horse, as capillary stress fractures are part of the etiology of exercise-induced pulmonary hemorrhage. Finally, Dempsey and Seals report that despite all of these age-related changes in lung physiology, "alveolar to arterial gas exchange and pulmonary vascular hemodynamics are only slightly modified by aging." The normal young equine lung is not built large enough to handle the demands of high intensity. Thus, data are needed to determine if patterns of aging-induced change in the horse are similar to humans.

### III. Age-Related Changes in the Cardiovascular Response to Exercise

Many articles have been published on the effects of aging on cardiovascular function in healthy older humans. Aging has profound effects on the cardiovascular system, with resulting decreases in HRmax changes in baroreceptor sensitivity, decreased vascular compliance, and hypertension in species such as rats, dogs, and humans. Data are mixed regarding the effect of age on stroke volume, with some studies demonstrating a decline and others suggesting that fit aged humans make up for the lower HRmax by increasing stroke volume. However, in very old individuals there appears to be a decrease in both HRmax and stroke volume that certainly results in a decline in maximal cardiac output in humans. The decline in HRmax and maximal cardiac output most likely contributes to the decline in maximal oxygen uptake and exercise capacity seen in older horses.

Mechanistically, decreases in HRmax with age appear to be due to several mechanisms including aging-induced changes in the number of pacemaker cells in the sinoatrial (SA) node, increases in the elastic and collagenous tissue in all parts of the conducting system, and the deposition of adipose tissue around the SA node. In humans, aging also alters autonomic tone with a resulting downregulation of sensitivity to the sympathetic nervous system. This appears to influence the ability to increase heart rate during exercise. The horse appears to use similar autonomic mechanisms to control heart rate and indirect evidence suggests that the horse may also undergo aging-induced changes in the neuroendocrine control of cardiovascular function.

The decrease in central cardiac function may also affect the ability to perform aerobic exercise. Maximal aerobic capacity is the product of the ability to deliver oxygen (central limitations, ie, cardiac output) and the ability to utilize oxygen (peripheral factors limiting the distribution of blood flow and actual factors within the muscle limiting utilization). Data are mixed regarding the contribution of central and peripheral cardiovascular factors in the decline in exercise performance seen in horses, dogs, and humans. In humans and other species, an age-related decline in central cardiovascular function accounts for some of the observed decrease in VO2max. However, decreased muscle mass, alterations in muscle capillary density, and decreased vascular compliance may also limit exercise capacity by limiting blood flow to working muscles. Thus, some of the decline in aerobic capacity is also due to changes in peripheral mechanisms affecting the ability to utilize oxygen. Unfortunately, these data have been extrapolated from submaximal studies of humans and the debate continues on whether age-related declines in cardiovascular capacity in humans are predominated by central or peripheral mechanisms.

Older horses undergo a decline in VO2max similar to that seen in healthy older humans. Such is the case in a study by McKeever and Malinowski that demonstrated a decrease in VO2max. Submaximal oxygen consumption appeared to be similar in young and old horses subjected to an incremental exercise test. However, as expected, the amount of work needed to reach VO2max was lower in older horses. There was also a decline in the capacity to tolerate high intensity anaerobic exercise in older horses. Those observations were similar to well-documented, aging-induced decreases seen in humans. In terms of physiological age the older horses mentioned above were analogous to humans ranging from 60 to 80 years of age. Interestingly, compared with other species, the older mare has a tremendous innate aerobic capacity. For example, maximal aerobic capacity in moderately fit, healthy, postmenopausal women averages 22 mL/kg/min. Whereas, elite, female Olympic caliber, human athletes typically have maximal aerobic capacities ranging from 60 to 80 mL/kg/min. The average mass specific VO2max of 90 mL/kg/min seen in old mares is well below their fit equine counterparts (145–200 mL/kg/min), but still above levels reported for young, fit, elite human athletes.

Another benefit of the greater aerobic capacity seen in younger horses is a delay in the need to increase the rate of anaerobic glycolysis to fuel higher intensity exercise. Younger horses must work harder to reach their "anaerobic threshold." This is the point where one observes the onset of blood lactate accumulation (OBLA) conventionally marked by a blood lactate concentration of 4 mmol/L. At this point there is a curvilinear increase in blood lactate concentration indicative that lactate production by the working muscles has exceeded lactate utilization throughout the rest of the body. This variable is important, as the velocity to produce a blood lactate concentration of 4 mmol/L (VLA4) coincides with changes in several important physiological processes. Older horses appear to reach the VLA4 at both a lower speed and at a lower relative work intensity, suggesting a possible central limitation on the ability to perform work. However, the older mares were also not able to run as long or as hard (Vmax) before reaching fatigue, suggesting a reduction in factors affecting peripheral mechanisms associated with general exercise tolerance. More work is needed to determine the relative role of central versus periph-
eral limitations in the decline of the ability to transport and utilize oxygen during exercise in older horses.

Until recently data on the effects of age on central cardiovascular function, cardiac output, HRmax and stroke volume have been lacking in horses. However, a recent study by Betros and coworkers attempted to see if there were age related declines in HRmax and if any of the changes in cardiovascular function were reversed with training. That study found that HRmax (218 vs 213 beats/min), VO2max (116 vs 109 mL/kg/min), maximal oxygen pulse (OPmax) (0.55 vs 0.52 mL/kg/beat), and velocity at HRmax (9.0 vs 9.3 m/s) or velocity at VO2max (8.8 ± 0.2 m/s vs 8.8 ± 0.2 m/s) was similar in young and middle-aged horses. However, there appeared to be a breakpoint once a horse was over 20 years of age. Old horses had a lower HRmax (193 beats/min), VO2max (95 mL/kg/min), and OPmax (0.43 mL/kg/b) and reached those maximal values at lower velocities compared with young and middle-aged horses. Interestingly, the authors found that training resulted in substantial improvements in VO2max and OPmax but did not alter HRmax in young, middle-aged, or old horses. Two important findings of that study include the observation of an age-related decline in HRmax and maximal stroke volume in the horse. This observation may be important to horse owners who use heart rate monitoring to judge the physiological intensity of the work their horses are performing. Second, training can partially reverse some of the decline in cardiovascular function in the older horse.

IV. Age-Related Changes in Thermoregulation and Fluid and Electrolyte Balance

The horse’s athletic capacity can be considered elite among mammalian species, but its ability to dissipate heat during exercise is limited due to a relatively small surface area to mass ratio. During high work intensities, the rate of heat production of the horse can exceed basal levels by 40- to 60-fold. If the excess metabolic heat generated during exercise is not dissipated, life-threatening elevations in body temperature may develop, and the horse’s athletic performance will be adversely affected. The adverse effects of hyperthermia on the health and performance of horses can develop during all exercise intensities and weather conditions. Failure to dissipate metabolic heat can cause a continuous and excessive rise in internal body temperature. If heat loss mechanisms are impaired by aging, then the only way that a horse would be able to decrease its body temperature is to decrease the rate of heat gain by decreasing the intensity of the exertion.

Studies comparing the thermoregulatory responses of older and younger men and women during exercise in the heat have shown that age influences thermoregulatory function during exercise. Suggested reasons for this age-related decline in the ability to thermoregulate properly during exercise in humans include lower cardiovascular capacity due to the age-related decrease in cardiac output, alterations in mechanisms associated with the control of skin blood flow, and a possible state of hypohydration in the elderly. Data are mixed on the role of each of these factors alone and in combination in exercising older humans. In research performed specifically on humans, lower stroke volumes and cardiac outputs have been seen in older men when compared with younger men during upright exercise. These differences are also present when skin venous pooling is augmented by the imposition of an additional heat stress. In studies of older men and women it has been demonstrated that older individuals have lower cardiac outputs than younger subjects even though they were exercising at the same absolute low-intensity workload. There are many articles reporting data on thermoregulation in young horses. However, only a few studies have addressed effects of age on the thermoregulatory response to exercise in the horse. Exercise is a costly endeavor energetically and the generation of ATP fuels work but also generate a great deal of heat that must be dissipated. If one presumes that two horses are the same weight and have similar mechanical efficiencies, then the cost of the activity for any given submaximal activity should be similar. Thus, old and young horses running at the same submaximal speed should generate the similar amount of metabolic heat that must be dissipated. The ability to deal with that heat was tested in a study by McKeever and coworkers. In that experiment they exercised young and old horses at the same submaximal absolute work intensity of 1625 W until they reached a core body temperature of 40°C. Old horses reached a core temperature of 40°C in almost half the time required by the younger mares. Heart rates were substantially greater in the older mares compared with the younger mares when they reached 40°C. However, both groups had similar heart rates and core temperatures by 10 minutes after exercise. This suggested that older mares were not able to thermoregulate as effectively as younger mares during exercise. The greater heart rate seen in the older mares suggested that their hearts had to work harder to muster sufficient cardiac output to accommodate the combined exercising demand of increased blood flow to the organs and muscles as well as to the skin for thermoregulation. Even with the more rapid heart rate older horses were still unable to dissipate the heat generated from exercise as quickly as younger mares, therefore leading to a faster increase in core temperature after the onset of exercise. Interestingly, both groups had similar core temperatures and heart rates 10 minutes after exercise. The authors interpreted this to suggest that the old mares could handle the demands of thermoregulation alone but not the combined demand of exercise and thermoregulation. Human studies may shed light on mechanisms causing the impairment of thermoregulation with age. During exercise, delivery of oxygen to active muscle involves a local decrease in vascular resistance, which in turn creates a challenge to blood flow delivery that is met by both increases in cardiac output and adjustments in vascular resistance in nonactive tissues. Increasing cardiac output during exercise helps meet the dual demand for increased blood flow to working muscle and the skin, especially when coupled with the redistribution of blood flow from visceral organs to augment perfusion of skin and active muscle vascular beds. In aged horses and humans cardiac output is limited and thus there is blood flow to sufficiently support flow to both the working muscles and skin blood flow. This leads to a compromise of the ability to dissipate heat and defend against hyperthermia. In the older horse, there may have been an age-related decrease in maximal cardiac output that in turn led to compromised thermoregulatory capacity during exercise. Age-related alterations in fluid and electrolyte balance can also impair thermoregulatory capacity in older individuals. Older humans commonly have lower total body water, plasma...
volume, and reserves of fluid for sweating.\textsuperscript{10,40,41} Data are mixed, however, as to whether older humans are chronically hypohydrated.\textsuperscript{40,41} Interestingly, changes in the above-mentioned markers of fluid status suggested that fluid shifts were of a similar relative magnitude in young and old horses.\textsuperscript{10,41} However, another study revealed that older horses have a substantially lower preexercise plasma volume compared with younger animals.\textsuperscript{25} Thus, while the relative reduction in plasma volume during exercise was similar, the older horses started off with a significantly lower absolute plasma volume. This would lead to lower venous return, stroke volume, and cardiac output and a compromise of thermoregulatory stability.

Skin blood flow was not measured in the above-mentioned horse studies; however, studies of humans have demonstrated that aging impairs the skin blood flow response to exercise.\textsuperscript{40,51,45} The paradoxical inability to keep cool despite an increase in the sweat rate in older horses is consistent with an impairment of skin blood flow observed in humans. While pure speculation, the mechanism for an age-related decline in skin blood flow during exercise could involve alterations in the sensitivity of mechanisms affecting vascular tone. Recognizing that older horses have a decreased ability to thermoregulate during exercise should lead to improved monitoring practices for heat stress and therefore a decreased occurrence of exercise-induced hyperthermia during equine athletic activities. The increased susceptibility of older horses to overheating exemplified by this study will enable veterinarians, owners, and riders of horses to identify certain horses as more likely than others to develop hyperthermia during exercise so that exercise regimens and athletic events can be designed to prevent heat stress.

\section*{V. Effects of Age on Body Composition and Muscle Fiber Type}

Another measure that may have an important bearing on the ability to perform exercise is a horse’s body composition and, more important, total fat-free mass (FFM).\textsuperscript{44-46} Older humans exhibit substantial decreases in muscle mass and in many cases increases in fat mass that affect the ability to perform exercise.\textsuperscript{14,47-49} Data from recent work in horses suggest they may undergo similar aging-induced changes.\textsuperscript{21-23} That study found that old horses could be divided into two groups by appearance.\textsuperscript{21,22} Some horses were either very lean or very fat.\textsuperscript{21,22} The “skinny” old mares had significantly smaller rump fat thickness, lower percent body fat, and less fat weight than both the fat old mares and the young mares.\textsuperscript{21,22} The skinny old mares had significantly less body weight than the fat old mares but not compared with the young mares.\textsuperscript{21,22} They also had greater lean body weight than the young mares but there was no significant difference in this parameter when compared with the old fat mares.\textsuperscript{21,22} In turn, the old fat group had a significantly larger rump fat thickness, percent body fat, and fat weight when compared with the young mares.\textsuperscript{21,22} Those data suggest that as mature horses gain weight, they gain fat mass at a rate faster than FFM. This is indicated by an increased percent fat (%Fat) per given body weight.

The larger fat mass seen in some older horses may be detrimental to performance\textsuperscript{22} and may lead to other complications in older horses such as insulin resistance.\textsuperscript{23} The observed morphometric differences may have resulted from some of the same factors at play in aged humans.\textsuperscript{14,47-49} For instance, aged horses exhibit similar clinical metabolic and endocrine disorders as those seen in aged humans, including hyperinsulinemia and hyperglycemia, pituitary and thyroid adenomas, Cushing’s disease, decreased somatotropin concentrations, and so on.\textsuperscript{2,23} While old horses appear to retain muscle mass one wonders if it is functional muscle mass. There are many studies that have documented muscle fiber type, enzymatic activity, and substrate storage and utilization patterns in the horse.\textsuperscript{50-56} However, only limited studies have examined peripheral changes associated with aging in the horse and those studies have focused on changes in fiber type associated with aging.\textsuperscript{21,22,52} We are aware of only two articles that have attempted to present data grouped by age.\textsuperscript{21,22,52} Riviero and coworkers\textsuperscript{52} examined muscle fiber type distribution in a number of horses; however, the mean age of the oldest age group in that study was only 15 years, an age where many horses are still in their prime, athletically and physiologically analogous to 40+-year-old humans.\textsuperscript{52} A more recent study, on the other hand, compared young and very old horses and found that older horses had less type I and IIa fibers than the young mares.\textsuperscript{21,22} Old horses had more type IIX fibers than the young horses.\textsuperscript{21,22} On a functional level, this suggests that the older horse undergoes a switch in fiber type population away from that which would be favorable to endurance exercise. This may, in part, explain the decrease in $V_{O_{2\text{max}}}$ documented in other studies.\textsuperscript{3}

On a cellular level, aging appears to alter muscle structure and function.\textsuperscript{21,31,33,37-39} Studies of other species (rats and humans) demonstrate that connective tissue content in the muscle is altered with evidence of significant amounts of collagen, changes that would tend to interfere with normal contractile function.\textsuperscript{14,48,72} Other studies have reported changes in skeletal muscle blood capillarity and decreases in blood flow in older men.\textsuperscript{10} Oxidative capacity, glucose utilization, GLUT-4 activity, insulin insensitivity, insulin-regulative glucose transporter, and glycogen depletion/repletion patterns in skeletal muscle appear to be altered by age in rats and humans.\textsuperscript{10,21,60,69,72} Unfortunately, no data have been published that have examined the effect of exercise on muscle enzyme concentrations or glycogen depletion and repletion patterns in the old horse.

\section*{VI. Aging-Related Alterations in the Endocrine Response to Exercise}

Exercise involves the integration of multiple organ systems that communicate via neural and endocrine pathways. Humans undergo substantial alterations in neural control mechanisms, with primary alterations in sympathetic nervous system responsiveness.\textsuperscript{10,18,48,71} No such information exists for the horse. Aging also alters the endocrine response to exercise, with reported changes in hormones associated with the control of cardiovascular function, stress hormones, and endocrine/paracrine factors related to the control of metabolic function and substrate utilization.\textsuperscript{10,18,71}

A recent study reported on the effect of aging on four of the hormones related to the control of cardiovascular function in the horse. McKeever and Malinowski\textsuperscript{22} reported similar resting concentrations of the various hormones involved in the control of cardiovascular and renal function including atrial natriuretic peptide (ANP), arginine vasopressin (AVP), plasma renin activity (PRA), aldosterone (ALDO), and endothelin-1 (ET-1) in healthy old and young horses. Similar observations have been
reported for normal healthy humans and other species. Old and young horses had directionally similar exercise-induced alterations in plasma renin activity, ANP, AVP, and ALDO. However, the major finding of their investigation was an aging-related change in the magnitude of the response to exertion. While old horses had different concentrations of these hormones, the observed concentrations were still within the range of normal for maximally exercised horses and other species. Interestingly, plasma concentrations of the vasoconstrictor ET-1 were not affected by exercise in either group of horses, a phenomenon previously reported for young horses and humans. Age-related differences in PRA and the plasma concentrations of the ANP, AVP, and ALDO may reflect differences in sensitivity in the regulation of blood pressure and blood flow during exertion. Younger horses were observed to have greater plasma concentrations of the vasodilator ANP. Functionally, this ANP-induced vasodilation would aid in the redistribution of blood flow during exercise. ANP also inhibits PRA and the production and release of antagonistic hormones like AVP, and ALDO. Thus, greater concentrations of plasma ANP in younger animals may enable the ability to optimally vasodilate blood vessels in the periphery, especially in the working muscles.

McKeever and Malinowski also reported that older horses had greater PRA at speeds eliciting VO2max. This change may be physiologically important as part of the defense of blood pressure during exercise and defense of fluid and electrolyte balance after exercise. Increases in circulating plasma angiotensin I and II aid in the vasoconstriction in nonobligate tissues that is part of the redistribution of blood flow. Furthermore, increases in PRA and angiotensin also act to stimulate thirst and cause an increase in the synthesis and release of aldosterone. Meditation of this neuroendocrine defense of blood pressure involves the integrative actions of both the low and high pressure baroreceptors. However, aging appears to alter baroreceptor sensitivity and the normal feedback loop that integrates cardiovascular control. One might speculate then that reported differences in ANP and PRA may reflect an age-related difference in baroreceptor sensitivity to the challenge of exercise. It may also reflect differences in autonomic control and input from the sympathetic nervous system and other stimuli that affect the control of central and peripheral cardiovascular function. This may be important as increases in renal sympathetic nerve activity and the stimulation of the juxtaglomerular apparatus is the primary stimulus for renin release during exertion. A recent study of humans suggests that aging-induced changes in PRA may also affect renal function and may indirectly contribute to possible alterations in skin blood flow. The later speculated aging-induced change could be important as it potentially could alter the ability to thermoregulate in humans. It would also be important to the horses as well as they are the only other athletic species to sweat to thermoregulate.

Any age-related difference in blood volume, HRmax, and vascular tone may have also influenced the integrative neuroendocrine defense of blood pressure. Surprisingly, younger horses appear to have a greater vasopressin response during exercise. Plasma AVP concentration increases when the cardiopulmonary baroreceptors sense that cardiac filling pressure is inadequate, when the high pressure baroreceptors sense that mean arterial blood pressure is too low and/or when hypothalamic osmoreceptors sense that plasma osmolality is too high. Vasopressin causes vasoconstriction in nonobligate tissues during exercise. It also facilitates the uptake of water and electrolytes from the large intestine, another important action during exercise. Postexercise AVP causes a retention of solute free water by the kidney and stimulates thirst and drinking. Studies are needed to explore the role of aging in these later functions, as some studies suggest that aged humans do not drink as much and many times are hypohydrated. Suppression of thirst and drinking is an important consideration for those concerned with postevent care of the horse.

It is well recognized that older horses have lower plasma concentrations of the thyroid hormones, somatotropin (ST), and IGF-I compared with young animals, suggesting an age-related decline somatotropic axis in horses that is similar to that observed in other mammalian species. The aging-induced changes including decreases in cardiopulmonary function, decreased aerobic and exercise capacity, decreased immune function, impaired nutrient utilization, decreased nitrogen retention, and decreased lean body mass. Similar changes have been observed in other species and comparative physiological data from rats, dogs, and humans have shown that there is a causal relationship between plasma concentrations of somatotropin and what has been termed the “aging phenotype.” Endorphins and cortisol have been utilized as markers of the degree of physiological stress during exercise. The release of these two hormones is a normal response to exercise; however, the direction and the magnitude of their response differentiates between what one can consider a normal response to the physiological challenge of exertion and a true stress response. Increases in these hormones are linked to duration and intensity and their release may provide protection from the physiological challenge of exertion. β-Endorphin functions as a natural opiate, forestalling the central mechanisms that would induce fatigue. Cortisol functions as a metabolic hormone during exercise influencing glucose metabolism. After exercise, cortisol exerts antiinflammatory and immunosuppressive activity, possibly aiding in the repair of tissue altered by exertion and protecting against the inflammation associated with overexertion.

We are aware of only one study that has attempted to determine if training and age affected the plasma β-endorphin, cortisol, and immune function (see below) responses to acute exercise in untrained Standardbred mares. Unfortunately, β-endorphin and cortisol were measured at rest and at 5, 10, 20, 40, 60, and 120 minutes post GXT but not during exercise. The authors reported that cortisol rose by 5 minutes post GXT in young and middle-aged mares before and after training. However, there was no rise in cortisol in the old mares post GXT either before or after training. Before training, plasma β-endorphin increased by 5 minutes post exercise in all mares. After training, β-endorphin was higher compared with pretraining in all three age groups; however, the peak in the old mares occurred later than in the other groups.

Aging substantially alters metabolic function in humans and is frequently associated with glucose intolerance and insulin resistance in both humans and horses. Participation in regular exercise activity may elicit a number of favorable responses that contribute to healthy aging. Only one study that has attempted to examine the effects...
of aging and training on the glucose and insulin response following acute exertion in horses.62 The primary finding of that study was that old horses required greater concentrations of insulin to successfully manage their response to an oral glucose tolerance test (OGTT).62 The authors also reported that there was an age-related effect on the glucose and insulin responses to acute exercise both before and after 12 weeks of exercise training.62 Interestingly, 12 weeks of exercise training resulted in a post-GXT increase in insulin in all age groups.62 The authors concluded that the resultant hyperinsulinemia post exertion after training may have been related to an increased need for glycogen repletion in the muscle following exercise.62 Interestingly, this posttraining response was highest in the oldest horses quite possibly because of a greater need to replenish muscle glycogen.62 They also reported that exercise training altered the insulin responses more in the old horses and that it did not affect the glucose response of any of the age groups of horses, regardless of age.62 This was interpreted to suggest an improvement in insulin sensitivity in the older animals.62 The exact mechanisms to explain the age-related difference in glucose and insulin metabolism are unknown, but published reports from studies of rats and humans suggest that it may be related to differences in fuel utilization, mitochondria respiration rates, and skeletal muscle content of GLUT-4 transporters.58,63,65,72

VII. Alterations in the Immune Response to Exercise

Studies of humans have demonstrated that aging alters the immune response in general and more importantly the immune response to the challenge of exercise.42,48 Two studies have reported on the effect of aging on the immune response to acute exertion in horses.20,52 Horohov and coworkers20 reported that there were differences in the immune system of young and old horses both before and after exertion. Interestingly, acute exercise caused a decrease in the lymphoproliferation response in the younger horses but not the old mares.20 Old horses also exhibited a lower proliferative response to mitogens, suggesting an aging-related alteration in T cell-mediated function and an immunosenescence that the authors suggested may have been related to a lower cortisol response to exertion in the old horses.20 A more recent experiment examined the effects of aging and training by measuring immune responses to a graded exercise test performed before and after 12 weeks of training.62 The older horses had lower monocyte counts post GXT after training.62 Age also affected the lymphocyte response to acute exercise before and after training suggesting a degree of immunosenescence.62 Together these studies suggest that special preventative care may be needed for the older athletic horse.

VIII. Renal, Gastrointestinal, Other Systems

Research using humans has suggested that many of the observed changes in renal function seen with aging are not inevitable and are the combined effect of pathologies coupled with the aging process. We are aware of only limited data on the effect of age on the renal response to acute exercise in humans.50,41,67 Those studies have primarily focused on the effect of aging on the normal reduction in blood flow seen with acute exertion.50,41,67 Functionally older individuals have smaller reductions in renal blood flow and smaller increases in skin blood flow compared with humans.40,41,67 This may alter renal function as well as thermoregulatory capacity because the redistribution of blood flow away from nonobligate tissues toward the working muscles and skin is an important response to exertion.40,41,67 No work has been performed in the horse. More work is also needed to determine if aging alters mechanisms affecting the glomerular filtration rate and tubular function both during exercise and afterward. The latter may be important, as long-term control of total body water, plasma volume, and fluid and electrolyte balance appear to be altered in humans and horses.

In other species, the gastrointestinal tract, bones, and ligaments as well as the integumentary system are altered with age.50,51 Changes in the gastrointestinal tract from wear down of teeth to decreased absorptive capability, all influence the uptake of water and nutrients and have the potential to alter the ability to perform exercise. Bone pathology ranging from osteoarthritis to demineralization certainly can alter the ability to perform exercise in the old horses. Changes in the skin have the potential to alter sweating and thermoregulation. We are unaware of any data on the effects of age on these organ systems in the horse.

Conclusions

Surveys indicate that equine population in the United States over 20 years of age is growing larger.1–3 As with humans, these geriatric equine athletes have the ability to continue to perform in athletic events. Unfortunately, many horse owners continue to train their active older animals using exercise training protocols that, while appropriate for a younger animal, may not be appropriate for the older equine athlete. Studies of aged humans have led to a fine tuning of exercise prescription for the older human athlete to prevent the adverse and potential dangerous effects of excessive work. Published results have led to new and improved programs to promote fitness for the growing population of older adult humans. Future studies of the effects of aging on exercise capacity in equine athletes should have similar goals.

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