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ORIGINAL ARTICLE

Normal Canine Prostate Gland: Repeatability, Reproducibility, Observer-Dependent Variability of Ultrasonographic Measurements of the Prostate in Healthy Intact Beagles

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Summary

Most prostatic diseases in dogs are associated with prostatomegaly, and transabdominal ultrasonography has become the imaging modality of choice for evaluation of the prostate gland in the dog. The aim of the present study was to assess the reproducibility, the repeatability and interobserver variations of sonographic measurements of prostate and to determine which measurement had the lowest variability. Length and height of prostate gland were measured on longitudinal views, width of the prostate gland and height of left and right lobes of the gland on transversal views. The within-day and between-day variabilities of the prostatic parameters were determined by performing 1350 (270 length, 270 height, 270 width, 270 height of right lobe and 270 height of left lobe) examinations on ten healthy intact beagle dogs on six different days, in a two-week period (three days for the five dogs, three different days for the five others). Three observers with different levels of experience in ultrasonography performed the examinations. The lowest within-day and between-day standard deviation and coefficient of variation values were observed for the width of the prostate. The width of the gland measured on transverse frozen images seems to be the most reliable measurement for evaluating size of prostate glands in healthy dogs, although the shape, position, outline, and echogenicity of the prostate should also be assessed.

Introduction

The prostate gland (*Prostata*) is the only accessory sex gland in the male dog. It is an encapsulated, bilobed, and bilaterally symmetrical ovoid gland, located caudal to the bladder (*Vesica urinaria*), encircling the proximal (*Pars prostatica*) urethra (*Urethra masculina*). Most prostatic diseases in dogs are associated with prostatomegaly (Feeney et al., 1987; Barsanti and Finco, 1995; Cruz-Arambulo and Wrigley, 2003). There are several clinical methods to evaluate prostate size in the dog, including rectal palpation, radiography, transabdominal ultrasonography (Cartee and Rowles, 1983; Blum et al., 1985; Vilman et al., 1987; Ruel et al., 1998), transrectal ultrasonography (Bartsch et al., 1982; Hastak et al., 1982), computed tomography (CT) (Peeling and Griffiths, 1984) and magnetic resonance imaging (MRI) (Rahmouni et al., 1992).

In the last 25 years, transabdominal ultrasonography has become the imaging modality of choice for evaluation of the prostate gland in the dog (Cartee and Rowles, 1983; Finn and Wrigley, 1989; Barsanti and Finco, 1995). This method allows precise prostatic measurements in addition to the evaluation of the prostatic parenchyma (*Parenchyma*) (Nyland et al., 2002). This method has proven to be accurate in both men and dogs (Cartee and Rowles, 1983; Juniewicz et al., 1989). Previous studies have shown that the prostatic size increases with the weight, breed and the age of the dog (Berry et al., 1986; Atalan et al., 1999b; Nyland et al., 2002). Another study has determined prostatic size (length, width, height on longitudinal and transverse images) by means of ultrasonography in a group of healthy intact adult male dogs of a wide variety of breed, size and age and has determined maximum values of prostatic dimensions (Ruel et al., 1998).

However, to properly interpret ultrasonographic measurements, it is essential to be aware of their relevance and accuracy, dependant on many different factors. All measurements can be divided into two terms: actual value and noise. Evaluating the performance of a technique relies on dividing the noise term into several components, namely, reproducibility, repeatability and interobserver variation. Reproducibility corresponds to between-day variability, whereas repeatability corresponds to within-day variability.

Ultrasonography is a highly dependent diagnostic imaging modality, meaning that measurements can depend on the observer's experience. In previous studies about prostatic ultrasonography, the conditions of the measurements of the prostatic parameters (length, width, height on longitudinal and transverse images) are always described technically, but relevant information, such as the number of observers involved and their level of experience, is rarely provided. Such information would be extremely useful not only for interpreting the results of such studies but also for designing further studies using the same variables. Within-day and between-day variations for prostatic measurements must be known to evaluate measurement accuracy in a large population of dogs.

The aim of this study was to assess reproducibility, repeatability and interobserver variations of prostate sonographic measurements and to determine which measurement had the lowest variability.

Materials and Methods

Dogs

The procedure used in this experiment was carried out in accordance with the Guide for the Care and Use of Laboratory Animals. Ten healthy intact Beagle dogs of 2 ($\pm$ 0.8) years of age with mean body weight of 12.5 ($\pm$ 0.4) kg and a body condition score of 3–4 were used.

The ten dogs were used during a two-week period: three days for the first week (for the first five dogs) and 3 days for the second week (for the five other dogs). The dogs came from an accredited experiments breed (Avogadro, France). All dogs had a normal physical examination, no history of urologic disorders and no previous hormonal treatment.

As previous studies showed that the prostatic size increases with the size, breed and the age of the dog, the use of dogs with same size, breed and age was necessary to assess the reproducibility, the repeatability and interobserver variations of sonographic measurements of prostate without bias.

Ultrasonography of the prostate

Before each examination, the dogs were walked and allowed to empty their bladder and colon (*Colon*).

Longitudinal and transverse images of the prostate gland were obtained using a microconvex (6–10 MHz) transducer (Imagic Agile, Kontron Medical, France). All ultrasound examinations were carried out on fully awake dogs, gently restrained in dorsal recumbency. Because of the thin hair coat present in the suprapubic area, no clipping was needed. Coupling gel was applied on the skin to improve contact.

For each dog, longitudinal and transverse views of the prostate gland were obtained. The technique for locating the prostate gland was the same as described by Nyland and others (Nyland et al., 2002). True longitudinal view was confirmed by observation of the hypoechoic urethral tract. Length and height were measured on longitudinal frozen images (Fig. 1). Length was defined as the maximum diameter of the gland along the urethral axis. Height was defined as the maximum diameter perpendicular to the axis of the length. Moreover, a longitudinal cross-sectional anatomical image of the pelvic region (personal data of Anatomia unit, ENVT) in a Beagle dog had been added in the fig. 1 for illustrating the ultrasonographic scan.

Transducer was then rotated 90 degrees to obtain a transverse image of the gland. On transverse views, the height of the right lobe (*Lobus dexter*) was defined as the maximum ventro-dorsal diameter of the right of the gland, the height of left lobe (*Lobus sinister*) as the maximum ventro-dorsal diameter of the left lobe of the gland and the width as the maximum diameter perpendicular to the axis of height of right and left lobe (Fig. 2). Moreover, a transversal cross-sectional anatomical image of the pelvic region (personal data of Anatomia unit, ENVT) in a Beagle dog had been added in the fig. 2 for illustrating the ultrasonographic scan.

During the examination, an effort was made to keep the transducer in the longitudinal and transverse planes to avoid oblique sections of the prostate.

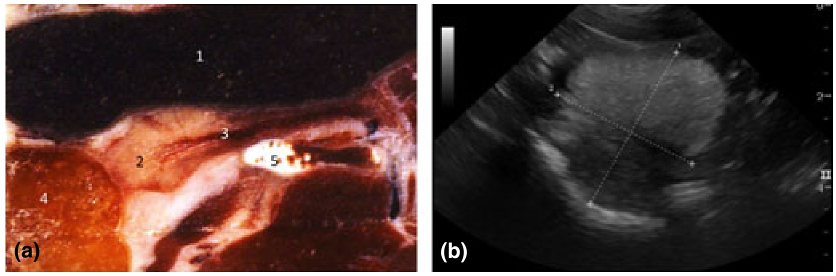

Fig. 1. (a) Longitudinal cross-sectional anatomical image of the pelvic region in a Beagle dog. 1: colon; 2: prostate gland; 3: urethra; 4: bladder; 5: pelvic symphysis. (b) Longitudinal ultrasonography of the prostate gland recorded in an awake dog in dorsal recumbency. The length of the prostate is represented by the '+' calipers '1', the height of the prostate by the '+' calipers '2'.

Fig. 2. (a) Transversal cross-sectional anatomical image of the pelvic region in a Beagle dog (caudal view). 1: colon; 2: left lobe of the prostate gland; 2′: right lobe of the prostate gland; 3: urethra. (b) Transverse ultrasonography of the prostate gland recorded in an awake dog in dorsal recumbency. The heights of right and left lobes of the prostate are represented by the '+' calipers '1' and '2', the width of the prostate by the '+' calipers '3'.

Experimental design

Within-day and between-day variability of the five prostatic measurements (length, height, width, heights of left and right lobes) were determined by performing 1350 (270 length, 270 height, 270 width, 270 height of left lobe and 270 height of right lobe) measurements on the ten healthy intact beagle dogs on six different days during a two-week period (3 days for the first five dogs and 3 days for the others).

Three observers with different levels of experience in ultrasonography performed the examinations. Observers 1, 2 and 3 were veterinarians with 10 years, 4 years and 1 year of experience in ultrasonography, respectively. All observers were familiar with the ultrasonography examination procedure described in the part 'Ultrasonography of the prostate' and the ultrasound machine.

Each day, the three observers examined the dogs at three non-consecutive times, so each of them performed 225 measurements per day (45 measurements for the length, 45 measurements for the height, 45 measurements for the width, 45 measurements for the height of left lobe and 45 measurements for the height of right lobe). All of the examinations were randomised and blinded. For each examination, the observer performed measurements using electronic callipers, and measurement values were hidden from the observer on the screen. An assistant (none of the three observers) was in charge of collecting all of the data.

Statistical analysis

A software program (R version 2.10.0; R Foundation for Statistical Computing) was used to perform the analysis. The following linear mixed-effects model was used.

For each observer and each ultrasonographic measurement:

$$Y_{ijk} = \mu + \mathrm{Day}_i + \mathrm{Dog}_j + \varepsilon_{ijk}$$

where Y_{ijk} is the kth value measured in dog j on day i, μ is the general mean, Dog_j is the fixed effect of dog j, Day_i is the random effect of the ith day and ε_{ijk} is the model error.

The standard deviation (SD) of repeatability and reproducibility was respectively determined as the residual SD and the SD of the day effect. Because the dogs included in this experiment were *a priori* chosen, the dog was considered a fixed-effects factor. The observer effect was quantified using the following general linear model:

$$Y_{ijkl} = \mu + \mathrm{Day}_i + \mathrm{Day}_j + \mathrm{Ob}_k + \varepsilon_{ijkl}$$

where Y_{ijkl} was the lth value measured for dog j on day i by observer k, μ is the general mean, Day_i and Dog_j have the same meaning as in the previous model, Ob_k is the differential effect (considered fixed) of observer k and ε_{ijkl} is the model error. The level of significance was set at $P < 0.05$.

Results

100 per cent of the measurements were performed meaning that each observer could have seen the prostate gland each time.

Table 1 shows the values for longitudinal and transversal measurements of the prostate, performed by each observer, for each of the ten beagle dogs (in total, 1350 measurements were attempted). There were significant differences ($P < 0.001$) between the three observers for the length, the height, the width and the height of the right lobe of the prostate gland, and there was significant difference between observer 3 and the two others for the height of the left lobe of the prostate (Table 1).

Table 2 shows the corresponding within-day and between-day variability results (standard deviation and coefficient of variation). Overall, the results from all observers on all measurements showed mean standard deviation values of 2.1 mm for the length of the prostate gland, 1.6 mm for the height of the prostate gland, 1.5 mm for the width of the prostate gland and 1.9 and 2 mm for the heights of right and left lobes of the gland, respectively.

The within-day and between-day coefficients of variation were not significantly different for the length and the height of the prostate gland between the three observers; however, they were significantly different between observer 1 and the two others for the width and for the height of the right lobe of the prostate gland and between the three observers for the height of the left lobe of the prostate gland (Table 2).

The lowest within-day and between-day standard deviation and coefficient of variation values were observed by observer 1 for the width of the prostate. Moreover, the within-day and between-day coefficients of variation for the width were the lowest for all the observers. The highest within-day and between-day standard deviation and coefficient of variation values were observed by observer 3 for the height of right and left lobes of the prostate gland.

Discussion

One of the major challenges for ultrasound measurements is method validation because of the observer-dependant nature of ultrasonography. It is therefore necessary to assess the effect of the observer on the measurements. The coefficient of variation is usually used to assess within-day, between-day and interobserver variability. However, it is interesting to know the difference between two and three repeated measures of the same animal using standard deviation. Indeed, if this difference is important, measurement must be interpreted with care. Moreover, the within-day and between-day variabilities are different from one observer to another.

This study provides data on the intra- and interoberserver variability of ultrasonographic measurements of the prostate in healthy intact beagles. The methods for locating and visualizing the prostate by ultrasound have been described in previous studies (Cartee and Rowles, 1983; Ruel et al., 1998; Atalan et al., 1999b,c; Nyland et al., 2002). Ultrasonographic prostatic measurements are more accurate and reliable than radiologic ones because the margins of the prostate are better outlined, and because there is no magnification effect, as opposed to radiology (Atalan et al., 1999a). However, although ultrasonography of the prostate gland is supposed to be easy compared with other intra-abdominal organs (Nyland et al., 2002; Cruz-Arambulo and Wrigley, 2003), our results show between-day and within-day coefficient of variations being to reach 11.5% for the less-trained observer. Standard deviation values presented in Table 2 were rather low in comparison with the mean values (Table 1), suggesting little intra-observer variation; however, data show significant differences between the three observers for the majority of the measurements (Table 1). This is likely to be because the more experienced an observer is, the more likely he is to see the entire organ.

The within-day and between-day standard deviation and coefficient of variation values for the length of the prostate gland were not significantly different between the three observers with a mean standard deviation value of 2.1 mm for the three observers. However, this is the highest mean standard deviation value compared with standard deviation values of the others measurements. This result can be explained by difficulties to identify precisely the margins of the organ and so, to delimit the

Table 1. Mean ± standard deviation of different measurements of prostate gland (mm) measured for each observer obtained by ultrasonography in 10 awake, healthy intact dogs

	Longitudinal section of prostate gland		Transversal section of prostate gland		
Observer	Length	Height	Width	Height of Right Lobe	Height of Left Lobe
1	29.5 ± 0.5^a	22.2 ± 0.3^a	33.2 ± 0.1^a	23.0 ± 0.5^a	24.0 ± 0.5^a
2	32.2 ± 0.9^b	23.0 ± 0.7^b	34.2 ± 0.4^b	24.0 ± 0.8^b	24.0 ± 0.6^a
3	27.3 ± 0.3^c	21.2 ± 0.5^c	31.5 ± 0.4^c	22.5 ± 0.2^c	22.3 ± 0.4^b

[a,b,c]Superscript letters for mean (± SD) that differ represent a significant difference ($P < 0.001$) between this and the same measurement for another observer.

Table 2. Within-day and between-day variability (SDs and CVs) of measurements of prostate gland for each observer obtained by ultrasonography in 10 awake, healthy intact dogs

Observer		Longitudinal section of prostate gland		Transversal section of prostate gland		
		Length	Height	Width	Height of Right Lobe	Height of Left Lobe
1	Within-day SD (mm)	1.9	1.4	1.0	1.4	1.4
	Between-day SD (mm)	2.1	1.5	1.0	1.5	1.8
	Within-day CV (%)	6.4[a]	6.3[a]	3.0[a]	6.1[a]	6.0[a]
	Between-day CV (%)	7.1[a]	6.7[a]	3.0[a]	6.3[a]	7.3[a]
2	Within-day SD (mm)	2.1	1.6	1.8	2.1	2.1
	Between-day SD (mm)	2.1	1.7	2.0	2.6	2.3
	Within-day CV (%)	7.7[a]	6.8[a]	5.2[b]	8.8[b]	9.6[b]
	Between-day CV (%)	7.7[a]	7.3[a]	5.7[b]	10.5[b]	9.8[b]
3	Within-day SD (mm)	2.1	1.6	1.6	2.1	2.6
	Between-day SD (mm)	2.1	1.9	1.6	2.5	2.6
	Within-day CV (%)	7.7[a]	7.2[a]	5.7[b]	9.3[b]	11.5[c]
	Between-day CV (%)	7.7[a]	8.7[a]	5.7[b]	11.5[b]	11.5[c]

SD, standard deviation; CV, coefficient of variation.
[a,b,c]Superscript letters for CV that differ represent a significant difference ($P < 0.05$) between this and the same measurement for another observer.

caudal pole of the prostate. These problems associated with imaging the canine prostate have been reported previously as, among other things, indistinct margins of the prostate because these margins are adjacent to other tissues with acoustic impedances similar to that of the prostate (Atalan et al., 1999b,c). Moreover, difficulty to visualize caudal contour have been reported in a previous study for an another reason: because of its caudal location, prostate gland can be partially hidden by pubis, which may create acoustic shadowing and therefore prevent to see correctly caudal contour of the gland (Atalan et al., 1999c). Also, the difficulties in identification prostate margins can explain the results for measurement of the height of the prostate gland in longitudinal plane (within-day and between-day standard deviation and coefficient of variation values not significantly different between the three observer); however, the mean standard deviation values are lower (1.6 mm) than these for the length (2.1 mm) because the dorsal and ventral poles are better vizualized than the caudal pole (Atalan et al., 1999c; Nyland et al., 2002).

In transversal plane, the within-day and between-day coefficients of variation for the width of the prostate gland were the lowest for all the observers. So, this parameter seems to be a good indicator in comparison with the length because the within-day and between-day coefficient of variation values for the most experienced observer (observer 1) are 2-fold between length (1.9 mm, 6.4%) and width (1.0 mm, 3.0%). This result is partly in accordance with previous studies showing that prostatic length and width measurements were the best predictors of prostate size in the dog (Cartee and Rowles, 1983). However, a study showed a reproducibility, which might not be quite high enough for the width on transverse section (Atalan et al., 1999c). This different result can perhaps be explained by the fact that the dog population of this study was consisted of a wide variety of breeds, body weights and ages, whereas in our study, the dog was considered as a fixed effect in our statistical analysis. However, the within-day and between-day standard deviation and coefficient of variation values for the height of the two lobes of the prostate gland are significantly different between observer 1 and the two others for the height of the right lobe of the prostate gland and between the three observers for the height of the left lobe. For the most experienced observer, the standard deviation and coefficient of variation values for the height of the two lobes are not significantly different from these of the width of the prostate gland and these values are rather low. However, the within-day and between-day CV values for the height of the two lobes increased by 50 per cent between observer 1 and 2 and were 2-fold between observer 1 and 3. This result can be explained by a difficulty for a less-experienced observer to obtain symmetrical prostatic lobes in the transversal plane. A previous study has described the effects of selecting suboptimal imaging planes on ultrasonographic measurements; for the transverse section, 30° rotation of the transducer resulted in an increase in measured height of 7.5–17.4% and lateral displacement in an increase of 4–8.1% (Atalan et al., 1999c). Moreover, the observer can have difficulties in the positioning of the transducer in the transverse plane due to dog's penis (*Penis*) and difficulties when the prostate is located intrapelvically (Atalan et al., 1999c). A previous study has also showed that rectal manipulation of the prostate can help to define its border and make more accurate measurements possible (Atalan et al., 1999c). This manipulation was not made in the present study because unnecessary.

Previous studies showed that the size of the prostate gland in healthy intact dogs increases with the size and the age of the dog (Cartee and Rowles, 1983; Ruel et al., 1998; Atalan et al., 1999c). For our study, dogs were chosen of approximately the same age (2 ± 0.8 years) and weight (12.5 ± 0.4 kg) to overcome the effects of age and weight on the prostate gland measurements statistical analysis. Values of prostatic measurements in our study were similar to those of previous studies, for dogs with similar age and size (Ruel et al., 1998). Measurements of the prostate gland are used in the clinical evaluation of prostatic disorders, like bacterial prostatitis, prostatic cyst, benign prostatic hyperplasia (BPH), prostatic abscesses and prostatic adenocarcinoma, and in monitoring the response to therapy (Krawiec, 1994). A study presented maximum predicted values for prostatic parameters for a given body weight and age, based on the upper limit of the 95% confidence interval of the mean predicted values (n dogs = 100) with a specificity of 97.5% (Ruel et al., 1998). Such values represented a useful tool for ultrasonographic evaluation of the prostate in the dog. However, for values near upper limit, it is interesting to know the intra- and interobserver variabilities of ultrasonographic measurements of the prostate to avoid including false-negative or false-positive results when attributing a diagnosis of a prostatic hypertrophy. However, as predicted, the standard deviation and coefficient of variation values are inversely proportional with the experience of the observer. Moreover, it should be emphasized that prostatic size is not the only parameter used to assess prostatic diseases, and that other parameters such as shape, position, outline and echogenicity should also be used for a complete evaluation (Ruel et al., 1998; Nyland et al., 2002).

Different methods were described to assess the volume of the prostate using the size parameters of the gland (Vilman et al., 1987; Rahmouni et al., 1992; Atalan et al., 1999c; Kamolpatana et al., 2000). It would be interesting in further studies to determine the influence of the variability of the different size parameters described here on the variability of the volume calculated with different methods.

In conclusion, as with any quantitative technique, prostate gland measurements should be validated for a given observer, and a well-trained and experienced observer will deliver the best performance. When measuring prostate gland, the standard deviation and coefficient of variation values are the smallest for the width of the gland on transverse images, and this information should be taken into account for prostate size interpretation and for further studies concerning prostate gland measurements by ultrasonography.

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