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Ultrasonographic determination of day of parturition based on fetal biparietal diameter in pregnant bitches: Comparison of simple linear regression and mixed linear regression in breed-specific models and maternal weight grouped models

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ABSTRACT

The aim of this retrospective study was to compare simple linear regression and mixed linear regression on data grouped by breed or maternal weight group. The comparison was done to find the most accurate model for predicting day of parturition in pregnant bitches in clinical practice. The retrospective data consisted of fetal biparietal diameter determined by ultrasonography and day of parturition for all included bitches. The study population was divided into five maternal weight groups (miniature (≤5 kg), small (>5 to 10 kg), medium (>10 to 25 kg), large (>25 to 40 kg), and giant (>40 kg)) with three breeds in each group with 26 miniature-breed bitches, 13 small-breed bitches, 19 medium-breed bitches, 22 large-breed bitches, and 20 giant-breed bitches. The data was used to develop models to determine the number of days before parturition based on fetal biparietal diameter. A statistically significant effect was seen for grouping by maternal weight group ($p<0.0001$) and by breed ($p=0.0057$). Breed-specific models were derived and compared to each other within the same maternal weight group. Statistically significant differences between some miniature-breed and small-breed bitches were found using mixed linear regression analysis. The accuracies of all models were given as number of births within ±1 and ±2 days of estimated day of parturition and compared to an acceptable limit of 80% at ±2 days. All breeds and maternal weight groups except Dogue de Bordeaux and giant-breed bitches met the limit. Poor accuracies were seen when applying data from each breed to the maternal weight grouped model. Simple linear regression analyses were compared to mixed linear regression analyses. The simple linear regression analyses obtained the best accuracies for most of the breeds which is most likely to be caused by overestimation. Comparison of Chihuahua and German Shepherd to other studies showed similar accuracies between the highest reported and the two linear models. We recommend the use of breed-specific models based on mixed linear regression analysis in clinical practice. Further research is needed to analyze the differences between the two linear models and to confirm the tendency of more accurate predictions of day of parturition for medium-breed, large-breed, and giant-breed bitches when using breed-specific models.

1. Introduction

In companion animal practice, it can be difficult to know the exact date of conception in bitches and consequently difficult to know or estimate gestational age (GA) and day of parturition [1]. The normal canine gestation length is 63 days ± 1 day from

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ovulation but it can also be timed from LH peak or periovulatory progesterone rise [2–4]. Furthermore, the time from mating or insemination to conception varies according to the length of time from the onset of estrus to ovulation [3,5] and maturation of the oocyte [5] and also with the quality [6], survival [3,5], and type of semen [6]. For these reasons, the act of mating or insemination cannot be used as indications of conception [1,3,7]. Knowing GA is useful in the decision-making regarding when to perform a cesarean section [8–10] so as to avoid postmature delivery resulting in fetal death due to lack of placental nutritional support [2]. Also, a knowledge of GA allows veterinary care professionals to prevent or mitigate whelping problems in predisposed breeds [7,8,11]. Ultrasonography has proven to be a very efficient aid in GA estimation using inner chorionic cavity (ICC) and biparietal measurements (BP) as reliable parameters in determining GA in pregnant bitches [4,12,13]. ICC and BP are used in the early and late pregnancy, respectively [8,9,14]. Due to a large variation in size of the canine breeds, maternal weight grouped models have been used to allow more accurate estimates of GA [4,7,9]. Even though many studies have presented different maternal weight grouped models [4,8,9,13–18], multiple studies stated the need for breed-specific models [7,9,13,19]. This need has been confirmed by the poor accuracy of GA estimates when applying models for small- and medium-breed bitches to large- and giant-breed bitches [2,18]. We hypothesized that breed-specific models are more accurate than maternal weight grouped models in predicting parturition date in bitches as breed-specific models can take morphological differences, e.g. head shape [2,19], and different gestational lengths [20,21] into account. The aim of the present study was to compare the use of BP in breed-specific and maternal weight grouped models based on both mixed linear regression and simple linear regression for miniature-breed, small-breed, medium-breed, large-breed, and giant-breed bitches to determine which of the models was the most accurate in predicting parturition date in pregnant bitches.

2. Materials and methods

2.1. Study design

The data was collected from February 2008 to January 2021 on privately owned pregnant bitches at Nysted Dyreklinik, Nysted, Denmark or Canicold, Glumsø, Denmark. First day of presentation at the clinics and the total number of ultrasonographic examinations during the pregnancy were individual decisions made by the owner. Measurements of BP were made as soon as it was visualized. The data for this study was extracted from a larger dataset including data from 66 different canine breeds. All data are based on litters containing live puppies without apparent malformations.

The bitches were divided into five groups based on maternal weight; miniature-breed (≤5 kg), small-breed (>5–10 kg), medium-breed (>10–25 kg), large-breed (>25–40 kg), and giant-breed (>40 kg). Maternal weight was not obtained for each bitch but was defined as the mean value of the weight interval described in the breed standards by the Danish Kennel Club (DKK). Each group consisted of three breeds as seen in Table 1. The enrolled breeds were selected based on highest number of observations available within each maternal weight group. Date of parturition was reported by the owner. All litters were born after natural onset of labor. The parturition date was defined as the day of birth of the first pup in the litter. The method of fertilization, type of delivery (natural birth, assisted vaginal birth, cesarean section), litter size, sex ratio in the litter, maternal parity, and maternal age were not considered as exclusion criteria.

2.2. Ultrasonographic examinations

The examinations were made using different ultrasound scanners over time (Falco, Esaote Mylab 30, Esaote Mylab 30 Gold, Esaote Masterclass C, and Alpinion E-Cube 8 LE) with a microconvex transducer (3–10 MHz) and a linear transducer (3–17 MHz). All examinations were performed by the same veterinarian over the years of data collection who thus had between 1 and 15 years of experience with ultrasonographic fetometry at the time of the examinations. The ultrasonographic examination was made with the bitch in lateral recumbency or standing up if the bitch did not tolerate lateral recumbency. Neither clipping nor sedation was used but the skin of the bitch was prepped with alcohol and acoustic coupling gel. The BP measurement was obtained in a transverse plane as the greatest distance between the parallel parietal bones in cm and converted to mm. The calipers on the ultrasonographic image were placed in the center of the parietal bone on each side of the head as seen in Figs. 1 and 2. The number of measurements per examination was independent of the number of fetuses and BP could have been measured multiple times on the same fetus. Averages and ranges for number of pregnancies, number of examinations, and number of biparietal measurements according to breed are shown in Table 1.

2.3. Statistical analysis

All statistical analyses were performed using SAS Enterprise Guide (version 7.1) and Microsoft 365 Excel. The confidence limits were set at 95% and the level of statistical significance was defined as $p<0.05$.

All BP measurements noted for each bitch at each day of examination and the actual days before parturition (DBP) calculated from the reported date of parturition were used as variables. All BP measurements were plotted to identify outliers and to investigate the cause of the outlying measurement. If possible, outlier measurements were reassessed and corrected if appropriate by reviewing stored images and the original medical records. Two measurements from the same pregnancy of a Labrador Retriever were identified as outliers without any apparent explanation and the bitch was excluded. A mixed linear regression analysis allowing for repeated measurements was performed for each of the enrolled breeds. A mixed linear model was used due to some bitches contributing with multiple pregnancies, multiple measurements within the individual pregnancy, and multiple measurements at each examination during the study period creating repeated measurements. All models were presented in the same format: $y = ax + b$ where y was DBP and x was BP in mm. In the models, the slopes (a) represent the decline in DBP for each mm BP increases while the intercepts (b) represent the estimated DBP when BP equals 0. The mixed linear regression analyses were used to compare slopes and intercepts for the breed-specific models within the same weight group to determine the presence of statistically significant differences between the models. Scatter plots were made with the actual DBP and the predicted DBP to assess the applicability of the models. In addition to the mixed linear regression analysis, simple linear regression analysis was also performed for comparison. This simple linear regression analysis was used for all enrolled breeds as this form of analysis is most common in other studies [4,7–10,14,17–19,22]. Measurements of BP were calculated as simple averages per bitch per examination and plotted against the actual DBP to obtain trend lines and r^2. The same simple linear regression analysis was applied to the data grouped according to maternal weight. Models derived from mixed linear regression analysis and from simple linear regression analysis of data grouped by breed and from simple linear regression

Table 1
Number of bitches, number of pregnancies, number of examinations and number of fetal biparietal measurements for each breed. In brackets, the averages and the ranges are noted for the pregnancies per bitch, examinations per pregnancy and biparietal measurements per examination.

Breed	Number of bitches	Number of pregnancies	Number of examinations	Number of biparietal measurements
Chihuahua	15	18 (1.20; 1–2)	56 (3.11; 1–5)	197 (3.52; 1–8)
Coton de Tulear	5	10 (2.00; 1–3)	34 (3.40; 2–5)	132 (3.88; 1–6)
Toy Poodle	6	14 (2.33; 1–4)	39 (2.79; 1–5)	112 (2.87; 1–5)
Shetland Sheepdog	6	11 (1.83; 1–4)	35 (3.18; 1–6)	110 (3.14; 1–6)
Cavalier King Charles Spaniel	4	8 (2.00; 1–3)	24 (3.00; 2–4)	85 (3.54; 1–6)
Pug	3	4 (1.33; 1–2)	13 (3.25; 1–5)	53 (4.08; 2–7)
Staffordshire Bull Terrier	10	13 (1.30; 1–2)	38 (2.92; 1–5)	136 (3.58; 1–7)
Border Collie	6	9 (1.50; 1–3)	28 (3.11; 1–5)	96 (3.43; 1–7)
Miniature Bull Terrier	3	4 (1.33; 1–2)	17 (4.25; 2–6)	53 (3.12; 1–6)
Golden Retriever	7	12 (1.71; 1–4)	46 (3.83; 1–6)	128 (2.78; 1–7)
German Shepherd	7	9 (1.29; 1–2)	45 (5.00; 1–15)	108 (2.40; 1–7)
Labrador Retriever	7	9 (1.29; 1–2)	17 (1.89; 1–4)	44 (2.59; 1–5)
Newfoundland	7	7 (1.00; 1)	25 (3.57; 1–5)	85 (3.15; 1–7)
Dogue de Bordeaux	9	12 (1.33; 1–2)	39 (3.25; 2–4)	66 (1.69; 1–7)
Leonberger	4	5 (1.25; 1–2)	19 (3.80; 1–5)	59 (3.11; 1–9)

analysis of data grouped by maternal weight are shown in Table 7 in Appendix A. Additionally, the difference between the actual DBP and the predicted DBP was calculated for each examination to obtain the accuracy of the prediction for both the mixed linear models and the simple linear models. The accuracies were subdivided into two levels at ±1 and ± 2 days and compared to each other. All accuracies were also compared to an acceptable accuracy for indicators of GA at 80% at ±2 days [13] meaning that 80% of the bitches should give birth within 2 days of predicted DBP.

3. Results

The earliest measurements of BP were obtained in a Staffordshire Bull Terrier and a Cavalier King Charles Spaniel at 34 DBP. Measurements were obtained between 33 and 1 DBP for miniature-breed bitches, between 34 and 1 DBP for small-breed bitches, between 34 and 3 DBP for medium-breed bitches, between 33 and 1 DBP for large-breed bitches, and between 32 and 0 DBP for giant-breed bitches.

3.1. Results derived from the study population

All measurements of BP from all breeds were plotted and a clear linearity was observed along with a wide variation of BP within the population increasing with GA as seen in Fig. 3. Division into maternal weight groups or breeds resulted in a smaller variation of

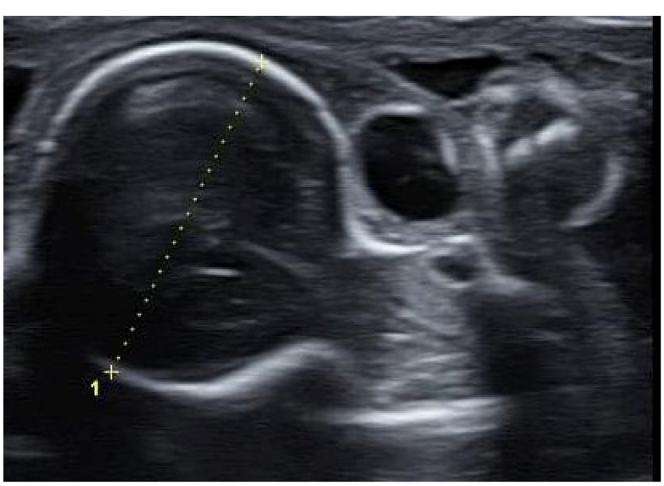

Fig. 1. Biparietal diameter measured in the transverse plane. The cursors were placed in the centre of the parietal bone on both sides of the cranium.

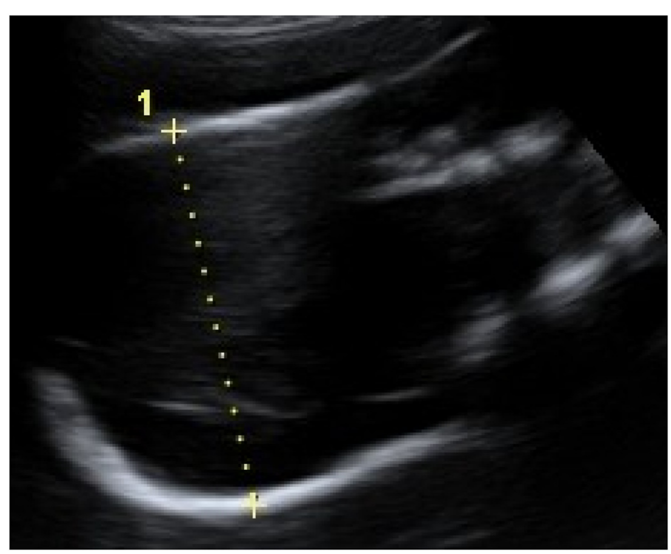

Fig. 2. Biparietal diameter measured in the longitudinal plane. The cursors were placed in the centre of the parietal bone on both sides of the cranium.

BP within the groups. A greater variation of BP was seen for giant-breed bitches compared to other maternal weight groups. The variation for the giant-breed bitches was most pronounced for Dogue de Bordeaux. The effect of grouping by maternal weight resulted in a statistically significant result ($p<0.0001$). Application of the effect of further grouping by breed also resulted in a statistically significant result ($p=0.0057$). The statistically significant results from grouping by maternal weight and breed showed that the resulting trend lines were different from each other. When comparing slopes and intercepts between breed-specific models within the same maternal weight group, statistically significant differences between both slopes and intercepts were found for Chihuahua vs Coton de Tulear ($p=0.0392$ and $p=0.0229$), Coton de Tulear vs Toy Poodle ($p=0.0018$ and $p=0.0033$), and Cavalier King Charles Spaniel vs Shetland Sheepdog ($p=0.0045$ and $p=0.0027$). Furthermore, a statistically significant difference between slopes was found for Shetland Sheepdog vs Pug ($p=0.0277$) while the difference between the intercepts was not statistically significant ($p=0.0822$). The statistically significant differences between the slopes and intercepts support grouping by breed. No statistically significant difference between slopes and intercepts were found for medium-breed bitches, large-breed bitches, or giant-breed bitches.

3.1.1. *Mixed linear model and accuracies*

The difference between the actual DBP and predicted DBP by the mixed linear model for each BP measurement was plotted against BP. The measurements were centered around the predicted day of parturition and mostly within the acceptable difference from the actual day of parturition of ±2 days. When the acceptable difference was exceeded, most of the pregnancies were prolonged. A scatter plot between actual DBP and predicted DBP as seen in Fig. 4 demonstrated a clear linearity for the breeds within the maternal weight groups.

Since no statistically significant differences were detected between slopes or intercepts for any of the medium-breed, large-breed, or giant-breed bitches, the accuracies were investigated for both the breeds and the maternal weight groups with the mixed linear regression analysis. Accuracies for the mixed linear regression analyses are displayed in Table 2. All breeds and maternal weight groups except Dogue de Bordeaux and giant-breed bitches met the acceptable limit of 80% at ±2 days. The data for each breed were also applied to the maternal weight grouped model. This resulted in accuracies between 14.3% and 40.0% at ±1 day and between 25.7% and 53.0% at ±2 days as displayed in Table 3.

3.1.2. *Comparison of mixed linear model and simple linear model statistics*

A simple linear regression analysis was performed on the data sorted according to breed. This resulted in breed-specific models. A good fit of the models was seen as r^2 were above 0.9 [9] for all but one of the models (range 0.9228–0.9966). The r^2 for the Dogue de Bordeaux was 0.8652. A comparison between the accuracies for the breed-specific mixed linear regression analysis and simple linear regression analysis was made and results are displayed in Table 4. All breeds except Dogue de Bordeaux met the acceptable limit of 80% at ±2 days. When better accuracies were obtained with the simple linear regression analysis compared to the model obtained from the mixed linear regression analysis, the increased accuracy ranged from 2.9% to 11.8% at ±1 day and from 1.9% to 12.0% at ±2 days. On the other hand, better obtained accuracies with the mixed linear model compared to the simple linear model resulted in increased accuracies between 4.1% and 8.0% at ±1 day and 5.2% and 5.9% at ±2 days.

4. Discussion

To the authors' knowledge, this is the first large-scale study to compare maternal weight grouped models and breed-specific models and also the first study comparing mixed linear regression with simple linear regression analysis and discussing overestimation of simple linear regression analysis. The findings of the present study support the superiority of breed-specific models for prediction of parturition date in pregnant bitches. A statistically significant effect of grouping by maternal weight group and by breed was identified. Comparisons of slopes and intercepts

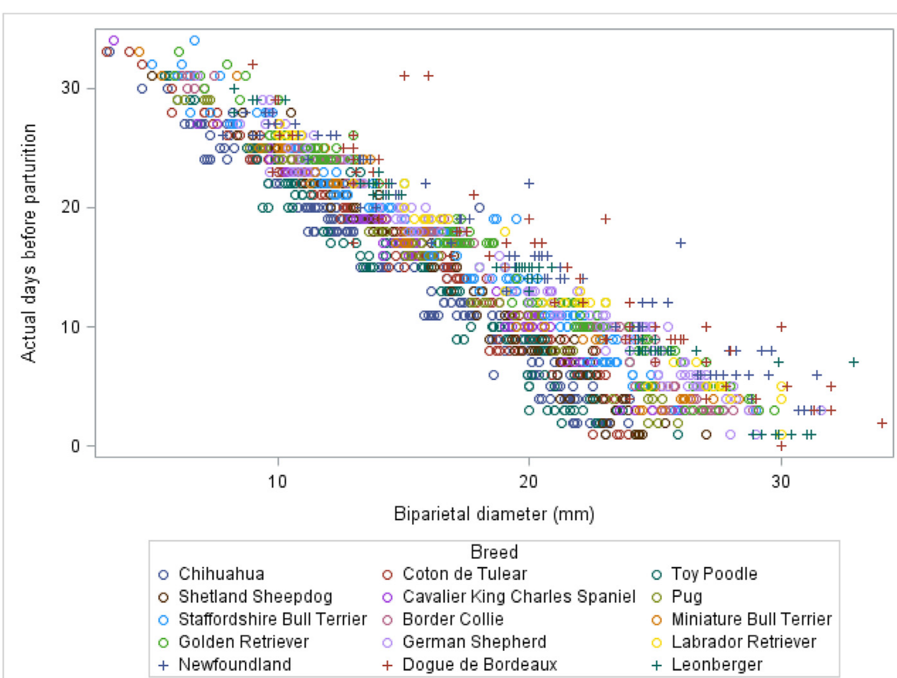

Fig. 3. Scatter plot of all measurements of fetal biparietal diameter (BP) for all enrolled canine breeds in relation to days before parturition. Every symbol represents a measurement of BP.

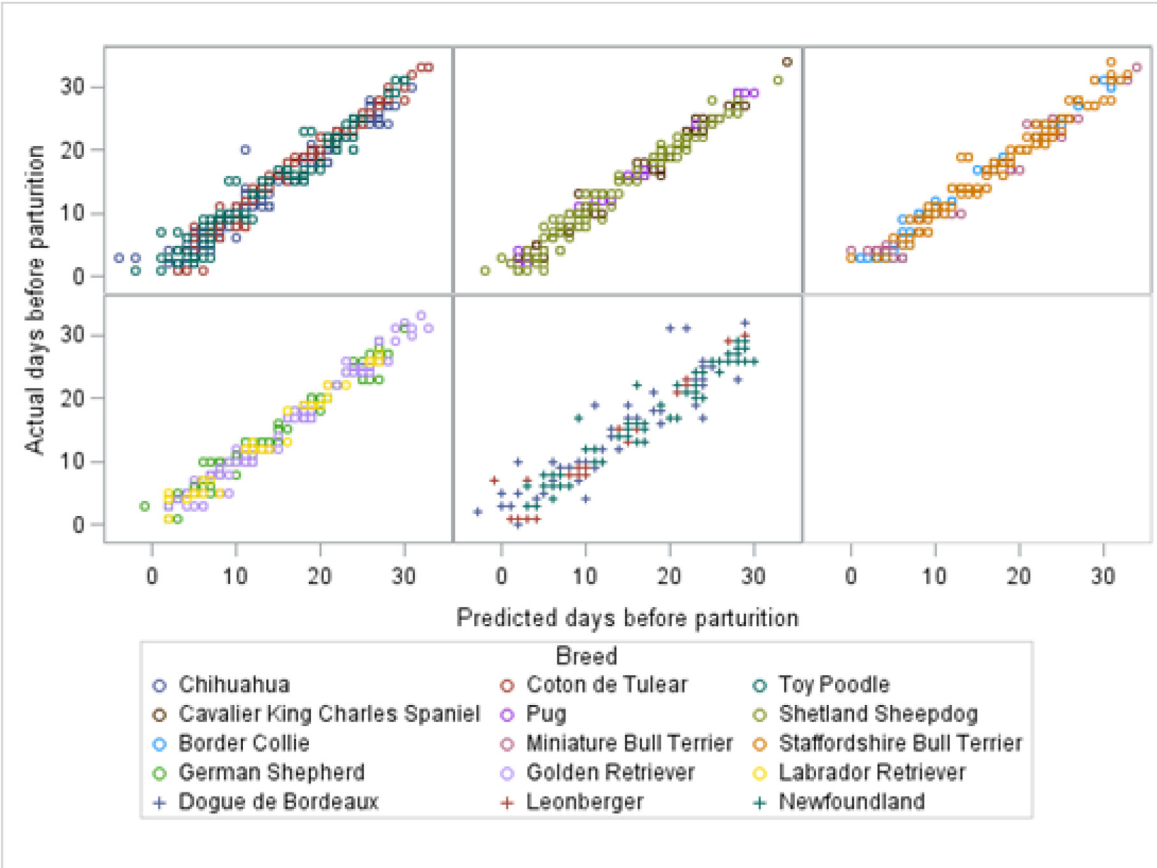

Fig. 4. Scatter plot between actual days before parturition and predicted days before parturition (DBP) using measurements of fetal biparietal diameter (BP) derived from mixed linear regression analysis in pregnant bitches. All breeds are displayed with other breeds within the same maternal weight group. Each symbol represents DBP for a BP measurement.

between breed-specific models within the same maternal weight group indicated that breed-specific models should be applied for the breeds of miniature-breeds and small-breeds. The scatter plot between actual DBP and predicted DBP showed a clear linearity indicating good applicability of the mixed linear models in clinical practice. The largest variation was observed in the group of giant-breed bitches and thus this model was expected to make the poorest predictions. When evaluating the accuracies in accordance with the acceptable level [13], only the models for Dogue de Bordeaux was below the accepted accuracy at 80% at ±2 days. Dogue de Bordeaux were mainly presented in the early part of the study period and therefore the measurements might be influenced by the performing veterinarian's skills and the image quality of the scanner itself. In pregnancies were the discrepancy between predicted DBP and actual DBP exceeded the acceptable limit of ±2 days, the predicted DBP was most often greater than the actual DBP. In clinical practice, this might be an advantage as a caesarean section would not be performed preterm and hereby preventing neonatal death as a result of incomplete maturation [2].

Since at least two out of three breeds within each maternal weight group had better accuracies at ±2 days with the breed-specific models than maternal weight grouped models, it is

Table 2
Accuracies at ±1 and ± 2 days for breed-specific models and maternal weight grouped models derived from mixed linear regression.

Breed	±1 day		±2 days	
	Breed-specific model	Maternal weight grouped model	Breed-specific model	Maternal weight grouped model
Chihuahua	40/56 (71.4%)	80/129 (62.0%)	51/56 (91.1%)	113/129 (87.6%)
Coton de Tulear	28/34 (82.4%)		32/34 (94.1%)	
Toy Poodle	21/39 (53.8%)		32/39 (82.1%)	
Shetland Sheepdog	27/35 (77.1%)	59/72 (81.9%)	34/35 (97.1%)	68/72 (94.4%)
Cavalier King Charles Spaniel	19/24 (79.2%)		23/24 (95.8%)	
Pug	12/13 (92.3%)		13/13 (100.0%)	
Staffordshire Bull Terrier	32/38 (84.2%)	60/83 (72.3%)	35/38 (92.1%)	77/83 (92.8%)
Border Collie	24/28 (85.7%)		28/28 (100.0%)	
Miniature Bull Terrier	9/17 (52.9%)		16/17 (94.1%)	
Golden Retriever	32/46 (69.6%)	82/108 (75.9%)	45/46 (92.8%)	103/108 (95.4%)
German Shepherd	36/45 (80.0%)		44/45 (97.8%)	
Labrador Retriever	16/17 (94.1%)		17/17 (100.0%)	
Newfoundland	15/25 (60.0%)	43/83 (51.8%)	20/25 (80.0%)	64/83 (77.1%)
Dogue de Bordeaux	18/39 (46.2%)		27/39 (69.2%)	
Leonberger	14/19 (73.7%)		18/19 (94.7%)	

Table 3
Accuracies within ±1 and ± 2 days for data for each breed applied to the maternal weight grouped model.

Breed	±1 day	±2 days
Chihuahua	10/56 (17.9%)	17/56 (30.4%)
Coton de Tulear	8/34 (23.5%)	9/34 (26.5%)
Toy Poodle	9/39 (23.1%)	11/39 (28.2%)
Shetland Sheepdog	5/35 (14.3%)	9/35 (25.7%)
Cavalier King Charles Spaniel	5/24 (20.8%)	9/24 (37.5%)
Pug	3/13 (23.1%)	5/13 (38.5%)
Staffordshire Bull Terrier	11/38 (28.9%)	16/38 (42.1%)
Border Collie	4/28 (14.3%)	10/28 (35.7%)
Miniature Bull Terrier	3/17 (17.6%)	5/17 (29.4%)
Golden Retriever	8/46 (17.4%)	15/46 (32.6%)
German Shepherd	12/45 (26.7%)	18/40 (40.0%)
Labrador Retriever	5/17 (29.4%)	9/17 (53.0%)
Newfoundland	10/25 (40.0%)	13/25 (52.0%)
Dogue de Bordeaux	9/39 (23.1%)	19/39 (48.7%)
Leonberger	6/19 (31.6%)	10/19 (52.6%)

recommended to use breed-specific models in clinical practice. However, some breeds would have obtained better accuracies with the maternal weight grouped models. The reason for this was unclear. Possible causes might be high biological variation within the breeds, a low number of bitches, poor image quality due to overweight or deep thorax/abdomen, the operator's lack of experience in the early part of the study period or morphological differences in head shapes. Further research is needed to address this. Application of the data from each breed to the maternal weight grouped model resulted in unsatisfactory accuracies since the acceptable limit was not met for any of breeds. Furthermore, the accuracies for the individual breeds applied to the maternal weight grouped models were markedly poorer than the accuracies of the breed-specific models. This finding also supports the use of breed-specific models. From a clinical point of view, the models should be optimized for even better accuracies as a higher accuracy at ±1 day is more valuable, e.g. for planning a caesarean section when needed.

4.1. Differences between the mixed linear regression and the simple linear regression

The results of the present study show that the mixed linear model is preferable compared to the simple linear model. Relatively high accuracies were seen with the simple linear model. These results should be interpreted with caution since overestimation is likely to make the accuracies falsely high. The simple linear model does not take repeated measurements into account unlike the mixed linear model. Therefore, the simple linear models and their accuracies are affected by several measurements obtained from the same bitch, the same pregnancy, and even the same fetuses correlated to the same DBP. This results in a model describing low biological variation and high accuracies when the model is tested on the data it was derived from. However, it is not expected that the accuracies of the simple linear models will be representative for the general population of bitches. Therefore, the accuracies of the simple linear models will be poorer when using data from another study population. Consequently, the difference between the accuracies obtained with this study population and a control group is expected to be more pronounced when using the simple linear model compared to the mixed linear model. A relevant limitation of the present study is that the models are evaluated on the same data as the models are derived from. To truly confirm the accuracies and the best model in clinical practice, a verification of the models with a control group using both models should be carried out. This is a subject for further investigation.

4.2. Comparison of models derived in this study with those reported in other studies

Models for Chihuahuas and German Shepherds were compared to the models from other studies and are summarized in Table 5 for Chihuahuas and in Table 6 for German Shepherds. Surprisingly for Chihuahuas, the model reported by Socha & Janowski (2018) and Vieira et al. (2020) exceeded the accuracies obtained with the both the mixed linear and simple linear models based on the current study population. The accuracies obtained with the model by Luvoni & Grioni (2000) were markedly poorer than the remaining accuracies for both ±1 and ± 2 days indicating that the model could not be applied to Chihuahua. This statement is supported by Socha & Janowski (2014).

For German Shepherds, the mixed linear and simple linear models showed the best accuracies. Reported accuracies from other studies were highly similar to the obtained accuracies from the mixed linear and simple linear models but use of our data in the reported models resulted in markedly poorer accuracies. The only comparable accuracy was seen at ±2 days for the model by Groppetti et al. (2015). The model presented by Milani et al. (2013) showed the poorest accuracies of all and did not meet the acceptable level of 80% at ±2 days. This was also found by other authors [13]. Maternal weight grouped models showed poorer accuracies than the breed-specific models in our models suggesting better accuracy may be obtained with a breed-specific model compared to maternal weight grouped models for German Shepherds. These results were in accordance with the findings of Socha & Janowski (2017) and supported the statistical findings of this study.

Table 4
Accuracies at ±1 and ± 2 days for breed-specific models derived from mixed linear regression and simple linear regression.

Breed	±1 day		±2 days	
	Mixed linear	Simple linear	Mixed linear	Simple linear
Chihuahua	40/56 (71.4%)	40/56 (71.4%)	51/56 (91.1%)	51/56 (91.1%)
Coton de Tulear	28/34 (82.4%)	29/34 (85.3%)	32/34 (94.1%)	32/34 (94.1%)
Toy Poodle	21/39 (53.8%)	24/39 (61.5%)	32/39 (82.1%)	32/39 (82.1%)
Shetland Sheepdog	27/35 (77.1%)	28/35 (80.0%)	34/35 (97.1%)	34/35 (97.1%)
Cavalier King Charles Spaniel	19/24 (79.2%)	20/24 (83.3%)	23/24 (95.8%)	24/24 (100.0%)
Pug	12/13 (92.3%)	13/13 (100.0%)	13/13 (100.0%)	13/13 (100.0%)
Staffordshire Bull Terrier	32/38 (84.2%)	31/38 (88.6%)	35/38 (92.1%)	36/38 (94.7%)
Border Collie	24/28 (85.7%)	25/28 (89.3%)	28/28 (100.0%)	28/28 (100.0%)
Miniature Bull Terrier	9/17 (52.9%)	11/17 (64.7%)	16/17 (94.1%)	15/17 (88.2%)
Golden Retriever	32/46 (69.6%)	35/46 (76.1%)	45/46 (92.8%)	45/46 (97.8%)
German Shepherd	36/45 (80.0%)	38/45 (84.4%)	44/45 (97.8%)	44/45 (97.8%)
Labrador Retriever	16/17 (94.1%)	16/17 (94.1%)	17/17 (100.0%)	17/17 (100.0%)
Newfoundland	15/25 (60.0%)	13/25 (52.0%)	20/25 (80.0%)	23/25 (92.0%)
Dogue de Bordeaux	18/39 (46.2%)	16/38 (42.1%)	27/39 (69.2%)	27/38 (71.1%)
Leonberger	14/19 (73.7%)	14/19 (73.7%)	18/19 (94.7%)	17/19 (89.5%)

Table 5
Comparisons of different accuracies within ±1 and ± 2 days derived from the study population and presented models from other studies along with reported and calculated accuracies for Chihuahua bitches. No reported accuracies are marked with a hyphen.

Source	Method	±1 day	±2 days
Mixed linear model	Calculated	40/56 (71.4%)	51/56 (91.1%)
Breed-specific			
Simple linear model	Calculated	40/56 (71.4%)	51/56 (91.1%)
Breed-specific			
Socha & Janowski (2018)	Calculated	41/56 (73.2%)	50/56 (89.3%)
Miniature-breed	Reported	–	–
Luvoni & Grioni (2000)	Calculated	27/56 (48.2%)	40/56 (71.4%)
Small-breed	Reported	15/22 (68.2%)	–
Vieira et al. (2020)	Calculated	39/56 (69.6%)	52/56 (92.9%)
Breed-specific	Reported	–	–

Table 6
Comparisons of different accuracies within ±1 and ± 2 days derived from the study population and presented models from other studies along with reported and calculated accuracies for German Shepherd bitches. The * denotes reported accuracies by Socha & Janowski (2014) using the model by Luvoni & Grioni (2000). No reported accuracies are marked with a hyphen.

Source	Method	±1 day	±2 days
Mixed linear model	Calculated	36/45 (80.0%)	44/45 (97.8%)
Breed-specific			
Simple linear model	Calculated	38/45 (84.4%)	44/45 (97.8%)
Breed-specific			
Luvoni & Grioni (2000)	Calculated	29/45 (64.4%)	40/45 (88.9%)
Medium-breed	Tested*	29/46 (63.0%)*	42/46 (91.3%)*
	Reported	17/24 (70.8%)	–
Alonge et al. (2016)	Calculated	27/45 (60.0%)	38/45 (84.4%)
Large-breed	Reported	64/102 (62.8%)	90/102 (88.3%)
Groppetti et al. (2015)	Calculated	31/45 (68.9%)	41/45 (91.1%)
Breed-specific	Reported	40/48 (83.3%)	44/48 (91.7%)
Milani et al. (2013)	Calculated	24/45 (53.3%)	35/45 (77.8%)
Breed-specific	Reported	2/9 (22.2%)	4/9 (44.4%)

4.3. Study population and design

Some parts of the study population might not be fully representative. This was caused by a small number of bitches and a large number of observations as seen with Pug and Miniature Bull Terrier with three bitches each resulting in 53 observations. This might result in a falsely high accuracy due to a low biological variation described by the models. Also, a great variation was observed between the number of examinations per bitch and per pregnancy. For this reason, some bitches contributed more to the model than others and this might also influence the accuracy in clinical practice.

The study populations of other studies were often dominated by miniature- or small-breed bitches resulting in a lack of research on larger canine breeds, especially giant-breed bitches. This also applies in the case of the present study. Our investigation of giant-breed bitches showed a large variation within the group. This large variation combined with the small study group and the lack of research should prompt further investigation into these breeds.

To the authors' knowledge, giant-breed bitches are difficult to obtain precise images due to the size of the animal and the deep thorax/abdomen. The long study period resulted in improvement of the operator's skills and the quality of the images due to technical development over time. Some of the earlier measurements might be influenced by this making the measurements more inaccurate and thereby influencing the model. This might have been the case with Dogue de Bordeaux having the most examinations performed in the early part of the study period. Shortening the time span of the study would result in smaller groups of bitches leading to lower statistical powers of the models.

Some differences were observed between studies regarding assigning the breeds into the different weight groups due to different cut-offs. A standardization is needed to promote better comparisons between the models if maternal weight grouped models should be used. The body condition score should be considered for both underweight and overweight bitches when using the actual maternal weight to assign the bitch to a weight group. To avoid misplacing of bitches, an objective scale could be used, e.g. breed standards.

5. Recommendations

We recommend the use of breed-specific models rather than maternal weight grouped models in clinical practice. This recommendation was supported by (1) statistically significant effect from grouping by breed indicating a higher precision of predicted day of parturition, (2) statistically significant differences between slopes and intercepts for some miniature-breed and small-breed bitches supporting grouping by breed due to statistically detectable differences between breeds, and (3) at least two out of three breeds obtained better accuracies with the breed-specific model at ±2 days.

Also, we recommend the use of models based on mixed linear models instead of simple linear models. This recommendation is based on the mixed linear model taking repeated measurements into account minimizing the risk of overestimation seen with the simple linear model.

6. Conclusion

In conclusion, breed-specific models are different from maternal weight grouped models due to a statistically significant effect of breed on the model. Also, breed-specific models are more accurate than maternal weight grouped models since 2 out of 3 of breeds within the maternal weight group obtained a better accuracy on ±2 days. Further investigation of the causes for discrepancies between predicted DBP and actual DBP is needed in order to increase the accuracies of the models. The authors suggest the use of mixed linear models for predicting day of parturition as ultrasonographic measurements of BP very often consists of repeated measurements from the same bitch and/or the same pregnancy. Accuracies obtained with the simple linear models in the present study should be interpreted with caution since they are calculated from the same data as the models are based upon. The effect of overestimation seen with the simple linear models will make the models appear more accurate than they truly are. It is expected that the accuracies of the mixed linear models will reflect the general population of bitches more accurately.

CRediT authorship contribution statement

Monica Due Pedersen: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Anja Bach Klesiewicz:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization. **Henriette Medom Marqvorsen:** Conceptualization, Methodology, Investigation, Resources, Writing – review & editing. **Hanne Gervi Pedersen:** Conceptualization, Supervision, Writing – review & editing. **Jan Bojsen-Møller Secher:** Conceptualization, Methodology, Software, Formal analysis, Supervision, Writing – review & editing.

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Appendix A. Models

Table 7
Breed-specific models and maternal weight grouped models from the study population derived from mixed linear regression analysis and breed-specific models derived from simple linear regression analysis along with r^2.

Breed	Mixed linear model	Simple linear model	Maternal weight grouped model
Chihuahua	DBP = -0.6562*BP+25.1119	DBP = -1.4911*BP+37.6103 r^2 = 0.9681	DBP = -0.6573*BP+25.2357
Coton de Tulear	DBP = -0.6915*BP+26.4288	DBP = -1.4694*BP+38.6023 r^2 = 0.9835	
Toy Poodle	DBP = -0.6295*BP+24.5305	DBP = -1.5425*BP+38.5365 r^2 = 0.9487	
Shetland Sheepdog	DBP = -0.6206*BP+25.7627	DBP = -1.5914*BP+41.1929 r^2 = 0.9807	DBP = -0.6638*BP+26.4461
Cavalier King Charles Spaniel	DBP = -0.7049*BP+27.2530	DBP = -1.4051*BP+38.4082 r^2 = 0.9856	
Pug	DBP = -0.6979*BP+26.8555	DBP = -1.4200*BP+38.4733 r^2 = 0.9966	
Staffordshire Bull Terrier	DBP = -0.7278*BP+28.9938	DBP = -1.3666*BP+39.7636 r^2 = 0.9717	DBP = -0.7269*BP+29.1359
Border Collie	DBP = -0.7327*BP+29.5890	DBP = -1.3454*BP+40.0579 r^2 = 0.9916	
Miniature Bull Terrier	DBP = -0.7002*BP+28.9938	DBP = -1.3829*BP+39.6763 r^2 = 0.9751	
Golden Retriever	DBP = -0.7661*BP+30.9052	DBP = -1.3041*BP+40.3259 r^2 = 0.9840	DBP = -0.7785*BP+30.8860
German Shepherd	DBP = -0.7869*BP+30.5496	DBP = -1.2531*BP+38.7819 r^2 = 0.9830	
Labrador Retriever	DBP = -0.7987*BP+31.3938	DBP = -1.2304*BP+39.0647 r^2 = 0.9889	
Newfoundland	DBP = -0.8660*BP+34.0807	DBP = -1.0672*BP+37.0694 r^2 = 0.9228	DBP = -0.8163*BP+32.6374
Dogue de Bordeaux	DBP = -0.7833*BP+31.8940	DBP = -1.1390*BP+38.5097 r^2 = 0.8652	
Leonberger	DBP = -0.8179*BP+32.1334	DBP = -1.1911*BP+38.7359 r^2 = 0.9590	

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