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ORIGINAL RESEARCH

Characterising keratometry in different dog breeds using an automatic handheld keratometer

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Abstract

Background Keratometry is clinically important and is routinely performed as part of human ophthalmic examination. In veterinary ophthalmology, little is known about keratometry in dogs, and its practical application has been limited. The present study aimed to describe keratometry in some dog breeds popular in Japan using a handheld keratometer.

Methods Client-owned dogs of various signalment were enrolled prospectively in the keratometry examination. Interbreed variations in mean corneal curvatures (R1R2avg) and corneal astigmatism (Δ(R1–R2)) were evaluated statistically with respect to their bodyweight based on the data which fulfilled the predetermined inclusion criteria. $P<0.05$ was considered statistically significant.

Results On examination of 237 dogs from 16 different breeds, R1R2avg (mean±sd) ranged from 7.54±0.30 mm in Pomeranians to 9.28±0.19 mm in golden retrievers. Δ(R1–R2) (mean±sd) ranged from 0.22±0.11 mm in miniature schnauzers to 0.57±0.30 mm in French bulldogs.

Conclusion The present study successfully described keratometry in 16 dog breeds. The study revealed considerable interbreed variations in both R1R2avg and Δ(R1–R2), which did not necessarily correlate with bodyweight. These results are useful both clinically in fitting contact lenses in the management of corneal diseases and non-clinically in optometric studies in dogs.

Introduction

Keratometry is defined as the measurement of corneal curvature, which determines the power of the cornea and astigmatism.[1 2] It is an essential part of ophthalmic examinations and is routinely performed to evaluate the refractive functions of the cornea in human ophthalmology. The values of the mean corneal curvature are referred to in various clinical settings. For instance, it is mainly used in fitting contact lenses, determining intraocular lens power, and evaluating corneal astigmatism in association with various corneal refractive surgeries during the perioperative period.[2–5] Keratometry plays an important role in providing individually tailored therapeutic interventions for quality management of vision.

Nevertheless, keratometry remains uncommon in veterinary ophthalmology, and the practical application of keratometry in animals has been limited. From a clinical perspective, there has been an increasing interest in medical and surgical interventions which modify or alter the refractivity of the cornea in animals. For example, fitting of a contact lens has been reported to correct aphakia in a dog[6] and to provide support to the corneal surface during treatment of various corneal diseases such as spontaneous chronic corneal epithelial defects in dogs, corneal sequestrum in cats and corneal ulcers in horses.[7–16] Cataract extraction surgeries, which potentially create corneal astigmatism, have become increasingly popular especially in dogs and horses over the past few decades.[17] Keratometry in veterinary patients is expected to provide veterinarians valuable information to further optimise therapeutic interventions offered to individual patients. Keratometry

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would be especially valuable in dogs due to the large morphological variations between breeds.

Several studies have documented keratometry in animals using various instruments. These studies examined dogs and cats, as well as several other species.[1 18–28] The instruments used in these studies included ultrasonography devices, photokeratometers and Scheimpflug keratometers. In these studies, animals, especially dogs and cats, were often placed under sedation or general anaesthesia to improve the accuracy of measurements. More recently, three studies reported the results of keratometry in dogs and cats using automatic handheld keratometers.[21 25 29] One of the major advantages of this type of device is its ability to measure corneal curvatures rapidly within a few seconds.[2 30–32] It has proven useful in human paediatric and elderly patients who have difficulties in maintaining visual fixation when sitting upright.[30 31 33 34] Gorig *et al* evaluated the applicability of automatic handheld keratometers in awake dogs and demonstrated that the measurements obtained awake and under sedation or general anaesthesia were comparable.[29] This result was encouraging and has led to such keratometers gaining popularity in the field of veterinary ophthalmology.

Although some data have been published regarding keratometry in dogs, details of keratometry in different breeds have not yet been reported. The breeds covered in previous studies were limited, with relatively small sample sizes of miniature breeds, which are more commonly seen in Japan. Hence, little is known about the normal values of corneal curvatures in dogs of various breeds, particularly measurements obtained when awake using an automatic handheld keratometer. Therefore, the present study aimed to describe the reference values for breed-specific corneal curvature and corneal astigmatism in some dog breeds popular in Japan. Additionally, the study evaluated interbreed and intrabreed variations in the mean corneal curvature and the degree of corneal astigmatism observed in dogs of various age and bodyweight (BW).

Materials and methods

Animals

Client-owned dogs of various breeds, sex and age presented to the Tottori University Veterinary Medical Center (TUVMC) between April 2017 and December 2018 were included in the study. The dogs were first evaluated for their eligibility for enrolment in the study according to the following inclusion criteria:

1. General health conditions and characteristics: the dog was clinically stable and could tolerate manual restraint of the head for thorough ophthalmic and keratometry examinations without sedation or general anaesthesia.
2. Age: the dog was aged 10 months or older.
3. Ocular health: the dog had no ocular or periorbital diseases which could potentially affect ocular morphology or corneal conformations of both eyes at the time of examination. Such diseases included, but were not limited to, corneal diseases such as corneal ulcers and oedema; glaucoma; and ocular, retrobulbar or periorbital neoplasia.

Dogs that met all of these criteria at the time of presentation underwent keratometry examination prospectively.

Instrument

An automatic handheld refractor keratometer, HandyRef-K (Nidek), was used to perform the keratometry examinations. The instrument measures the corneal curvature of the central 3-mm to 4-mm diameter according to the size and shape of the mire ring image reflected on the anterior surface of the cornea. It automatically takes multiple readings consecutively and provides measurements of both the minor (R1) and major (R2) meridians, as well as the mean of the two meridians (R1R2avg). It also generates a 'representative value' for each of these parameters from the set of consecutive readings accumulated within the device for each measurement session. These values are automatically drawn by the device according to the functions preset by the manufacturer. For the purpose of this study, the instrument was set to accumulate a maximum of 10 consecutive readings in each session. The measurements were expressed in millimetres, and the scale interval was set to 0.01 mm.

Procedures

The dogs were positioned either in sternal recumbency or sitting position on an examination table. The head of the dog was manually held upright so that the muzzle pointed forward and was parallel to the floor. The instrument was held in front of the eye so that the centre of the eye matched the centre of the reference ring image displayed on the device screen. The measurement was taken repeatedly to obtain at least three readings and up to 10 stable readings on each eye, depending on how tolerant the dog was of the examination. Keratometry was performed on both eyes one after another in a single session. All measurements were performed by a single operator to eliminate interoperator variability.

Data analysis

To facilitate statistical analyses, the data obtained were entered into a Microsoft Excel 2013 spreadsheet (Microsoft). First, the data were evaluated for their suitability for inclusion in the statistical analyses according to the following criteria:

4. Reliable measurement: both the right and left eyes were measured successfully, and the difference in the R1R2avg between the right and left eyes was less than 4.5 per cent.
5. Sample size sufficient for statistical examination: data from more than five individuals per breed were available when the dogs were classified by breeds.

The data which did not satisfy either or both of these criteria were excluded from statistical analyses described in the next paragraph. Criterion 4 was set to assure the reliability of measurements by comparing

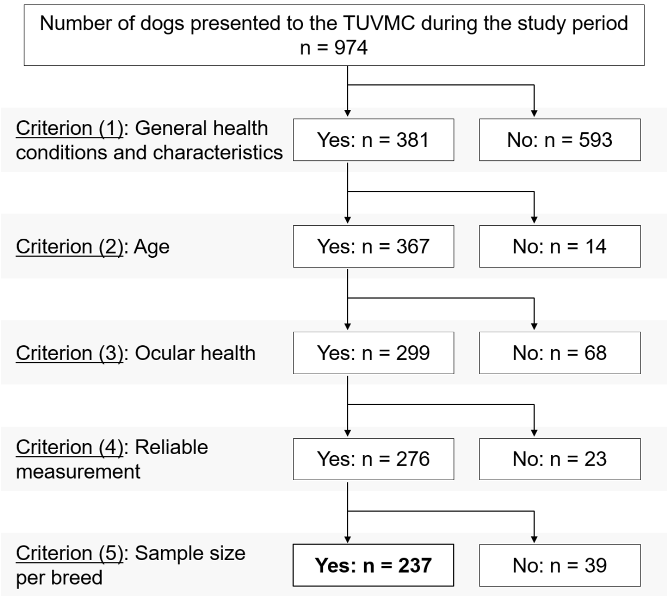

Figure 1 The algorithm for the inclusion and exclusion of dogs. The inclusion criteria were as follows: (1) the dog was clinically stable and could tolerate manual restraint of the head for thorough ophthalmic and keratometry examinations without sedation or general anaesthesia; (2) the dog was aged 10 months or older; (3) the dog had no ocular or periorbital diseases which could potentially affect ocular morphology or corneal conformations of both eyes; (4) both the right and left eyes were measured successfully and the difference in R1R2avg between the right and left eyes was less than 4.5 per cent; and (5) data from more than five individuals per breed were available when the dogs were classified by breeds. R1R2avg, mean of R1 (radius of the minor meridian) and R2 (radius of the major meridian); TUVMC, Tottori University Veterinary Medical Center.

between the eyes of the same individual. It was assumed that the normal corneas of a healthy dog would yield similar keratometry readings between the right and left eyes, as reported previously.[22 23] A difference greater than 4.5 per cent between the eyes of an individual dog was considered a measurement error attributable to the dog, such as failure of visual fixation and existence of non-diagnosed or subclinical ocular pathologies. A threshold of 4.5 per cent was set based on the results of a preliminary study which evaluated intraoperator variability using extracted porcine globes. Criterion 5 was set to allow statistical analyses of the data classified by breeds.

Statistical analyses were conducted using the free software R V.3.4.1 (The R Foundation). The autogenerated representative values of R1, R2 and R1R2avg in each session were used in all statistical analyses. The data were expressed as group mean±sd, unless otherwise indicated. For all tests mentioned in the next paragraph, where applicable, $P<0.05$ was considered statistically significant.

First, the mean R1, R2 and R1R2avg were calculated for each breed. The difference between R1 and R2, or Δ(R1–R2), was also calculated for each breed to evaluate the degree of corneal astigmatism. Interbreed variations in age, BW, R1R2avg and Δ(R1–R2) were evaluated using Kruskal-Wallis tests. Pairwise comparisons using Bonferroni tests were further conducted to identify breed pairs with statistically significant differences between measurements when $P<0.05$ was noted on Kruskal-Wallis tests. Spearman's correlation coefficient was calculated between R1R2avg and age, BW, and Δ(R1–R2) for all data, regardless of the breed. Additionally, intrabreed variations in R1R2avg were evaluated for breeds with more than 10 dogs enrolled in the study. Spearman's correlation coefficient was calculated for each of these breeds between R1R2avg and age, BW, and Δ(R1–R2).

Results

Of the 974 dogs presented to the TUVMC during the study period, 381 were considered potential candidates for the study after they were evaluated according to criterion 1. Further screening of the dogs in terms of criteria 2 and 3 resulted in an enrolment of 299 dogs for keratometry examination. With regard to criterion 4, all these dogs were successful in providing measurements of both eyes. However, 23 dogs were excluded from the statistical analysis because the difference in R1R2avg between the right and left eyes was greater than 4.5 per cent (mean±sd: 7.1±1.9 per cent; range: 4.5–11.9). Finally, evaluation according to criterion 5 resulted in an exclusion of 39 dogs from 16 different breeds. This left a total of 474 corneas from 237 dogs (117 males and 120 females) of 16 different breeds for analysis. The algorithm for the inclusion and exclusion of dogs and the number of dogs which met or did not meet the criteria are shown in figure 1. Overall mean (±sd) age and BW of the dogs ranged from 0.8 to 16.9 (8.3±3.9) years old and from 1.2 to 45.0 (8.5±7.9) kg, respectively.

Table 1 summarises the descriptive statistics of signalment, BW and keratometry of the 16 different breeds examined. The breed-specific mean of R1R2avg ranged from as small as 7.54±0.30 mm in Pomeranians to as large as 9.28±0.19 mm in golden retrievers. Δ(R1–R2) ranged from 0.22±0.11 mm in miniature schnauzers to 0.57±0.30 mm in French bulldogs. Interbreed variations in age, BW, R1R2avg and Δ(R1–R2) evaluated using Kruskal-Wallis tests revealed $P<0.01$ for all variables. On further analysis using Bonferroni tests, significant differences in age were mostly identified when the breeds were compared against miniature dachshunds and miniature schnauzers (table 1). Breed pairs identified to have significant differences in BW and R1R2avg following Bonferroni tests are summarised in table 2. The results revealed that shih tzus and French bulldogs had an R1R2avg value similar to those of some other breeds with significantly heavier BWs ($P<0.05$). Shiba inus and Shetland sheepdogs were characterised by an R1R2avg value close to the breeds which weighed significantly less ($P<0.05$). With regard to Δ(R1–R2), French bulldogs had the largest value among all of the breeds evaluated, and a statistically significant difference was present when compared with six other breeds, as shown in table 1. On evaluating the overall relationship between R1R2avg and BW, Spearman's correlation coefficient revealed a relatively strong positive correlation between these two variables

Table 1 Descriptive summary of signalment, BW and keratometry of the dogs enrolled in the study, according to breed

Breed	n (dogs)	Sex (male/female)	Age (years)	BW (kg)	R1 (mm)	R2 (mm)	R1R2avg (mm)	Δ(R1–R2) (mm)
Chihuahuas	26	17/9	8.2±4.1	3.2±1.0	8.06±0.34	7.66±0.33	7.86±0.32	0.41±0.21
Yorkshire terriers	10	6/4	9.3±2.2	3.4±0.8	7.89±0.55	7.57±0.46	7.73±0.49	0.33±0.23
Pomeranians	6	2/4	7.1±4.9	3.5±1.2	7.70±0.40	7.38±0.23	7.54±0.30	0.32±0.27
Toy poodles	44	21/23	6.6±3.8*†	4.1±1.6	7.99±0.38	7.68±0.39	7.84±0.38	0.31±0.21‡
Miniature pinschers	5	4/1	9.4±4.3	4.5±1.2	7.98±0.25	7.63±0.23	7.81±0.23	0.34±0.10
Shih tzus	7	3/4	5.8±3.1*†	5.5±0.6	9.20±0.48	8.68±0.40	8.94±0.43	0.52±0.24
Italian greyhounds	7	2/5	9.0±2.9	5.6±0.6	8.44±0.35	8.16±0.39	8.30±0.36	0.28±0.18
Miniature dachshunds	51	27/24	10.5±3.2	6.1±1.9	8.73±0.39	8.41±0.34	8.58±0.34	0.32±0.25‡
Miniature schnauzers	5	4/1	11.6±2.1	8.5±1.5	8.56±0.31	8.34±0.28	8.45±0.29	0.22±0.11‡
French bulldogs	9	1/8	7.0±3.4*	9.3±2.2	9.56±0.45	9.00±0.38	9.28±0.39	0.57±0.30
Beagles	13	6/7	5.9±4.1*	9.7±2.2	9.01±0.31	8.75±0.35	8.88±0.33	0.26±0.11‡
Shiba inus	16	10/6	6.7±3.4*†	9.8±2.0	8.32±0.48	7.93±0.39	8.13±0.40	0.39±0.36
Welsh corgis	9	2/7	8.1±3.2	10.8±1.8	8.87±0.27	8.59±0.30	8.73±0.28	0.28±0.16‡
Shetland sheepdogs	5	0/5	10.1±3.0	12.0±1.7	8.34±0.16	8.03±0.08	8.19±0.09	0.32±0.17
Labrador retrievers	16	6/10	8.4±4.1	29.0±6.5	9.34±0.24	9.04±0.21	9.19±0.21	0.30±0.15‡
Golden retrievers	8	6/2	10.3±3.1	30.3±7.0	9.45±0.24	9.12±0.17	9.28±0.19	0.33±0.15

Breeds are listed in order of increasing mean BW.
Data are expressed as mean±sd, where applicable.
*P<0.05 when compared with the mean age of miniature dachshunds (Bonferroni test).
†P<0.05 when compared with the mean age of miniature schnauzers (Bonferroni test).
‡P<0.05 when compared with the mean Δ(R1–R2) of French bulldogs (Bonferroni test).
BW, bodyweight; R1, radius of the minor meridian; R2, radius of the major meridian; Δ(R1–R2), difference between R1 and R2; R1R2avg, mean of R1 and R2.

(r=0.72, P<0.01) (figure 2A). However, both age and Δ(R1–R2) were poorly correlated with R1R2avg (r=0.18, P<0.01; r=0.08, P=0.09) (figure 2B,C).

Intrabreed variations between R1R2avg and BW and between R1R2avg and age were analysed in the following seven breeds: chihuahuas, Yorkshire terriers, toy poodles, miniature dachshunds, beagles, shiba inus and labrador retrievers. Spearman's correlation coefficient calculated for R1R2avg and BW, as shown in figure 3, revealed a relatively strong positive correlation in beagles (r=0.81, P<0.01), mild-to-moderate positive correlations in toy poodles and shiba inus (r=0.64, P<0.01; r=0.61, P<0.01), and a weak positive correlation in miniature dachshunds (r=0.38, P<0.01). No or little correlations were found in the other three breeds. Evaluations between R1R2avg and age only identified weak to very weak positive correlations in labrador retrievers and miniature dachshunds (r=0.39, P=0.03; r=0.33, P<0.01). Shiba inus was the only breed which was identified to have a weak positive correlation between R1R2avg and Δ(R1–R2) (r=0.43, P=0.02). The rest of the breeds had no or little correlations between these variables.

Discussion

The present study revealed considerable interbreed variations in R1R2avg among the 16 studied breeds. Generally, R1R2avg showed a tendency to increase as the size of the dog increased, but no such trend was identified between R1R2avg and age, or between R1R2avg and Δ(R1–R2). In other words, the shape of the cornea tended to be significantly rounder in smaller dogs and flatter in larger dogs. Ageing and the degree of corneal astigmatism were not necessarily correlated with the changes in corneal shape in dogs. This result was comparable with the trend reported by Gaiddon *et al*[22], who compared measurements among small, medium and large dogs (8.09, 8.30 and 9.03 mm, respectively). However, a closer examination of R1R2avg according to breed showed that some breeds did not follow this trend. Shiba inus and Shetland sheepdogs were characterised by smaller corneal curvatures than were other similarly weighing breeds such as beagles and Welsh corgis. Shih tzus and French bulldogs, in contrast, were found to have larger corneal curvatures comparable with those of labrador retrievers and golden retrievers. This result has important implications in the clinical setting, particularly when contact lenses are prescribed to dogs of various breeds for therapeutic purposes.

Similarly, this study found varying degrees of corneal astigmatism among the dog breeds examined, with statistically significant differences identified between French bulldogs and six other breeds. The results indicated that the shape of the cornea of dogs varies significantly depending on breeds, from the cornea being ovoid to some degree as in French bulldogs to that being more spherical as in miniature schnauzers and beagles, for example. Some previous studies reported that mild astigmatism was common in dogs based on keratometry examinations,[22] while others reported it being relatively uncommon based on retinoscopy examinations.[35 36] It is important to remember that corneal astigmatism noted with keratometry is based only on measurements of the anterior corneal curvature. It does not account for the effects of other structures such as the posterior corneal curvature, the lens and the axial length of the

Table 2 Results of pairwise comparisons between the studied breeds using Bonferroni test with respect to BW and R1R2avg

Breed	Chihuahuas	Yorkshire terriers	Pomeranians	Toy poodles	Miniature pinschers	Shih tzus	Italian greyhounds	Miniature dachshunds	Miniature schnauzers	French bulldogs	Beagles	Shiba inus	Welsh corgis	Shetland sheepdogs	Labrador retrievers	Golden retrievers
Chihuahuas	–															
Yorkshire terriers		–														
Pomeranians			–													
Toy poodles				–												
Miniature pinschers					–											
Shih tzus	◎	◎	◎	◎	●	–										
Italian greyhounds	◎	○	●	◎		●	–									
Miniature dachshunds	◎	◎	◎	◎	●			–								
Miniature schnauzers	◎	○	◎	◎		○	○		–							
French bulldogs	◎	◎	◎	◎	◎	○	◎	◎	●	–						
Beagles	◎	◎	◎	◎	◎	○	◎	◎			–					
Shiba inus	◎	○	◎	◎	○	◎	○	◎		●	●	–				
Welsh corgis	◎	◎	◎	◎	◎	○	○	○		●		●	–			
Shetland sheepdogs	○	○	◎	○	○	◎	○	◎		●	●		●	–		
Labrador retrievers	◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	◎	◎	◎	–	
Golden retrievers	◎	◎	◎	◎	◎	○	◎	◎	◎	○	◎	◎	◎	◎		–

Breeds are listed in order of increasing mean BW.
Breed pairs with statistically significant differences in either or both variables are shown.
◎ = P<0.05 in both BW and R1R2avg; ○ =P<0.05 in BW only (no significant differences in R1R2avg); ◎, P<0.05 in both BW and R1R2avg.
BW, bodyweight; R1, radius of the minor meridian; R2, radius of the major meridian; R1R2avg, mean of R1 and R2.

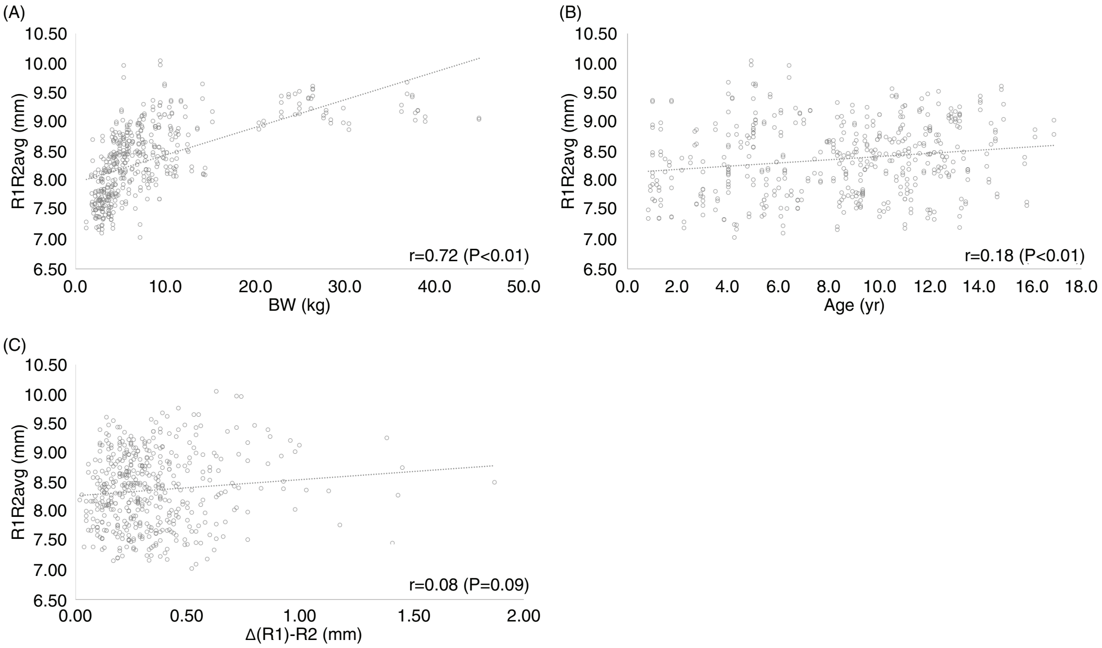

Figure 2 Scatter plots with a linear regression line showing the relationships (a) between BW and R1R2avg, (b) between age and R1R2avg, and (c) between Δ(R1−R2) and R1R2avg of all dogs enrolled in the study (N=237). Δ(R1−R2), difference between R1 and R2; BW, bodyweight; R1, radius of the minor meridian; R2, radius of the major meridian; R1R2avg, mean of R1 and R2.

eye on visual consequences. Recent studies in human beings revealed that the posterior corneal curvature effectively reduces total corneal astigmatism, partially compensating for anterior corneal astigmatism.[37] In dogs, it is quite possible that the posterior corneal curvature, together with other morphological and structural variations reported in the face and the retina,[38–40] may also vary between breeds, minimising the impact of interbreed variations noted in the anterior corneal curvature on vision. However, none of the previous studies has particularly evaluated French bulldogs to prove that this breed is not an exception. The finding in this study using a device that employs the mire ring principle is novel and could provide a new perspective for future optometric studies in dogs by describing reference values for anterior corneal astigmatism specific to some breeds.

Another point worth mentioning is that the correlation between R1R2avg and BW of dogs of the same breed was inconsistent depending on the breed, while a relatively strong positive correlation was found when these were compared across breeds. Among the seven different breeds evaluated in the present study, good intrabreed correlation was found in beagles, shiba inus and toy poodles, but not in chihuahuas, Yorkshire terriers, miniature dachshunds and labrador retrievers. This result could partly be related to the body condition score of the dogs enrolled in the study. Usui *et al*[41] reported that miniature dachshunds and chihuahuas were the top 2 breeds with the highest prevalence of obesity among many other dog breeds seen in private veterinary clinics in Japan.[41] Other factors such as lifestyle and social status of the owners, as well as the genetics of dogs, could have also contributed to the result. However, their impact could not be clearly determined in this study owing to the small sample size for each breed and due to limited information, including lack of information on body condition score of the studied dogs, for extensive evaluations, thus necessitating further investigations.

One of the major limitations of this study is the possible measurement errors associated with the use of a handheld device on awake dogs. These errors were attributable either to the operator due to instability of the hand holding the device or to the dogs due to poor vision fixation or headshaking due to, for example, panting. While such errors were difficult to completely eliminate, the reliability of the measurements taken in this study was maximised by employing the following measures. First, all measurements were obtained by a single trained operator (MK) to eliminate possible interoperator variability. IIntraoperator variability of the data obtained by this operator was minimised by conducting training sessions before the start of the study and was validated to be less than 4.5 per cent based on a preliminary study using extracted porcine globes. Secondly, criterion 4 was set to eliminate data which fall outside the range explained by intraoperator variability. It was considered that the data which did not meet criterion 4 might have been affected by poor animal cooperation. In the present study, all dogs which underwent keratometry examination successfully provided measurements of both eyes, while the threshold of 4.5 per cent resulted in the removal of approximately 8 per cent of dogs from further analyses. Although animal cooperation could become a source of measurement errors, a validity of over 90 per cent was achieved on the data taken from awake dogs, suggesting that animal cooperation was not a major constraint to obtaining reasonably reliable measurements when

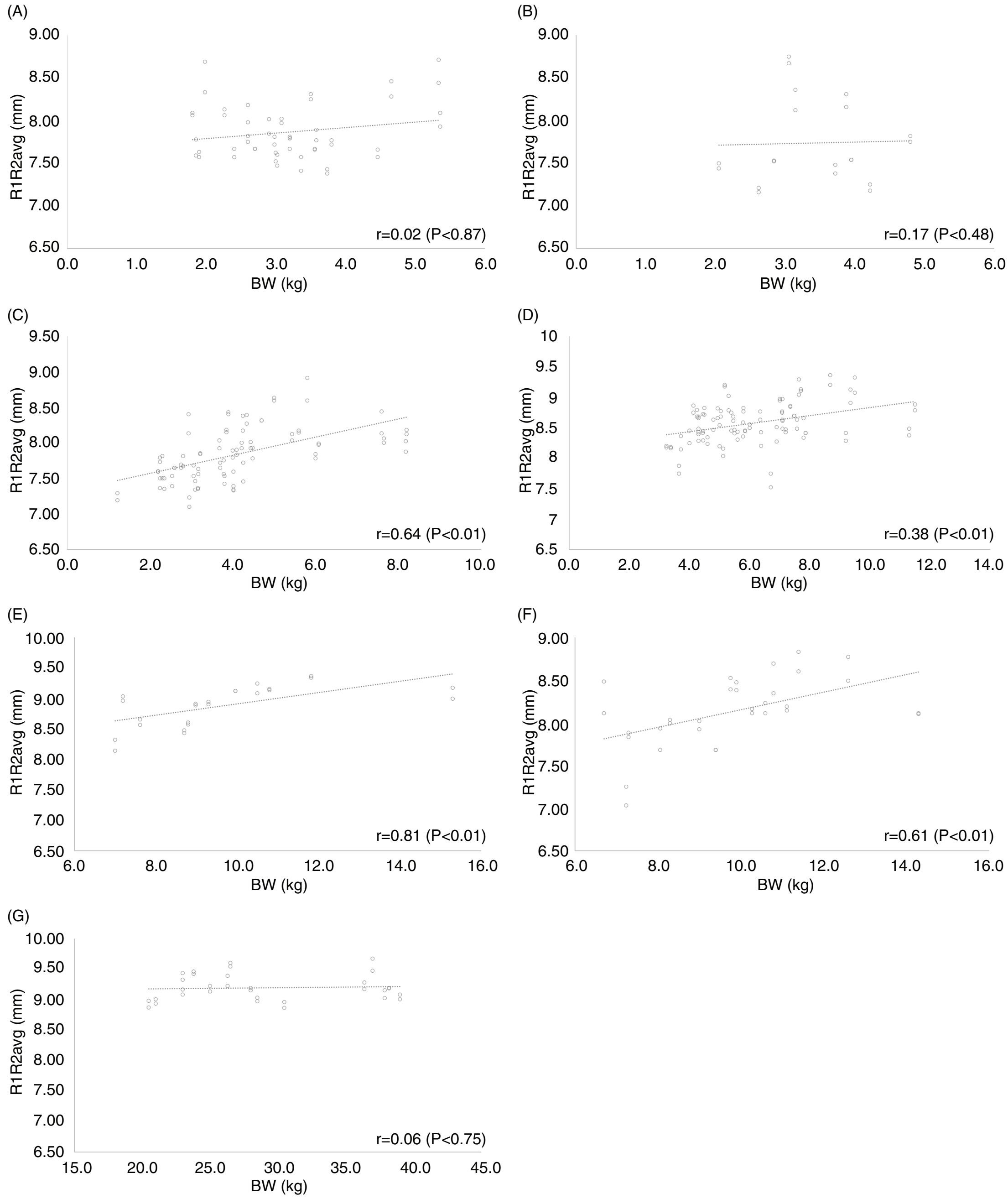

Figure 3 Scatter plots with a linear regression line showing intrabreed relationships between BW and R1R2avg of the following seven breeds: (a) chihuahuas (n=26), (b) Yorkshire terriers (n=10), (c) toy poodles (n=44), (d) miniature dachshunds (n=51), (e) beagles (n=13), (f) shiba inus (n=16) and (g) labrador retrievers (n=16). BW, bodyweight; R1, radius of the minor meridian; R2, radius of the major meridian; R1R2avg, mean of R1 and R2.

performing keratometry using the device adopted in this study.

Other limitations of this study included those inherent to keratometers: (1) the area of the cornea measured using keratometers is limited to the central area 3–4 mm in diameter, which does not account for the shape of the cornea peripheral to this range; (2) the device is preset to measure major and minor meridians at a right angle to each other assuming that the cornea has a symmetric spherical shape; thus, irregular astigmatism cannot be evaluated using keratometers; and (3) the distortion of the mire rings reflected on the corneal surface precludes the measurement, resulting in inaccuracy or failure in reading. These limitations need to be overcome by employing more sophisticated evaluation modalities, such as anterior segment optic coherence tomography and corneal topographers, if more accurate and comprehensive evaluations of the cornea are required, such as for correction of refractive error and evaluation of astigmatism following refractive surgery, as is often conducted in human ophthalmology.

In conclusion, the present study successfully described keratometry in 16 selected breeds of dogs which are popular in Japan using an automatic handheld keratometer. Only few reports have been published on keratometry in dogs.[22 23 29] They generally discussed keratometry in dogs across several breeds involved in the studies, thus lacking detailed data regarding breed-specific keratometry. Devices which employ different measuring principles have advantages and disadvantages different from each other. Limitations associated with keratometry examinations in awake dogs included those attributable to operators, animals and devices. In the present study, reliability of the data was improved by employing a single well-trained operator and by adopting a device that employs the mire ring principle. The present study contributed to widening knowledge on keratometry in some breeds which had not been examined previously. The results also provided a valuable data set which could serve as a useful reference for breed-specific keratometry in normal dogs. Possible interoperator variability in the use of the device should be taken into consideration when multiple operators were involved in examinations. These results have implications in determining therapeutic interventions, particularly in the treatment of various corneal diseases using therapeutic contact lenses in dogs, as well as in exploring variations of canine corneal topography by filling the knowledge gap for future research.

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Competing interests None declared.

Ethics approval 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 dog owners using printed documents before examinations.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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