Pelvimetry: the repeatability and reproducibility of the Rice pelvimeter in South-African beef cattle

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Abstract

The main determinants for dystocia in beef cattle are the birthweight of the calf and the size of the pelvic area of the dam. The disproportion of these factors is the Foeto-Pelvic-Incompatibility (FPI). To reduce the incidence of dystocia, heifers with a pelvic size below an established cut-off value could be excluded in breeding program. Pelvimetry could be used to measure the pelvic size but it has to be a reliable method to prevent unnecessary culling. In the current study pelvic measurements are performed in 230 beef cattle (186 females and 44 males) divided in 4 different breeds in South Africa, with the Rice pelvimeter. The pelvic height and pelvic width were measured two times by three observers. One observer is experienced with pelvimetry and the Rice pelvimeter the other two observers are inexperienced.

The Pearson correlation for the pelvic measurements within the experienced observer is 0.95 and within the inexperienced observers it is around 0.86. The Pearson correlations between the observers for the respective pelvic measurements are all above 0.9. The difference between the first and second measurement within the same animal is for the experienced observer about 80% within a range of +/- 0.5 cm and around 65% for both inexperienced observers. Compared to the experienced observer the inexperienced observers underestimate the pelvic width and overestimate the pelvic height. The bias for the experienced observer is smaller. The intraclass correlation coefficient for the observer within the same animal is 0.72, 0.53 and 0.66. If training and experience are taken into consideration pelvic measurement can be used to exclude the heifers with the smallest pelvic area within a breeding program.

Introduction

Calving difficulties, dystocia, have great influence on the beef cattle industry (1,2). Dystocia has a negative impact on the economics of the industry (3) and the welfare of the animals (4). There already has arisen ethical resistance because some beef cattle cannot calve in a natural way but need a caesarean section as standard procedure (5).

Calving difficulties, with even the slightest assistance at birth is associated with delayed uterine involution and delayed onset of luteal activity post-partum in cows (2). Calves born after dystocia can experience a reduced transfer of passive immunity. A total failure of passive immunity transfer was diagnosed in 43% of the calves born after dystocia compared with 27% in calves born without assistance and this results in a higher treatment and mortality rates in calves born after dystocia (4).

Multiple factors are associated with dystocia including the size, gender, birth weight and position of the calf, length of gestation, the pelvic size and Body Condition Score (BCS) of the calving cow (2). The main determinants for dystocia are calf birth weight and the pelvic area of the dam (6-8). The disproportion of the factors is defined as the Foeto-Pelvic Incompatibility (FPI): the size of the calf is not proportional to the size of the pelvis (9). To decrease the risk of dystocia the birth weight of the calf can be reduced by selecting sires with offspring with low birth weight or by optimizing the nutrition of the calving cow (2). The other option is to enlarge the pelvic size of the dam because 22.1% of the calving difficulties are caused by a small pelvic area. The pelvic conformation has a heritability of 0.43 – 0.59 for pelvic height and 0.36 – 0.82 for pelvic width in Aberdeen and Hereford breeds (10). The pelvic area has a heritability of 0.24 – 0.92 with an average of 0.51 (1). An enlargement of the pelvic area of 12.2 cm^2 could be achieved in one generation if direct selection for pelvic area is applied. Pelvic size and body weight are positively correlated but about 90% of the enlargement in pelvic size is independent of body weight. This means that increasing the pelvic area can be accomplish without causing a significant growth in cow size (10). To decrease the risk of dystocia a breeding program with animals with a minimum pelvic size can be considered (11).

The pelvic size can be measured with the method of pelvimetry. To select animals with a minimal pelvic size for a breeding program pelvimetry must produce reliable results. The measurements have to be accurate and consisted, regardless of the observer or circumstance (12). In order to make practical use of the relationship between the pelvic area and birth problems the measurements must show similarity:

- The repeatability of measurements is the variation in two repeated measurements, measured by the same observer under identical conditions. This is the repeatability within observer (13).
- The reproducibility of measurements is the variation in measurements with different conditions. For example, the variation between two measurements of the same subject made by different observers under identical conditions. This is the repeatability between observers (13).

The repeatability within observer and the repeatability between observers was studied in Van Donkersgoed et al. (1993). Two experienced veterinarians measured 256 animals with two different pelvimeters: the Rice pelvimeter and the Krautmann pelvimeter. The repeatability for pelvic area was based on kappa scores and was classified using three different cut-off values. Between the observers was a poor level of agreement in selecting the heifers with a pelvic area below of above the predetermined cut-off point for both pelvimeters (0.02 – 0.43). Within observer the repeatability was moderate (0.4 – 0.6). The Rice pelvimeter had a higher measurement of agreement within observer compared to the Krautmann pelvimeter (0.63 and 0.37 receptively). In the second part of the study the predictive value of pelvimetry on dystocia was studied. The mean of the pelvic area of heifers with dystocia was smaller in comparison to the animals without dystocia. However, the predictive value was low to moderate. Dystocia was expected in 36% of the heifers, these heifers had a pelvic area of 140cm^2 or smaller. Only 30% of the heifers that were expected to have dystocia experienced dystocia. The sensitivity for dystocia was 59% indicating that 41% of the heifers with dystocia was not identified with pelvimetry because the heifers had a pelvic area larger than 140cm^2.

Paputungan et al. (1993) studied the accuracy of pelvic measurements with the Rice pelvimeter and the effect of the operator on the pelvic measurements using the Intraclass Correlation Coefficient (ICC). The model did not take account for variation between animals within breed. The within observer repeatability was based on explained variance and was classified as moderate. For the pelvic height the correlation was 0.53 and for and pelvic width it was 0.46. To increase accuracy for pelvic height and pelvic width at least two measurements must be performed. Two experienced and two inexperienced operators measured in a period of 8 days 4 times 30 heifers. The estimated operator variance was very small (0.02 and 0.06 for pelvic height and pelvic width respectively) compared to the residual variance (0.39 and 0.36 for pelvic height and pelvic width respectively). This implied that the observer had a small contribution to the total variability.

Kolkman et al. (2009) studied the accuracy of measurements with the Rice pelvimeter for pelvic height and pelvic width performed 12 hours before and 2 hours after slaughtering beef cattle. All measurements were performed once by the same observer. The Pearson correlation coefficient between the measurements in living and dead animals was moderate for pelvic height, pelvic width and pelvic area (0.56, 0.46 and 0.59 respectively). The mean differences between measurements on living and dead animals were -0.2 cm for pelvic width (95% limits of agreement: -2.5 – 2.1) and 1.2 cm for pelvic height (95% limits of agreement: -1.8 – 4.1). The agreement between the performed measurements at living and dead animals was a moderate to good. In contrast to Van Donkersgoed et al. (1993), Kolkman et al. (2009) recommend pelvimetry with the Rice pelvimeter as a proper method to select heifers in breeding programs to decrease the incidence of dystocia.

The purpose of this cross-sectional study is to determine whether pelvic measurements in four different South African beef breeds are repeatable and reproducible using the Rice pelvimeter applied by one experienced observer and two inexperienced observers and the influence of the experience of the observers on the variability. When pelvimetry is found precise it can be considered as an additional selection method in a breeding program. This study is part of a research about the predictive value of pelvimetry in relation with dystocia.

Material & methods

Animals

All data was collected between July 21 and August 5 of 2015. On behalf of this research 230 beef cattle were included: 186 females and 44 males. Four different breeds have been measured for this study, from six herds:

- 41 animals of the Brahman breed, a bos indicus breed: one herd, 30 females and 11 males.
- 54 animals of the Nguni breed, a bos Taurus Africanus breed: two herds, both from to the same farm, the first herd consisted of 37 females and the second herd consisted of 17 males.
- 75 animals of the Bonsmara breed, a composite breed: two herds. The first herd consisted of 35 cattle of which 29 females and 6 males. The second herd consisted of 40 females.
- 60 animals of the Hereford breed, a bos Taurus breed: one herd of which 50 females and 10 males.

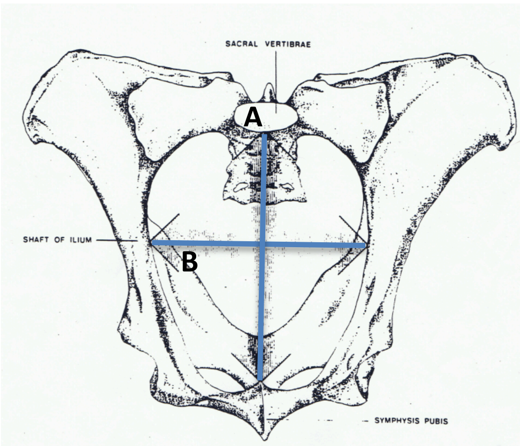
All animals were clinically healthy during measurements. Three animals were excluded because they were too dangerous to handle.

The sample size is not calculated but based on earlier studies about the repeatability of pelvimetry. These studies had sample sizes as n = 1146 (14) , n = 466 (11) and n = 143 (15). In the studies were a different number of observers. Van Donkersgoed et al. (1993) had a sample size of 1146 animals, the study had two observers instead of three as in the current study. More observers increase the precision of the observations. The study of Kolkman et al. (2009) had only one observer with 466 animals. In Paputungan et al. (1993) 30 animals were measured twice by four observers and 143 animals were measured four times by one observer. For the current study it was decides to measure 50 animals of each breed, approximately 200 animals in total. The farms were selected based on the number of animals that were available, their willingness to participate, availability of records, facilities and for efficiency in time and cost: their proximity to Onderstepoort, the location of the faculty of veterinary science.

Measurements

Body length, shoulder height and heart girth were measured collectively. The Body Condition Score (BCS), pelvic height and pelvic width were measured individually. The first observer also examined the female animals for pregnancy. Date of birth was provided by the farm, gender and identification number were collected during measurements. The body length was measured from the shoulder joint to the trochanter major, the shoulder height was the distance from the ground to the withers and the heart girth was the circumference of a square standing animal, just behind the elbows (Figure 2). All measurements are in centimetres. The BCS was scored using a 9-point scale (16). For the intrapelvic measurements, the Rice pelvimeter (Lane Manufacturing, 2075 So. Balentia St., Unit C, Denver, Colorado, USA) was required. The instrument consists of two aluminium arms. One side has a 0.5 cm scale up to 20 centimetres. The measurements on the inside of the animal are corresponding with the centimetres on the scale on the outside of the animal. One side of the Rice pelvimeter enters the rectum by hand guidance. The pelvic height is measured between the pubic symphysis and the sacral vertebrae (Figure 1: A). The pelvimeter tends to slip off the symphysis and sacral vertebrae so the pelvimeter has to be held in place with one hand during measurements. The pelvic width is the distance between the shafts of the ilium at the widest point (Figure 1: B).

To determine the repeatability and the reproducibility within and between observers, every animal is measured by all three of observers, and every observer measured pelvic height and pelvic width in all animals twice on one day with several hours between the two measurements. Observer 1 was an experienced veterinarian, with extensive experience with the Rice pelvimeter. Observers 2 and 3 were master students in veterinary science from Utrecht University, The Netherlands, with no experience with the Rice pelvimeter or pelvimetry. To achieve the smallest human error as possible the inexperienced observers were trained before measurements started. They got explained how to use the Rice pelvimeter in the right way and they were able to practice four times for several hours on artificial animals and cattle of the faculty of veterinary science.



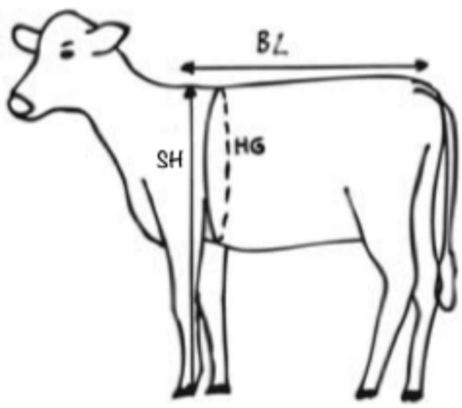


Figure 1. A: distance measured for the pelvic height and B: distance measured for pelvic width. Adjusted from LeFever, 2016 (17).
Figure 2. Lateral view of the cow with the body length (BL), heart girth (HG) and shoulder height (SH). Adjusted from Kolkman et al., 2007 (18).

Methods
Observer 1 measured the pelvic height and the pelvic width with the pelvimeter, scored the BCS and examined if the female cattle were pregnant or not. During the measurements of observer 1, observer 2 and 3 measured the heart girth, shoulder height and body length (Figure 2). Followed by observer 2 which measured the pelvic height, the pelvic width and scored the BCS. Observer 3 measured the same as observer 2. To secure the safety of the observers all animals were fixated in a neck clamp during measurements. To prevent influence on another every observer measured individual and measurements were written on separate sheets. After all the animals were measured once the measurements of the pelvic height and pelvic width were repeated in random order.

Statistics
Data was collected on paper during measurements, later incorporated in Microsoft Excel and checked. For statistical analysis the data was exported to IBM SPSS Statistics 24 (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp). The

intrapelvic area was calculated by multiplying the pelvic height and the pelvic width. Descriptive statistics provide an overview on the population.

To perform statistics between observers the mean of the pelvic height, pelvic width and pelvic area of each observer was calculated first. The mean of observer 1, the experienced observer, was compared to observer 2 and observer 3, the inexperienced observers. The Pearson correlation coefficients is calculated for the correlation between the first measurement and the second measurement for each of the observers separately. This reflects whether the repetition has the same result within the same subject, by the same observer. The Pearson correlation coefficient is calculated between the means of the different observers within the same animal as well.

The absolute difference can be calculated between both measurement (measurement 1 – measurement 2) within observer and between the mean of the observers. The Bland-Altman plots can indicate the difference between the measurements within observer. The mean of the two measurements is plot towards the difference between first and second measurement. If the bias is close to 0, the difference between the first and second measurement is the smallest. In the Bland-Altman plots systematic differences and outliers that may have influenced the Pearson correlation can emerge.

In the Bland-Altman plot the agreement between two quantitative measurements is described and in the Pearson correlation coefficient the measure of correlation is defined (19). The Intraclass Correlation Coefficient (ICC) is a method to determine agreement and include both methods of the Bland-Altman plots and the Pearson correlation coefficient. Unlike the Pearson correlation coefficient; the ICC takes into account systemic errors. The ICC is expressed as a relative measure of explained variance of the total random variance (20). An ICC close to 0 indicates a low correlation between the measurements. To estimate the ICC, a fixed effects linear mixed model (21) is used for pelvic height, pelvic width and pelvic area. Random effects are added for the observer and animal for the correlation between the two measurements. Animal characteristics like breed, BCS, gender, heart girth, shoulder height and body length are added to the model as fixed effects so the variation between animals is taken into account in the model. The results of the model are used to calculate the ICC by the following formulas (20):

1. The ICC for observer between different animals:
$$ICC\ observer = \frac{\sigma^2\ observer}{\sigma^2\ residual + \ \sigma^2\ observer + \ \sigma^2\ animal}$$

2. The ICC for animal between different observers:
$$ICC\ animal = \frac{\sigma^2\ animal}{\sigma^2\ residual + \ \sigma^2\ observer + \ \sigma^2\ animal}$$

3. The ICC for observer within the same animal:
$$ICC\ animal + \ observer = \frac{\sigma^2\ animal + \ \sigma^2\ observer}{\sigma^2\ residual + \ \sigma^2\ observer + \ \sigma^2\ animal}$$

Results

In total 230 animals from 4 different South African breeds were studied (Table 1). The number of males, females, pregnant females and animals per breed are not evenly distributed. In all breeds mostly females were measured and no pregnant animals of the Nguni breed are included in this study. The date of births of one herd of Bonsmara cattle and one herd of Nguni cattle herd are unknown. The animals of the Nguni breed are the smallest animals in mean body length, shoulder height and heart girth. The largest mean of all body measurements is measured in the animals of the Hereford breed. Age is highly variable between breeds and within breed. The animals of the Bonsmara breed are on average the oldest animal in this study. The breeds with the lowest mean age are the Brahman (247 days) and Hereford (202 days).

Table 1. Descriptive statistics of number and distribution of animal characteristics by breed. Body length, shoulder height and heart girth are measured once before the pelvic measurements.

		Bonsmara	Brahman	Nguni	Hereford	Total
Animals (n)		75	41	54	60	230
Male (n)		6	11	17	10	44
Female (n)		69	30	37	50	186
	Pregnant	30	5	0	20	55
Body length (cm)	*Mean*	118.3	118	110.6	120	
	Range	102 – 141	102 – 140	98 – 131	98 – 134	
Shoulder height (cm)	*Mean*	119.8	120.2	111.8	121.4	
	Range	107 – 132	108 – 134	101 – 127	109 – 135	
Heart girth (cm)	*Mean*	170.5	166.8	146.9	189	
	Range	148 – 203	140 – 199	124 – 175	154 – 234	
Age (days)*	*Mean*	849	581	781	617	
	Range	589 – 1105	247 – 942	578 – 1187	202 – 822	
Pelvic height (cm)**	*Mean*	15.6	15.3	14.1	15.7	
	Range	12 – 20	13 – 17.5	12 – 17	11 – 19	
Pelvic width (cm)**	*Mean*	12.5	10.4	9.7	13.7	
	Range	9.0 - 16	8.0 – 13.0	7.5 – 12.5	7.5 – 17	
Pelvic area (cm^2)**	*Mean*	197.1	160.1	138.2	218.2	
	Range	120 – 300	112 – 212.5	90 – 212.5	90 – 304	

** Date of birth is unknown for 41 animals of the Bonsmara breed, 19 animals of the Nguni breed & 2 animals of the Hereford breed.*
*** Based on the first measurements of the experienced observer.*

The pelvic height and pelvic width are also displayed in Figure 3. Animals of the Nguni breed have on average the smallest pelvic area (mean: 138.2) and the animals of the Hereford breed have on average the largest pelvic area (mean: 218.2). The box plot of the pelvic area is included in Appendix 1. The shape of the pelvic area is variable. Compared to the animals of the Hereford and Bonsmara breed the animals of the brahman and Nguni breed have a more vertically oval-shaped pelvis.

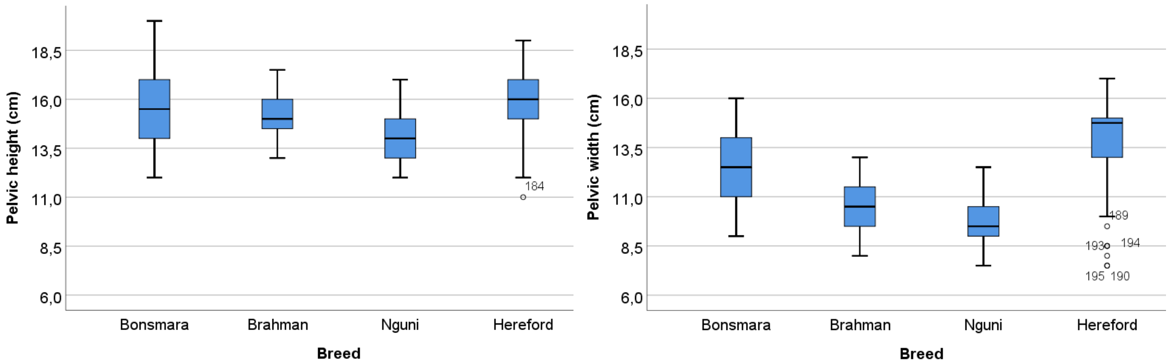


Figure 3. Box plots of the pelvic height and pelvic width for each of the four breeds. Based on the first measurements of the experienced observer.

In Figure 4 the pelvic area is related to the age of the cattle in days. The ages of the four measured breeds are variable. Most cattle have an age between 600 and 800 days. The growth curves of pelvic area seem to be different between the breeds (Figure 4). The animals of the Nguni breed seem to have the lowest growth. This is mainly caused by the pelvic width (Appendix 2). The animals of the Hereford breed show the most growth of the pelvic area.

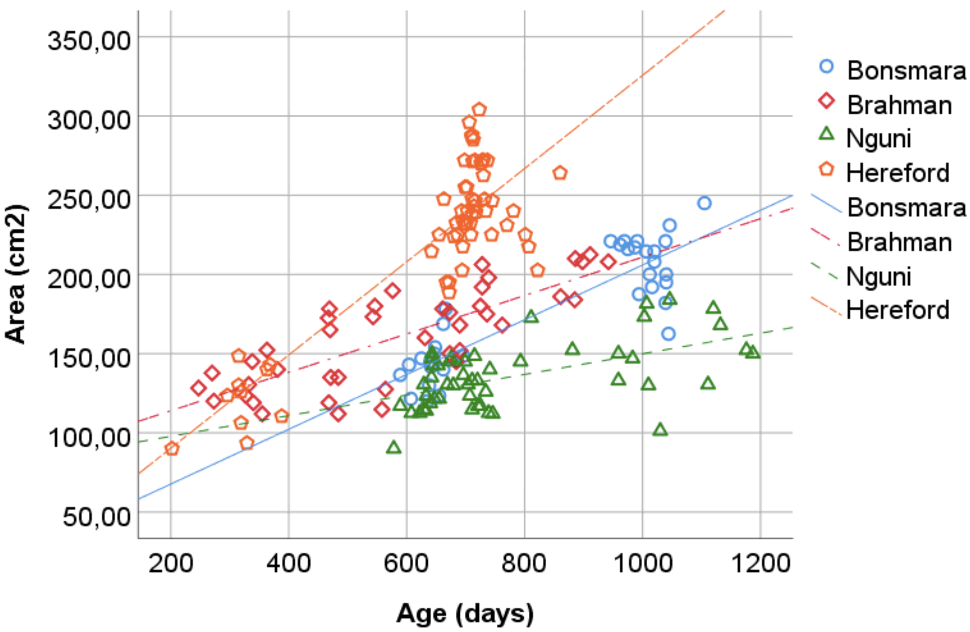


Figure 4. Scatterplot of age versus pelvic area with markers and linear regression line set for breeds.

The Pearson correlation coefficients (Table 2) are calculated between pelvic measurements within observer and between the mean of the measurements of observer 1 and 2 and between observer 1 and 3. The correlation within observer 1 for the pelvic height, pelvic width and pelvic area are all above 0.95. The correlation coefficient within observer 1, the experienced observer is the highest in comparison to inexperienced observers 2 and 3. All within correlation coefficients are above 0.80. Between the observers means the correlation coefficient is not below 0.90.

Table 2. Correlation between the both measurements within observer 1, 2 and 3 and between the observer means of both measurements.

	Pearson correlation coefficient		
Within observer	**1***	**2**	**3**
Pelvic height	0.95	0.80	0.87
Pelvic width	0.96	0.90	0.87
Pelvic area**	0.97	0.92	0.91

Between observers	**1 – 2**	**1 – 3**
Pelvic height	0.90	0.90
Pelvic width	0.96	0.95
Pelvic area**	0.96	0.96

** Observer 1 is the experienced observer*
*** Calculated area = pelvic height x pelvic width*

Table 3. Estimates for linear regression coefficient and 95% confidence interval (95% CI) between the mean of measurements of observer 2 and observer 3 respectively with observer 1*.

	Linear regression coefficient	
Between observers	**1 – 2**	**1 – 3**
	Estimate (95%CI)	**Estimate (95%CI)**
Pelvic height	0.89 (0.83 – 0.94)	0.95 (0.89 – 1.01)
Pelvic width	1.02 (0.98 – 1.06)	1.14 (1.09 – 1.18)
Pelvic area**	0.94 (0.91 – 0.98)	1.05 (1.01 – 1.09)

** Mean observer 1 = a + b · mean observer 2 / 3*
***Calculated area = pelvic height x pelvic width*

If the regression coefficient in Table 3 would be 1, the measurements on the same animal performed by different observers are on average equal. The observers measure similar values if the confidence interval of the slope includes 1. The regression coefficient for pelvic height is below 1, this means the inexperienced observers overestimate the pelvic height on average. Between the mean of observer 1 and 3 the overestimation is not significant because the 95% CI contains 1. The pelvic width is underestimated by the inexperience observers but the 95% CI between the mean of observer 1 and observer 2 contains 1: the observers measure similar values. The pelvic width is not significant underestimated by observer 2. Observer 2 overestimated the pelvic area and observer 3 underestimated the pelvic area compared to observer 1.

Table 4. The number (n) and percentage (%) of the differences in cm between the first and second measurement of the observer (within observer) and between the means of the observers (between observers) for pelvic height and pelvic width.

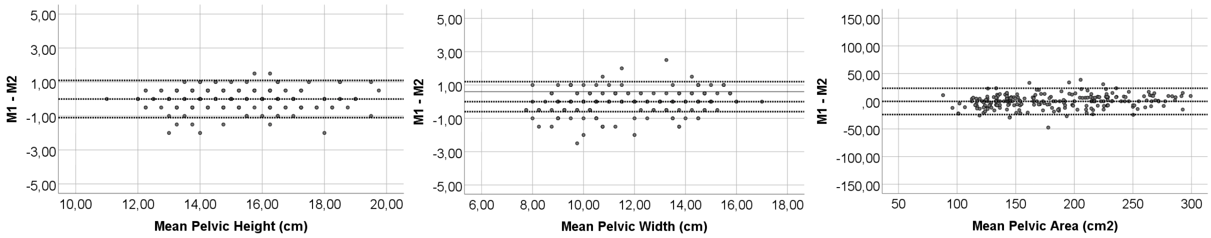
	Within observer			Between observers		
Observer:	**1**	**2**	**3**	**1 – 2**	**1 – 3**	**2 – 3**
Pelvic height	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
-4.5 – -1.75*	0 (0.0)	10 (4.3)	10 (4.3)	3 (1.3)	1 (0.4)	2 (0.8)
-1.5 – -1.25**	2 (0.9)	10 (4.3)	11 (4.8)	4 (5.3)	5 (2.7)	6 (2.6)
-1.0 – -0.75	14 (6.1)	23 (10.0)	20 (8.7)	6 (2.6)	13 (5.7)	23 (10.0)
-0.5 – -0.25	50 (21.7)	43 (18.7)	57 (24.8)	16 (6.9)	24 (10.4)	37 (16.1)
0.0	105 (45.7)	77 (33.5)	68 (29.6)	17 (7.4)	21 (9.1)	48 (20.9)
0.25 - 0.5	43 (18.7)	35 (15.2)	38 (16.5)	69 (30)	66 (28.7)	64 (27.8)
0.75 - 1.0	9 (3.9)	18 (7.8)	16 (7.0)	73 (31.7)	62 (27)	33 (14.4)
1.25 - 1.5	4 (1.7)	6 (2.6)	5 (2.2)	24 (10.4)	28 (12.2)	13 (5.7)
1.75 – 4.5*	3 (1.3)	8 (3.5)	5 (2.2)	18 (7.8)	10 (4.3)	4 (1.7)
Pelvic width	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
-6.5 – -1.75*	2 (0.9)	10 (4.3)	10 (4.3)	0 (0.0)	3 (1.3)	3 (1.3)
-1.5 – -1.25	2 (0.9)	9 (3.9)	14 (6.1)	5 (2.2)	12 (5.2)	4 (1.7)
-1.0 – -0.75	19 (8.3)	21 (9.1)	25 (10.9)	14 (6.0)	21 (9.1)	17 (7.4)
-0.5 – -0.25	42 (18.3)	51 (22.2)	52 (22.6)	36 (15.7)	43 (18.6)	55 (23.9)
0.0	102 (44.3)	69 (30.0)	58 (25.2)	35 (15.2)	28 (12.2)	32 (13.9)
0.25 - 0.5	32 (13.9)	36 (15.7)	38 (16.5)	83 (36.1)	70 (30.5)	75 (32.7)
0.75 - 1.0	20 (8.7)	17 (7.4)	15 (6.5)	36 (15.7)	37 (16.1)	22 (9.6)
1.25 - 1.5	8 (3.5)	13 (5.7)	9 (3.9)	14 (6.0)	9 (3.9)	14 (6.1)
1.75 – 3.5*	3 (1.3)	4 (1.7)	9 (3.9)	7 (2.9)	7 (3.0)	8 (11.6)

** Maximum difference between measurements is -4.5, 4.5, -6.5 and 3.5.*
***Within observer the measurements can differ with increments of 0.5 cm. Between the means of the observers the measurements can differ with increments of 0.25.*

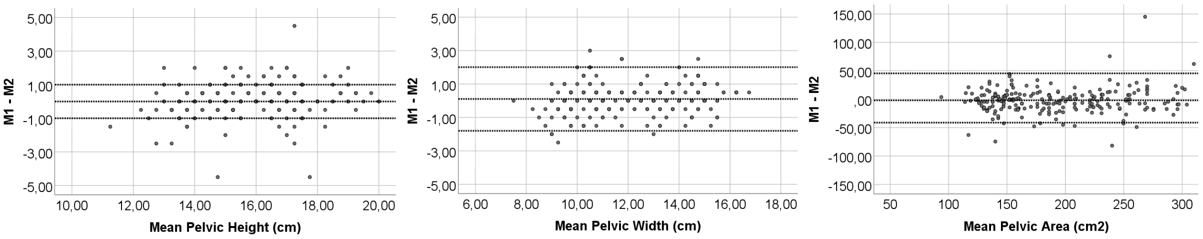
The absolute differences within observer and between observers are presented in Table 4. The experienced observer (observer 1) has more measurements with equal results (pelvic height 45.7% and pelvic width 44.3%) compared to the inexperienced observers. The inexperienced observers have both around 30% equal measurements in pelvic height and pelvic width. More than three-quarters of the difference between both measurements (86.1% and 76.5% for pelvic height and pelvic width respectively) of observer 1 is within the range -0.5 to 0.5 cm. For observer 2 and 3: 60-70% of the differences between both measurements are between -0.5 cm and 0.5 cm. Within the inexperienced observers around 7% of the absolute difference between measurements was larger than 1.5 cm. The maximum difference between two measurements is 4.5 cm for pelvic height and 6.5 cm for pelvic width. Observer 3 has the most differences between the first- and second- time measurements as only 29.6% of the pelvic height and 25.2% of the in pelvic width have equal results. The differences between the means of the observers for pelvic width are comparable: about 60-70% of the differences were in the range of -0.5 cm and 0.5 cm. Between the mean of the pelvic height of the inexperienced observers 65% is between -0.5

cm and 0.5 cm. Between the experienced and either of the inexperienced observers it is around 46% for the pelvic height.
In the Bland-Altman plots (Figure 5) the middle, dotted line represents the mean difference between the repeated measurements. For observer 1 the mean difference between the measurements is the smallest: the bias is closest to 0. The bias is negative this implies the first measurement is on average smaller in comparison to the second measurement. The inexperienced observers have in contrast a positive bias, in this case the second measurement is smaller. The standard deviation in observer 1 is smaller than the standard deviation of observer 2 and 3. No systemic differenced or outliers have emerged in the Bland-Altman plots.

Observer 1:
A) Bias: -0.03 STD: 0.66 B) Bias: -0.01 STD: 0.68 C) Bias: -0.25 STD: 12.13



Observer 2:
D) Bias: 0.07 STD: 0.97 E) Bias: 0.11 STD: 0.97 F) Bias: 2.09 STD: 22.14



Observer 3:
G) Bias: 0.15 STD: 0.84 H) Bias: 0.11 STD: 0.98 I) Bias: 3.71 STD: 20.10

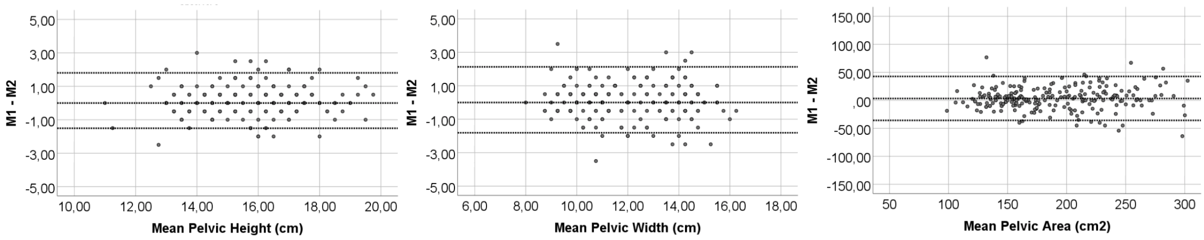


Figure 5. Bland-Altman plots of the mean of the pelvic measurements (M1, M2) versus the difference between both measurements (M1-M2) in the same animal within observer. The plots in the rows are based on observer and the plots in the columns describe the pelvic size: Pelvic height (A, D, G), pelvic width (B, E and H) and pelvic area (C, F and I. The middle, dotted line represents the mean of the differences (bias) between the first and the second measurement within observer. The upper and lower dotted lines are the limits of agreement (mean +/- 1.96·STD). Each point in the Bland-Altman plot can represent multiple measurements.

Table 5. Intraclass Correlation Coefficient (ICC) for pelvic height, pelvic width and pelvic area respectively estimated from the results of the linear mixed effects model with adjustment for the variables: animal characteristics (breed, BCS and gender) and covariates (heart girth, shoulder height and body length). Calculated by the formula (20) described in materials & methods.

Measurement	$ICC_{observer}$	ICC_{animal}	$ICC_{observer\ within\ animal}$
Pelvic height	0.07	0.65	0.72
Pelvic width	0.02	0.52	0.53
Pelvic area	0.04	0.62	0.66

The outcome of the linear mixed effects model is presented in Table 5. The estimated $\sigma^2_{observer}$, σ^2_{animal}, $\sigma^2_{residual}$ which are used to calculate the ICC are presented in Appendix 3. ICC values close to 1 indicate excellent reliability when close to 0 the reliability is poor. The ICC for the observers between different animals ($ICC_{observer}$) is 0.07, 0.02 and 0.04 meaning there is a comparable distribution of measurements between observers and it means the correlation between the measurements in different animals within the same observer is low. The ICC of measurements of the same animals by different observers (ICC_{animal}) is much higher compared to the $ICC_{observer}$. The ICC for measurement within observer within the same animal ($ICC_{observer\ within\ animal}$) has the highest correlation for pelvic height, pelvic width and pelvic area (respectively 0.72, 0.53 and 0.66).

Discussion

The aim of this study was to determine whether pelvic measurements are repeatable and reproducible and to estimate the influence of the experience of the observer. The Pearson correlation for the pelvic measurements within observer 1 is very strong (0.95) (22). In observer 2 and 3 the correlation within observer is lower but still strong (0.80 – 0.92). Between the measurements of the experienced and inexperienced observers the correlation is 0.90 – 0.96: also classified as very strong. In the ICC multiple animal characteristics are added. The $ICC_{observer\ within\ animal}$ is for pelvic height, pelvic width and pelvic area: 0.72, 0.53 and 0.66 respectively (Table 5). This correlation is classified as a moderate reliability (21). In the Bland-Altman plots the experience observer has a smaller bias and a lower standard deviation compared to the inexperienced observers. The inexperienced observers tend to overestimate or underestimate the pelvic measurements (Table 3). Compared to observer 1 the calculated pelvic area is overestimated by observer 2 and underestimated by observer 3.

According to Holm et al. (2014) parity, age, body weight and BCS are related to the pelvic area (23). During measurements for this current study there was not a possibility to weigh the cattle and the age of 62 animals was unknown. Body weight and age are therefore not included as animal characteristics. However, age is related to body measurements and heart girth has a high correlation with body weight (24) on that account the animal characteristics are indirectly included in the model. In the ICC multiple animal characteristics (body length, heart girth and shoulder height) are added to the model to reduce the various sources of variability. Nevertheless, the non-explained variance is between 28 - 47% of the total random variance. This is mainly caused by the between animal variation. The proportion variance between animals is 0.1 for pelvic height and 0.01 for pelvic width (Appendix 3). This difference between pelvic height and pelvic width is not supported in current literature. The correlation coefficient between pelvic height and heart girth is equal to the correlation coefficient between pelvic width and heart girth (25). Both pelvic height and pelvic width are correlated equal to carcass weight (11).

Measurements were performed without local anaesthesia so cattle might have moved during measurements. The moving could have caused the pelvimeter to slip off the symphysis and sacral vertebrae and might have enlarged the measurement of the pelvic height. An inexperienced observer can have a slip off without notice which can explain the overestimation. This also might have happened when the pelvimeter was not held firmly into place. The ICC for the observer is below 0.1, this means a low level of clustering by the observers. Even though two observers were inexperienced all three observers scored in the same range. The positive bias in the Bland-Altman plots (Figure 5) of the inexperienced observers implicates an underestimation of the pelvic height and pelvic width during the second measurement. A high number of measurements were performed during the day all with one hand. This may affect the concentration and fitness of the inexperienced observer and could explain the underestimation.

Van Donkersgoed et al. (1993) found a moderate repeatability within observer based on kappa scores (0.4 – 0.6). The Pearson correlation within observer in Kolkman et al. (2009) was also moderate (0.46 – 0.59). In the current study a high Pearson correlation within observers is found (0.8 – 0.97). In Paputungan et al. (1993) the repeatability of pelvimetry was moderate based on the ICC: for the pelvic height it was 0.53 and for and pelvic width it was 0.46. In the current study the ICC for the repeatability of pelvimetry is moderate to good for pelvic height and pelvic with; 0.72 and 0.53 respectively. The small observer variances found in the current study are corresponding with the results in Paputungan et al. (1993).

In this current study multiple measurements per animal are taken by the observers. Taking multiple measurements is advised by Paputungan et al. (1993) because it can reduce the number of measurement errors which results in a lower number of misclassifications for culling, especially for inexperienced observers. When pelvic measurements become part of a breeding program it is inefficient in time and practice to perform multiple measurements. The experienced observer had the most measurements with equal results (Table 4) about 80% of the measurements have a maximum difference of +/- 0.5 cm; this is hypothetically +/- 0.5 cm is an acceptable error. During calving the pelvis can increase minimally due increased mobility of the ilio-sacral joints and relaxation of the pelvic ligaments (26). In the inexperienced observers about 65% of the measurements has a maximum difference of +/- 0.5 cm.

Between pre-breeding pelvic area and pre-calving pelvic area is a significant correlation (0.71) (7). This suggests that the pre-breeding area could be used to select heifers before insemination. Beef improvement federation (2016) adjust the actual pelvic area to a standard age of 365 days (27,28). However, the timing of performing measurements is essential. Synthetic oestrogen and progesterone were found to influence the pelvic sizes in young animals (29); this means that heifers must have reached puberty before pelvic measurements are performed. Ramin et al. (1995) concluded that cattle who already reached puberty had a larger pelvic area compared to the cattle of the same age who did not had reached puberty. Especially the pelvic height grows between 12 and 18 months in animals of the Belgian blue breed the average growth is 3.4 cm (25). A growth curve is different between breeds (30). The growth curve in Figure 4 might be slightly distorted because the age is not equally distributed between breeds. The animals of the Nguni breed have a smaller pelvic area, reach puberty at a significant ($P<0.01$) younger age and show less growth compared to the animals of the other breeds. Nevertheless, dystocia caused by FPI hardly occurs because the offspring of the animals of the Nguni breed is also smaller (31). It would be advised to include onset of puberty, pelvic size and growth curve of a specific breed in a formula before using pelvic measurements as a selection method for culling heifers with a pelvic area below a cut-off value.

The maximum width of the pelvimeter (20 cm) was reached in 5 animals of the Bonsmara breed. Animals with a larger pelvic height of pelvic width could not be measured properly and must be excluded from the study. In this current study the maximum width of the Rice pelvimeter was not a problem but must be taken into account when larger cattle must be measured.

Heritability estimates are at a considerable level meaning that selection on a larger pelvic size can lead to a higher percentage of cows that can calve without dystocia. It is not an option to change the pelvic size in one generation. A cut-off value has to be set per breed. To avoid inbreeding the heifers with the smallest pelvic area in ranking can to be culled in the first generations. If pelvic height and pelvic width are underestimated, the heifer could be culled unnecessarily. However, if the pelvic measurements are overestimated, heifers with increased risk for dystocia will be selected for breeding. A large pelvis remains large after a misclassification and the same applies to a small pelvis. For heifers with a pelvic area around the defined cut-off value this could have major consequences. The measuring of animals for selection can best be performed by one observer so the underestimation and overestimation will affect all animals in the same amount. The Rice pelvimeter is a user-friendly device but new observers must be well trained for valid measurements. In the Netherlands a number of organisations want to increase the percentage of cows that can calve without assistance within 20 years. In 4 – 5 generations they expect a structural effect of quadruplication of the percentage of cows that can have a natural calving (32).

The other factor in FPI is the birth weight of the calf. Selecting sires with low birth weight offspring is an important part to prevent dystocia (2). The dams of the Brahman breed have influence on the birth weight of the calf: they can suppress the foetal growth potential and have offspring with a maximal birth weight (6).

In conclusion, the pelvic measurements have good repeatability and reproducibility based on high Pearson correlation and a moderate to good $ICC_{\text{observer within animal}}$. Pelvimetry can be used in a breeding program to select the heifers with a too small pelvic area. The pre-breeding pelvic area of heifers can be used because it has a high correlation with the pre-calving area (7). However, heifers must have reached puberty (30). The importance of experience is emphasised in this current study. Training the observers is highly important to reduce the measurement error. Over 50% of the calving difficulties are caused by Foeto-

Pelvic-incompatibility (FPI) (3). Next, to decrease dystocia, sires with low birth weight offspring must be selected for breeding.

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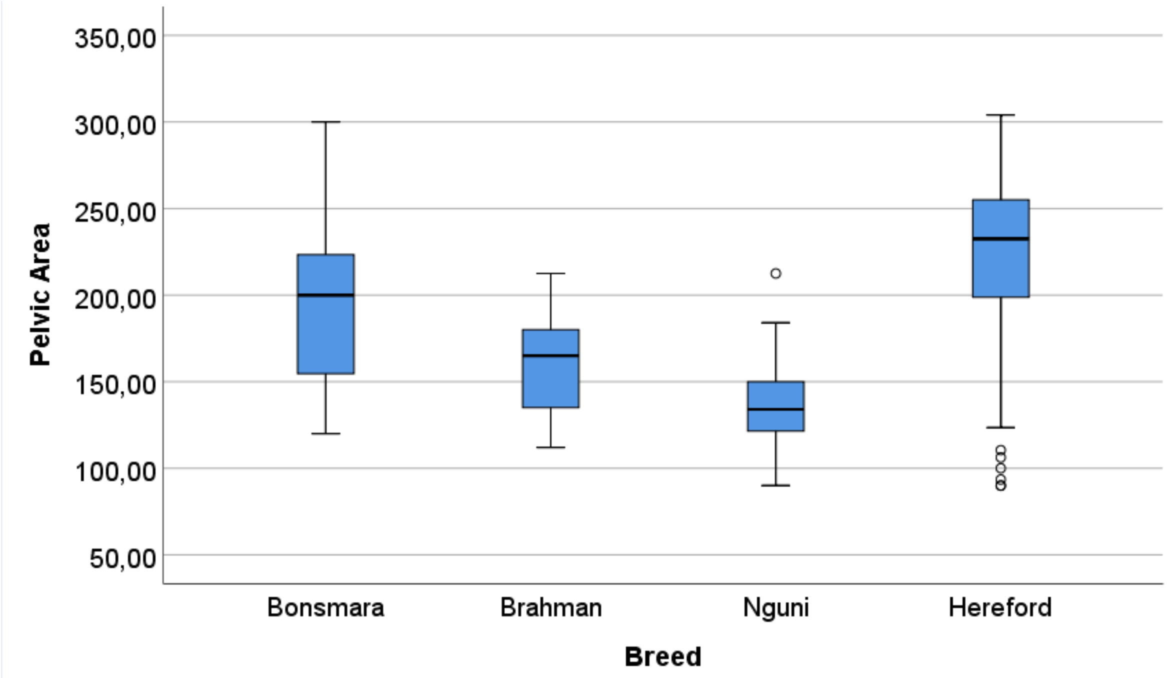
Appendix

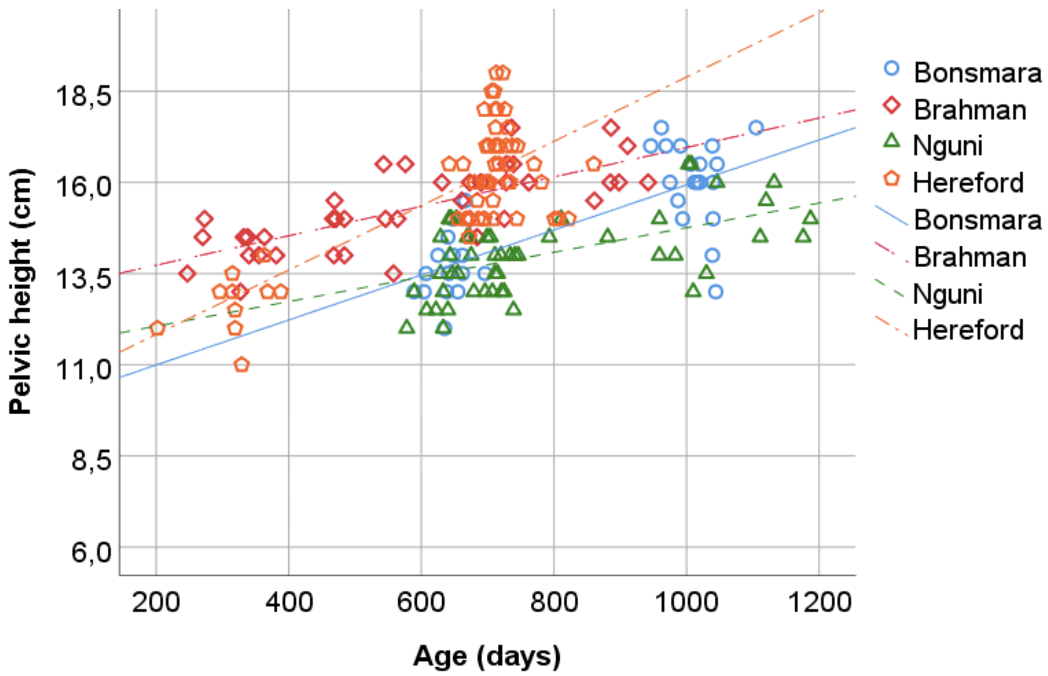
1. Box plot pelvic area



Box plot of the pelvic area in cm^2 for each of the four breeds. The animals of the Hereford breed have the largest pelvic area. The animals of the Nguni breed the smallest.

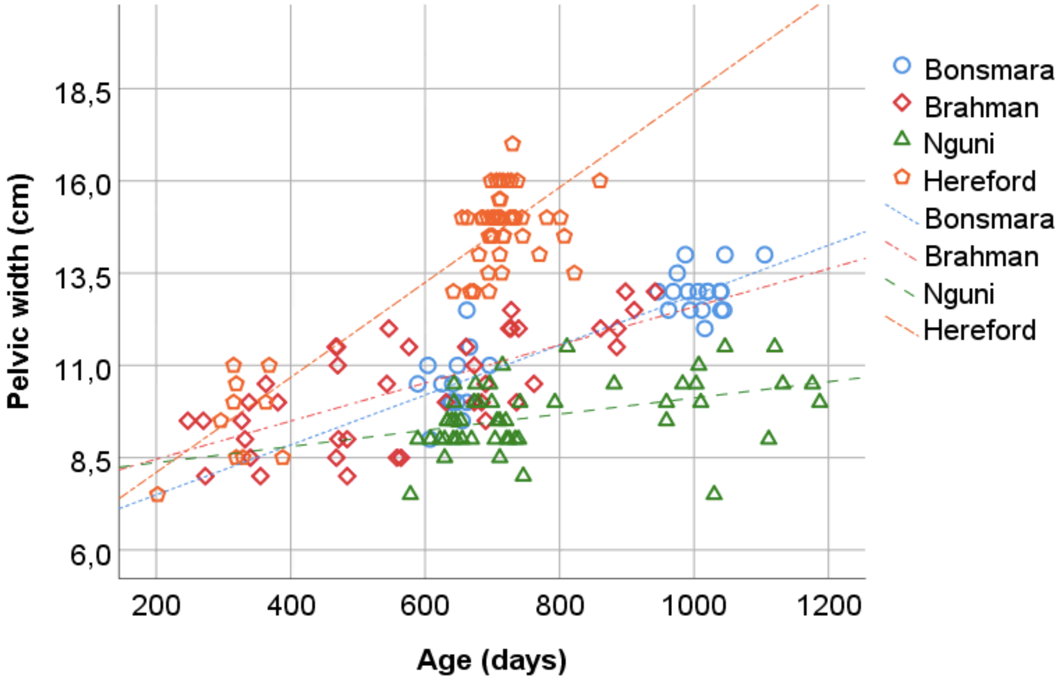
2. Scatterplot pelvic measurement versus age

2.1 Scatterplot of pelvic height versus age in days



Markers and linear regression line set for breeds. Date of birth is unknown for 19 animals of the Nguni breed, 41 animals of the Bonsmara breed & 2 animals of the Hereford. The slopes for the animals of the Nguni breed and the animals of the Hereford breed are the flattest.

2.3 Scatterplot of pelvic height versus age in days.



Markers and linear regression line set for breeds. Date of birth is unknown for 19 animals of the Nguni breed, 41 animals of the Bonsmara & 2 animals of the Hereford. The slope for the animals of the Nguni breed is the most flat.

2. Intraclass Correlation Coefficient

To calculate the ICC for pelvic height, pelvic width and pelvic area a linear mixed effects model is used. Multiple animal characteristics are added in fixed effects to take account of the variation between animals. The characteristics are: breed, BSC, gender, heart girth, shoulder height and body length. In 3.1, 3.2 and 3.3 the outcome of the linear mixed effect model is shown and completed formula of Shrout & Fleiss (1979) (20).

2.1 Calculation of the Intraclass Correlation Coefficient for the pelvic height

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	271,511	5,103	,025
BCS	5	1163,035	1,768	,117
Gender	1	215,549	96,713	,000
Breed1bonsmara2brahman3nguni4hereford	3	318,796	8,591	,000
body_length	1	309,873	21,373	,000
schoulder_height	1	405,504	6,949	,009
Heart_girth	1	326,984	48,111	,000

a. Dependent Variable: Pelvis_V.

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error
Residual		,429417	,018268
AnimalID	Variance	1,003025	,113832
PersonHEF	Variance	,103688	,104628

a. Dependent Variable: Pelvis_V.

Residual = σ^2 residual = 0.429
Animal ID = σ^2 animal = 1.003
Person HEF= σ^2 observer = 0.104

1. The ICC for observer between different animals:

$$\frac{0.104}{0.429 + 1.003 + 0.104} = 0.068$$

2. The ICC for animal between different observers:

$$\frac{1.003}{0.429 + 1.003 + 0.104} = 0.653$$

3. The ICC for observer within the same animal.

$$\frac{1.003 + 0.104}{0.429 + 1.003 + 0.104} = 0.720$$

2.2 Calculation of the Intraclass Correlation Coefficient for the pelvic width

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	289,965	101,857	,000
BCS	5	1233,037	2,263	,046
Gender	1	234,627	274,816	,000
Breed1bonsmara2brahman3nguni4hereford	3	314,266	27,696	,000
body_length	1	318,550	14,322	,000
schoulder_height	1	350,917	66,248	,000
Heart_girth	1	314,120	60,093	,000

a. Dependent Variable: Pelvis_H.

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error
Residual		,427199	,017885
AnimalID	Variance	,473986	,053534
PersonHEF	Variance	,015394	,016333

a. Dependent Variable: Pelvis_H.

Residual = σ^2 residual = 0.427
Animal ID = σ^2 animal = 0.474
Person HEF= σ^2 observer = 0.015

1. The ICC for observer between different animals:
$$\frac{0.015}{0.427 + 0.474 + 0.015} = 0.016$$

2. The ICC for animal between different observers:
$$\frac{0.474}{0.427 + 0.474 + 0.015} = 0.517$$

3. The ICC for observer within the same animal.
$$\frac{0.474 + 0.015}{0.427 + 0.474 + 0.015} = 0.534$$

2.3 Calculation of the intraclass correlation coefficient for the pelvic area

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	288,529	205,978	,000
BCS	5	1189,507	,511	,768
Gender	1	226,630	199,794	,000
Breed1bonsmara2brahman3nguni4hereford	3	324,052	17,136	,000
body_length	1	320,180	28,471	,000
schoulder_height	1	391,644	50,468	,000
Heart_girth	1	328,593	41,927	,000

a. Dependent Variable: Pelvic_area.

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error
Residual		246,227552	10,390761
AnimalID	Variance	453,538231	50,460203
PersonHEF	Variance	28,932195	29,471929

a. Dependent Variable: Pelvic_area.

Residual = σ^2 residual = 246.228
Animal ID = σ^2 animal = 453.538
Person HEF= σ^2 observer = 28.932

1. The ICC for observer between different animals:
$$\frac{28.932}{246.228 + 453.538 + 28.932} = 0.040$$

2. The ICC for animal between different observers:
$$\frac{453.538}{246.228 + 453.538 + 28.932} = 0.622$$

3. The ICC for observer within the same animal.
$$\frac{453.538 + 28.932}{246.228 + 453.538 + 28.932} = 0.662$$