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Intraocular pressure changes in equine athletes during endurance competitions

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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 5 different competitions at 3 different locations with 59 horses ridden once, 9 horses ridden in two competitions, and 1 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 competitions. Heart rates and subjective veterinary scores were recorded on ride cards at each time point.
Results For horses with shorter finishing times (≤400 minutes), 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), though 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: horse, equine, intraocular pressure, IOP, endurance, exercise

INTRODUCTION
In numerous studies intraocular pressure (IOP) has been shown to decrease in humans during exercise as summarized in a recent review article.(1) This has been shown with conditions of acute dynamic exercise,(2-7) continuous strenuous exercise,(8), isometric exercise,(9) and even brisk walking.(10) 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.(2, 3, 9-12) 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.(1, 5, 6) 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.(13)

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.(3, 7, 8, 14, 15) 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.(1, 8) 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 through osmotic dehydration of the globe, reduced aqueous ultrafiltration, or a hypothalamic reflex.(1-3, 16)

Equine endurance riding is a relatively young sport with growing popularity.(17) Based on number of events, endurance riding is the most rapidly growing Federation Equestre Internationale (FEI) discipline and the second most popular.(17) However participation is not limited to elite competitors, as hundreds of rides are offered all over the world by various organizations and recreational riders are encouraged to compete following adequate conditioning. Endurance rides cover 50 miles or more within a maximum amount of time. Monitoring of health status is of utmost importance to ensure that horses are “fit-to-continue” with required veterinary evaluations occurring prior to, at multiple times during, and immediately following rides. The ride veterinarian makes note of the horse’s general attitude and determines their overall impression of the ability of the horse to continue in the competition based on objective and subjective examination data which are recorded on a horse and rider’s ride card. If problems are noted during any examination, including after the ride, horses can be eliminated by the ride veterinarian and those entries are considered non-completions with the aim of elimination to protect the horse and avoid serious injuries.(17) The first ten equine finishers are able to compete for the “Best Condition” award which is factored on finish time, weight carried (rider and tack), and a veterinary score one hour after completing the ride.(American Endurance Ride Conference Rider Handbook, available at www.aerc.org/AERC_Rider_Handbook.pdf)

Numerous studies have reported normal values for IOP in horses, with a typical range of approximately 15-30 mm Hg.(18-22) Additional studies have examined variables such as sedative drugs,(23-26) head position,(27) and even circadian rhythm(28) documenting how these factors alter equine IOP; however, no study has evaluated the effect of exercise on equine IOP. Portable devices that measure IOP in horses allow reliable assessment outside the clinic setting and can be obtained from unsedated, unblocked horses in a normal standing position. Additionally due to the small probe size and brief contact time of the rebound tonometer, topical anesthesia is not required for that instrument which further facilitates use and compliance.(29)

With extensive documentation of normal equine IOP and the knowledge of IOP changes in humans during exercise, we were interested in evaluating equine athletes to assess IOP fluctuations with exercise, as well as baseline IOP in individuals of various levels of fitness. The objective of the study reported here is to assess IOP in conditioned equine athletes and document changes before, during, and after endurance
exercise, with an expectation of IOP reduction by end of endurance exercise. A secondary objective was to assess associations between IOP and heart rate, as well as with other subjective physical parameters.

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 5 different competitions at 3 different locations with 59 horses ridden once, 9 horses ridden in two competitions, and 1 horse ridden in three competitions for a total of 80 horse-ride combinations. Though 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 was 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 pre-ride 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 4 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 pre-ride 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 in order 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 post-ride examination for each horse (End). Measurements were taken while a horse and rider were waiting in line for the ride veterinarian evaluation or immediately afterwards, 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 mm Hg. The statistical model included the fixed effects of exam (Pre, VC1, VC2 and End), eye (Left or Right) and their 2-way interaction. Random effects included horse and its cross-product with eye in order to recognize the horse as a blocking factor for left and right observations, as well as the eye as the unit for 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 exam. 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 minutes 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-exam 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 exam 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 exam, as no evidence for differences between eye sides were 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 exam (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 minutes into the ride, as previously described. Each clinical indicator was evaluated one 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 mm Hg in horses with slower finishing times (600 minutes) to 24.3±1.2 mm Hg in horses with faster finishing times (300 minutes) (P=0.0667). We found evidence for an interaction between exam 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 minutes) showed IOP fluctuation of greater magnitude and earlier in the race relative to slower horses (Figure 1). Furthermore, faster horses (finishing time ≤ 400 minutes) 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; Figure 1). In turn, these IOP changes were either of smaller magnitude or not apparent in horses with longer finishing times (P>0.15; Figure 1). In addition to mean differences, IOP in horses with finishing times over 500 minutes 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 to those not receiving this award (exam-by-best condition interaction P=0.0575; Figure 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 the ride, there was no evidence for any significant association between IOP and heart rate, nor between IOP and any of the subjective parameters evaluated as clinical indicators from the ride card.

DISCUSSION
In this study, we assessed IOP in conditioned equine athletes and documented changes before, during, and after endurance exercise. Our findings indicate that IOP in equine athletes fluctuated during endurance riding competitions in a manner that depended on finishing time of the horse. In addition, horses completing a 50 mile ride in shorter finishing times had decreased IOP relative to baseline than slower counterparts.

Undulating fluctuations in the faster horses (finishing time ≤400 minutes) were evident during the endurance ride, with an overall decrease in IOP by the end of the ride relative to baseline. A human aerobic exercise study performed using a cycle ergometer showed a similar undulating IOP pattern (decrease, increase, decrease) when measured over 30 minutes 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 uncertainty for inference in this group. Diurnal variation was not thought to be the cause of IOP changes given the difference 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 daylight and decreased during dark hours to a minimum at the end of the dark phase. Additionally, in our study some Pre and End exams were actually performed near the same time of day due to horses presenting for pre-ride veterinary exams the afternoon or evening prior to competition. The reason for differences between finishing groups is unclear and may reflect differences in relative intensity of exercise during the endurance ride, equine fitness level (conditioning differences between competitive
and recreational riders), or other horse preparation factors such as feed, electrolyte use, and hydration supplements.

The fact that faster finishing horses had marginally higher baseline IOP values than slower horses may reflect variables involved with competitive versus 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 minutes), 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 internal 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 association 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 voluntary nature of participating in this study, which can 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. Though it is unlikely these minor time variations impacted IOP assessment, future studies could potentially incorporate IOP into the veterinary exam 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 exam 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. Since 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, trailering distance to a ride, or other individual factors.

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