Evaluation of healthy equine eyes by use of retinoscopy, keratometry, and ultrasonographic biometry

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Objective—To assess natural variations in degree of refraction, corneal curvature, corneal astigmatism, corneal radius, and intraocular distance of healthy equine eyes.

Animals—159 horses with healthy eyes that were admitted to a veterinary teaching hospital for nonophthalmic surgeries.

Procedures—Eyes of horses were examined with a retinoscope prior to anesthesia and with a keratograph and A- and B-scan ultrasonographic biometers during surgery. In addition, manual caliper measurements of horizontal and vertical corneal radii were obtained.

Results—Mean ± SD degree of refraction in the horizontal meridian of eyes was –0.06 ± 0.68 diopters (D). Vitreous body length and horse age correlated negatively with refraction values. The horizontal corneal radius (15.96 ± 1.28 mm) was larger than the vertical corneal radius (15.02 ± 1.09 mm). Accordingly, the vertical corneal curvature (21.56 ± 1.68 D) was greater than the horizontal corneal curvature (22.89 ± 1.65 D). Axial globe length (40.52 ± 2.67 mm), anterior chamber depth (6.35 ± 0.59 mm), lens thickness (12.30 ± 0.83 mm), and vitreous body length (21.87 ± 1.85 mm) were positively correlated with body weight, height, and age. Results of keratograph and caliper measurements correlated well for horizontal corneal diameter but poorly for vertical corneal diameter. Results of A- and B-scan ultrasonography differed by ≤ 1 mm in 64% of measured eyes.

Conclusions and Clinical Relevance—Results of keratometry and ultrasonographic biometry varied widely. Additional research is needed to validate the keratograph used in our study for measurements in equine eyes. (*Am J Vet Res* 2010;71:677–681)

Several tools have been developed to aid in the performance of ophthalmic examinations. Streak retinoscopy has not changed since its inception in the 19th century[1] and is often used in horses.[2–6,a,b] However, few attempts have been made to measure the equine cornea with a keratometric device such as an ophthalmometer[7,b] or a videokeratophakometer.[4] One reason for the lack of attempts is that it has proven difficult to restrain horses for such measurements.[8–15] Furthermore, the available keratometric devices are designed to measure the human cornea and not the considerably larger equine cornea.

A few reports exist regarding the axial dimensions of globes in equine eyes. In the related studies, investigators used an A-scan biometer[14,16–19] or a B-scan biometer[20] or performed measurements manually.[9,15] The purpose of the study reported here was to assess natural variation in degree of refraction, corneal curvature, corneal astigmatism, corneal radius, and intraocular distances in healthy equine eyes. In addition, we sought to determine the effect of age, type of horse, body weight, height, and sex on these ocular characteristics. A final objective was to compare keratometric findings with manually obtained values and A- and B-scan ultrasonographic findings with manually obtained values.

Abbreviation	
D	Diopter

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Materials and Methods

Animals—Horses that were admitted for surgery to the Clinical Department for Small Animals and Horses of the Veterinary University of Vienna between October 2005 and July 2006 were eligible for inclusion in the study. To be included, horses were required to be scheduled for deep sedation or general anesthesia for a nonophthalmic reason. They were also required to undergo an ophthalmic examination by the same examiner (PG) that included direct ophthalmoscopy[c] and slit-lamp[d] examination before and after initiation of mydriasis.[e] Horses in which pathological changes in the refractive media of the eyes were detected were excluded.

In most horses, it was only possible to examine 1 eye via retinoscopy, keratometry, and ultrasonographic biometry; however, in 6 horses, both eyes were examined. In those 6 horses, 1 eye was randomly selected to be measured first. Measurements of intraocular distances and lens diameters were also performed on 6 enucleated eyes from horses that had been euthanatized for reasons unrelated to the study. These measurements were performed with ultrasonographic devices immediately after death, and eyes were frozen at –80°C until manually measured with a caliper. This study was approved by the ethics commission of the Veterinary University of Vienna. For every examined horse, an owner's written informed consent was obtained.

Retinoscopy—Retinoscopy was carried out by use of a streak retinoscope[f] and 2 skiascope bars.[g] Horses were examined in a darkened room before sedatives or anesthetics were administered. The horizontal meridian was examined with the examiner at a working distance of 67 cm (1.5 D).[1]

Keratometry—Before each evaluation, the keratograph device[h] was calibrated by use of calibration discs. Each horse was positioned on the operating table with its head horizontal to the table. When necessary, eyelids were retracted manually. An integrated monitor and crosshair were used to set the keratograph in the appropriate position and distance from the eye (approx 40 mm away). Subsequently, 3 to 5 recordings/eye were obtained. Between measurements, the cornea was moistened with lactated Ringer's solution.[i] Corneal astigmatism and horizontal and vertical corneal radius were determined after completion of all measurements through use of computer software that accompanied the keratograph. To evaluate the accuracy of the keratograph, a Jameson caliper[j] was used to manually measure the horizontal and vertical corneal radii.

Ultrasonographic biometry—A-scan ultrasonographic biometry was performed on each horse by use of a modified ultrasonographic machine.[k] This biometer allows measurement of intraocular distances with A-mode ultrasonography up to a length of 50 mm. Prior to measurement, 1 drop of anesthetic[l] was topically applied to the eye or eyes to be examined. Subsequently, the transducer was apposed directly against the cornea. The ultrasound velocity was chosen for each segment of the eye separately (anterior and vitreous chamber, 1.532 m/s; lens, 1.641 m/s) in accordance with the equipment manufacturer's instructions. Three recordings obtained consistently along the optical axis were saved, and the length of each intraocular distance was determined afterward. Finally, the axial length of the globe was calculated.

To verify the accuracy of A-scan readings, B-scan ultrasonographic biometry was performed on a subset of horses by use of a B-scan ultrasonographic machine.[m] One measurement was obtained along the optical axis by use of coupling ultrasound gel.[n] Optimal positioning was confirmed when the posterior wall of the globe was clearly visible and the reflections from the 4 principal landmarks along the optical axis (cornea, anterior and posterior lens surface, and retina) were perpendicular.

After completion of all measurements, eyes were cleaned with lactated Ringer´s solution and a vitamin A–containing ointment[o] was applied to keep eyes moistened until the end of the anesthesia. Enucleated eyes from euthanatized horses were similarly measured with the ultrasonographic devices immediately after death. A caliper was subsequently used to measure axial globe length, anterior chamber depth, lens thickness, and vitreous body length of the frozen eyes.

Statistical analysis—In the 6 horses in which both eyes were examined, only data for the eye examined first were included in the analyses. Data for the second eye were used only for within-horse comparison. Statistical analyses were performed with commercially available software.[p,q] Values are reported as mean ± SD. Normal distribution of data was confirmed by use of the Kolmogorov-Smirnov test. Correlations between body weight, height, age, refraction values, corneal diameters, and intraocular distances; keratometric and manual measurements; and A- and B-scan readings and manual measurements were evaluated by calculation of Pearson (r) or Spearman (ρ) correlation coefficients. Multivariate ANOVA was used to determine the influence of the type of horse, body weight, height, age, and sex on the examined quantitative variables. A value of $P \leq 0.05$ was considered significant for all analyses.

Results

Animals—During the study period, retinoscopy, keratometry, ultrasonographic biometry, and manual measurements were performed on eyes of 159 horses (28 females and 131 castrated males). Approximately 15 minutes was required for completion of all measurements.

Types of horses represented included warmblood (n = 74 eyes), trotter (31), pony (27), Thoroughbred (14), western horse (10), and coldblood (9). A miniature donkey was also included in the pony group. Age distribution was as follows: 0 to 2.5 years, 33 eyes; 2.6 to 5 years, 50; 5.1 to 7.5 years, 24; 7.6 to 10 years, 17; 10.1 to 12.5 years, 13; 12.6 to 15 years, 12; 15.1 to 17.5 years, 8; 17.6 to 20 years, 5; 20.1 to 22.5 years, 1; 22.6 to 25 years, 0; 25.1 to 27 years, 1; and 27.1 to 30 years, 1. Body weight distribution was as follows: 50 to 150 kg, 5 eyes; 151 to 250 kg, 5; 251 to 350 kg, 11; 351 to 450 kg, 40; 451 to 550 kg, 60; 551 to 650 kg, 37; 651 to 750 kg, 6; and 751 to 850 kg, 1. The distribution of horses by height at the top of the shoulders (withers) was as follows: 80 to 100 cm, 5 eyes; 101 to 120 cm, 4; 121 to 140 cm, 15; 141 to 160 cm, 60; 161 to 180 cm, 62; and 181 to 200 cm, 2.

Retinoscopy—The horizontal meridian was examined in healthy eyes of 158 horses. The mean refractive state was –0.06 ± 0.68 D (**Figure 1**). Emmetropia (0 D) was present in 77 of 158 (48.7%) horses. Hyperopia, with a maximum value of +1.5 D, was present in 38 (24.1%) horses, and myopia, with a maximum value of –1.5 D, was present in 40 (25.3%) horses. Two (1.3%) horses were myopic to the degree of –2 D, and 1 (0.6%) horse was myopic to the degree of –3 D.

The type of horse, body weight, height at the withers, and sex were not associated with refraction values ($P > 0.1$; n = 158 eyes). On the other hand, refraction values shifted toward myopia with increasing age ($\rho = -0.25$; $P = 0.008$; n = 158). Thus, by the age of 7.5 years or older, more horses were myopic. No interaction was detected between refraction in the horizontal meridian and corneal radius or curvature ($P > 0.2$; n = 141). Except for vitreous body length, none of the intraocular distances had an influence on refraction values ($P > 0.07$; n = 156). Vitreous body length was negatively correlated with the refraction values ($\rho = -0.25$; $P = 0.001$; n = 156). Anisometropia of 0.5 to 2 D was present in all 6 bilaterally examined horses.

Keratometry—Keratograms were obtained for 141 horses. In all examined horses, the mean ± SD horizontal corneal curvature (21.56 ± 1.68 D) was less than the vertical corneal curvature (22.89 ± 1.65 D). This meant that the mean degree of astigmatism rectus was 1.3 D. Toward the periphery, the vertical corneal curvature decreased considerably with a mean difference of 0.33 D between the central and peripheral regions. In contrast, the central and peripheral regions of the horizontal corneal curvature had a mean difference of 0.18 D only.

The vertical corneal radius (15.02 ± 1.09 mm) was consistently smaller than the horizontal one (15.96 ± 1.28 mm). Statistical analysis revealed a significant ($P < 0.01$) influence of the type of horse, body weight, height at the withers, and age on the horizontal and vertical corneal radii ($\rho > 0.42$; n = 141). The taller and heavier the horses were, the larger the corneal radii became. A significant ($P = 0.001$) positive correlation also existed for horizontal and vertical corneal radii and the axial length of the globe ($r > 0.5$; n = 141). Sex of horse was not associated with the size of the corneal radii ($P = 0.09$; n = 141). Radius values for the right and left eyes of the 6 bilaterally examined horses were strongly correlated ($r > 0.9$; $P < 0.001$).

For assessment of the accuracy of the keratograph in measuring corneas, manual caliper measurements were made in 107 horses. Mean results for horizontal corneal diameters correlated well with each other (keratograph, 31.87 mm; caliper, 31.92 mm; $r = 0.512$; $P = 0.001$); 59.3% of values differed by ≤ 2 mm. The same was not true for mean results for vertical corneal diameters (keratograph, 26.15 mm; caliper, 30.04 mm; $r = 0.258$; $P = 0.001$), for which only 16.8% of values differed by ≤ 2 mm.

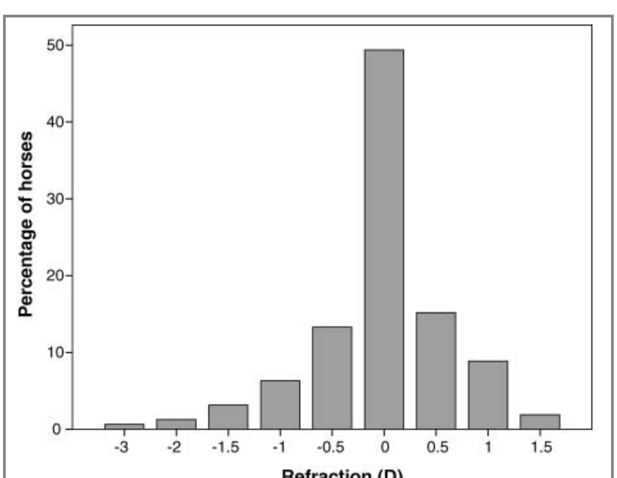

Figure 1—Distribution of ocular refraction values in 158 horses with healthy eyes.

A- and B-scan ultrasonographic biometry—A-scan ultrasonographic biometry of the eye was performed on 156 horses. Afterward, intraocular distances were also measured in 90 horses by use of B-scan ultrasonography. Overall mean values of the 156 A-mode examined horses were as follows: axial length of the globe, 40.52 ± 2.67 mm; anterior chamber depth, 6.35 ± 0.59 mm; lens thickness, 12.30 ± 0.83 mm; and vitreous body length, 21.87 ± 1.85 mm. The range of values among horses was large for all intraocular distances.

No relationship existed between horse sex and the various types of intraocular distances ($P = 0.168$; n = 156). However, all types of intraocular distances were positively correlated with body weight, height at the withers, and age ($\rho > 0.5$; $P \leq 0.01$; n = 156). The taller, heavier, and older that horses were, the larger the intraocular distances were. Values for the right and left eyes of the 6 bilaterally examined horses were strongly correlated ($r > 0.9$; $P < 0.01$).

Results of A- and B-scan ultrasonographic biometry in 90 horses were examined for congruence. The mean values measured with the B-scan device were as follows: axial length of the globe, 41.04 ± 2.67 mm; anterior chamber length, 6.19 ± 0.75 mm; lens thickness, 11.74 ± 0.71 mm; and vitreous body length, 22.98 ± 1.86 mm. Differences in mean values ranged from 0.16 to 1.18 mm. Comparison of the values revealed a good correlation ($r > 0.6$; $P < 0.01$; n = 90), indicating that for 64% of the results, a difference of ≤ 1 mm existed.

The accuracy of both methods was once again examined with measurements made in the 6 enucleated eyes of euthanatized horses. Values of sonographic and manual measurements obtained before and after freezing of the eyes correlated well for all intraocular distances ($r > 0.62$; $P < 0.01$), except for anterior chamber depth, in which only a weak correlation existed ($r = 0.14$; $P = 0.01$). Lens diameter was measured in the contralateral eye of 3 horses; 2 lenses had a diameter of 19 mm, and 1 had a diameter of 20 mm.

Discussion

In the study reported here, 3 techniques (retinoscopy, keratometry, and ultrasonographic biometry) were used to measure various aspects of healthy equine eyes. Retinoscopy was performed without administration of cycloplegics or mydriatics because other studies[21,22,a] failed to demonstrate a difference between refraction values obtained during mydriasis and miosis. We decided to determine refraction values only once because another study[r] in dogs revealed that multiple examinations yield only minimally different values.

In other studies[3–5] involving horses, retinoscopy was performed in the ocular horizontal and vertical meridians; however, the mean result of the 2 meridians was used in statistical analyses. We decided to measure refraction in the horizontal meridian only and to compare this result with the other biometric values. The mean refraction in the horizontal meridian of equine eyes in the present study was –0.06 ± 0.68 D, which is consistent with findings of other recent studies.[3–5] In those studies, the mean refraction value was between +0.25 D and –0.48 D. In our study, emmetropia (0 D) was present in 48.7% of horses, which is similar to the percentage reported for another study[a] (49.1%). However, in other studies,[2,6,b] < 36% of horses were emmetropic.

A correlation between type of horse and ametropia was detected in 2 previous studies[a,b]; however, in our study, no influence of type of horse, body weight, or height on refraction values was evident. Moreover, we did not detect a difference in refraction values between castrated male and female horses. On the other hand, a negative correlation was detected between age and refraction values such that, by 7.5 years of age, more horses were myopic. A similar relationship between age and refraction values in horses has been reported elsewhere.[6] Corneal radius and curvature did not have an effect on refraction in the horizontal meridian of the horses in our study. None of the intraocular distances measured except for vitreous chamber depth had an influence on degree of refraction. Whereas a negative correlation was found between refraction values and vitreous chamber depth, another study[a] revealed a positive correlation between these 2 variables.

Anisometropia ranging from 0.5 to 2 D was present in all 6 bilaterally examined horses. From our point of view, this was not clinically relevant because none of the owners claimed their horses were shy or easily startled.

To the authors' knowledge, the present study is the first in which a keratograph was used to measure the horizontal and the vertical corneal curvatures and radii and astigmatism in living horses. In humans, the device allows measurement of the entire cornea. Most other studies in which keratometry was used involved enucleated horse eyes[8–10,12,15] or measurement with a caliper[11,13,14,23] or B-scan ultrasonography[19] in living animals. Because the keratograph used in our study has a maximal coverage range of 16 mm, we were only able to measure the central and the paracentral region of equine corneas. The position of the horse's head during anesthesia precluded use of the keratograph in its supportive rack, so all measurements were performed with the device in hand.

Our values for mean horizontal (21.56 D) and vertical (22.89 D) corneal curvatures corresponded to the value of the mean corneal curvature (21.45 D) reported elsewhere.[15] Mean values for horizontal (15.96 mm) and vertical (15.02 mm) corneal radii were also similar to the values reported for other studies.[7–10,12,14,15,a,b] The largest corneal radii were found in the largest horses, and the smallest corneal radii were found in ponies (data not shown). Other studies involving Miniature horses[14] and foals[11] revealed a similar relationship between breed and corneal radii. We also found a positive relationship between age and corneal radii, as have other researchers.[14,24] In addition, use of the keratograph allowed us to find a positive correlation between corneal radius and axial length of the globe.

Although there was good correlation between mean values for keratographically and manually measured horizontal corneal diameter, there was a remarkable difference (3.89 mm) between mean values for vertical corneal diameter. This might have been attributable to the keratograph having been designed to measure the round human cornea and not the oval equine cornea. The position of the keratograph and the globe during anesthesia could also have affected the results. During measurement of optical corneal diameter with a caliper, errors are possible because measurements of the central widest horizontal and vertical portion are somewhat subjective. Moreover, the precision of the Jameson caliper used was only to 1 mm. However, caliper measurements in horses have yielded reliable results.[11,13,23] Additional research is needed to validate the keratograph for use in horses.

To the authors' knowledge, there exists only 1 other study[19] of A-scan ultrasonographic biometry involving eyes of horses of various breeds and ages. Other studies in which intraocular distances were measured involved only specific types of horses[14,16,18] or other devices.[7,9,10,15,20] Optimal ultrasound velocities in equine eyes have yet to be determined. In the veterinary literature, optimal ultrasound velocities are reported only for the lens and the vitreous of dogs,[25,26] pigs,[25,27] and rabbits.[25] Therefore, for our study, we chose the ultrasound velocity established for human medicine[28] and as suggested by the manufacturer of the devices used.

Compared with results of earlier studies,[7–10,14,15,19,20,29,30] our findings were similar for axial globe length, anterior chamber depth, lens thickness, and vitreous chamber depth. However, our minimum axial globe length (32.28 mm) and minimum vitreous chamber depth (15.5 mm) were less than and the maximum axial globe length (48.21 mm) and maximum vitreous chamber depth (28.17 mm) were greater than previously reported values (33.11, 17.37, 44.75, and 21.7 mm, respectively).[7,18] Moreover, greater maximum values were obtained in the present study for anterior chamber depth (7.65 vs 7.07 mm[30]) and lens thickness (14.45 vs 13.25 mm[8]).

In the present study, the shortest intraocular distances existed in the smallest horses (ponies), and the greatest distances existed in the largest horses (warmbloods), as has been reported elsewhere.[14,a] A positive correlation was also identified between increasing intraocular distances and increasing age, as has also been reported before.[14,18]

Intraocular distances measured via A- and B-scan ultrasonography correlated well with each other in our study. Similar correlations are reported for dogs.[31,s] Values deviated by ≤ 1 mm between methods for 87% of lens thickness, 78% of anterior chamber depth, 58% of axial globe length, and 28% of vitreous chamber depth values. In human medicine, values typically deviate by ≤ 0.1 mm, particularly in terms of intraocular lens calculation[32]; however, only 7% of our A- and B-scan values attained this degree of agreement.

Results of sonographic and manual measurements of enucleated eyes before and after freezing correlated well for all intraocular distances except anterior chamber depth. This might have been attributable to postmortem hypotony and loss of aqueous humor in the eyes. The reason the other intraocular distance values were not influenced by postmortem changes to a similar extent is unclear; however, a study[31] in canine eyes showed results of postmortem measurements are significantly greater for all intraocular distances than results of in vivo measurements.

Overall, the study reported here revealed wide ranges in keratometric and biometric values in healthy equine eyes. Although the correlation between keratograph and caliper values for vertical corneal diameter was low, A- and B-scan ultrasonographic biometry yielded comparable results for intraocular measurements. Additional research is needed to validate the keratograph used in our study for measurements in equine eyes.

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