

Effects of different climatic conditions on intraocular pressure in Arabian horses

Efectos de diferentes condiciones de temperatura sobre la presión intraocular en caballos árabes

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ABSTRACT

This study aimed to investigate the effects of different climatic conditions on intraocular pressure in Arabian horses. Intraocular pressure is a critical parameter for the diagnosis and management of ocular diseases such as glaucoma and anterior uveitis, and accurate measurement is essential for equine eye health. The present study was conducted on 15 clinically healthy Arabian horses aged between 6 and 10 years and kept under the climatic conditions of Eastern Anatolia, Türkiye. Intraocular pressure measurements were performed at two different environmental temperatures, 5 °C and -20 °C, to evaluate the effect of ambient temperature on ocular physiology. During the measurements, the head position of the horses was kept at shoulder level, and no sedatives or topical anesthetics were administered to avoid possible interference with intraocular pressure values. Measurements were obtained using an Icare® rebound tonometer, and for each eye, six consecutive readings were recorded, with the mean value used for statistical evaluation. The analysis showed no statistically significant difference between the right and left eyes at either temperature level, indicating that intraocular pressure measurements obtained from both eyes can be used interchangeably without introducing systematic bias. At 5 °C, mean intraocular pressure values were 28.53 ± 4.88 mmHg in the right eye and 28.07 ± 4.30 mmHg in the left eye. When the ambient temperature decreased to -20 °C, mean intraocular pressure values increased to 32.33 ± 3.05 mmHg and 32.00 ± 2.09 mmHg for the right and left eyes, respectively. Statistical analyses, including paired t-tests and Bland-Altman evaluation, demonstrated that this increase was significant and consistent, and that it was not dependent on the magnitude of the measurements. These findings indicate that low environmental temperature has a clear physiological effect on intraocular pressure in Arabian horses. The absence of interocular differences further supports the reliability of the measurements and the suitability of using either eye for clinical assessment. Taken together, the results emphasize the importance of considering environmental temperature when interpreting intraocular pressure values, particularly in regions with extreme climatic conditions. Future studies involving different climatic zones, breeds, and age groups would be valuable to confirm and expand upon these findings.

Key words: Intraocular pressure; arabian horses; environmental temperature; tonometry; equine ophthalmology.

RESUMEN

Este estudio tuvo como objetivo investigar los efectos de diferentes condiciones climáticas sobre la presión intraocular en caballos árabes. La presión intraocular es un parámetro fundamental para el diagnóstico y el manejo de enfermedades oculares como el glaucoma y la uveítis anterior, y su medición precisa es esencial para la salud ocular equina. El estudio se realizó en 15 caballos árabes clínicamente sanos, con edades comprendidas entre 6 y 10 años, mantenidos bajo las condiciones climáticas de Anatolia Oriental, Turquía. Las mediciones de la presión intraocular se llevaron a cabo a dos temperaturas ambientales diferentes, 5 °C y -20 °C, con el fin de evaluar el efecto de la temperatura ambiental sobre la fisiología ocular. Durante las mediciones, la posición de la cabeza de los caballos se mantuvo a la altura del hombro, y no se utilizaron sedantes ni anestésicos tópicos para evitar posibles interferencias con los valores de la presión intraocular. Las mediciones se realizaron utilizando un tonómetro de rebote Icare®, y para cada ojo se registraron seis lecturas consecutivas, utilizándose el valor medio para el análisis estadístico. El análisis no mostró diferencias estadísticamente significativas entre el ojo derecho y el izquierdo en ninguna de las dos condiciones térmicas, lo que indica que las mediciones de presión intraocular pueden utilizarse de forma intercambiable sin introducir sesgos sistemáticos. A 5 °C, los valores medios de presión intraocular fueron de 28,53 ± 4,88 mmHg en el ojo derecho y de 28,07 ± 4,30 mmHg en el ojo izquierdo. Cuando la temperatura ambiental descendió a -20 °C, los valores medios de presión intraocular aumentaron a 32,33 ± 3,05 mmHg y 32,00 ± 2,09 mmHg para el ojo derecho e izquierdo, respectivamente. Los análisis estadísticos, incluidos la prueba t pareada y el análisis de Bland-Altman, demostraron que este incremento fue significativo y consistente, y que no dependió de la magnitud de las mediciones.

Estos hallazgos indican que la baja temperatura ambiental ejerce un efecto fisiológico claro sobre la presión intraocular en caballos árabes. La ausencia de diferencias interoculares respalda además la fiabilidad de las mediciones y la idoneidad del uso de cualquiera de los ojos en la evaluación clínica. En conjunto, los resultados subrayan la importancia de considerar la temperatura ambiental al interpretar los valores de presión intraocular, especialmente en regiones con condiciones climáticas extremas. Estudios futuros que incluyan diferentes zonas climáticas, razas y grupos etarios contribuirán a confirmar y ampliar estos hallazgos.

Palabras clave: Presión intraocular; caballos árabes; temperatura ambiental; tonometría; oftalmología equina.

INTRODUCTION

Intraocular pressure (IOP) is widely accepted as one of the most important parameters in the assessment of ocular health. Alterations in IOP are closely associated with several ocular disorders. Increased IOP is commonly linked to glaucoma, whereas decreased IOP is often associated with anterior uveitis. If these conditions are not diagnosed and managed promptly, they may result in progressive visual impairment or even permanent vision loss [1, 2, 3].

For this reason, the measurement of intraocular pressure plays a key role in both the diagnosis and follow-up of ocular diseases in horses, as in other animal species. In horses (*Equus caballus*), normal IOP values are generally accepted to range between 15 and 30 mmHg. Values exceeding 35 mmHg are commonly associated with glaucoma, whereas measurements below 15 mmHg are considered indicative of an increased risk of anterior uveitis. Regular monitoring of IOP is therefore essential for the early detection of ocular disorders and for guiding appropriate therapeutic interventions [4].

Intraocular pressure is known to be influenced by a wide range of factors, including age, sex, genetic background, stress level, hormonal status, and environmental conditions. Among these factors, climatic variables—particularly ambient temperature—play an important role in ocular physiology by affecting vascular dynamics as well as the production and outflow of aqueous humor. Previous studies have demonstrated that environmental and seasonal variations can lead to measurable changes in IOP in both humans and various animal species, highlighting the sensitivity of ocular parameters to external conditions [5, 6, 7, 8].

Investigating the influence of temperature on intraocular pressure provides valuable information for both veterinary ophthalmology and equine health management. Understanding how environmental conditions affect IOP can contribute to a more accurate interpretation of clinical measurements and improve the reliability of ophthalmic evaluations in horses. Additionally, clarifying the role of temperature in ocular physiology may help explain the variations observed under different climatic conditions [7]. This study aims to assess IOP in Arabian horses under two different climatic conditions, 5°C and -20°C, to investigate the effect of environmental temperature on IOP.

MATERIALS AND METHODS

Experimental animals

The study was carried out in Ağrı province, located in the Eastern Anatolia Region of Türkiye (approximately 39°43' N latitude and 43°03' E longitude), an area characterized by a continental climate with marked daily and seasonal temperature fluctuations. A total of 15 clinically healthy Arabian horses, consisting of 4 females and 11 males aged between 6 and 10 years, were included in the study. Before data collection, all animals underwent a detailed clinical and ophthalmological examination. During this evaluation, the cornea, iris, lens, eyelids, and lacrimal structures were examined macroscopically, visual

reflexes were assessed, and no pathological abnormalities were detected.

Based on these findings, all eyes included in the study were considered clinically healthy for intraocular pressure measurements. The horses were kept under standard stable management conditions, and all experimental procedures were conducted in accordance with the approval of the Animal Experiments Ethics Committee of the Ministry of Agriculture and Forestry (HADMEK, Approval No: 2019/44.06, dated March 11, 2019).

All 15 horses were evaluated under both ambient temperature conditions (5 and -20 °C), and each horse served as its own control. All measurements were carried out on the same day, between 09:00 and 16:00, following an adaptation period that allowed the animals to acclimate to the environmental temperature. During this period, the horses remained outdoors for at least 30 minutes (min) and were handled calmly through gentle contact to reduce stress and ensure familiarity with the measurement procedure.

During tonometric measurements, each horse's head was positioned at shoulder height to ensure consistency, and the upper eyelid was gently stabilized to obtain accurate readings. No sedative or topical anesthetic agents were administered at any stage of the procedure to prevent any potential influence on IOP values.

Tonometry

Intraocular pressure was measured using a rebound tonometer (Icare® Rebound Tonometer, Icare Finland Oy, Espoo, Finland). Before each measurement session, the device was calibrated in accordance with the manufacturer's recommendations to ensure measurement accuracy. All measurements were performed in a standardized manner, starting with the right eye followed by the left eye, and were conducted by the same operator (SY) in order to minimize inter-operator variability. For each eye, six consecutive measurements were obtained, and the mean of these values was used for subsequent statistical analyses.

Statistical analysis

The required sample size was calculated using G*Power software (version 3.1), with a significance level set at 5 % ($\alpha = 0.05$) and a statistical power of 90% ($1 - \beta = 0.90$). The distribution of the data was first evaluated using visual inspection of Q-Q plots, followed by the Shapiro-Wilk test to assess normality. As the data were found to be normally distributed, parametric statistical methods were applied. Differences in intraocular pressure between the right and left eyes were analyzed using a paired t-test. In addition, the effect size of the interocular differences was calculated using Cohen's d, which indicated that the observed differences were clinically negligible [9].

The effect of environmental temperature on intraocular pressure was evaluated by comparing measurements obtained at 5 °C and -20 °C using a paired t-test. For this analysis, mean

IOP values calculated from the right and left eyes of each horse were used. In addition, Bland–Altman analysis was performed to assess the level of agreement between measurements and to identify any potential systematic bias. The mean difference (bias), standard deviation, and 95% limits of agreement were calculated to provide a comprehensive evaluation of measurement consistency [10].

Bland–Altman plots were used to visually assess the distribution of differences between measurements obtained from the right and left eyes. In addition, a simple regression analysis was performed to examine the relationship between the measurement differences and their mean values in order to identify any potential proportional bias. A significance level of $P < 0.05$ was used for all analyses, and statistical analyses were performed using SPSS software (version 25.0).

RESULTS AND DISCUSSION

At an ambient temperature of 5 °C, the IOP of 15 Arabian horses was 28.53 ± 4.88 mmHg in the right eyes and 28.07 ± 4.30 mmHg in the left eyes. Paired t-test showed no significant difference between the eyes ($t = 0.406$; $df = 14$; $P = 0.69$), with a mean difference of 0.46 mmHg and a tiny effect size (Cohen’s $d = 0.105$).

The 95 % confidence interval for the mean difference ranged from -2.57 to 3.77 mmHg. Bland-Altman analysis indicated that most differences fell within the ± 1.96 SD limits, with a mean difference of 0.47 mmHg and upper and lower limits of 1.72 mmHg and -0.79 mmHg, respectively (TABLE I, FIG. 1). These results suggest that IOP measurements of the right and left eyes can be used interchangeably, without evidence of systematic bias.

At -20 °C, the IOP of the right and left eyes of 15 Arabian horses was 32.33 ± 3.05 mmHg and 32.00 ± 2.09 mmHg, respectively. Paired t-test revealed no significant difference between the eyes ($t = 0.125$; $df = 14$; $P = 0.90$), with a mean difference of 0.13 mmHg and a tiny effect size (Cohen’s $d = 0.032$). The 95 % confidence interval for the mean difference ranged from -8.00 to 8.27 mmHg. Bland-Altman analysis indicated that most measurement differences were within the ± 1.96 SD limits, with a mean difference of 0.3 mmHg and upper and lower limits of 6.1 mmHg and -5.4 mmHg, respectively (TABLE II, FIG. 2). These findings suggest that IOP measurements of the right and left eyes can be used interchangeably, without evidence of systematic bias.

Temperature	Eye	Mean \pm SD (mmHg)	Min–Max (mmHg)	P-value (Right vs Left)	Cohen’s d
5 °C	Right	28.53 \pm 4.88	20–36	0.69	0.105
	Left	28.07 \pm 4.30	21–35		
-20 °C	Right	32.33 \pm 3.05	27–38	0.90	0.032
	Left	32.00 \pm 2.09	28–36		

Values are presented as mean \pm standard deviation (SD). P-values represent comparisons between right and left eyes using paired t-tests. Cohen’s d indicates effect size.

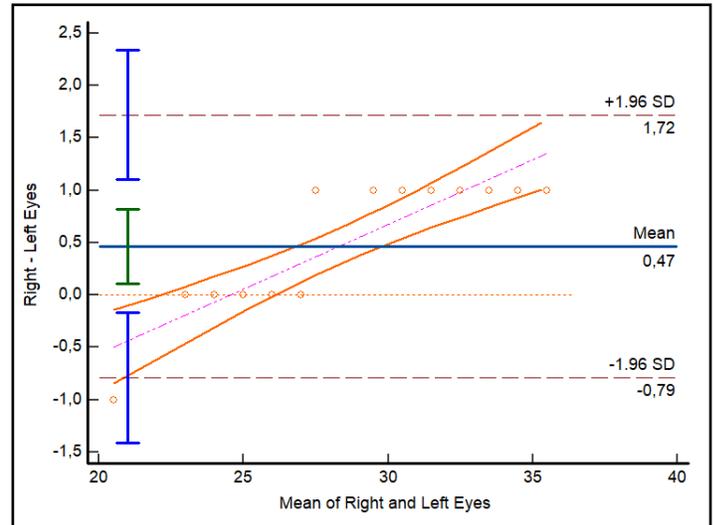


FIGURE 1. Bland–Altman limits of agreement plot of right and left eye IOP measurements at 5 °C. The thick black line shows the mean difference (bias) between the right and left eye measurements. The brown dashed lines represent the upper and lower limits of the measurement. The orange curved lines show the linear relationship between the measurement differences and the mean intraocular pressure. The pink dashed line in the middle represents the 95 % confidence interval of the regression line. The orange circles represent the individual measurement values. This analysis supports the reliable interchangeability of measurements between the right and left eyes in both groups.

When comparing IOP measurements of the right eyes of 15 Arabian horses at ambient temperatures of 5 °C and -20 °C, a significant increase was observed under colder conditions. At 5 °C, the mean IOP was 28.53 ± 4.88 mmHg, whereas at -20 °C it was 32.33 ± 3.05 mmHg. Paired t-test revealed that this difference was statistically significant ($t \approx 4.53$; $df = 14$; $P < 0.05$), and Cohen’s d was 1.17, indicating a large effect of low ambient temperature. Bland–Altman analysis showed a mean difference (bias) of 3.3 mmHg, with lower and upper limits of -11.3 mmHg and 4.8 mmHg, respectively, encompassing most measurement differences. Bland–Altman regression analysis ($y = -27.0658 + 0.7907x$) indicated that the difference between temperatures was largely independent of measurement size. These results demonstrate that lower ambient temperature causes a significant and systematic increase in IOP in Arabian horses (TABLE III; FIG. 3).

Eye	IOP at 5 °C (Mean \pm SD)	IOP at -20 °C (Mean \pm SD)	Difference (mmHg)	Paired t-test	Cohen’s d	Interpretation
Right	28.53 \pm 4.88	32.33 \pm 3.05	+ 3.80	$P < 0.05$	1.17	Significant increase
Left	28.07 \pm 4.30	32.00 \pm 2.09	+ 3.93	$P < 0.05$	1.10	Significant increase

Values are presented as mean \pm standard deviation (SD). Differences between temperatures were analyzed using paired t-tests. Cohen’s d indicates effect size.

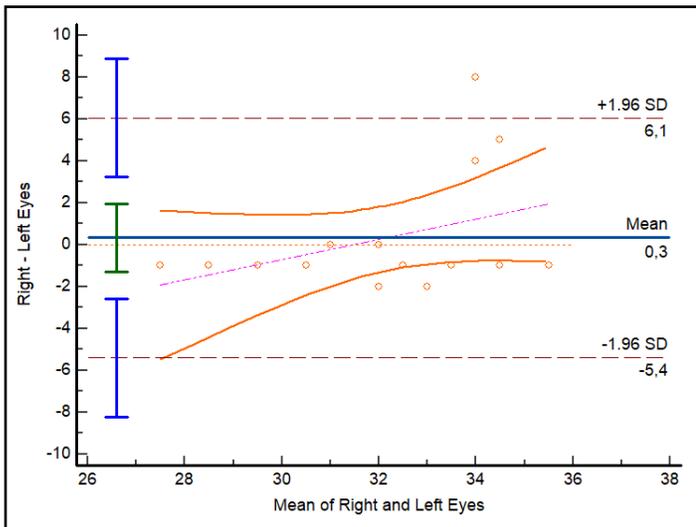


FIGURE 2. Bland–Altman limits of agreement plot of right and left eye intraocular pressure measurements at -20 °C. The thick black line shows the mean difference (bias) between the right and left eye measurements. The brown dashed lines represent the upper and lower limits of the measurement differences. The orange curved lines show the linear relationship between the measurement differences and the mean intraocular pressure. The pink dashed line in the middle represents the 95 % confidence interval of the regression line. The orange circles represent the individual measurement values. This analysis supports the reliable interchangeability of measurements between the right and left eyes in both groups.

Several studies have reported relationships between environmental conditions and intraocular pressure, including associations with ambient temperature and atmospheric pressure [6, 11]. In general, IOP values tend to be higher in winter and lower in summer, and this difference is attributed to environmental temperature, atmospheric pressure, humidity, and photoperiod. Particularly in low temperatures, increased vascular tone and changes in aqueous humour circulation may contribute to elevated intraocular pressure, whereas in summer, lower values may be observed due to fluid loss and decreased vascular resistance [12, 13]. In addition, it has been proposed that the duration of sunlight may indirectly affect aqueous humour production through hormones such as cortisol and melatonin [14].

Condition	Mean Difference (Bias)	Lower LOA	Upper LOA	Systematic Bias	Interpretation
5 °C (Right–Left)	0.47 mmHg	-0.79	1.72	None	Right and left eyes show strong agreement
-20 °C (Right–Left)	0.30 mmHg	-5.4	6.1	None	Right and left eyes show strong agreement
Difference between 5 °C and -20 °C	3.3 mmHg	-11.3	4.8	None	Low temperature increases IOP systematically

Bias represents the mean difference between paired measurements. LOA (limits of agreement) indicates the range in which 95 % of the measurement differences fall. No systematic bias was detected.

The effects of seasonal changes on IOP in animals have been investigated in a limited number of studies. In Sapsaree dogs, the influence of all four seasons on IOP was evaluated, and it

was determined that the mean IOP values obtained in winter were significantly higher than in the other seasons, while those in summer were significantly lower. No significant difference was observed between the values measured in spring and autumn. Based on these findings, the mean IOP in healthy dogs was reported to be highest in winter and lowest in summer [7].

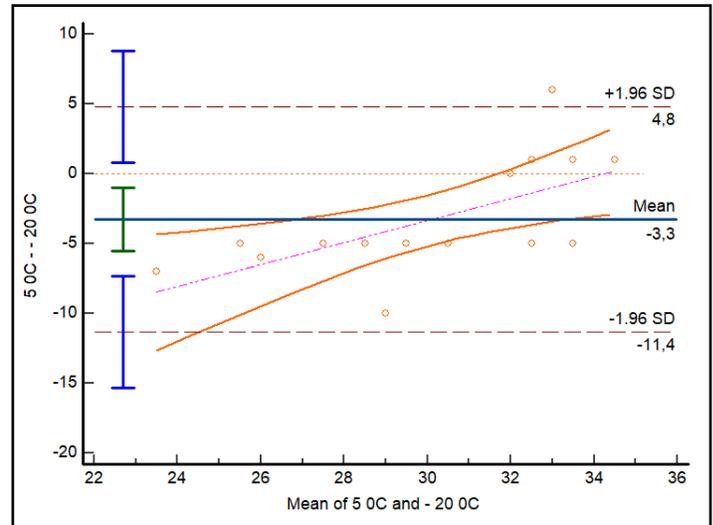


FIGURE 3. Bland–Altman limits of agreement plot of right eye intraocular pressure measurements at 5 °C and -20 °C. The thick black line shows the mean difference (bias) between the right and left eye measurements. The brown dashed lines represent the upper and lower limits of the measurement differences. The orange curved lines show the linear relationship between the measurement differences and the mean intraocular pressure. The pink dashed line in the middle represents the 95 % confidence interval of the regression line. The orange circles represent the individual measurement values. This analysis supports the reliable interchangeability of measurements between the right and left eyes in both groups.

Studies conducted in rabbits (*Oryctolagus cuniculus*) have also demonstrated that seasonal variations influence IOP. In one study, higher IOP values were reported in winter and lower values in summer [15], whereas another study observed peak IOP levels during both summer and winter months [16]. These differing results may stem from variations in environmental conditions; the studies on dogs (*Canis lupus familiaris*) and rabbits were conducted under uncontrolled conditions, whereas in the second rabbit study, light and temperature were controlled throughout the year.

In this study, the change in IOP in Arabian horses in relation to environmental temperature was investigated, and the mean IOP was found to be 28.30 ± 3.62 mmHg at 5 °C and 31.50 ± 2.46 mmHg at -20 °C. A statistically significant difference was detected between the measurements, demonstrating that low temperature conditions caused a systematic increase in IOP.

Bland–Altman analysis showed that the measurements at -20 °C were on average 4.2 mmHg higher than those at 5 °C, and that most of the differences were within the defined limits of agreement. Regression analysis revealed that the difference was independent of the measurement magnitude, thereby confirming that low temperature has a systematic and significant effect on IOP in Arabian horses.

The findings of this study support the researcher's results. Since the present study was conducted under uncontrolled environmental conditions, the results are more consistent with the dog study and the previous report in rabbits [7, 15].

In this study, no significant difference in IOP was found between the right and left eyes under either 5 or -20 °C temperature conditions. At both temperatures, the results of the paired t-test indicated that the interocular difference was not statistically significant, and the Bland–Altman analyses supported the absence of systematic bias in the measurements. The very small mean differences (0.46 mmHg and 0.13 mmHg) and negligible effect sizes (Cohen's $d < 0.11$) demonstrate that the right and left eyes can be used interchangeably with confidence in tonometric applications. This finding is consistent with studies in the literature reporting that the difference between eyes is clinically insignificant in most animal species [17, 18, 19].

In this study, IOP measurements were performed using an Icare® Rebound Tonometer, and six consecutive readings were obtained for each eye, with the mean value used in the analyses. This approach improved measurement repeatability and accuracy while minimizing variability related to the observer [15].

These findings highlight the importance of taking environmental conditions into account during clinical ophthalmic examinations in horses. In particular, accurate interpretation of intraocular pressure measurements is essential for the early detection of ocular disorders such as glaucoma. To reduce the potential influence of environmental factors, the use of standardized measurement protocols is strongly recommended. Such an approach can help ensure the reliability and consistency of IOP measurements in both clinical settings and experimental studies.

Although the manufacturer of the Icare® Rebound Tonometer recommends an operating temperature range between $+10$ °C and $+35$ °C, measurements in the present study were conducted at 5 °C and -20 °C. Despite these conditions being outside the suggested range, the measurements demonstrated high repeatability and minimal interocular differences.

Furthermore, Bland–Altman analysis did not reveal any evidence of systematic bias, indicating that the device provided consistent results even under low-temperature conditions. Furthermore, the observed increases in IOP under lower temperatures are consistent with physiologically expected responses, such as increased vascular tone and changes in aqueous humor dynamics. Similar off-range applications of this device have been reported in previous studies conducted under extreme climatic conditions. For example, reliable intraocular pressure measurements were successfully obtained in *Pygoscelis* penguins living in the Antarctic Peninsula, where subzero environmental temperatures prevailed, and the same type of rebound tonometer was used [20].

These findings indicate that, although the measurements were obtained outside the manufacturer's recommended operating range, the device was able to provide reliable and physiologically meaningful results under the environmental conditions evaluated in this study.

In addition, studies conducted on different breeds and age groups may reveal genetic and age-related differences in environmental effects and provide more comprehensive information regarding their impact on the general health and performance of horses.

Cold environmental conditions appear to influence the physiological dynamics of aqueous humor regulation in horses, and the increased IOP values observed at lower temperatures align with previous reports indicating that climatic factors can modulate ocular parameters in various species [7, 11, 14].

These findings suggest that the ocular responses of Arabian horses may be particularly sensitive to environmental stressors, highlighting the need for clinicians and researchers to account for temperature-related variability when assessing tonometric measurements.

Moreover, the observed interocular consistency supports the reliability of bilateral assessments in equine ophthalmic examinations. Future research that incorporates broader climatic variation, larger sample sizes, and different breeds will help clarify the mechanisms underlying temperature-dependent changes in IOP and expand the applicability of these findings within equine ocular health.

CONCLUSIONS

The present study demonstrated that exposure to low environmental temperatures leads to a significant increase in intraocular pressure in Arabian horses. The higher IOP values observed at -20 °C compared with those recorded at 5 °C indicate that ambient temperature exerts a clear and systematic influence on ocular physiology. In addition, no statistically significant differences were detected between the right and left eyes under either temperature condition, suggesting consistent bilateral responses to environmental changes.

The consistency of the measurements and the absence of systematic bias support the interchangeable use of values obtained from either eye in clinical practice. These findings further highlight the importance of considering environmental temperature when interpreting intraocular pressure measurements in horses. Future studies including animals from different climatic regions, breeds, and age groups would help to strengthen the generalizability of these observations and provide a more comprehensive understanding of temperature-related ocular changes.

Financial support

This study was not financially supported by any institution or organization.

Conflict of interests

The authors declare that they have no conflict of interest.

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