Abstract

Objective To assess intraocular pressure (IOP) in conditioned equine athletes and document changes with exercise. A secondary objective was to assess associations between IOP and heart rate, as well as with other subjective physical parameters.

Sample population Horses were evaluated during 50 mile endurance ride competitions. Data were collected on 69 horses during five different competitions at three different locations with 59 horses ridden once, nine horses ridden in two competitions, and one horse ridden in three competitions for a total of 80 horse-ride combinations.

Procedures Intraocular pressure was measured using a TonoVet® tonometer in both eyes of each horse prior to, at two time points during, and immediately after endurance exercise. Heart rates and subjective veterinary scores were recorded on ride cards at each time point.

Results For horses with shorter finishing times (≤400 min), IOP decreased by at least 3.1 ± 0.9 mmHg (least square mean estimate ± SEM) from baseline to the end of endurance exercise (P < 0.007), although upward fluctuation was apparent during the ride. For horses with longer finishing times, IOP did not change significantly from baseline to the end of exercise. Responses also differed between horses awarded ‘Best Condition’ relative to other horses, whereby the latter, but not the former, showed an overall decrease in IOP by end of exercise relative to baseline (estimate decrease of 3.2 ± 0.6 mmHg; P < 0.001). There was no evidence for any association between IOP and heart rate, nor between IOP and subjective clinical scores.

Conclusions Intraocular pressure fluctuated in horses during endurance riding competitions.

Key Words: endurance, equine, exercise, horse, intraocular pressure

INTRODUCTION

In numerous studies, intraocular pressure (IOP) has been shown to decrease in humans during exercise as summarized in a recent review article. This has been shown with conditions of acute dynamic exercise, continuous strenuous exercise, isometric exercise, and even brisk walking. Dynamic exercise has been shown to have greater IOP-lowering effects than isometric exercise, with intensity of exercise being the most closely associated parameter with IOP reduction. Physical fitness also plays a role in IOP reduction with exercise as physically fit individuals have lower baseline IOP but diminished acute postexercise IOP-lowering effects than sedentary individuals. The only case when IOP has been shown to increase with exercise in humans is during weight lifting if breath is held and a Valsalva maneuver is being performed concurrently.

The mechanism for IOP reduction during dynamic exercise in humans has been investigated. No evidence for any correlation has been found between IOP and blood pressure, heart rate, body mass index, hematocrit, or plasma protein concentration. Three leading theories include decreased blood pH, elevated blood lactate, or elevated plasma osmolarity, with the latter being most supported by current literature and the only one present in aerobic as well as anaerobic exercise. Several studies have reported that dehydration causes an increase in plasma osmolality, which in turn may lower the rate of aqueous humor formation and result in documented IOP reduction.
Horses were evaluated during 50 mile endurance ride competitions held in Oklahoma and Missouri during October 2009 and April 2010, respectively. Data were collected on 69 horses during five different competitions at three different locations with 59 horses ridden once, nine horses ridden in two competitions, and one horse ridden in three competitions for a total of 80 horse-ride combinations. Although the majority of riders and horses were amenable to IOP assessments, one rider declined participation and two horses were too challenging to obtain readings from, so complete data were not possible for every ride participant. The study was approved by the Kansas State University Institutional Animal Care and Use Committee, and research was conducted in accordance with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research.

During the preride examination, brief assessments of the anterior segment and pupil were performed by the same evaluator (RAA) on both eyes of each horse participating in the study using a transilluminator (Welch Allyn, Skaneateles Falls, NY, USA). Minor or inactive lesions were noted on four eyes, but these were not considered compromising of equine study recruitment. Complete ocular examination including fundic evaluation was not performed, so additional lesions may have been missed. At the preride examination, baseline IOP readings (Pre) were obtained using a rebound tonometer (TonoVet®; Tiolat Ltd, Helsinki, Finland). The IOP measurements were taken on horses in a normal standing position with the head maintained upright and the eyelids manipulated minimally to avoid inadvertent pressure on the globe. Intraocular pressure measurements were also obtained during the endurance ride at the two intermediate veterinary checkpoints (Vet Check 1 = VC1; Vet Check 2 = VC2) and at the postride examination for each horse (End). Measurements were taken, while a horse and rider were waiting in line for the ride veterinarian evaluation or immediately afterward, as preferred by the rider. At the completion of the ride, ride cards for each horse were scanned so that pertinent data from each horse could be collected. Ride card data from the veterinary checkpoints included heart rate, mucus membrane assessment, capillary refill, jugular refill, gut sounds, skin tenting, anal tone, muscle tone, back and withers assessment, tack galls, wounds assessment, gait evaluation, impulsion, attitude, and overall impression.

Statistical analysis
A general linear mixed model was fitted to the response ‘IOP’, measured in mmHg. The statistical model included the fixed effects of examination (Pre, VC1, VC2, and End), eye (Left or Right), and their 2-way interaction. Random effects included horse and its cross-product with eye to recognize the horse as a blocking factor for left and right observations, as well as the eye as the unit for

MATERIALS AND METHODS

Horses were evaluated during 50 mile endurance ride competitions held in Oklahoma and Missouri during October 2009 and April 2010, respectively. Data were collected on 69 horses during five different competitions at three different locations with 59 horses ridden once, nine horses ridden in two competitions, and one horse ridden in three competitions for a total of 80 horse-ride combinations. Although the majority of riders and horses were amenable to IOP assessments, one rider declined participation and two horses were too challenging to obtain readings from, so complete data were not possible for every ride participant. The study was approved by the Kansas State University Institutional Animal Care and Use Committee, and research was conducted in accordance with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research.

During the preride examination, brief assessments of the anterior segment and pupil were performed by the same evaluator (RAA) on both eyes of each horse participating in the study using a transilluminator (Welch Allyn, Skaneateles Falls, NY, USA). Minor or inactive lesions were noted on four eyes, but these were not considered compromising of equine study recruitment. Complete ocular examination including fundic evaluation was not performed, so additional lesions may have been missed. At the preride examination, baseline IOP readings (Pre) were obtained using a rebound tonometer (TonoVet®; Tiolat Ltd, Helsinki, Finland). The IOP measurements were taken on horses in a normal standing position with the head maintained upright and the eyelids manipulated minimally to avoid inadvertent pressure on the globe. Intraocular pressure measurements were also obtained during the endurance ride at the two intermediate veterinary checkpoints (Vet Check 1 = VC1; Vet Check 2 = VC2) and at the postride examination for each horse (End). Measurements were taken, while a horse and rider were waiting in line for the ride veterinarian evaluation or immediately afterward, as preferred by the rider. At the completion of the ride, ride cards for each horse were scanned so that pertinent data from each horse could be collected. Ride card data from the veterinary checkpoints included heart rate, mucus membrane assessment, capillary refill, jugular refill, gut sounds, skin tenting, anal tone, muscle tone, back and withers assessment, tack galls, wounds assessment, gait evaluation, impulsion, attitude, and overall impression.

Statistical analysis
A general linear mixed model was fitted to the response ‘IOP’, measured in mmHg. The statistical model included the fixed effects of examination (Pre, VC1, VC2, and End), eye (Left or Right), and their 2-way interaction. Random effects included horse and its cross-product with eye to recognize the horse as a blocking factor for left and right observations, as well as the eye as the unit for

© 2014 American College of Veterinary Ophthalmologists, Veterinary Ophthalmology, 1–6
repeated measures during the ride; the former was removed from the final model as its variance component converged to zero. The statistical model also included the fixed effects of best condition and its interaction with examination. The covariates heart rate (in bpm) and finish time (in minutes) were also incorporated into the model. Random effects of competition and rider were fitted as blocking factors. Heterogeneous residual variances due to finish time above or below 500 min were fitted to the model to improve model fit to the data, as assessed by Bayesian Information Criteria. Degrees of freedom were approximated using Kenward-Roger’s approach. The model was fitted using the MIXED procedure of SAS (Version 9.2; Cary, NC, USA). Model assumptions were evaluated using studentized residual plots, and assumptions were considered to be appropriately met. Estimated mean IOP and corresponding standard errors are presented. Pairwise comparisons were conducted using Bonferroni’s adjustment to avoid inflation of Type I error rate. Two observations corresponding to the Pre-examination for one horse were considered highly influential outliers based on a conservative Bonferroni test and, thus, were excluded from analyses.

As follow-up from the modeling approach on IOP, we evaluated potential associations between IOP and 14 clinical indicators recorded at each veterinary examination on the ride card including mucus membrane assessment, capillary refill, jugular refill, gut sounds, skin tenting, anal tone, muscle tone, back and withers assessment, tack galls, wounds assessment, gait evaluation, impulsion, attitude and overall impression based on ride veterinarian grading. The response variable consisted of the IOP average between left and right eye at each examination, as no evidence for differences between eye sides was apparent from previous analysis. For the purpose of model selection, we augmented the statistical model with clinical indicators selected based on a forward selection strategy driven by maximum-likelihood (ML)-based Bayesian information criteria (BIC). The base model consisted of the main effect of examination (Pre, VC1, VC2, and End) and the covariate finish time, along with random blocking effects of competition, rider and horse, as well as heterogeneous residual variances as a function of whether the horse finished before or after 500 min into the ride, as previously described. Each clinical indicator was evaluated once at a time for inclusion into the base model based on their contribution to model fit using BIC, and a final model was selected as best fitting based on ML-BIC with variance components estimated using restricted maximum likelihood for efficient estimation.

RESULTS

Estimated mean baseline IOP (±SEM) for conditioned equine athletes ranged from 20.9 ± 1.6 mmHg in horses with slower finishing times (600 min) to 24.3 ± 1.2 mmHg in horses with faster finishing times (300 min; \( P = 0.0667 \)). We found evidence for an interaction between examination and finishing time on IOP (\( P < 0.0001 \)), whereby fluctuations in IOP during the ride depended on how long the horse took to finish the race. More specifically, horses with shorter finishing times (≤400 min) showed IOP fluctuation of greater magnitude and earlier in the race relative to slower horses (Fig. 1). Furthermore, faster horses (finishing time ≤400 min) showed a significant decrease in IOP from baseline to VC1 (\( P < 0.001 \)), followed by a significant increase by VC2 (\( P < 0.0001 \)) and a final drop in IOP by the end of the ride (\( P < 0.01 \); Fig. 1). In turn, these IOP changes were either of smaller magnitude or not apparent in horses with longer finishing times (\( P > 0.15 \); Fig. 1). In addition to mean differences, IOP in horses with finishing times over 500 min was found to be approximately three times more variable than that of horses with shorter finishing times (estimated variances of 12.8 vs. 4.3 mmHg², respectively).

Furthermore, IOP fluctuations during an endurance ride seemed to differ between horses awarded ‘Best Condition’ compared with those not receiving this award (exam-by-best condition interaction \( P = 0.0575 \); Fig. 2). Baseline IOP values were not significantly different between the two groups (\( P = 0.77 \)), and both ‘Best Condition’ groups showed fluctuations in IOP during the endurance ride. However, whereas horses not awarded ‘Best Condition’ showed a marked decrease in IOP relative to baseline by end of ride (\( P < 0.0001 \)), this difference was not apparent in ‘Best Condition’ horses (\( P = 0.57 \)).

The forward model selection approach indicated that, after accounting for finish time and fluctuations during

![Figure 1](image-url). Least-squares mean estimates of intraocular pressure (IOP) in mmHg (and estimated standard errors) at baseline (Pre), veterinary checkpoint 1 (VC1), veterinary checkpoint 2 (VC2), and finish (End) evaluations for horses with increasing finishing times in minutes. A, B Different letters indicate significant differences in IOP between examinations within a group of horses with similar finishing times; groups sharing letters indicate no significant difference.
with diminished IOP reduction in more fit human study other competing horses (non-BC) did. This is consistent decrease in IOP from baseline to end of ride, whereas all ever, ‘Best Condition’ horses did not show any significant showed an undulating IOP pattern during the ride; how-

In this study, we assessed IOP in conditioned equine ath-

Figure 2. Least-squares mean estimation of intraocular pressure (IOP) in mmHg (and estimated standard errors) at baseline (Pre), veterinary checkpoint 1 (VC1), veterinary checkpoint 2 (VC2), and finish (End) evaluations for horses that were and were not awarded ‘Best Condition.’ A, B Different letters indicate significant differences in IOP between examinations within a group of horses with similar finishing times; groups sharing letters indicate no significant difference.

DISCUSSION

the ride, there was no evidence for any significant associa-
tion between IOP and heart rate, nor between IOP and any of the subjective parameters evaluated as clinical indi-
cators from the ride card.

In this study, we assessed IOP in conditioned equine ath-

the human aerobic exercise study performed using a cycle ergometer showed a similar undulating IOP pattern (decrease, increase, decrease) when measured over 30 min of total exercise time and an overall significant decrease in IOP with exercise. Horses awarded ‘Best Condition’ and non-‘Best Condition’ horses showed an undulating IOP pattern during the ride; however, ‘Best Condition’ horses did not show any significant decrease in IOP from baseline to end of ride, whereas all other competing horses (non-BC) did. This is consistent with diminished IOP reduction in more fit human study participants. This may also be explained by the very small sample size in the ‘Best Condition’ group (n = 5; only one award per ride), thus leading to greater uncer-
tainty for inference in this group. Diurnal variation was

not thought to be the cause of IOP changes given the dif-
ference in our observed IOP pattern compared to that shown by Bertolucci et al. where IOP increased during daylight hours reaching the peak value at the end of day-
light and decreased during dark hours to a minimum at

The fact that faster finishing horses had marginally higher baseline IOP values than slower horses may reflect variables involved with competitive vs. recreational riders preparing their horses for a ride and not necessarily fitness level. A common practice among endurance riders is to provide electrolytes, beet pulp, and other modalities to encourage hydration prior to a ride to improve equine metabolic status during a ride and prevent dehydration. These techniques may result in over hydration and affect baseline IOP in the opposite manner as that proposed with dehydration and IOP reduction.2,3,16

Exercise intensity and hydration status during the 50 mile ride may have both played a role in the undulating IOP results within all groups. It is common for horses to maintain a faster pace during the first segment of an endurance ride and not be willing to drink water during that segment given individual equine or group excitement. Following the first veterinary checkpoint, horses generally eat and drink during the required ‘hold time’ (30–60 min), then are more willing to maintain a moderate pace during the second ride segment and will even eat and drink on the trail. During the final ride segment riders may increase pace and forgo horse eating and drinking opportunities with a desire to simply complete the ride. The variable work load, losses, and gains throughout a ride cause inter-
nal redistribution and may reflect the changes seen here with the end of the ride still reflective of overall loss given a horse is simply more exhausted and dehydrated from the duration of the event.

In addressing our secondary objective, we evaluated the associations between IOP and heart rate, as well as with other subjective physical parameters. After accounting for repeated measures over the duration of the ride and for overall finishing time, there was no evidence for any associa-
tion between IOP and heart rate, nor between IOP and any of the clinical indicators assessed on the ride card.

Limitations with this study include lack of control over the horse preparation factors already mentioned (feed, electrolyte use, hydration supplements) as well as the vol-

© 2014 American College of Veterinary Ophthalmologists, Veterinary Ophthalmology, 1–6
potentially induce sampling bias. There was also mild inconsistency related to when the IOP was measured during the rides and after the ride as some riders allowed IOP measurement immediately after coming off the trail while waiting in line for veterinary evaluation and others preferred tonometry after veterinary evaluation. Although it is unlikely these minor time variations impacted IOP assessment, future studies could potentially incorporate IOP into the veterinary examination for greater consistency and cooperation. The same evaluator (RAA) always measured IOP; however, the veterinary evaluations were performed by different veterinarians between rides and sometimes even within rides, which could have led to inconsistencies in subjective data grading and contributed to the lack of evidence for associations between these subjective parameters and IOP.

The veterinary examination is an important part of endurance riding from the standpoint of horse safety during performance. Finding a rapid, simple, noninvasive objective measure to predict or identify equine exhaustion indicating the need to remove a horse from competition would be of great benefit. As there were no eliminations due to exhaustion at the rides attended, we were unable to assess associations between IOP and exhaustion status; however, as an anecdotic observation, we note that one very dehydrated horse had the lowest end IOP (13 mmHg) of all horses evaluated. Therefore, as previously mentioned by Hunt et al.16 there is a potential for using fluctuations in IOP as useful indicators of dehydration during performance of equine athletes in endurance rides; however, other influential factors may present too much challenge for practical use. Future studies should consider evaluating IOP at longer rides (75–100 miles) and in more challenging environmental conditions (heat, humidity, tough terrain) where exhaustion eliminations occur more often.30–32 This would allow assessing the predictive value of IOP for diagnosis of exhaustion in equine endurance athletes. Evaluation could also be performed in concert with measurement of other metabolic indicators such as plasma osmolarity via blood testing, as well as with questionnaires to learn more about management strategies, conditioning, trailing distance to a ride, or other individual factors.

ACKNOWLEDGMENTS

Funded by a Kansas State University Small Research Grant. The authors wish to thank Dr. Karie VanderWerf and Yarixa Quinones for their help with technical assistance as well as the ride managers, ride veterinarians, riders, and horses for their cooperation in this study.

REFERENCES


