Evidence that rotational deworming selects for anthelmintic resistance necessitates that veterinarians regain an active role in the design and monitoring of equine parasite-control strategies. Anthelmintic treatment should focus on horses whose parasite loads justify treatment to preserve parasites that lack anthelmintic-resistance genes. The concept of zero tolerance is not sustainable. Proper timing and interpretation of quantitative parasite fecal egg counts can be used in adult horses to identify individuals that require treatment as well as monitor for anthelmintic resistance. However, treatment thresholds for the control of *Parascaris equorum* are problematic and have not been validated. Accordingly, the recommendations that follow should be restricted to populations >18 mo of age after the onset of age immunity to *Parascaris equorum*. Authors’ addresses: Department of Veterinary Clinical Sciences, College of Veterinary Medicine, Mississippi State University, Mississippi State, MS 39762 (Swiderski); and Department of Veterinary Clinical Sciences, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA 70803 (French); e-mail: swiderski@cvm.msstate.edu. © 2008 AAEP.

1. Introduction
For several decades, equine anthelmintic programs have focused on rotational deworming strategies in which horses are dewormed with different anthelmintic classes separated by predictable intervals. This approach is no longer sustainable because rotation does not slow, and in fact, it actually selects for resistance to all drugs in the rotation.\(^1\)–\(^5\) Rotational regimens may mask anthelmintic resistance by the regular substitution of efficacious products in the deworming schedule. Slow rotation, in which a single anthelmintic is applied for an entire year without monitoring anthelmintic effectiveness by a reduction in fecal egg counts (FEC), is particularly concerning due to the prevalence of resistance among small strongyles.\(^6\) Without monitoring, resistant parasites can dominate the population because parasites that are sensitive to an anthelmintic are selectively killed, whereas resistant parasites propagate unchecked for a prolonged period. In addition, research to develop new anthelmintics and sustainable methods of equine parasite control has not been prioritized, which limits therapeutic alternatives in the face of expanding anthelmintic resistance. The purpose of this paper is to review current principles used to generate appropriate parasite-control programs in horses in order to minimize anthelmintic resistance. Veterinarians are uniquely qualified to assist in the detection, management, and prevention of anthelmintic resistance in equine populations. A proactive role by veterinary practitioners in employing these paradigms
will enhance the quality of their preventative health maintenance program while preserving anthelmintic efficacy.

2. Foundations of the New Paradigm
The most important concept in the design of parasite-control programs is the interaction between host and environment. A working knowledge of the parasite life cycle and epidemiology is integral to the successful management of parasite populations. The life cycles and epidemiology of the major equine parasites, including small and large strongyles, tapeworms, bots, pinworms, roundworms, and threadworms, have been reviewed. In horses >18 mo of age, the fecundity, rapid generation time, and emergence of anthelmintic resistance make control of small strongyles the primary focus of anthelmintic strategies. Consideration must also be given to tapeworms (Anoplocephala spp.), bots (Gastrophilus spp.), large strongyles (Strongylus spp.), and equine pinworms (Oxyurus equi). Anthelmintic strategies in horses <18 mo of age are modified by the lack of age immunity to the equine roundworm Parascaris equorum, and horses <6 mo of age may also be sporadically affected by the equine threadworm Strongyloides westeri. This paper focuses on control measures in horses >18 mo of age.

3. The Concept of Refugia
A central tenet to controlling anthelmintic resistance is the preservation of a population of parasites termed “refugia” or said to be “in refugia.” The most basic biological meaning of refugia is an isolated population of a once widespread species. In terms of anthelmintic resistance, refugia can be viewed as “wild-type” parasites that have not been subjected to anthelmintic pressure and therefore, lack anthelmintic resistance genes. The major unifying goal in preventing anthelmintic resistance is to increase the frequency of anthelmintic-susceptible parasites in the environment. Because refugia are by definition anthelmintic susceptible, minimizing the frequency of anthelmintic administration favors their preservation and expansion. The negative effects of anthelmintic pressure on refugia are even more critical during seasons in which parasite numbers are low in the environment. This would occur with strongyles during the hot summers of the southern United States. Refugia are protected during anthelmintic treatment of the host in two instances: if the parasites are outside the host (on pasture), and in the case of non-larvicidal anthelmintics, when the larvae are protected while encysted. Balancing a desire for decreased anthelmintic administration while maintaining the health of the horse can only be achieved through the rational application of routine quantitative FEC to differentiate horses that need treatment from those that do not.

4. Individual Horses Vary in Their Susceptibility to Gastrointestinal Parasites
A phenomenon of individual variability in susceptibility to gastrointestinal parasites has been identified in many species, including the horse. A minority of ‘more susceptible’ horses can be considered ‘permissive’ to strongyle infection. These horses maintain higher quantitative FEC than their herd mates despite identical exposures, and they account for the majority of pasture contamination. Another minority can be identified that limits strongyle infections and passes few to no eggs in their feces. Characterizing an individual’s strongyle susceptibility hinges on strategically timed quantification of FEC at times when epidemiologic factors should favor strongyle egg production and detection in the feces. The variation in strongyle susceptibility among individuals creates a phenomenon of anthelmintic overuse in animals whose immune response can limit the infection and suboptimal parasite control when the same treatment regimen is applied to susceptible individuals. Anthelmintic overuse hastens development of anthelmintic resistance. Therefore, the time-honored principle of simultaneous anthelmintic treatment of all herd mates is being rewritten to characterize the strongyle susceptibility of all herd mates and provide anthelmintic treatment only to those horses with moderate and high strongyle susceptibility as documented by elevated FEC.

5. Climatic Conditions Influence Strongyle Pasture Contamination
Parasite control in adult horses strives to minimize infective small strongyle larvae on pasture. Three factors influence the timing of administration and selection of an anthelmintic agent: (1) the load of infective larvae in the environment, (2) the residual capacity of the anthelmintic, and (3) the horse’s ability to limit egg excretion because of an effective immune response.

Ambient temperature has a major impact on the load of infective larvae in the environment. Stage 3 strongyle larvae (L3), the infective form, possess a complete cuticle that prevents nutrient ingestion. When ambient temperatures exceed 85°F, exaggerated L3 activity in the absence of nutrient ingestion leads to larval death and a corresponding seasonal decrease in infective L3 on pasture. This reduces the need for anthelmintic treatment. It is important to recognize that refugia, the genetic key to preventing anthelmintic resistance, are also at their nadir on pasture in such conditions and that anthelmintic administration when refugia are depleted places tremendous selection pressure on the population. Continuing with this reasoning, climactic conditions that favor peak fecal egg production coincide with both pasture contamination and larger refugia populations. In this situation, more frequent anthelmintic administration may be required, but it will also impose less
selection pressure on the expanded population of refugia.

In the warm temperate and subtropical/tropical climates of the southern United States, numbers of infective strongyle L3 on pasture drop dramatically during the summer, which creates a period of grazing that is relatively free of exposure to small strongyles. Conversely, peak fecal egg production occurs from autumn (September) through spring (April). It is important to recognize that infective larvae are present on pastures in the warm temperate, subtropical, and tropical regions of the southern United States throughout the winter months.

In northern regions that are cool and temperate, infective L3 are at their lowest during the winter, whereas larval development is favored during spring, summer, and fall. Northern winter temperatures below 45°F (November to March) do not support hatching of eggs or larval development, although L3 that have already developed sufficiently to be competent for infection do persist during these months. Therefore, rested pastures in northern climates remain infective until early summer when rising temperatures finally cause the demise of L3. Although infective larvae are present on pasture in northern climates during winter, stabling and manure removal from stalls limit the winter exposure to infective larvae. This reflects the requirement for a moist environment for strongyle larvae to develop into infective L3, which is not achieved in the stall. Furthermore, ammonia from a dirty wet stall environment is toxic to nematode larvae. Together, these factors create a winter period in northern climates that is relatively free from exposure to infective strongyle larvae.

6. Anthelmintic Class Influences Administration Intervals

In addition to climatic factors, anthelmintic class is an important factor in determining the frequency of anthelmintic administration. Anthelmintics vary in the duration of time that they will continue to suppress egg excretion in the host, a characteristic that is reflected in the egg reappearance period (ERP). ERP is the duration of time after anthelmintic treatment that a horse’s feces will remain negative for strongyle eggs. The ERP has generally been reported to be 8 wk for ivermectin versus 12 wk for moxidectin. Shortening of the ERP for ivermectin to 6 wk on some farms has raised concerns regarding reduction in efficacy and emerging resistance to macrocyclic lactones. For pyrantel, the ERP is approximately 4–6 wk. Longer ERPs reflect the residual ability of an anthelmintic to prevent emergence and sexual reproduction of encysted small strongyle larvae. Monitoring of FEC reduction with benzimidazole administration is especially important, because benzimidazole resistance is widespread in small strongyle populations. When formulating an anthelmintic treatment regimen, the ERP is a useful interval for reevaluating FEC after anthelmintic therapy to determine if an individual horse requires subsequent anthelmintic therapy. Shortening of the ERP may also be an early indicator of reduction in anthelmintic efficiency.

7. Strongyle Contamination Potential Provides an Index of Strongyle Immunity

The ability of a horse’s immune response to limit strongyle infections and egg production impacts the interval length between anthelmintic dosing. Strongyle resistance is reflected in an index termed the strongyle contamination potential (SCP), which is defined as the FEC 4 wk after the ERP of the previously administered anthelmintic. By this time, anthelmintic effects are exhausted, and the ability to limit fecal egg production is reflective of the immunity of the host. SCP has been categorized as low (<150 eggs/g of feces), medium (150–500 epg), and high (>500 epg), and this corresponds to approximately 40%, 25%, and 35% of the population, respectively. FEC at the beginning of the parasite season (September in the south and April in the north) are also reflective of the relative immunity of the individual to small strongyles because infective larvae are in low numbers on pasture at these times. Accordingly, FEC at these times are proportional to the individual’s tendency to permit the development and sexual reproduction of the few larvae that are ingested, or more significantly, hypobiotic strongyle larvae that are emerging to complete their lifecycle.

8. Parasite Control Strategy for Adult Horses

Effective parasite-control strategies must be multifactorial and responsive to the husbandry and dynamics of the premise/owner, ages of the patients, and epidemiology of the parasites. Anthelmintic resistance issues highlight the need to employ all measures that minimize pasture contamination, particularly feces removal. Removing feces from the environment before eggs become infective provides parasite control that is superior to anthelmintic administration. Horses maintained in environments with fecal removal had lower FEC, and grazing area was increased by 50% compared with cohorts that were given anthelmintics. Pasture vacuuming and manual removal of feces from pasture may not always be feasible, and such measures have been dismissed in deworming schemes of the past. However, with anthelmintic resistance rising and a need to minimize reliance on anthelmintics to protect refugia, the ability of manure removal to virtually eliminate anthelmintic use should cause responsible veterinarians to strongly encourage some degree of environmental management.
In warm temperate and subtropical/tropical climates of the southern United States, the deworming season begins in September versus April in the cool temperate climates found in the northern regions of North America.\textsuperscript{15,47} Quantitative FEC at these times reflect the small strongyle susceptibility of the individual, because environmental loads are minimal. Anthelmintic treatments are administered according to treatment thresholds, which range from 100 to 500 strongyle-type epg (generally 150–200 epg). Evidence-based medicine indicates that these thresholds are efficacious in decreasing anthelmintic administration while preserving health.\textsuperscript{5,10,24,29} Lowering the treatment threshold increases selection pressure for resistance, and by decreasing parasite exposure, it serves to limit the generation of beneficial (although incomplete) immunity to small strongyles. After the initial evaluation and treatment at the beginning of the parasite season, FEC are repeated at intervals according to the ERP of the prior anthelmintic. Subsequent anthelmintic treatments are administered to individuals with FEC that exceed the treatment threshold. Within this program, the fall deworming should include a macrocyclic lactone/praziquantel combination to target \textit{Gasterophilus} spp. and \textit{Anoplocephala} spp.

Macrocylic lactones are particularly beneficial on farms where \textit{Strongylus vulgaris} has been a problem. Incorporating macrocyclic lactones into the deworming regime of all horses at 5 month intervals will eradicate \textit{S. vulgaris} within 18 months.

The cost of repeated fecal examinations may be concerning initially to owners employing targeted deworming. However, these approaches are economically viable, because they decrease anthelmintic use by as much as 78%.\textsuperscript{5} Repeated evaluations of FEC indicate that individuals exceeding the treatment threshold at the beginning of the parasite season (or 4 wk after the ERP of the previous anthelmintic) are likely to maintain elevated FEC, and they require repeated deworming at intervals consistent with the ERP. Animals with FEC below the treatment threshold should have FEC monitored according to the appropriate ERP and should be dewormed when the treatment threshold is reached.

It is proposed that horses whose FEC exceeds 500 epg after the ERP or in the beginning of the parasite season (i.e., those with high SCP), should be singled out for larvalid anthelmintic therapy with high-dose fenbendazole\textsuperscript{a} (10 mg/kg, q 24 h for 5 days) or moxidectin.\textsuperscript{25,31–33b} High FEC at these times reflect animals that are permissive to strongyle infection. These horses are a significant reservoir for contaminating the environment, because they allow both pasture-derived larvae and emerging encysted larvae to complete their lifecycle and produce high levels of strongyle eggs. These animals also maintain a large reservoir of hypobiotic larvae that continuously emerge to repopulate the gastrointestinal (GI) lumen and complete their lifecycle when adults are removed by deworming. It is important to recognize that neither moxidectin nor larvalid dose regimens of fenbendazole are 100% efficacious in removing encysted larvae.\textsuperscript{.31–33} A report of small strongyle resistance to larvalid fenbendazole doses in Kentucky yearlings should prompt caution in the use of such protocols, because they exert extreme resistance pressure.\textsuperscript{34}

A cornerstone of every deworming program is identifying anthelmintic resistance. This is particularly concerning in small strongyles where resistance to all commonly used anthelmintics, with the exception of the macrocyclic lactones, has been identified.\textsuperscript{6} Shortening of the ERP is an important indicator of anthelmintic resistance in the horse.\textsuperscript{35,36} However, the gold standard for detecting resistance has been the FEC reduction test (FECRT).\textsuperscript{36} FEC reduction (FECR) is determined by comparing FEC before and 10–14 days after anthelmintic administration. The percentage of reduction is calculated using the following formula:

\[
\text{FECR} = \frac{\text{Pre-treatment EPG} - \text{Post-treatment EPG}}{\text{Pre-treatment EPG}} \times 100
\]

The FECRT has several problems. First, the action levels to identify anthelmintic resistance have not been determined for equine parasites. Instead, the values are extrapolated from other species. Second, the FECRT is relatively insensitive, meaning that resistance genes are widely disseminated within the parasite population when anthelmintic resistance is identifiable by FECRT. At this time, FECR in excess of 90% is considered evidence of benzimidazole and tetrahydropyrimidine efficacy. Values between 80% and 90% are suspicious of resistance, and FECR <80% indicates that resistance is present. In the case of the macrocyclic lactones ivermectin and moxidectin, egg reductions <98% are cause for resistance concerns.\textsuperscript{6,36}

New additions to a herd can introduce resistant strongyles to a previously sensitive population.\textsuperscript{6} In this respect, it is especially important that farms without anthelmintic resistance take precautions to prevent the introduction of resistant strongyles. FECRT should be performed in conjunction with the initial dewormings, and larvicidal treatment regimens should be selected to kill encysted parasites that might bear resistance genes. Both moxidectin and larvicidal regimens of fenbendazole may be used. However, the widespread prevalence of benzimidazole resistance in small strongyles must be considered, because larvalid doses of fenbendazole may be inferior to moxidectin to prevent the introduction of resistant worms in new additions. Accordingly, new arrivals should be treated with larvicidal fenbendazole regimens followed by single-dose administration of a macrocyclic lactone to remove remaining luminal worms. New additions should be quarantined until an appropriate re-
response to anthelmintic therapy, as supported by a reduction in FEC, is available to substantiate that resistant parasites will not be introduced to the herd. Horses visiting a premise for <6 wk can be transiently prevented from causing pasture contamination by ivermectin treatment, because ivermectin resistance is extremely uncommon; additionally, the ERP for ivermectin is 6–8 wk. However, because ivermectin is not larvicidal against encysted small strongyles, ivermectin therapy will prevent emergence beyond the 6 to 8 wk ERP.

9. A Note on Clean Pastures
Creating a pasture that is entirely devoid of parasites is impossible. However, parasite burden on pasture can be reduced. Pastures that have been vacant for at least 2 mo during the warm season, fields that have recently produced hay, and pastures grazed by alternate livestock species can be viewed as having a reduced parasite burden. Dragging and harrowing disperse parasite larvae, but this is only advantageous in the summer and only if pastures can be left unoccupied for 2 wk in the south or 4 wk in the northern climates. Pastures should not be harrowed after October 1 in the United States because parasite larvae dispersed by harrowing will not undergo the climate extremes required to kill them. Similarly, manure should not be spread on pasture. Reducing the stocking density of a pasture will decrease parasite exposure, because the horses are not forced to graze close to their feces to meet their forage demands. Often, decreasing the number of horses on a pasture is not practical, but even in such cases, useful pasture can be maximized and larval burdens minimized by removing feces from the pasture every few days. This interval exploits the nematode parasite’s requirement for a period of development outside of the horse to become infective. Removal of feces before this maturation prevents infection.

10. Challenges to Implementing the New Paradigm
The pillars of equine parasite control, the concepts of preserving refugia, focused anthelmintic treatment of horses responsible for significant pasture contamination, and restricting anthelmintic therapy to seasons in which horses can become infected from pasture are not particularly difficult to grasp. As with any paradigm shift in medicine, the practical implementation of the concept begins with a steep learning curve and an eye to potential challenges during the transition. Obviously, the simple division of the United States into northern and southern regions is overly simplistic, and each practitioner should be careful to identify the seasonal changes in strongyle pasture contamination appropriate to their region. It is also important to recognize that action levels based on changes in FECRT and ERP have not been determined specifically for equine parasites, but instead, they are extrapolated from other species; therefore, they may not be entirely valid. In fact, the FECRT is known to be insensitive for detecting resistance. This means that when anthelmintic resistance is identifiable by FECRT, resistance genes are widely disseminated within the parasite population. And finally, in horses <18 mo of age, *Parascaris equorum* is the major pathogen. Criteria for the use of FECRT to evaluate anthelmintic efficacy have not been validated for this parasite. Evidenced-based medicine has substantiated the efficacy of these principles in the control and elimination of anthelmintic-resistant equine parasite populations. Thus, it is reasonable to expect additional information on acceptable versus actionable changes in the FECRT and ERP in the future that will refine the application of this new paradigm to equine parasite control.

11. Summary
It is clear that rotational deworming selects for anthelmintic-resistant populations and that the concept of zero tolerance of strongyle-type eggs in quantitative fecals is not sustainable. Sustainable parasite control must identify individual horses that require treatment so as to minimize overtreatment and the associated depletion of anthelmintic-susceptible populations in refugia. Determining which horses need treatment can only be done through the rational application of quantitative fecal examinations. Three primary factors influence the timing of administration and selection of anthelmintic agent: (1) the load of infective larvae in the environment, (2) the residual capacity of the anthelmintic, and (3) the horse’s ability to limit egg excetration via an effective immune response. It becomes obvious that the prevention of anthelmintic resistance will require a more integral role for veterinarians in the planning and monitoring of anthelmintic therapy. Despite the requirement for quantitative fecal examinations, evidence-based medicine supports the efficacy and cost effectiveness of these approaches. As reports of anthelmintic resistance are increasing, veterinarians should become proactive in implementing parasite-control strategies that preserve the efficacy of current anthelmintics and eliminate anthelmintic-resistant parasites.

The subject of this submission is derived in part from the author’s submission to the following publication: Swiderski CE. Equine parasitic disease. In: Smith B, ed. *Large animal internal medicine*, 4th ed. St. Louis: Mosby, 2008:1623–1631. The information has been used with permission of the publisher.

References and Footnotes

2. Barnes EH, Dobson RJ. Population dynamics of *Trichostrongylus columbiformis* in sheep: computer model to


*Panacur Power Pak, Intervet, Millsborough, DE 19966.

*Quest Gel, Fort Dodge Animal Health, Overland Park, KS 66210.