



## NOTE

Surgery

# Keratometry in normal cats: a cross-sectional study in Japan using an automated handheld keratometer

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**ABSTRACT.** Keratometry was performed in 73 domestic cats of varied signalment in Japan using an automated handheld keratometer. The mean corneal curvature radius was significantly lower for cats younger than 1 year than for those older than 2 years (8.04 mm vs. 8.80–8.99 mm,  $P<0.01$ ). The radius was significantly greater in males than in females among the cats older than 11 years (9.22 mm vs. 8.84 mm,  $P=0.01$ ), while the age distributions of the males and females were similar. Corneal astigmatism did not significantly differ across the gender and age groups. The predictability of the corneal curvature and astigmatism was approximately 41–43% and less than 3%, respectively, as a function of age and bodyweight. The results highlighted some age- and sex-related keratometric variations in domestic cats in Japan.

**KEY WORDS:** automated handheld keratometer, cat, corneal astigmatism, corneal curvature, keratometry

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Keratometry, or the measurement of corneal curvature, is routinely performed in human ophthalmology. It provides essential information for various clinical purposes such as the fitting of contact lenses, diagnosing keratoconus, and planning refractive surgery. These applications, especially the fitting of contact lenses for therapeutic purposes, have become increasingly popular in veterinary ophthalmology. In cats, the use of bandage contact lenses has been reported in the management of various corneal diseases [1, 7, 15, 17]. While properly fitted contact lenses are safe and effective, poorly fitted ones often result in problems such as the premature detachment of the lens and the development of corneal edema and neovascularization [1, 19]. Although keratometry is rarely utilized in veterinary clinical ophthalmology, it guides the estimation of the optimal base curve of a contact lens and facilitates the optimal fitting of contact lenses for patients.

Several studies have conducted keratometry for cats, as well as other evaluations of morphological feline corneal features such as biometry and topography [2, 3, 8, 10, 11, 21, 25]. Most of these studies involved a small number of cats that were sourced from a closed breeding colony or a research population. Therefore, their results may have limited applicability to the general domestic cat population or other particular strains of cats seen at veterinary practices.

In humans, corneal curvature measurements show significant variations among different populations and across different sexes of the same nationality and race [6, 23, 26]. This was also evident when keratometry was performed for dogs of different breeds and breed groups segregated by their body size [9, 16]. In cats, these evaluations have not been conducted. Therefore, the degree of variations among different populations, if any, remains unknown. It is expected that investigating keratometry in cats with varied signalment will help to fill the current knowledge gap.

Most of the studies involving cats were conducted under sedation. While it may be helpful to achieve an optimal corneal alignment for measurement, this necessitates the regular application of artificial tears to prevent corneal desiccation. A study involving humans has demonstrated that the application of artificial tears and measurement in the lying posture have negative effects on the accuracy of keratometry [18]. Thus, it may be desirable to perform keratometry in cats in a sitting posture and without using sedation or general anesthesia.

An automated keratometer can rapidly measure anterior corneal curvature. It is useful for the examination of human pediatric patients [13, 22] and has also been used in some studies for dogs and cats [5, 10–12, 21]. Its applicability without sedation

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or general anesthesia has been validated in dogs [5, 12], but it has not yet been evaluated in cats. The present study aimed to assess the feasibility of keratometry in awake cats using an automated handheld keratometer and to describe normative values for the radius of the anterior corneal curvature and corneal astigmatism, in a cross-section of the feline population in Japan. The keratometric values for different sexes and age groups were compared, and their associations with the age and bodyweight of cats were also evaluated.

The radii of the anterior corneal curvatures of 146 eyes of 73 privately owned cats of varied signalment were recorded. Prior to their enrolment in the study, they underwent thorough physical and ophthalmic examinations by veterinarians at the ophthalmology department at the Tottori University Veterinary Medical Center. The ophthalmic examinations included slit-lamp biomicroscopy (SL-17; Kowa, Tokyo, Japan), fluorescein staining (FLUORES Ocular Examination Test Paper 0.7 mg; AYUMI Pharmaceutical Corp., Tokyo, Japan), and applanation tonometry (Tono-Pen XL; Reichert, Depew, NY, USA). Only those who were clinically stable and free of ocular disease that could potentially affect corneal conformations in both eyes were evaluated in this study. All aspects of the study were approved by the Animal Clinical Research and Ethics Committee of Tottori University (permission No.: H29-006). Full consent was obtained from all the cat owners using printed documents before the examinations.

Keratometry was performed using HandyRef-K (Nidek, Gamagori, Japan), an automated handheld refractor keratometer. The radii of the minor (R1) and major (R2) corneal meridians were recorded for each eye; they represent the radii of the flattest and the steepest corneal curvatures, respectively. The mean corneal curvature radius (R1R2avg) was calculated as the average of these two measurements. The degree of corneal astigmatism ( $|\Delta (R1-R2)|$ ) was also calculated as the absolute difference between the radii of the minor and major corneal meridians in diopters. All the measurements were obtained by a single examiner following a previously described technique [16]. At least three consecutive measurements were obtained for each eye, and the averages of these measurements were used for statistical analysis.

The statistical analyses were performed using R version 3.4.1 (The R Foundation). At first, the measurements of the right and left eyes were compared using the Wilcoxon signed-rank test. Because there was no significant difference between these measurements, the mean keratometric value for each animal, based on the measurements from pairs of right and left eyes, was used in the subsequent analyses. The cats were then classified into two groups according to their sex (male or female). The group means and medians for the measured variables were derived for the groups and compared using the Mann-Whitney *U* test. The cats were reclassified into five groups according to their age (less than 1 year old, 1–2 years old, 3–6 years old, 7–10 years old, and 11 years old or older). The Kruskal-Wallis test was used to compare the group medians of the measured values for the various age groups. Regression analysis using a least-squares method was used to evaluate the relationships between age and the mean corneal curvature radius, bodyweight and the mean corneal curvature radius, age and the degree of corneal astigmatism, and bodyweight and the degree of corneal astigmatism. The data were expressed as group medians unless otherwise indicated. *P*-values of <0.05 were considered statistically significant.

The cats evaluated in this study included 39 males and 34 females. Mixed-breed cats accounted for 78% of the study population. There were 12 pure breeds, with a few individuals belonging to each. These included American Shorthairs, British Shorthair, Chartreux, Chinchilla, Maine Coon, Munchkin, Norwegian Forest Cat, Persians, Ragdoll, Scottish Folds, Selkirk Rex, and Siberian. The age of the cats ranged from 2 months to 18 years old (mean  $\pm$  SD: 6.9  $\pm$  5.4; median: 5.5). The bodyweight of the cats ranged from 0.8 to 7.8 kg (3.8  $\pm$  1.3; 3.6). The male cats were significantly younger but heavier than the female cats (median age: 4.0 years old vs. 8.3 years old, *P*=0.01; bodyweight: 4.1 kg vs. 3.1 kg, *P*<0.01).

The radii of the minor and major meridians, the mean corneal curvature radius, and the corneal astigmatism of the right and left eyes were not statistically different (*P*=0.2–0.3) (Table 1). The overall mean of the mean corneal curvature radius was 8.82  $\pm$  0.49 mm (median: 8.85), with a range of 6.77–9.78 mm. The mean corneal astigmatism of all cats was 1.16  $\pm$  0.83 diopters (1.00), with a range of 0.00–4.75 diopters.

The corneas of the male cats were significantly flatter than those of the female cats (*P*<0.01) (Table 2). The degrees of corneal astigmatism in the males and females were not significantly different (*P*=0.85). The cats younger than 1 year consisted of small but almost an even number of males and females (male/female=5/4). In this group of cats, the median age and the mean corneal curvature radius were lower in the males than in the females (Table 3). The differences in these variables across the sexes were not statistically significant (*P*=0.28 and 0.29). The mean corneal curvature radius of the cats in this age group was significantly lower than those of the other age groups (8.04 mm vs. 8.80–8.99 mm, *P*<0.01). The mean corneal curvature radius of the cats aged 11 years or older was significantly greater in males than in females (9.22 mm vs 8.84 mm, *P*=0.01), while the median age of the cats did not differ with sex (13.0 years vs 14.0 years, *P*=0.38) (Table 3). The corneal curvature radii for the four age groups that had cats older than 1 year were not different (*P*=1.0). The degrees of corneal astigmatism in the age groups were also not different (0.69–1.38 D, *P*=0.43).

The overall relationship between age and the mean corneal curvature is shown in Fig. 1. In general, the mean corneal curvature radius was best fitted with a logarithmic curve. The general formula obtained in this study to predict the mean corneal curvature radius of the cats of different ages was as follows:  $R1R2avg=A * \ln (X) + B$ , where R1R2avg is the mean radius of the corneal curvature in mm, X is the age of a cat in years, and A and B are constants. For the overall population, A and B were determined as 0.2721 and 8.4137, respectively. The predictability of the mean corneal curvature radius obtained with this formula was approximately 43% ( $R^2=0.43$ ). The scatter plot revealed that the mean corneal curvature radius of the adult male cats was generally greater than that of the adult female cats (Fig. 1A). This trend was observed among the cats aged 1.3 years or older according to the regression curves drawn separately for male and female cats.

Higher predictability was achieved when the curve was fitted for the population of cats younger than 3 years ( $R^2=0.72$ ) (Fig. 1B). The predictive formula for this population was defined with the following constants: A=0.605 and B=8.4458. The formula

**Table 1.** Keratometric values for both eyes in 73 cats

Eye	Mean ± SD			Median (minimum, maximum)		
	Right	Left	Combined	Right	Left	Combined
R1 (mm)	8.94 ± 0.54	8.97 ± 0.52	8.95 ± 0.53	8.95 (6.82, 10.17)	9.00 (7.20, 10.31)	8.98 (6.82, 10.31)
R2 (mm)	8.66 ± 0.48	8.69 ± 0.44	8.68 ± 0.46	8.73 (6.72, 9.43)	8.74 (6.93, 9.57)	8.74 (6.72, 9.57)
R1R2avg (mm)	8.80 ± 0.50	8.83 ± 0.47	8.82 ± 0.49	8.83 (6.77, 9.70)	8.86 (7.07, 9.78)	8.85 (6.77, 9.78)
Δ (R1–R2)  (D)	1.19 ± 0.85	1.14 ± 0.82	1.16 ± 0.83	1.00 (0.00, 4.75)	1.00 (0.00, 4.25)	1.00 (0.00, 4.75)

R1=radius of the minor corneal meridian; R2=radius of the major corneal meridian; R1R2avg=mean of R1 and R2; |Δ (R1–R2)|=absolute difference between R1 and R2 in diopters.

**Table 2.** Keratometric values of 73 cats segregated by sex (male: n=39; female: n=34)

	Mean ± SD		Median (minimum, maximum)	
	Male	Female	Male	Female
R1 (mm)	9.01 ± 0.58	8.88 ± 0.45	9.03 (7.01, 9.86)	8.82 (7.91, 10.15) <sup>a</sup>
R2 (mm)	8.74 ± 0.52	8.61 ± 0.34	8.88 (6.83, 9.24)	8.59 (7.83, 9.43) <sup>a</sup>
R1R2avg (mm)	8.88 ± 0.54	8.75 ± 0.39	8.96 (6.92, 9.52)	8.68 (7.87, 9.71) <sup>a</sup>
Δ (R1–R2)  (D)	1.16 ± 0.73	1.17 ± 0.67	1.00 (0.00, 3.50)	1.00 (0.38, 3.13)

R1=radius of the minor corneal meridian; R2=radius of the major corneal meridian; R1R2avg=mean of R1 and R2; |Δ (R1–R2)|=absolute difference between R1 and R2 in diopters. <sup>a</sup>  $P < 0.01$  when compared between male and female cats.

**Table 3.** Age and the mean corneal curvature radius of 73 cats segregated by age and sex

	N (cats)	Age (years)		R1R2avg (mm)	
	Male/Female	Male	Female	Male	Female
<1 year old	5/4	0.4 (0.2, 0.9)	0.5 (0.4, 0.5)	7.86 (6.92, 8.80)	8.28 (7.87, 8.44)
1–2 years old	9/5	2.0 (1.2, 2.5)	2.8 (1.5, 2.9) <sup>a</sup>	8.89 (8.61, 9.49)	8.64 (8.23, 8.80) <sup>a</sup>
3–6 years old	11/7	4.7 (3.0, 6.2)	6.2 (3.0, 6.9) <sup>a</sup>	8.91 (8.60, 9.39)	8.76 (8.40, 9.54)
7–10 years old	6/7	9.3 (7.3, 10.3)	10.0 (9.7, 10.8) <sup>a</sup>	9.10 (8.81, 9.29)	8.75 (8.64, 9.56)
≥11 years old	8/11	13.0 (11.2, 17.0)	14.0 (11.2, 18.0)	9.22 (8.84, 9.52)	8.84 (8.50, 9.71) <sup>a</sup>

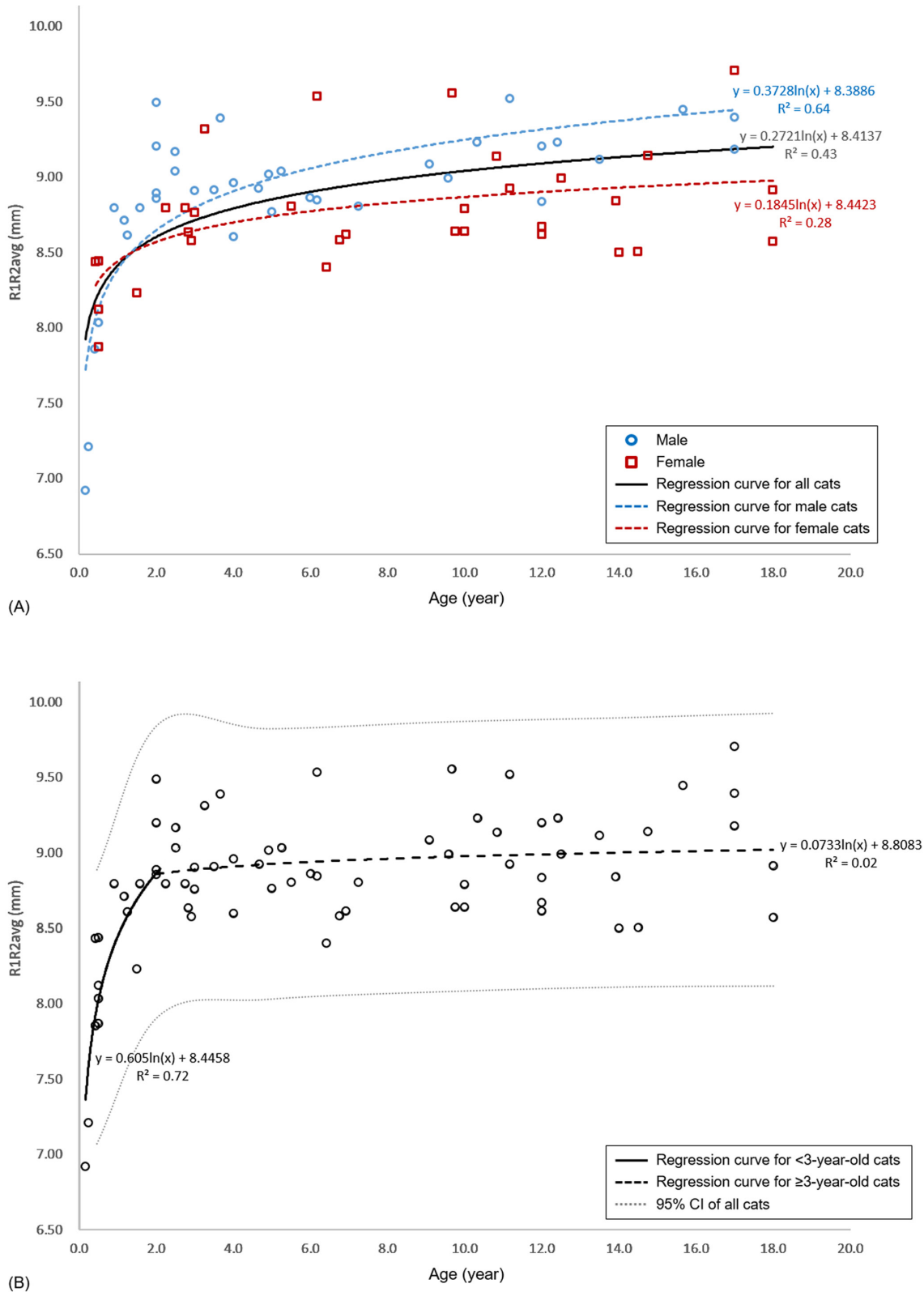
N=number of cats examined; R1R2avg=mean radius of the corneal curvature. Data are expressed as median and figures in brackets indicate minimum and maximum values, where applicable. <sup>a</sup>  $P < 0.05$  and <sup>a</sup>  $P < 0.01$  when compared between male and female cats.

for the population of cats older than 3 years used the following constants:  $A=0.0733$  and  $B=8.8083$ . However, the coefficient of determination of this formula was very low ( $R^2=0.02$ ), indicating that the mean corneal curvature radius cannot be predicted reliably in this group of cats due to a relatively high variation among individuals. Nonetheless, the predicted mean corneal curvature radius of the adult cats reached a plateau of 9.0 mm at the age of 7 years and for up to 20 years, based on this formula.

Figure 2 shows the relationship between bodyweight and mean corneal curvature radius, which was also best fitted with a logarithmic curve. The mean corneal curvature radius of the cats was predicted using the following formula as a function of bodyweight:  $R1R2avg=A * \ln(X) + B$ , where R1R2avg is the mean corneal curvature radius in mm, X is the bodyweight of a cat in kg, and A and B are constants. For the overall population, A and B were determined as 0.8414 and 7.7393, respectively. The predictability of the mean corneal curvature radius using this formula was approximately 41% ( $R^2=0.41$ ). The general trend observed on the scatter plot was not different for males and females.

The overall relationship between age and the degree of corneal astigmatism is shown in Fig. 3. In general, corneal astigmatism fitted poorly with any line or curve, indicating low predictability as a function of both age and bodyweight ( $R^2=0.03$  and 0.01). The scatter plot did not reveal different trends for male and female cats.

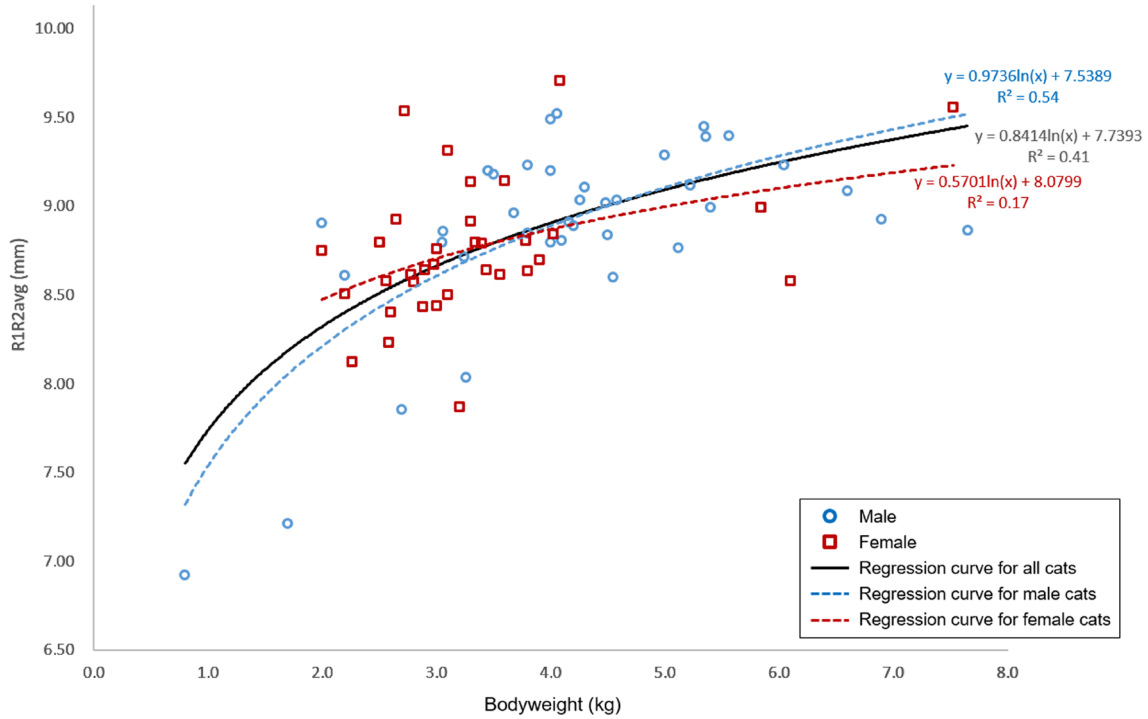
This study documented the radius of the anterior corneal curvature and corneal astigmatism in a cross-section of the normal domestic cats in Japan. The measurements were obtained successfully for both the right and left eyes of all cats enrolled in the study. The keratometry was well-tolerated by all cats. A close agreement between the measurement for the pairs of right and left eyes in this study was consistent with previous findings [3, 8, 10, 11, 21]. The result indicated that keratometry was feasible in awake cats regardless of their age using the automated handheld keratometer. This is especially important when considering the clinical application of keratometry, as not all feline patients are good candidates for sedation or general anesthesia depending on their general health condition. Additional studies may be designed to validate the accuracy of the measurement of the feline cornea using the medical device, thus further increasing its value in feline keratometry. Nonetheless, the major advantages of the device used in this study include its ability to rapidly and consecutively record multiple measurements without direct contact with the corneal surface and to measure multiple variables at a time. This includes both the minor and major corneal curvatures and corneal astigmatism. These features minimize the stress exerted on cats and the risks of compression artifacts as well as the spread of



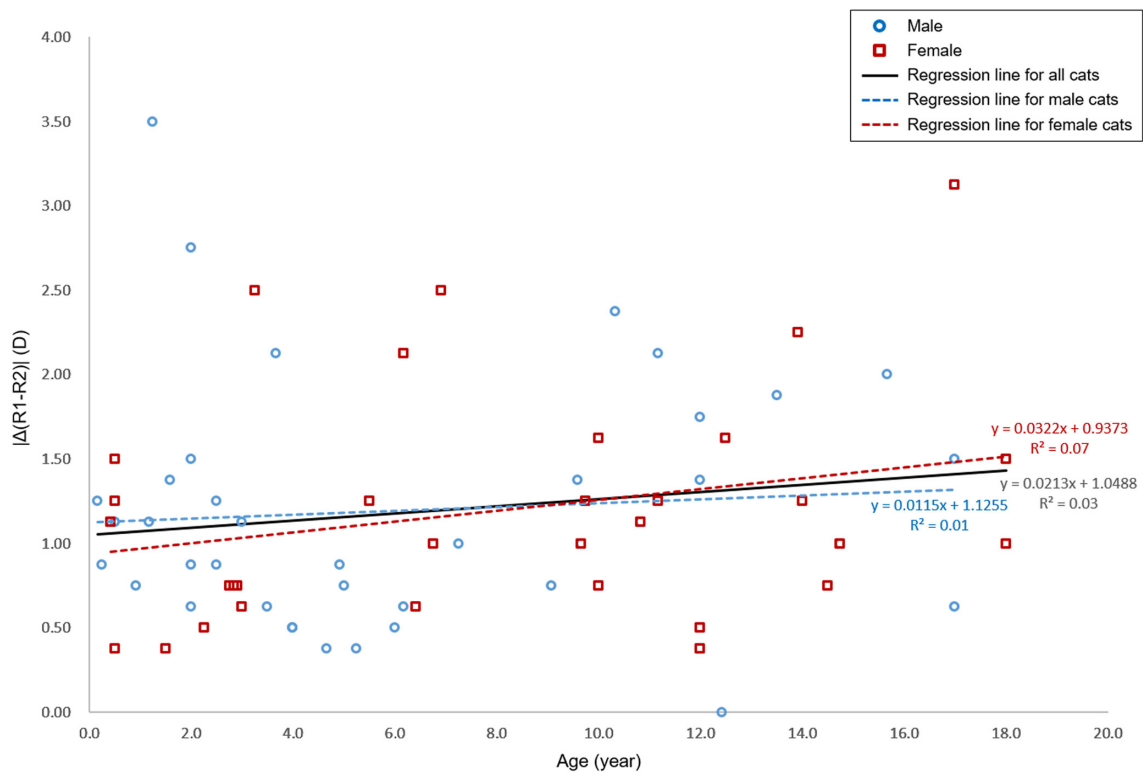
**Fig. 1.** Mean corneal curvature radius (R1R2avg) of 73 cats as a function of age. The regression curves are fitted to the data segregated by sex (A) and age (B). The 95% confidence intervals are calculated based on the regression curves.

infections that can result from the direct corneal contact during the measurement.

The mean corneal curvature radius in cats aged 1 year or older in this study was generally greater than the value reported previously for adult cats and obtained using manual or automated keratometers and a Scheimpflug system (between 8.58 and 8.79 mm) [3, 8, 10,



**Fig. 2.** Mean corneal curvature radius (R1R2avg) of 73 cats as a function of bodyweight. The regression curves are fitted to the data segregated by sex.



**Fig. 3.** Degrees of corneal astigmatism ( $|\Delta(R1-R2)|$ ) of 73 cats as a function of age. The regression lines are fitted to the data segregated by sex.

11, 21, 25]. The only study that reported a relatively high value of 9.13 mm used a photokeratoscope [2]. The inconsistent results of these studies may have been related to the differences in cat signalment such as breed, sex, or age. While the domestic shorthair was the most common breed evaluated in the previous studies, the age and sex of the cats were not specified. Therefore, the results cannot be compared in this regard. The results may also have been influenced by the differences in the measuring technique or the device used [4, 14, 20, 24]. Further studies are needed to investigate the factors that potentially affect the results of keratometry.

The present study found that the mean corneal curvature radius increased logarithmically with time in young cats aged less than 3 years and reached a plateau later in their life. The trend was similar to that described by Freeman and Moodie [8, 21]. They independently suggested a formula to predict the corneal curvatures of young cats as a function of age based on the examination of kittens aged less than 35 weeks old and up to 67 weeks old, respectively. The predicted values according to their formulas were similar, yet they tended to be lower and reached a plateau at a younger age than that predicted by our formula. This may be attributed to the generally flatter cornea of the cats in this study than those in previous studies, regardless of their age. Previously, it was suggested that the development of the feline cornea continues until approximately 18 months of age [21]. However, the result of this study suggests that the corneas of cats continue to develop or change shape until a much older age, although the extent of changes observed in adult cats is far lower than that in young cats.

Additionally, the present study documented a paradoxically greater mean corneal curvature radius in male cats than in female cats when the median age of the male cats tended to be lesser than that of the female cats. This trend was consistently observed across all age groups of cats older than 1 year. This study was not designed to take age-matched samples from different sexes. This limitation may have affected the ability to make reasonable comparisons of the groups. Nevertheless, the result would provide an important implication for further investigations by potentially highlighting a previously undescribed feature of the feline cornea. The corneas of male cats are generally flatter than those of female cats when they get older than 1 year of age and especially in those aged 11 years or older. Interestingly, while the trend is inconsistent with the feature described in dogs [5, 9], it aligned with the feature described in humans [6, 26]. This study involved a limited number of pure-breed cats. Therefore, the breed-related differences were not considered in this study although they could have also influenced the results. Further studies involving a wider range of age-matched cats, with more pure-breeds, are required to validate these findings.

The degrees of corneal astigmatism of the cats evaluated in this study were generally greater than those of the adult cats reported in most studies (between 0.3 and 0.6 diopters) [2, 3, 10, 11]. The use of different measuring techniques may have influenced the result. Previous studies determined corneal astigmatism based on the difference between the corneal curvatures measured along the vertical and horizontal axes [3, 8, 10, 11, 21, 25]. Our study based the degree of astigmatism on the difference between the flattest and steepest corneal axes, which were not necessarily the vertical and horizontal axes. Thus, a larger value was expected in this study. The present results may be more accurate than the previous findings. Earlier studies also reported a decreasing trend in the degree of corneal astigmatism from less than 4 diopters in young kittens to less than 1 diopter in adult cats [8, 21]. However, this trend was not observed in this study; an increasing trend was rather observed with increasing age. Detailed studies on the axis of corneal astigmatism will be of value in explaining these differences.

In conclusion, this is the first cross-sectional study on keratometry for the domestic cat population in Japan. An automated handheld keratometer is a useful tool for rapidly performing keratometry in awake cats. The keratometric values obtained in this study were generally greater than those in previous reports, suggesting that there may be some variations related to cat signalment. The limitations associated with the study design leave room for further studies to validate the results. These include the evaluation of the possible inter-operator variability when multiple operators were involved in examinations. Nonetheless, the present data will be valuable contributions to the current clinical and scientific knowledge of feline keratometry. Variations in the mean corneal curvature among different cat populations have important implications for making appropriate clinical decisions for each patient, especially when therapeutic interventions are considered for various corneal diseases.

CONFLICT OF INTEREST. The authors have nothing to disclose

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