The relationship between pelvis size and age, breed, gender, body measurements and reproductive status of South African beef cattle

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Abstract

Pelvis size, calf birth weight and their ratio are the most important predictors for dystocia. Selection of animals bases on pelvimetry can be used as a tool to prevent or decrease the cases of dystocia. This study looks for relationships between pelvis size and body measurements (body length, shoulder height, heart girth and body condition score (BCS)), reproductive tract score (RTS), gender and age in 4 different beef cattle breeds in the surroundings of Pretoria, South Africa. Pelvimetry is performed together with the body measurements in 230 animals (186 females + 44 males). Breed differences exist for pelvis size as well as body measurements. Mean pelvis area is different per breed, for Brahman it is 160.5 cm^2 (SD 30.0), Nguni 138.7 cm^2 (SD 20.3), Bonsmara 197.3 cm^2 (SD 45.0) and Hereford 217.6 cm^2 (SD 55.0). Pelvis size is related to all body measurements, BCS, RTS, age and gender in univariable General Linear Models (GLM). The multivariable GLM for pelvis area has a R^2 of 0.893, which means 89.3% of the variation in pelvis area is explained by the explanatory variables. The optimum BCS for the largest pelvis area is BCS3. In case predictions need to be done for precalving pelvis area in heifers, the best moment for prebreeding measurement of pelvis area is when the animal reaches puberty, which corresponds to RTS4 and/or RTS5, when the animal has had its first estrus cycle and a corpus luteum is present. In this data, age of onset of puberty is different per breed, for example the Nguni animals have a later onset of puberty compared to the other breeds.

Introduction

Dystocia

Dystocia in cattle is a problem which causes many health issues and economical losses. The factors influencing dystocia are numerous, for example parity, birth weight, pelvis size, duration of gestation, calf birth weight, choice of sire and (ab)normal position of the calf. In primiparous cows, the main cause for dystocia is a feto-pelvic disproportion (FPD), which means that the size of the calf is not proportional to the size of the pelvis (Bellows et al., 1983; Mee, 2008). Calf birthweight and maternal pelvis size are the two important determinants for FPD. Calf birthweight is influenced by genetics and breed of the sire and dam, as well as nutritional factors and gestation length of the primiparous dam. Pelvis size is influenced by weight, age, condition and genetics of the dam (Mee, 2008; Naazie et al., 1991).

To decrease the risk of dystocia by FPD, low calf birthweight and size of the pelvis are important factors. Calf birthweight can be influenced by the selection of bulls with offspring with low birthweight and by optimizing the gestational nutrition of the dam (Mee et al., 2014).
The other strategy in decreasing the risk of FPD is to have a breeding program with animals with a certain (minimum) pelvis size. For this breeding program, pelvis measurements could be used (Mee, 2008).

Relationship between pelvis measurements and dystocia

The relationship between pelvis measurements and dystocia is argued by several studies (Gaines et al., 1993; Van Donkersgoed et al., 1993; Price&Wiltbank, 1978). They did not find a strong relationship between a small pelvis size and a high risk of dystocia.

Van Donkersgoed et al., (1993), investigated the predictive value of pelvimetry on dystocia in 1146 heifers and 210 cows of a not reported breed with the Rice pelvimeter. The predictive value is low to moderate, too many animals with a small pelvis size did not have dystocia and too many animals with a large pelvis size did have dystocia. The existence of too many false positive and false negative predictions results in a discouragement to use pelvimetry as a predictive value for dystocia. In this study, intraobserver repeatability is low to moderate. *Gaines et al., (1993)* measured the pelvis size with the Krautmann pelvimeter in 129 Holstein x Hereford heifers. All animals were measured in the age of 10, 16 and 22 months of age, 76 animals were measured within 24 hours after calving. The results gave an association between pelvis area measured at calving and dystocia, pelvis measurements taken at other moments than calving did not show any association with dystocia ($p>0.05$). *Price&Wiltbank, (1978),* did research in 1000 crossbred heifers and cows of the Angus, Hereford and Charolais. A correlation coefficient of 0.42 ($p<0.01$) was found between pelvis area and dystocia in Angus animals, the coefficient in Angus cattle was the highest of the three breeds which were used.

After the publication of these studies, the interest in pelvimetry was lost for almost 10 years. However, interests in pelvimetry recurred and in more recent studies, a relationship between pelvis size and dystocia is found, which could mean that pelvimetry might be a useful tool in the prediction of dystocia (Gundelach et al., 2009; Johanson&Berger, 2003; Holm et al., 2014).

Gundelach et al., (2009) did research on 463 German Holstein heifers and cows. External as well as internal pelvis measurements were done, together with a full registration of all observations during partus of these animals. Duration of the partus, calf position and perinatal mortality were registrated. When the duration of the active stage of the partus was longer than 120 minutes, coworkers were supposed to assist with the partus, in other articles this is often classified as dystocia (Price&Wiltbank, (1978); Johanson&Berger, (2003)). Of all animals with a pelvis area >320cm^2, 27.9% experienced a duration of the active stage of the partus longer than 120minutes, compared to 43.9% of all animals with a pelvis area ≤320cm^2. *Johanson&Berger, (2003)*, investigated 4528 dairy cows with external pelvis measurements. Their results showed an 11% decrease in odds ratio for dystocia with a one square decimeter increase in pelvis area. *Holm et al., (2014)* supports the theory that pelvimetry is a useful tool in predicting dystocia, based on research which is performed on 484 Bovelder beef heifers.

These 3 articles who conclude that pelvimetry is a useful tool in predicting pelvimetry base their conclusions on the fact that the pelvimetry is an accurate and repeatable method (Gundelach et al., 2009; Johanson&Berger, 2003; Holm et al., 2014). The accuracy of pelvimetry is studied by *Kolkman et al. (2009)*, who measured the pelvis height and width in live animals with the Rice pelvimeter. These measurements are compared to measurements in the carcasses of the animals. The calculated mean differences between measurements on living and dead animals were -0.2 cm (95% limits of agreement: -2.5 and 2.1 cm) for pelvis width and 1.2 cm (95% limits of agreement: -1.8 and 4.1 cm) for pelvis height. *Paputungan et al., (1993)* reported moderate repeatability between operators, using the Rice pelvimeter.

Relationship between pelvis size and body measurements

Other body measurements which could be related to pelvis size are: body weight, shoulder height, heart girth, body condition score, age and maturation status of the animals. *Coopman et al., (2003)* performed internal and external measurements on living and dead Belgian Blue beef cattle, resulting in a formula for pelvis height with an R^2 of 0.77 (s.e. 1.16) with external body measurements, for example shoulder height.
Johnson et al., (1988) found a correlation between pelvis area and body weight of 0.56 (P<0.05) in Hereford heifers. A positive correlation between body weight and pelvis area is found in Angus, Charolais and Bovelder cattle too (Price&Wiltbank, 1978; Holm et al., 2014).

For body condition score (BCS), both positive and negative relationships with pelvis size are found. *Bellows et al., (1996)* found correlations between BCS and pelvis height and width in 650 crossbred heifers, the values for correlation lie between -0.04 and 0.34. In another study, low prebreeding body condition score was correlated with a larger pelvis area (Holm et al., 2014). The regression coefficient of BCS for pelvis area was found -3.25 (p<0.10) (Holm et al., 2016).
At last, the maturation status of the animals could have an effect on the pelvis size. *Nix et al., (1998)* reported a higher periparturent mortality rate for primiparous animals compared to multiparous cows in 2191 calvings of beef breed cattle. The maturation status and pelvis growth could be an important factor for this risk, however further research needs to be done. *Hoffman et al., (1996)* concluded that a high energy diet (for accelerated growth) in postpubertal animals (>10 months of age) is related to smaller precalving (10 days before calving) pelvis area, lower shoulder height and lower body weight in 70 Holstein heifers. *Ramin et al., (1995)* found a relationship between puberty and pelvis size. They concluded that an early onset of puberty is an indication for a bigger pelvis size at 15 months of age (Ramin et al., 1995). It is still unknown what the mechanism is for these conclusions.

The current study researches various body measurements that may correlate with pelvis area. These factors have already been researched in different breeds, however, the current study focuses on breeds on which minimal analysis is done before. Breed is known to influence pelvis size (Bellows et al., 1996). The relationships between pelvis dimensions and body measurements are still unclear for Brahman, Nguni or Bonsmara animals. Literature on Herefords is found, but only on body weight in relation to pelvis size.

Objectives

The aim of this cross-sectional study is to investigate the relationship between pelvis size and the breed, gender, age, body size, body weight and BCS in 4 different breeds of beef cattle with the age of at least 10 months. In case of heifers, Reproductive Tract Score (RTS, explained in Table 1) is performed too.

Materials & Methods

Study design & participants

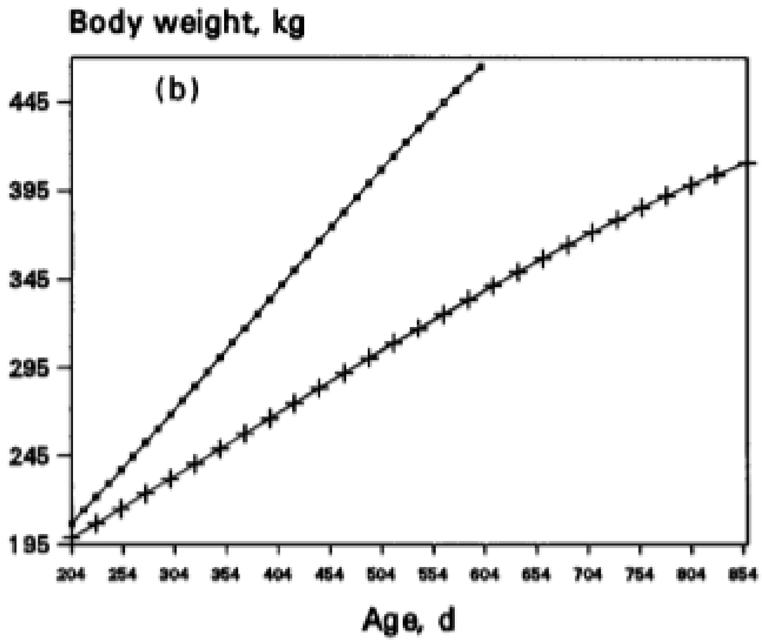
The data collected during this study is taken at one specific point in time, which means the study is cross sectional.

The setting in which the data collection is done is in the surroundings of Pretoria, South Africa. The farms which are visited are those with beef cattle.

The cattle which are used in the data collection are from different breeds. A Bos Indicus breed (Brahman), one Bos Taurus breed (Hereford), one composite breed of Bos Indicus and Bos Taurus (Bonsmara) and one Bos Taurus africanus breed (Nguni). There are 3 operators, each of them measured the animals twice, in total six measurements per animal. The mean of the two measurements of the first operator is used for this analysis, because this person is the most experienced in pelvimetry. This study focuses on the relationship between pelvic measurements and body measurements, that is why the data of only the experienced operator is used. The other data will be used in another study which focuses on repeatability of the pelvimeter.

All breeding males and females from the age of 7 months old at first measurement and before their first partus in case of a heifer are included. Bulls are selected if they are used in the breeding program and if they have the same birth year compared to the heifers.
The number of animals used in this project is 230 of which there are 75 Bonsmara, 41 Brahman, 54 Nguni and 60 Hereford. The cattle originate from 6 different farms, 2 Bonsmara, 1 Brahman, 2 Nguni and 1 Hereford farm.
Animals are excluded from measurements when they are not originating from this herd (when they are bought in) or when they are not typical of the breed. Health concern is another reason for animals to be excluded, for example when an animal is chronically sick or has a severely stunted growth. This severely stunted growth is based on the experience of breeders, observers and on the growth curve of Brahman cattle in Figure 1, which is used only in Brahman animals (Menchaca et al, 1996). The examination is done by a visual check of the animals. Health concern of the observers is important too, when the animal was too dangerous to handle it is excluded from the measurements.

Figure 1: Growth curve of Brahman animals in the age of 6-28 months (Menchaca et al., 1996)



The variables measured are:

- *Pelvis measure horizontal diameter (cm)*
- *Pelvis measure vertical diameter (cm)*
- *Body condition score (1-5, see Appendix 1)*(Houghton et al., 1990)
- *Reproductive tract score (RTS1-RTS5, see Table 1)* (Andersen et al, 1991)
- *Age (days)*
- *Size*
    - *Shoulder height (cm)*
    - *Body length (cm)*
    - *Heart girth (cm)*
- *Scrotum Circumference (cm)*
- *Gender*
- *Breed (Brahman, Nguni, Bonsmara or Hereford)*

The study size is determined based on practical issues and earlier studies. Research on correlations between pelvis size and other measures are performed by *Holm et al., (2014)* (n=484), *Johnson et al., (1988*) (n=186) and *Smeaton et al., (2004)* (n=249). Since the collected data of the current study is used in another study in which the repeatability of the Rice pelvimeter is researched, a correct sample size for both studies should be determined. Other studies on repeatability of pelvimetry have used sample sizes such as n=1146, the amount of breeds used in this study is unknown (Van Donkersgoed et al., 1993). The current study uses 3 operators instead of 2, using more operators increases the precision of the observations. Eventually, in order to be time and cost efficient it is decided to measure approximately 50 animals per farm, depending on the availability on the various farms. If 4 different breeds are measured, this will result in the measurements of at least 200 animals.

Measurements

The measurements of the pelvis are performed using a Rice Pelvimeter, shown in figure 2 (Lane Manufacturing**,** 2075. So. Balentia St., Unit C, Denver, Colorado 80231).

Figure 2: Picture of the Rice Pelvimeter which is used in the study.

Lane Manufacturing

After emptying the rectum, the pelvimeter was closed and slowly introduced in the rectum. The vertical measurement was done by placing the pelvimeter on the pubic symphisis and slowly opening the pelvimeter until the widest point was reached, at the sacral vertebrae. The horizontal distance is measured as the distance between the shafts of the ileum, the pelvimeter was placed on the tubercula psoadica of the ileum (Kolkman et al., 2009).
Body condition scores, using a 5 point scale are taken by the observers (Houghton et al., 1990). The scoring method for BCS is described in Appendix 1. Scoring the reproductive tract score (RTS) is done rectally with manual palpation. The scoring system for RTS is shown in Table 1. The size of the animals is measured with a yardstick. Shoulder height is measured when the cow is standing with both front legs next to each other, the yardstick is put down next to the front leg and the height of the withers is measured. Heart girth and body length is measured with a tape-measure, even as the scrotum circumference. Heart girth is measured as the body circumference just behind the front legs. Body length is measured from the most cranial tip of the scapular bone to the head of the femur (caput femoris). Age data is provided by the animals' owners.
In order to prevent bias, each observer writes down his/her own measurements so observers will not be influenced by one another. Each animal had to be measured twice, but to prevent the observer to be influenced by his/her first measurement, the herd was caught again to perform the second measurement.

RTS score is performed based on the system of *Andersen et al., (1991)*, which is described in Table 1 below. For the modeling procedure, a sixth category 'pregnancy' is added, so RTS will be implemented in the variable 'Reproductive status' which contains RTS and pregnancy.

Table 1: Reproductive tract score system (Andersen et al., 1991)

		Ovary			
RTS	Uterine horn	Length mm	Height mm	Width mm	Ovarian structures
1	Immature <20-mm diameter, no tone	15	10	8	No palpable structures
2	20- to 25-mm diameter, no tone	18	12	10	8-mm follicles
3	25- to 30-mm diameter, slight tone	22	15	10	8- to 10-mm follicles
4	30-mm diameter, good tone	30	16	12	>10-mm follicles, corpus luteum possible
5	>30-mm diameter, good tone, erect	>32	20	15	>10-mm follicles, corpus luteum present

Statistical methods

Data analysis is done using IBM SPSS Statistics 24 (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp).

Descriptive statistics are used to describe the observed population and to check the dataset for incorrect numbers and missing data.

Pelvis area is calculated by multiplying the measurements of pelvis height with pelvis width.

All body measurements are used as continuous data, except for BCS and RTS.

A Pearson's Correlation Matrix is calculated containing the pairwise correlation coefficients between all continuous variables.

Univariable General Linear Models (GLM) are made for pelvis height, width and area respectively against each variable (body length, shoulder height, heart girth, BCS, age, reproductive status, breed and gender). The residuals are checked for normality with a scatterplot and a normal Q-Q plot.

Eventually, for outcome variables pelvis height, pelvis width and pelvis area respectively, a Multivariable General Linear Model is made with all explanatory variables (body length, shoulder height, heart girth, BCS, age, reproductive status, breed and gender). This model is reduced with a backward selection approach. The variable with the highest value for significance is removed from the model, a re-run of the model is performed, this is repeated until all variables in the model are significant ($p<0,05$). The residuals were studied for the model assumptions by a visual check of both a q-q plot of the residuals as well as the residuals plotted against the predicted values, by this, normality and constant variance respectively are checked.

Results

Participants & Descriptive data

The number of animals used in this project is 230 of which 75 Bonsmara, 41 Brahman, 54 Nguni and 60 Hereford animals. These are divided in male, female non-pregnant and female pregnant animals, as shown in Table 2. The cows originate from 6 different farms, 1 Brahman, 2 Nguni, 2 Bonsmara and 1 Hereford farm. Some descriptive statistics for scrotum circumference related to pelvis area are attached in Appendix 2.

Table 2 : Male, Female Non-Pregnant en Female Pregnant participants by breed and Mean ± SD, 95% Confidence Interval (95% CI) of the mean and Range of measurement outcomes by breed.

	Brahman	Nguni	Bonsmara	Hereford
Male	11	17	6	10
Female Non-Pregnant	25	37	39	33
Female Pregnant	5	0	30	17
Male + Female	41	54	75	60
Pelvis Height (cm)	15.2 (1.1)	14.2 (1.1)	15.6 (1.8)	15.7 (1.9)
95% CI	*14.87-15.57*	*13.44-13.99*	*14.46-15.49*	*15.32-16.29*
Range	*13-17*	*12-17*	*12-20*	*11-20*
Pelvis Width (cm)	10.5 (1.4)	9.8(0.9)	12.5 (1.6)	13.7 (2.3)
95% CI	*10.05-10.91*	*9.38-9.89*	*11.40-12.42*	*13.30-14.38*
Range	*8-13*	*8-12*	*9-16*	*8-17*
Body Length (cm)	120.0 (8.3)	110.7 (7.7)	118.3 (8.6)	120.2 (9.9)
95% CI	*117.41-122.64*	*105.11-108.66*	*117.26-123.10*	*118.42-123.34*
Range	*102-140*	*98-131*	*102-141*	*98-135*
Shoulder Height (cm)	120.2 (6.7)	111.8 (7.1)	119.8 (6.2)	122.5 (6.7)
95% CI	*118.11-122.33*	*106.72-109.22*	*114.26-117.74*	*121.00-124.49*
Range	*108-134*	*101-127*	*107-132*	*109-137*
Heart Girth (cm)	166.8 (13.3)	146.9 (11.0)	170.5 (10.9)	190.4 (15.5)
95% CI	*162.60-171.01*	*139.20-143.49*	*166.56-175.27*	*187.35-195.20*
Range	*140-199*	*124-175*	*148-203*	*154-234*
Age (days)*	570 (198.7)	670 (65.0)	841 (190.5)	653 (156.9)
95% CI	*507.47-632.93*	*647.45-692.09*	*774.54-907.46*	*611.67-694.16*
Range	*236-931*	*568-871*	*581-1097*	*206-864*
BCS	3.4 (0.4)	3.0 (0.3)	3.3 (0.4)	3.6 (0.4)
95% CI	*3.25-3.50*	*2.97-3.17*	*3.20-3.49*	*3.48-3.67*
Range	*2.75-4.25*	*2.50-3.50*	*2.50-4.00*	*3.00-4.50*
RTS	3.00 (0.3)	1.57 (0.1)	3.83 (0.2)	4.80 (0.2)
95% CI	*2.36-3.64*	*1.31-1.82*	*3.33-4.32*	*4.46-5.14*
Range	*1-6*	*1-4*	*1-6*	*2-6*

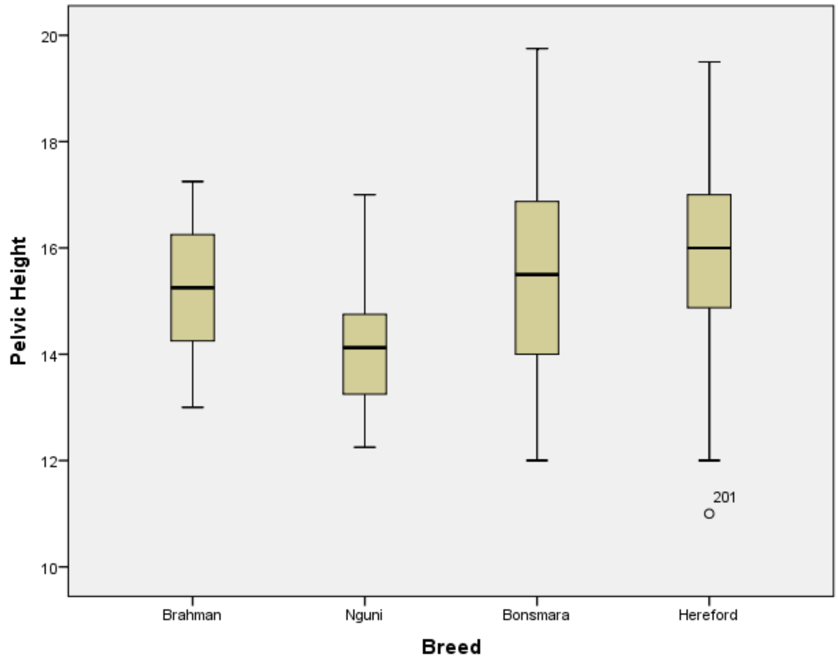
**Date of birth is unknown for 19 Nguni, 41 Bonsmara & 2 Hereford animals.*

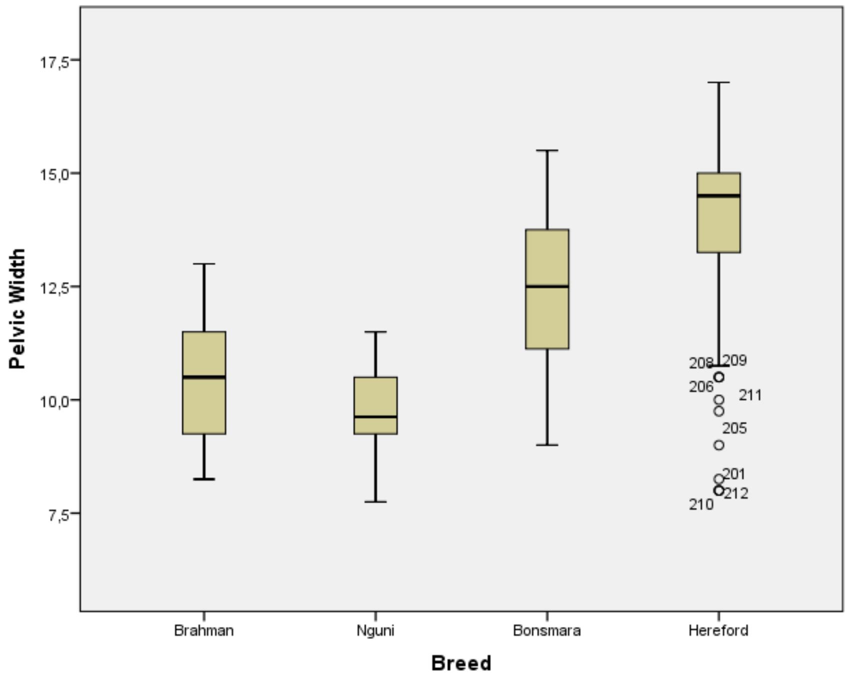
The amount of males, non-pregnant and pregnant females are not equally divided per group. There are no pregnant Nguni animals included and most of the pregnant animals are Bonsmara. One Bonsmara farm and one Nguni farm could not provide in birth dates of the animals.

The pelvis size of the different breeds is as shown in Table 2 and in Figure 3. As seen in these table and graphs the Hereford breed has the largest pelvis measures and the Nguni is the breed with the smallest pelvis measures. The shape of the pelvis is different for the 4 breeds. The Brahman pelvis is narrower compared to the Hereford pelvis (10.5 cm vs. 13.7cm) while pelvis width is almost equal (15.2cm and 15.7cm respectively).

Age is different per breed, the Bonsmara cows are on average 171-271 days older than the other breeds.
The Nguni cows have the smallest mean body measurements (body length, shoulder height, heart girth), followed by Bonsmara and Brahman, the Hereford cows have the highest mean body measurements in this study.
Mean RTS scores (including pregnancy) for the breeds are lowest for Nguni (1.57) and the highest for Hereford (4.80).

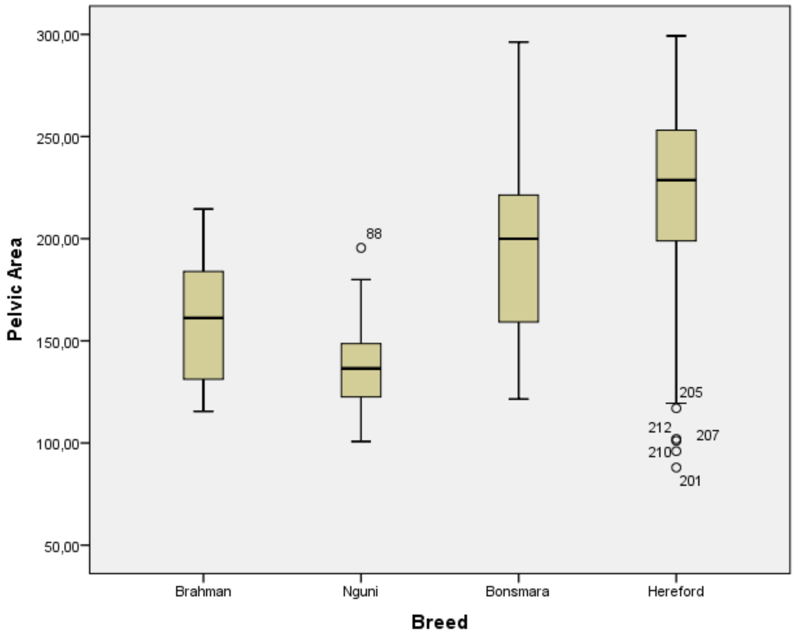
Figure 3: Box plots of vertical and horizontal pelvic measurements by breed.





When pelvis area is calculated, the Hereford and Nguni still have the largest and smallest area respectively. This is shown in the following box plot in Figure 4. Means and standard deviations (sd) for pelvis area in Brahman are 160.5 cm^2 (sd 30.0), Nguni 138.7 cm^2 (sd 20.3), Bonsmara 197.3 cm^2 (sd 45.0) and Hereford 217.6 cm^2 (sd 55.0).

Figure 4: Box plot of Pelvis area by breed.



Looking at the cross table (Table 3) of BCS categories by breed, the Nguni animals and Bonsmara are the only breeds that represent the lowest BCS category: BCS 2,5. The highest BCS category (BCS 4,5) is represented by Brahman and Hereford animals. So the animals with the smallest mean pelvis areas represent the lowest BCS and the animals with the largest mean pelvis areas represent the highest BCS category.

Table 3: Cross table of BCS categories by breed.

Category	Brahman	Nguni	Bonsmara	Hereford	Total
BCS 2,50	0	3	3	0	6
BCS 3,00	14	38	32	10	94
BCS 3,50	16	13	29	28	86
BCS 4,00	10	0	11	20	41
BCS 4,50	1	0	0	2	3

Table 4 shows the lack of animals with RTS5 or pregnant animals in the Nguni sample, while the Herefords lack animals with RTS1. Almost all pregnant animals are from the Bonsmara and Hereford herds.

Table 4: Cross table of RTS categories by breed.

Category	Brahman	Nguni	Bonsmara	Hereford	Total
RTS1	6	21	10	0	37
RTS2	9	12	18	3	42
RTS3	5	3	7	5	20
RTS4	4	1	3	8	16
RTS5	1	0	1	17	19
Pregnant	5	0	30	17	52

Table 5 shows the pairwise correlation coefficients for the different body measurements and the age of all animals in the study. Correlation coefficients for the 4 breeds apart as well as the correlation coefficients for all data combined are showed in the table.

Table 5: Pearsons Correlation matrix for body measurement data, correlations are given for the different breeds and for a combination of the data of all 4 breeds.

	Pelvis height	Pelvis width	Body length	Shoulder height	Heart girth
Pelvis width					
Brahman	.675**	-	-	-	-
Nguni	.553**				
Bonsmara	.762**				
Hereford	.822**				
Combination	.726**				
Body length					
Brahman	.644**	.499**	-	-	-
Nguni	.614**	.389**			
Bonsmara	.391**	.380**			
Hereford	.555**	.661**			
Combination	.564**	.534**			
Shoulder height					
Brahman	.621**	.526**	.553**	-	-
Nguni	.633**	.447**	.716**		
Bonsmara	.540**	.650**	.377**		
Hereford	.659**	.742**	.695**		
Combination	.643**	.672**	.654**		
Heart girth					
Brahman	.641**	.471**	.677**	.726**	-
Nguni	.704**	.562**	.729**	.866**	
Bonsmara	.565**	.676**	.615**	.524**	
Hereford	.615**	.704**	.643**	.828**	
Combination	.598**	.782**	.647**	.769**	
Age					
Brahman	.761**	.728**	.557**	.615**	.739**
Nguni	.213	.464**	.321	.545**	.457**
Bonsmara	.713**	.901**	.383*	.482**	.809**
Hereford	.746**	.895**	.518**	.706**	.651**
Combination	.485**	.527**	.348**	.278**	.339**

**Correlation is significant at the 0.05 level (2-tailed).*
*** Correlation is significant at the 0.01 level (2-tailed).*

Correlation coefficients in Table 5 for the combined data show a relation between pelvis height and pelvis width of 0.726 ($p<0.01$). Age does not show high correlations with the other body measurements (0.278-0.527; $p<0.01$) However, most of the correlation coefficients for age per breed are higher than those for the combined data, except for Nguni animals, they show the lowest relations with body measurements and show no significant correlation for pelvis height and body length ($p>0.05$).
Pelvis width is stronger correlated with the body measurements than pelvis height, except for body length, which is stronger correlated for pelvis height (0.564; $p<0.01$) than pelvis width (0.534; $p<0.01$) in the combined data.

General Linear Models

The results of the univariable and multivariable regression models are shown in the tables below, each table shows the results of either pelvis height, pelvis width or pelvis area. In Appendix 3, the parameter estimates, q-q plots and other box plots and diagrams are showed for all body measurement data against pelvis height, pelvis width and pelvis area.

Pelvis height

Table 6: Estimates and 95% Confidence intervals (95% CI) of Univariable and Multivariable General Linear Models of factors associated with pelvis height (cm).

Parameter	Univariable Regression Estimate	(95% CI)	Multivariable Regression* Estimate	(95% CI)
Body Length (cm)	0.10	(0.08-0.12)	-	-
Shoulder Height (cm)	0.14	(0.12-0.16)	0.05	(0.01- 0.09)
Hearth Girth (cm)	0.05	(0.04-0.06)	0.025	(0.003- 0.046)
BCS 2,50	2.41	(1.13- 3.69)	-	-
3,00	0**			
3,50	1.05	(0.59- 1.50)		
4,00	1.76	(1.19- 2.33)		
4,50	2.58	(0.80- 4.36)		
Age (d)	0.004	(0.003- 0.005)	0.002	(0.000- 0.004)
Male	-2.42	(-2.94- -1.90)	-1.66	(-2.30- -1.03)
Female RTS1* **	-2.82	(-3.37- -2.27)	-0.60	(-1.27- 0.07)
RTS2	-2.55	(-3.08- -2.02)	-0.77	(-1.39- -0.16)
RTS3	-1.88	(-2.55- - 1.21)	-0.65	(-1.27- -0.03)
RTS4	-0.99	(-1.72- -0.26)	-0.02	(-0.64- 0.61)
RTS5	-0.37	(-1.05- 0.32)	0.08	(-0.51- 0.66)
Pregnant	0**		0**	
Brahman	-0.08	(-0.63-0.46)	0.79	(0.19-1.40)
Nguni	-0.47	(-1.11-0.17)	0.21	(-0.86- 1.28)
Bonsmara	-1.51	(-2.10- -0.92)	-0.04	(-0.85- 0.77)
Hereford	0**		0**	

**R^2=0.675*
*** Reference category*
**** Reproductive Tract Score according to Andersen et al. (1991)*

Table 6 shows the regression coefficients of different parameters which are calculated with a General Linear Model based on the measurements of the pelvis height. In the univariable GLM model, body length, shoulder height, heart girth, body condition score, age, reproductive status and breed are each associated with pelvis height.
In the multivariable GLM, the body length and BCS are not significant associated with pelvis height, that is why body length and BCS dropped out of the model. The R^2 is 0.675 for this model.
Age has a very small positive effect on the pelvis height.
The reproductive status of the animals shows an increase in pelvis height between RTS1 and pregnancy. Between RTS3 and RTS4, the increase in pelvis height is bigger than between other subgroups within RTS, the regression coefficient of RTS3 and RTS4 are -0.65 and -0.02 respectively. After that, almost no difference is measured between RTS4, RTS5 and pregnant animals (estimates -0.02, 0.08 and 0 respectively).

Pelvis width

Table 7: Estimates and 95% Confidence intervals (95% CI) of Univariable and Multivariable General Linear Models of factors associated with pelvis width (cm).

Parameter	Univariable Regression Estimate	(95% CI)	Multivariable Regression* Estimate	(95% CI)
Body Length (cm)	0.13	(0.10-0.15)	-	-
Shoulder Height (cm)	0.20	(0.17-0.22)	0.07	(0.04- 0.10)
Hearth Girth (cm)	0.09	(0.08-0.10)	0.03	(0.02- 0.05)
BCS 2,50	1.00	(-0.69- 2.69)	-0.95	(-1.49- 1.30)
3,00	0**		0**	
3,50	1.64	(1.04- 2.23)	-0.09	(-0.37- 0.20)
4,00	2.23	(1.48- 3.00)	-0.60	(-0.98- -0.22)
4,50	3.88	(1.52- 6.23)	0.27	(-0.60- 1.15)
Age (d)	0.006	(0.005-0.007)	0.003	(0.002- 0.004)
Male	-3.95	(-4.53- -3.37)	-2.43	(-2.93- -1.94)
Female RTS1***	-3.81	(-4.42- -3.20)	-0.76	(-1.25- -0.27)
RTS2	-3.11	(-3.70- -2.52)	-0.77	(-1.22- -032)
RTS3	-2.16	(-2.91- -1.42)	-0.47	(-0.94- -0.01)
RTS4	-1.13	(-2.03- -0.41)	-0.38	(-0.84- 0.07)
RTS5	0.61	(-0.15-1.38)	0.13	(-0.29- 0.55)
Pregnant	0**		0**	
Brahman	-1.15	(-1.71- -0.59)	-1.63	(-2.09- -1.17)
Nguni	-3.16	(-3.82- -2.51)	-1.55	(-2.35- -0.76)
Bonsmara	-3.90	(-4.50- -3.29)	-1.10	(-1.69- -0.50)
Hereford	0**		0**	

**R^2=0.919*
*** Reference category*
**** Reproductive Tract Score according to Andersen et al. (1991)*

Table 7 shows the regression coefficients of different parameters which are calculated with a General Linear Model based on the measurements of the pelvis width. In the univariable GLM model, body length, shoulder height, heart girth, body condition score, age, reproductive status and breed are each associated with pelvis width.
In the multivariable GLM, body length is not significantly associated with pelvis width, therefore it dropped out of the model. The R^2 is 0.919 for this model.
In this model, the acceleration in pelvis growth takes place during RTS4. The turning point in the growth and development for pelvis width is at another moment during maturation compared to pelvis height, which was during RTS3. Age has a small but positive effect on pelvis width too, as well as for pelvis height.

Pelvis area

Table 8: Estimates and 95% Confidence intervals (95% CI) of Univariable and Multivariable General Linear Models of factors associated with pelvis area (cm2).

Parameter	Univariable Regression Estimate	(95% CI)	Multivariable Regression* Estimate	(95% CI)
Body Length (cm)	3.11	(2.53-3.68)	0.51	(0.05- 0.97)
Shoulder Height (cm)	4.65	(4.03-5.27)	1.31	(0.49- 2.14)
Hearth Girth (cm)	1.95	(1.73-2.17)	0.73	(0.29- 1.17)
BCS 2,50	48.11	(9.99- 86.23)	-0.37	(-36.06- 35.32)
3,00	0**		0**	
3,50	37.43	(23.92- 50.94)	-1.75	(-9.03- 5.52)
4,00	54.72	(37.77- 71.66)	-13.03	(-22.93- -3.12)
4,50	92.73	(39.64- 145.83)	7.26	(-15.44- 29.96)
Age (d)	0.15	(0.11- 0.18)	0.06	(0.03-0.09)
Male	-90.22	(-103.26- -77.17)	-58.01	(-70.54- -45.47)
Female RTS1***	-93.03	(-106.73- -79.33)	-19.84	(-32.36- -7.31)
RTS2	-79.47	(-92.68- -66.25)	-21.70	(-33.27- -10.12)
RTS3	-57.04	(-73.80- -40.29)	-16.22	(-28.07- -4.38)
RTS4	-31.03	(-49.24- -12.82)	-4.64	(-16.28- 6.99)
RTS5	4.65	(-12.42-21.73)	1.12	(-9.62- 11.86)
Pregnant	0**		0**	
Brahman	-20.35	(-34.46- -6.24)	-21.23	(-33.08- -9.38)
Nguni	-57.07	(-73.57- -40.56)	-23.06	(-43.36- -2.76)
Bonsmara	-78.89	(-94.17- -63.61)	-22.01	(-37.54- -6.47)
Hereford	0**		0**	

**R^2=0.893*

*** Reference category*

**** Reproductive Tract Score according to Andersen et al. (1991)*

Table 8 shows the regression coefficients of different parameters which are calculated with a General Linear Model based on the measurements of the pelvis area. In the univariable GLM model, body length, shoulder height, heart girth, body condition score, age, reproductive status and breed are each associated with pelvis area.

All these variables are associated with pelvis area in the multivariable GLM. The R^2 is 0.893 for this model.

An increase in body measurements is related to an increase in pelvis area, this applies to body length, heart girth, shoulder height and age. According to the model, the differences between Hereford-Brahman, Hereford-Nguni and Hereford-Bonsmara are quite similar (estimates -21.23cm, -23.06cm and -22.01cm respectively). The Hereford breed has a bigger mean pelvis area than the other breeds. The BCS influence is based on group differences compared to the reference category BCS3. Having a BCS lower than 3 is related to a smaller pelvis area (estimate -0.37cm^2), BCS3,5 and BCS4 are related to a smaller pelvis area, too (estimates -1.75cm^2 and -13.03cm^2 respectively), but having BCS4,5 is related to a larger pelvis area (estimate 7.26cm^2). In Appendix 4, a box plot is shown of age against BCS, there is no visual relationship between age and BCS.

Discussion

Key results

The aim of the study is to investigate the relationship between pelvis size and other body measurements in male and nulliparous female animals. Pelvis size is related to breed, gender, age, body size, RTS and BCS, so all these parameters have a relationship with the area of the pelvis. The older animals have bigger pelvis sizes than younger ones, and when the body measurements (shoulder height, heart girth, body length) increase, the pelvis size increases too.

Earlier studies investigated the relationship of body measurements and calving difficulty. For calving difficulty, calf birth weight and pelvis area are the most important predictors (Johnson et al., 1988). The analysis of the study of *Johnson et al., (1988)* was done by a stepwise regression analysis. The R^2 with calf birth weight is 0.33 and the cumulative R^2 when pelvis area is added to the model is 0.45. In the current study, when body measurements of the dam are studied for a relationship with pelvis area, 89% of the variation in pelvis area is explained by the body measurements. This means body measurement data might help in predicting the area of the pelvis. Eventually, this data might help a farmer in the decision whether or not to use an animal for breeding and in the decision which bull to use. For this use, further longitudinal studies have to be performed to measure the development of the pelvis dimensions in the animals. Based on that information, a threshold for pelvis size and body measurements might be determined on which animals can be in- or excluded from the breeding program.

The variation in pelvis height is for 67.5% explained by the other body measurements, while variation in pelvis width is explained for 91.9%. This difference could be caused by the method of measuring the pelvis height and pelvis width. Pelvis height is measured by palpating the pelvis symphysis, where after the pelvimeter is placed on the symphysis and the pelvimeter is opened until the sacral vertebrae are reached and the widest point can be measured. Pelvis width is determined by measuring the distance between the shafts of the ileum. The method of measuring pelvis height is more difficult than measuring pelvis width. This difficulty could be caused by the fact that the observer tends to be more careful with putting pressure on the vertebrae, or if the observer uses a different angle (the pelvimeter is not exactly perpendicular to the pelvis bones) between measurements. This is supported by the data of *Kolkman et al., (2009)* who measured the pelvis height and width with a Rice pelvimeter ante-mortem and compared this with post mortem measurements on the carcass. The study reports a mean difference of 1.2 cm (95% limits of agreement: -1.8 and 4.1 cm) for pelvis height and -0.2 (95% limits of agreement: -2.5 and 2.1 cm) for pelvis width. However, *Vernooij et al., (unpublished data)* reports an Intra Class Correlation for observer within the same animal of 0.69 for pelvis height and 0.51 for pelvis width.

In the regression model of pelvis height, body length is not in the model as an independent variable, in contrast to the model of pelvis width. Body length also has the lowest correlations with pelvis height and pelvis width (0.564 and 0.534 respectively; $p<0.01$) compared to shoulder height and heart girth (Table 6). A possible cause for body length to drop out of the model is multicollinearity. In de correlation matrix in Table 5 is a significant correlation between body length, shoulder height and heart girth. These 3 parameters have a relationship with pelvis height, too. The model scores this relationship to a certain value (regression coefficient), but because the explanatory variables have mutual relationships with the outcome variable, the model can estimate the explanatory value of one variable unequal compared to the second. This could be a reason why one variable drops out of the model.

In Table 8 the estimates of pelvis area are given for the different body condition scores. The estimates for BCS 3,5 and 4 are lower than BCS 3. *Holm et al., (2014)* speculated that a higher level of endogenous steroid hormones in animals can cause the development of a bigger pelvis area and a lower BCS. Secondly, a higher BCS is related to a higher incidence of dystocia due to fat deposition in the animal (Hoffman et al., 1996). Animals with BCS 2,5 have a smaller pelvis area than animals with BCS 3. However, in this study the group of BCS 2,5 is represented by Nguni and Bonsmara animals, while BCS 4,5 is represented by Brahman and Hereford cattle. This might be a bias in the results, because the Nguni have the smallest mean pelvis areas and the Hereford the biggest mean pelvis areas. For this data, it can be concluded that the optimum body condition score for the biggest pelvis area is BCS3.

Limitations

The animals of the different breeds are not equal divided in the different categories of RTS and BCS and do not have equal means and ranges of age and body measurements (Tables 2,3,4). As discussed earlier, when only Nguni and Bonsmara animals are included in BCS2,5, this parameter can be influenced by the fact that Nguni and Bonsmara cattle have smaller mean pelvis dimensions compared to the Brahman and Hereford animals in this study. The same argument applies to the use of age, this parameter is not equally divided over the breeds, as described in Table 2 and visible in the scatterplot in Appendix 4, Figure 2.

The body condition score is used as a categorical variable. After checking the BCS data for linearity with the pelvic measurements, it was allowed to use BCS as continuous data. However, it cannot be proven that, for example, a BCS 2 is half the value of BCS 4, besides, it is based on a scale from 1 to 5, so it is not possible for a cow to have BCS 6. Looking at the model, the R^2 of the model with a categorical BCS is higher than the R^2 of the model with continuous BCS. For this reasons, it is chosen to use BCS as categorical data. The data of BCS is combined for all breeds, a recommendation for further research is to use a larger sample size per breed. With a larger sample size per breed, it is possible to make an accurate analysis per breed, then breed differences can not influence the model. In the current research, breed groups are too small to make an accurate analysis per breed. Because this study used only 6 farms to collect data of 4 breeds, the results of the breeds might be highly influenced by farm differences. It is possible that due to differences in feeding strategies of dams and youngstock or other management factors, the differences in breed results are results of the management system.

The difference in pelvis measurements between male and female animals is included in the parameter Reproductive status. Male animals are included in this variable to prevent them from being excluded from the multivariable General Linear Model, because they do not fit in an RTS category. If there is any missing data of an animal, it will be excluded from the model. The disadvantage of adding male animals to the reproductive status parameter is that now male animals are compared to pregnant females. A male animal will never get pregnant, so this comparison is hard to interpret. The reason why it is chosen to continue is because it is the aim of the study to look at a possible relationship between pelvis measures and also gender, so it is not desirable that all male animals are excluded. A recommendation for further research could be to measure more males per breed so the males could be divided in subgroups based on their scrotum circumference, these subgroups might be an indication of maturation status for the bulls. In Appendix 2, a short description is given for the scrotal circumferences of the 44 bulls measured in the current study, related to pelvis area. In the plots made for scrotum circumference and pelvis area, a relationship between these two variables is visible, also when the bulls are divided in 3 subgroups for scrotum circumference. However, this contains only descriptive statistics so (multi)collinearity with other body measurements is not examined for these variables. In literature, significant correlations are found among age, body weight and scrotum circumference in pubertal and postpubertal bulls ($p<0.01$) (Devkota et al., 2008). From this information, it appears that measuring scrotum circumference might be interesting in relation to pelvis size as well.

Interpretation

The changes in pelvis height which occur during RTS3 to RTS4 could be related to an increased estrogen concentration. *Deutscher et al., (1986)* implanted young heifers with zeranol at 1, 6 or 9 months of age. Zeranol is a synthetic estrogen and used as growth supporter. Implantation of zeranol at 6 and 9 months increased the pre-breeding pelvis area with respectively 7 cm^2 ($p<0.01$) and 8 cm^2 ($p<0.01$).

The difference between RTS3 and RTS4 is the follicle diameter, which is 8-10 mm in RTS3 and >10mm in RTS4. When a follicle grows >10mm it means there is selection of a dominant follicle, one of the stages for development of an estrus cycle. However, follicular development happens in phases, called follicular waves. It is possible that an animal with RTS4 is incorrectly classified as RTS3 because the previous follicular wave is finished and a new follicular wave just started. Still, estrogen is produced by the granulosa cells of the predominant and dominant follicles, so the big follicles in RTS4 will cause an increase of estrogen concentration in the blood. In the results of *Deutscher et al., (1986)* the pelvis height has a significant ($p<0.05$) increase after implantation of zeranol, but no significant increase in pelvis width is detected. With these results, *Deutscher et al., (1986)*, but also *Staigmiller et al., (1983)* hypothesize a greater increase of the ilea shafts compared to the width between these shafts, so it is mainly the estrogen effect on which the pelvis height responds which causes the growth of the ilea shafts. If pelvis height and pelvis width are measured during this stage of maturation (RTS4), it is to be expected that pelvis width will increase more than pelvis height in the period between the measurements and the calving moment.

The changes in pelvis width which occur during RTS4 to RTS5 could be related to an increased progesterone concentration. Progesterone is produced by a corpus luteum, the follicular structure which is left on the ovary after ovulation, and is necessary to maintain pregnancy. This hypothesis of a progesterone effect on pelvis growth during RTS4, RTS5 and pregnancy is supported by *Anthony et al., (1981)*. Zeranol, a synthetic estrogen, is implanted in pregnant beef heifers, but no effect of zeranol on the pelvis growth was found compared to the control group, which means that during pregnancy the estrogen effect on pelvis growth has disappeared. Perhaps progesterone has taken over this function, because this hormone is highly present during pregnancy. *Hangcock et al., (1994)* implanted young heifers with a combination preparate of estrogen and progesterone at 2 and/or 6 months old, the duration of action of this preparate is approximately 70 days. This study measured a bigger precalving pelvis area in animals that were implanted at 6 months of age while implanting at 2 months age did only have an effect on prebreeding pelvis area (Hancock et al., 1994). Besides this, *Holm et al., (2016)* found a positive effect of the presence of a corpus luteum (CL) on pelvis area. All these hormonal changes occur during the sexual maturation of the animals. The presence of a CL is an important indication for the start of puberty in cattle, which means that the animal developed cyclicity (Steward et al., 1980). These hormone influences indicate that the best moment to perform pelvimetry on a heifer is when the animal is well developed and puberty is reached, the moment when the animal shows the first ovulatory estrus (Steward et al., 1980). Looking at the data in Table 2, the mean age for Nguni animals is comparable to the other breeds, but the mean RTS score is much lower (mean RTS of Nguni is 1.57, mean RTS of other breeds is between 3.00 – 4.80). This data suggests that the onset of puberty in Nguni animals is later compared to the Brahman, Bonsmara and Hereford. A later onset of puberty means that the optimum moment of pelvimetry is at an older age for the Nguni animals than the other breeds. Before performing pelvimetry in a particular breed, one should determine the age of onset of puberty.

Johnson et al., (1988) reported that the prebreeding pelvis area is significantly correlated with precalving pelvis area (0.71) which is why it is suggested that prebreeding pelvis area can be used as a predictor for precalving pelvis area. The predictability of the precalving pelvis area gives the opportunity to in- or exclude an animal from the breeding program based on the prebreeding pelvis area. The timing of this measurement is important in this case, because pelvis height and width might be influenced by estrogen and/or progesterone levels. When prebreeding pelvis area is used to predict the precalving pelvis area, the animal should at least have a CL present (RTS 4 or 5) to minimize the influence of the hormones. In an estrus cycle, a CL is not always present, dependent on the stage of the cycle. That is why an animal could incorrectly be classified as RTS4 instead of RTS5. The use of an ultrasound for RTS might be a solution to decrease the amount of misclassifications because sometimes a small CL is detectable by ultrasonography but not manually (Holm et al., 2016). Ultrasonographic scoring of RTS is validated by *Rosenkrans&Hardin, (2003)* as a repeatable and accurate screening of pubertal status in heifers prior to the breeding season. A recommendation for the performance of RTS would be to use an ultrasound to make the RTS score more accurate.

In the current study, the mean of two measurements of one person is used for analysis. When pelvimetry has become part of a breeding program, it is most likely that the cow is measured only once. So experimental situation and practical application are different in this case. In the experienced observer, in 77% - 80% of the measurements the differences between 2 measurements is ≤0.5cm (Vernooij et al., unpublished). This is something to take into account when interpreting the pelvis measurements in practice. Besides this, *Ramin et al., (1995)* found significant positive correlations (0.65-0.68; p<0.01) between weight at puberty and pelvis growth. A recommendation for the future is to weigh the animals on which pelvimetry is performed to investigate if a more accurate prediction of pelvis growth can be determined.

No power analysis is done before performing the measurements. The sample size is chosen based historical and practical considerations. The data of this study gives the opportunity to calculate a power for a possible new and comparable research.

Conclusion

In conclusion, the pelvis height and width are related to breed, the Nguni have the smallest pelvis sizes followed by the Brahman and the Bonsmara. Herefords have the largest mean pelvis size. These breed differences also apply to the other body measurements and make the combined data of all breeds hard to interpret. For selection of animals for breeding based on pelvis measurements, one should use data of the corresponding breed, because of breed differences.
Age is positively related to pelvis area. Body measurements and reproductive status are positively related to pelvis area, too. Female animals have bigger pelvis areas than male animals. Animals with BCS 3 have the optimum BCS for having the largest pelvis area in this study. Earlier studies conclude that the prebreeding pelvis area can be used as a predictor for precalving pelvis area (Johnson et al., 1998) the current study adds the information that the best timing for measuring this prebreeding pelvis area in heifers is when the animal reaches puberty, which means the animal has had its first estrus cycle. This fits in reproductive status RTS 4 or 5, when a corpus luteum is present.

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Bibliography

Andersen, K., LeFever, D., Brinks, J., & Odde, K. (1991). The use of reproductive tract scoring in a group of beef replacement heifers. *Agri-Practice*, 19-26.

Anthony, R., Kittok, R., Ellington, E., & Nielsen, M. (1981). Effects of zeranol on growth and ease of calf delivery in beef heifers. *Journal of Animal Science* , 1325-1332.

Bellows, R. (1983). Management of reproduction in beef cattle, sheep and pigs. *Journal of Animal Science*, 355.

Bellows, R., Genho, P., Moore, S., & Chase Jr., C. (1996). Factors affecting dystocia in Brahman-Cross heifers in subtropical southeastern united states. *Journal of Animal Science*, 1451-1456.

Coopman, F., de Smet, S., Gengler, N., Haegeman, A., Jacobs, K., van Poucke, M., . . . Groen, A. (2003). Estimating internal pelvic sizes using external body measurements in the double-muscled Belgian Blue beef breed. *Animal Science*, 229-235.

Deutscher, G., Zerfoss, L., & Clanton, D. (1986). Time of zeranol implantation on growth, reproduction and calving of beef heifers. *Journal of Animal Science*, 875-886.

Devkota, B., Koseki, T., Matsui, M., Sasaki, M., Kaveko, E., Miyamoto, A., . . . Miyake, Y.-I. (2008). Relationship among age, body weight, scrotal circumference, semen quality and peripheral testosterone and estradiol concentrations in pubertal and postpubertal holstein bulls. *Theriogenology*, 119-121.

Gaines, J., Peschel, D., Kauffman, R., Schaefer, D., Badtram, G., Kumi-Diaka, J., . . . Milliken, G. (1993). Pelvic growth, calf birth weight and dystocia in Holstein x Hereford heifers. *Theriogenology*, 33-41.

Gundelach, Y., Essmeyer, K., Teltscher, M., & Hoedemaker, M. (2009). Risk factors for perinatal mortality in dairy cattle: Cow and foetal factors, calving process. *Theriogenology*, 901-909.

Hancock, R., Deutschefi, G., Nielsens, M., & Colburn, D. (1994). Effects of Synovex C@ Implants on Growth Rate, Pelvic Area, Reproduction, and Calving Performance of Replacement Heifers. *Journal of Animal Science*, 292-299.

Hoffman, P., Brehm, N., Price, G., & Prill-Adams, A. (1996). Effect of Accelerated Postpubertal Growth and Early Calving on Lactation Performance of Primiparous Holstein Heifers . *Journal of Dairy Science*, 2024-2031.

Holm, D., Nielen, M., Jorritsma, R., Irons, P., & Thompson, P. (2016). Ultrasonographic reproductive tract measures and pelvis measures as predictors of pregnancy failure and anestrus in restricted bred beef heifers. *Theriogenology*, 495-501.

Holm, D., Webb, E., & Thompson, P. (2014). A new application of pelvis area data as culling tool to aid in the management of dystocia in heifers. *Journal of Animal Science*, 2296-2303.

Houghton, P., Lemenager, R., Moss, G., & Hendrix, K. (1990). Prediction of postpartum beef cow body composition using weight to height ratio and visual body condition score. *Journal of Animal Science*, 1428-1437.

Johanson, J., & Berger, P. (2003). Birth weight as a predictor of calving ease and perinatal mortality in holstein cattle. *Journal of Dairy Science*, 3745-3755.

Johnson, S., Deutscher, G., & Parkhurst, A. (1988). Relationships of pelvic structure, body measurements, pelvic area and calving difficulty. *Journal of Animal Science*, 1081-1088.

Kolkman, I., Hoflack, G., Aerts, S., Murray, R., Opsomer, G., & Lips, D. (2009). Evaluation of the Rice pelvimeter for measuring pelvic area in double muscled Belgian Blue cows. *Livestock Science*, 259-266.

Mee, J. (2008). Prevalence and risk factors for dystocia in dairy cattle: A review. *The Veterinary Journal*, 93-101.

Mee, J., Sánchez-Miguel, C., & Doherty, M. (2014). Influence of modifiable risk factors on the incidence of stillbirth/perinatal mortality in dairy cattle. *The Veterinary Journal*, 19-23.

Menchaca, M., Chase, C., Olson, T., & Hammond, A. (1996). Evaluation of Growth Curves of Brahman Cattle of Various Frame Sizes. *Journal of Animal Science* , 2140-2151.

Naazie, A., Makarechian, M., & Berg, R. (1991). Genetic, phenotypic, and environmental parameter estimates of calving difficulty, weight, and measures of pelvic size in beef heifers. *Journal of Animal Science*, 4793-4800.

Nix, J., Spitzer, J., Grimes, L., Burns, G., & Plyler, B. (1998). A retrospective analysis of factors contributing to calf mortality and dystocia in beef cattle. *Theriogenology*, 1515-1523.

Paputungan, U., Makarechian, M., & Liu, M. (1993). Repeatability estimates of pelvic diameters measured by Rice pelvimeter in beef heifers. *Canadian Journal of Animal Science*, 977-980.

Price, T., & Wiltbank, J. (1978b). Predicting dystocia in heifers. *Theriogenology*, 221-249.

Ramin, A., Daniel, R., Fenwick, D., & Verrall, R. (1995). Pelvic Parameters, Growth Rate, Puberty, and their Interrelationships in Young Dairy Heifers. *Reproduction of Domestic Animals*, 117-123.

Rosenkrans, K., & Hardin, D. (2003). Repeatability and accuracy of reproductive tract scoring to determine pubertal status in beef heifers. *Theriogenology*, 1087-1092.

Smeaton, D., Sctoo, M., Webby, R., Cameron, C., McGowan, L., & Brooky, A. (2004). Factors associated with calving difficulty in embryo transfer mated cattle. *Proceedings of the New Zealand Society of Animal Production*, 252-256.

Staigmiller, R., Bellows, R., & Short, R. (1983). Growth and reproductive traits in beef heifers implanted with zeranol. *Journal of Animal Science*, 527-534.

Steward, T., Long, C., & Cartwright, T. (1980). Characterization of cattle of a five-breed diallel. III Puberty in bulls and heifers. *Journal of Animal Science*, 808-820.

Van Donkersgoed, J., Ribble, C., Booker, C., McCartney, D., & Janzen, E. (1993). The predictive value of pelvimetry in beef cattle. *Canadian Journal of Veterinary Research*, 170-175.

Appendix

1. Body condition scoring system

For body condition score, a 5 point scale is used according to *Houghton et al., (1989)* which is described in Table 1 below.

Table 1: Body condition scoring system for beef cattle according to *Houghton et al., (1989)*.

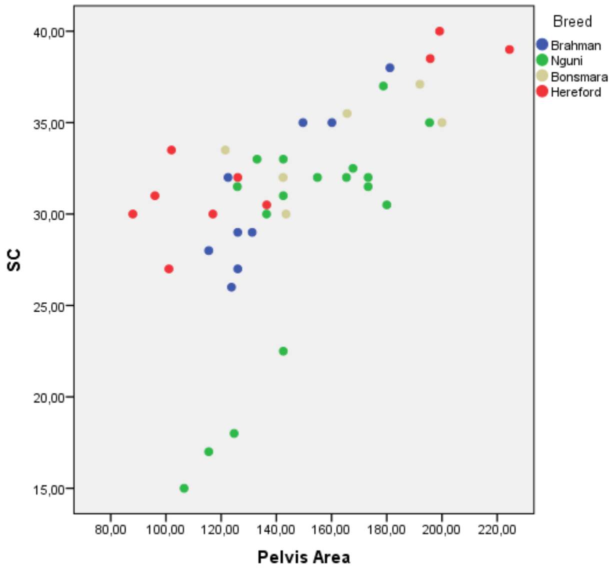
Group	BCS*	Description
Thin condition	1	EXTREMELY THIN with severe wasted muscle development; may appear humped in the back with feet close together; usually weak; extremely prominent backbone, hooks, pins and ribs.
	2	THIN with little or no wasting of muscle structure; vigorous; little or no fat in rump, rib or brisket; prominent backbone, hooks, pins and ribs but normal appearing muscle structure.
Moderate condition	3	IDEAL CONDITION, Thrifty with normal muscle structure; some evidence of fat deposited in the forerib, brisket and crops but limited around the tailhead; some smoothness over the shoulder, ribs, backbone, hooks and pins.
Fat condition	4	FAT but still firm; vigorous; considerable fat deposited over forerib; brisket protruding; tailhead full (bulging); very smooth over backbone with no skeleton visible except at hooks.
	5	VERY FAT with considerable softness; very fat over de forerib and shoulder; large, prominent brisket; broad, flat topline; large patchy fat deposits around the tailhead; body curvature becomes square in appearance.

**This system was expanded for more accuracy using 0.5 steps between each BCS score.*

2. Descriptive statistics for Pelvis area and Scrotum Circumference.

Scrotum circumference of 25 male animals divided over 4 breeds is used. The scatterplot in Figure 1 shows a positive relationship between scrotum circumference and pelvis area.

Figure 1: Scatterplot of pelvis area and scrotum circumference.



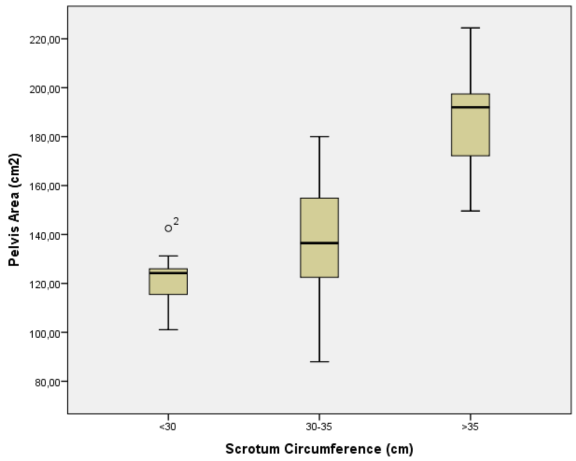
For eventual further analysis of this data, bulls could be divided in 3 subgroups based on their scrotum circumference. The cross table (Table 1) below shows the amount of animals per group, the groups are divided in: <30cm, 30-34.9cm and >35cm.

Table 1: Cross table of scrotum circumference per breed, divided in 3 groups

	Brahman	Nguni	Bonsmara	Hereford	Total
<30cm	5	4	0	1	10
30-35cm	1	11	3	6	21
>35cm	3	2	3	3	11
Total	9	17	6	10	42

The box plot for pelvis area and scrotum circumference based on these 3 groups shows an increase per group with a bigger scrotum circumference, as shown in Figure 2.

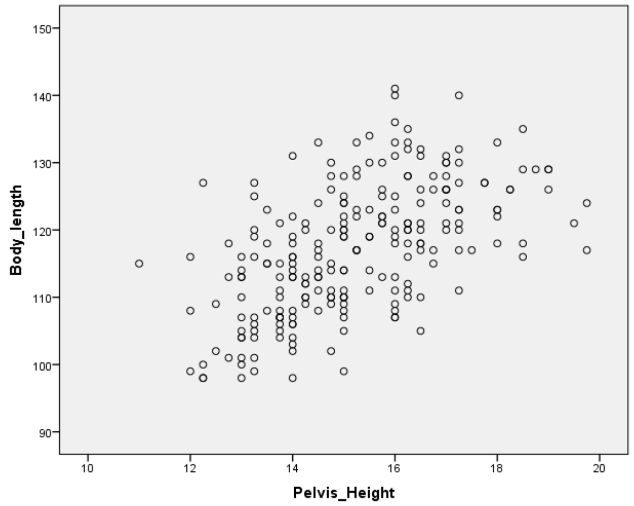
Figure 2: Box plot of pelvis area and scrotum circumference divided in 3 groups.



3. Univarable General linear models

3.1. Pelvis Height

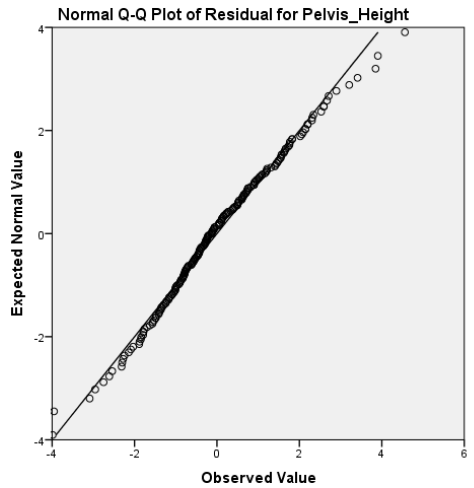
3.1.1. Scatterplot, Parameter estimates and q-q plots of Pelvis height & Body length.

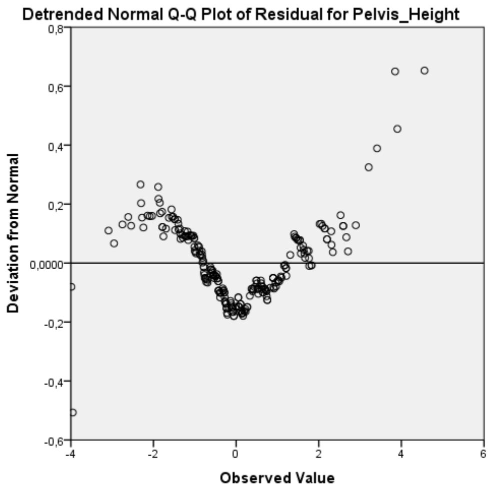


Parameter Estimates

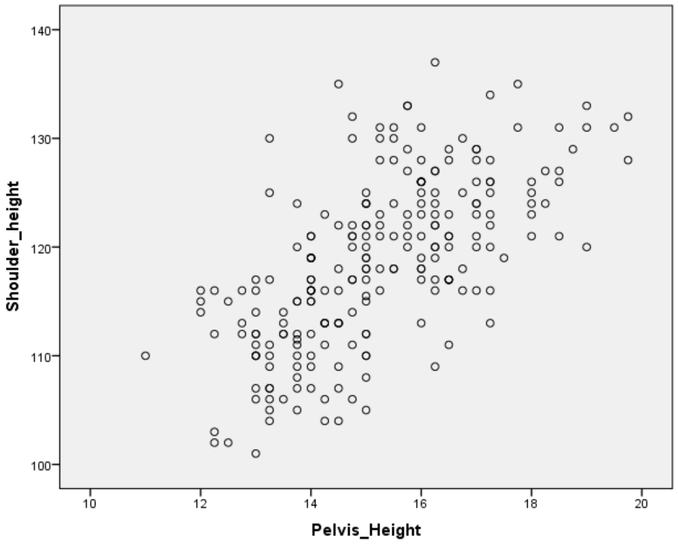
Dependent Variable: Pelvis_Height

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	3,315	1,158	2,863	,005	1,033	5,596
Body_length	,102	,010	10,317	,000	,082	,121





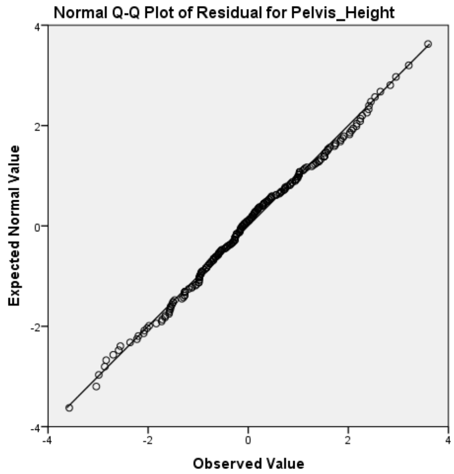
3.1.2. Scatterplot, Parameter estimates and q-q plots of Pelvis height & Shoulder height.

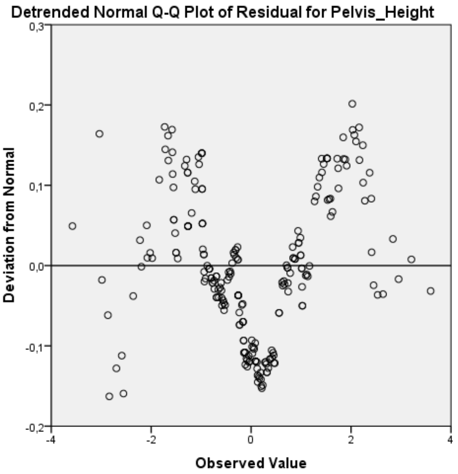


Parameter Estimates

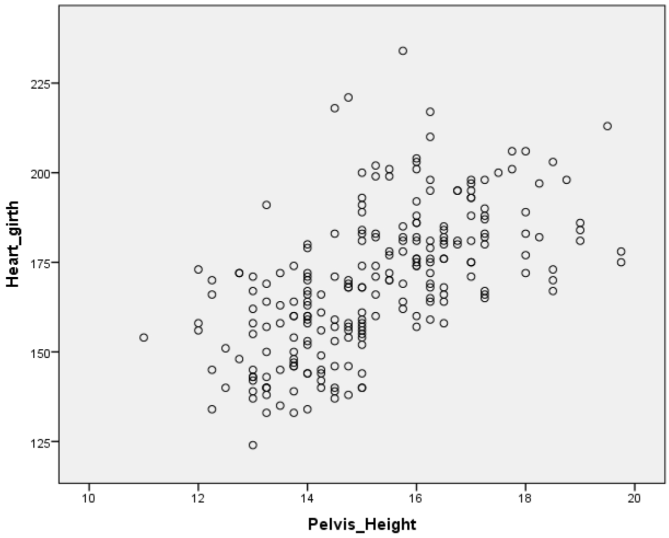
Dependent Variable: Pelvis_Height

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	-1,631	1,334	-1,223	,222	-4,259	,996
Shoulder_height	,142	,011	12,664	,000	,120	,164





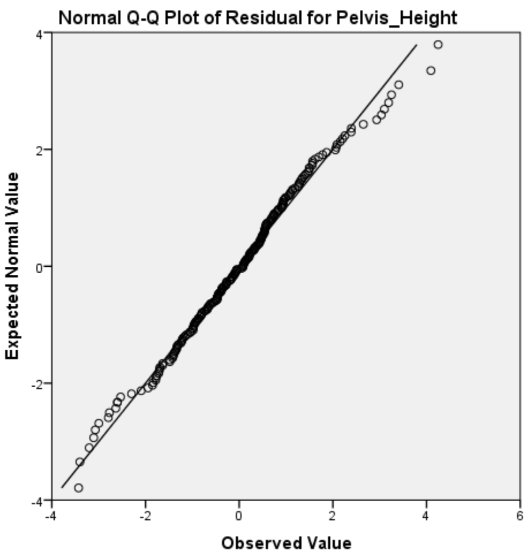
3.1.3. Scatterplot, Parameter estimates and q-q plots of Pelvis height & Heart Girth.

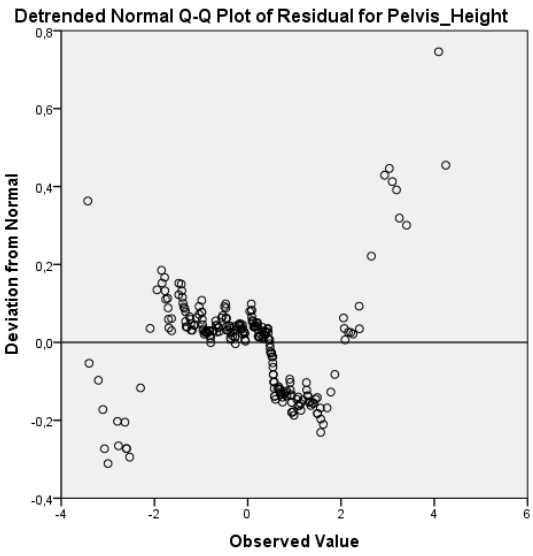


Parameter Estimates

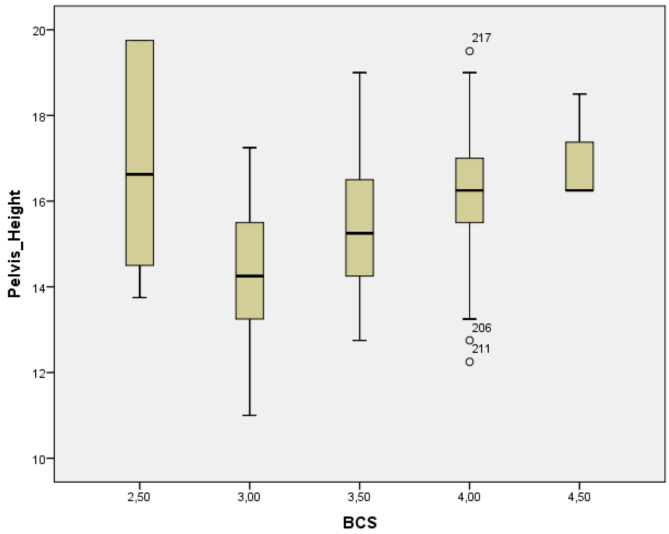
Dependent Variable: Pelvis_Height

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	6,553	,775	8,460	,000	5,027	8,079
Heart_girth	,051	,005	11,269	,000	,042	,060





3.1.4. Box plot, Parameter estimates and q-q plots of Pelvis height & BCS.

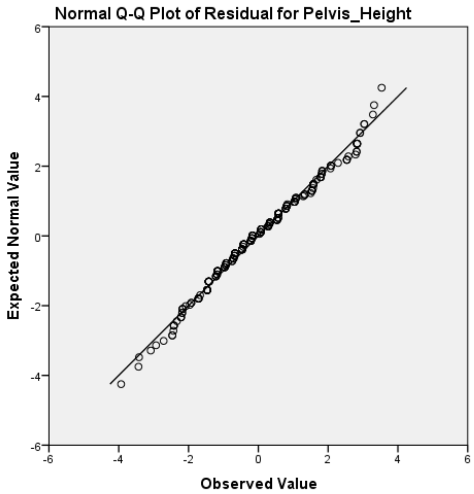


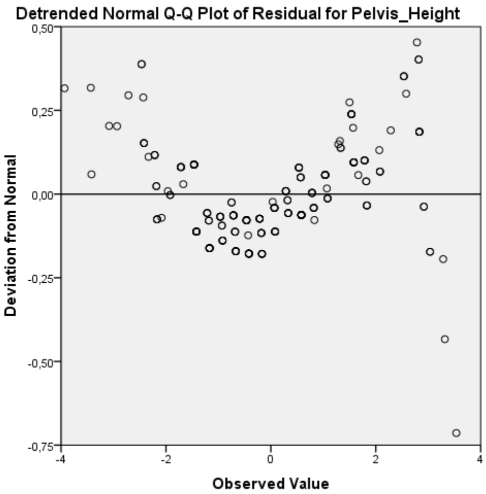
Parameter Estimates

Dependent Variable: Pelvis_Height

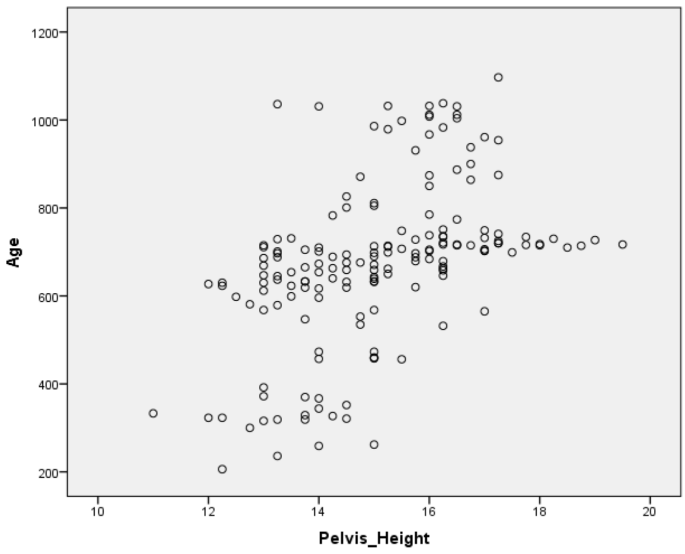
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	17,000	,890	19,100	,000	15,246	18,754
[BCS3=2,50]	-,167	1,090	-,153	,879	-2,315	1,981
[BCS3=3,00]	-2,580	,904	-2,853	,005	-4,362	-,798
[BCS3=3,50]	-1,535	,905	-1,695	,091	-3,319	,249
[BCS3=4,00]	-,817	,922	-,886	,376	-2,634	1,000
[BCS3=4,50]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





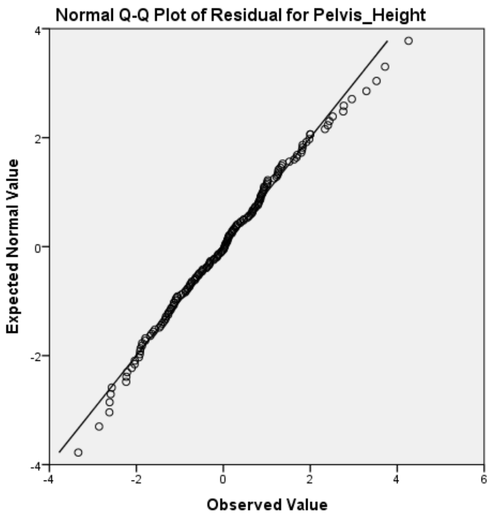
2.1.5. Scatterplot, Parameter estimates and q-q plots of Pelvis height & Age.

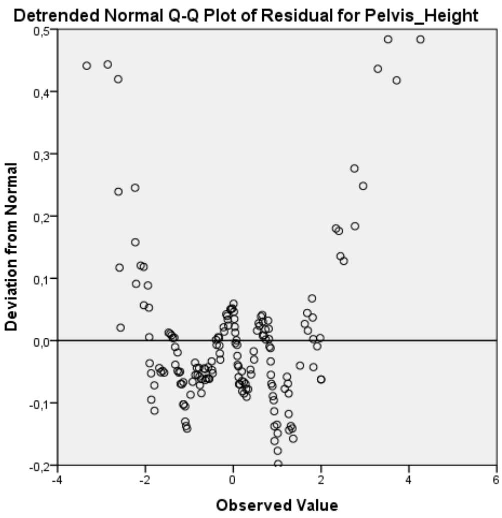


Parameter Estimates

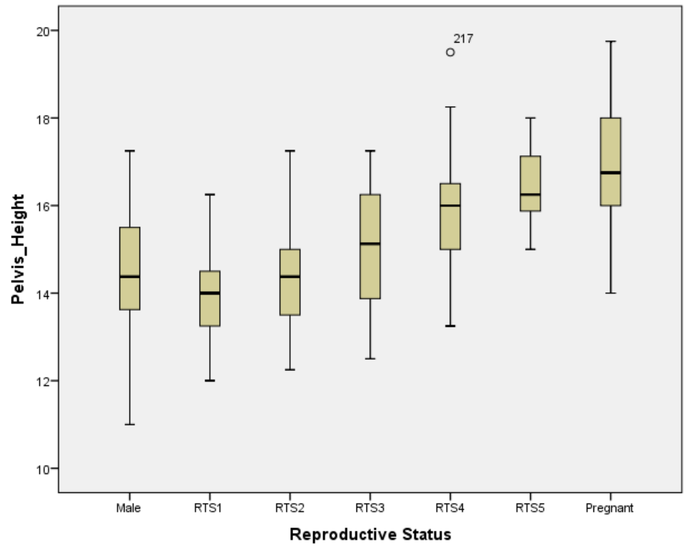
Dependent Variable: Pelvis_Height

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	12,208	,413	29,553	,000	11,393	13,024
Age	,004	,001	7,153	,000	,003	,005





2.1.6. Box plot, Parameter estimates and q-q plots of Pelvis height & Reproductive status.

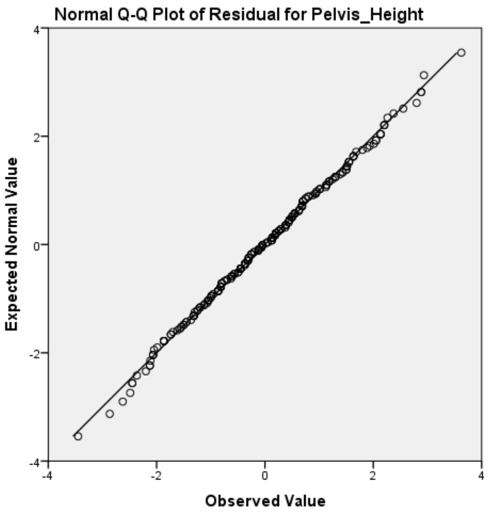


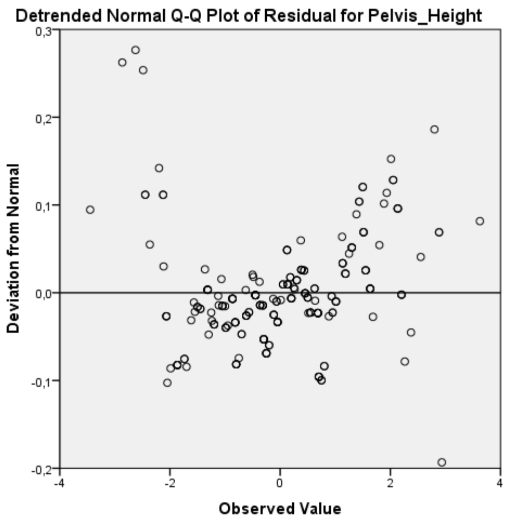
Parameter Estimates

Dependent Variable: Pelvis_Height

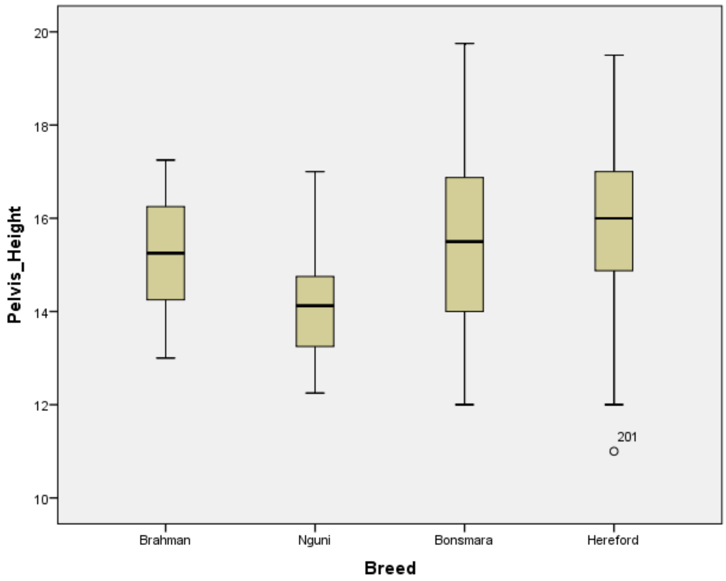
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	16,865	,179	94,172	,000	16,512	17,218
[RTS=0]	-2,417	,265	-9,135	,000	-2,938	-1,895
[RTS=1]	-2,818	,278	-10,146	,000	-3,365	-2,271
[RTS=2]	-2,550	,268	-9,517	,000	-3,078	-2,022
[RTS=3]	-1,878	,340	-5,526	,000	-2,548	-1,208
[RTS=4]	-,990	,369	-2,682	,008	-1,718	-,263
[RTS=5]	-,365	,346	-1,055	,292	-1,048	,317
[RTS=6]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





2.1.7. Box plot, Parameter estimates and q-q plots of Pelvis height & Breed.

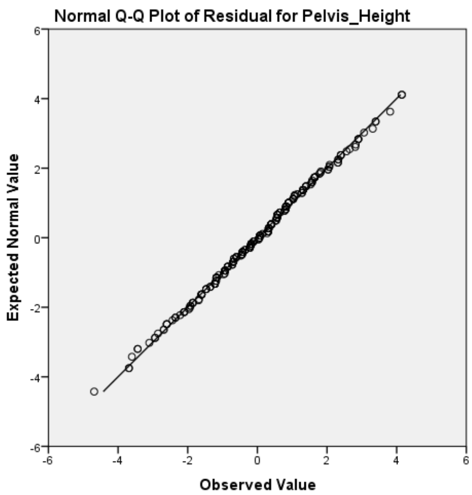


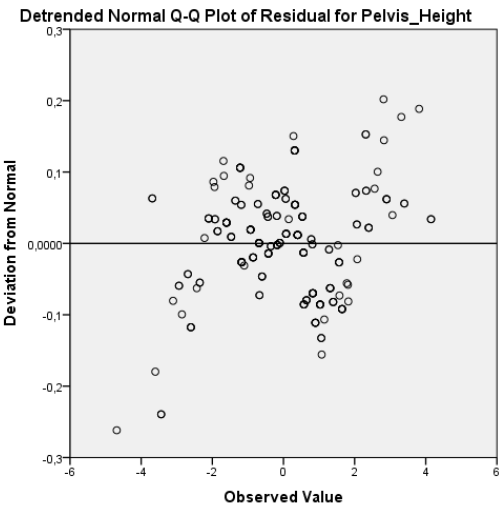
Parameter Estimates

Dependent Variable: Pelvis_Height

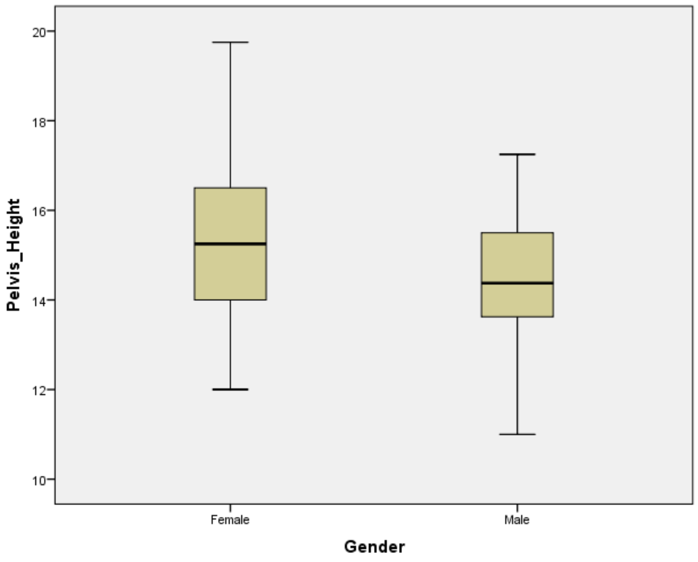
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	15,688	,207	75,840	,000	15,280	16,095
[Breed=1]	-,468	,325	-1,441	,151	-1,108	,172
[Breed=2]	-1,512	,301	-5,029	,000	-2,104	-,919
[Breed=3]	-,084	,278	-,303	,762	-,631	,463
[Breed=4]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





2.1.8. Box plot, Parameter estimates and q-q plots of Pelvis height & Gender.

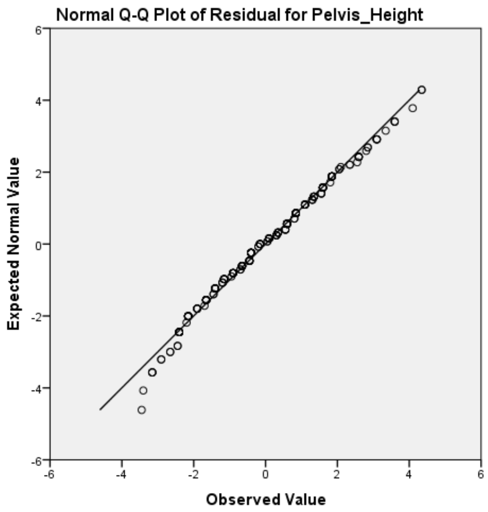


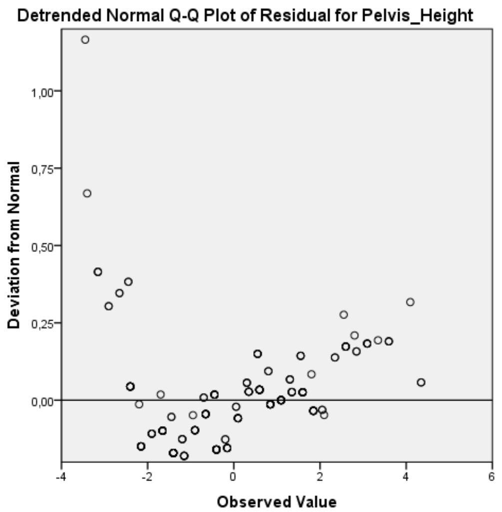
Parameter Estimates

Dependent Variable: Pelvis_Height

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	14,449	,251	57,626	,000	13,955	14,943
[Gender=0]	,956	,279	3,428	,001	,406	1,505
[Gender=1]	0[a]	.	.	.	.	.

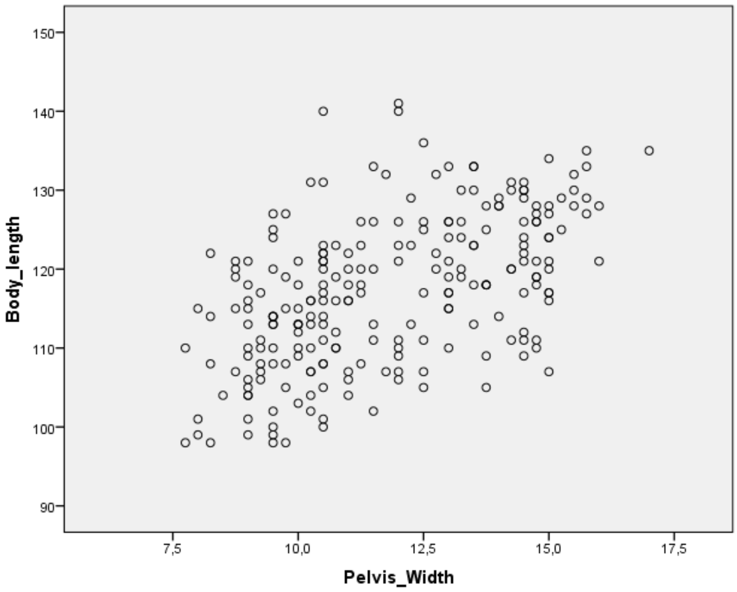
a. This parameter is set to zero because it is redundant.





3.2. Pelvis Width

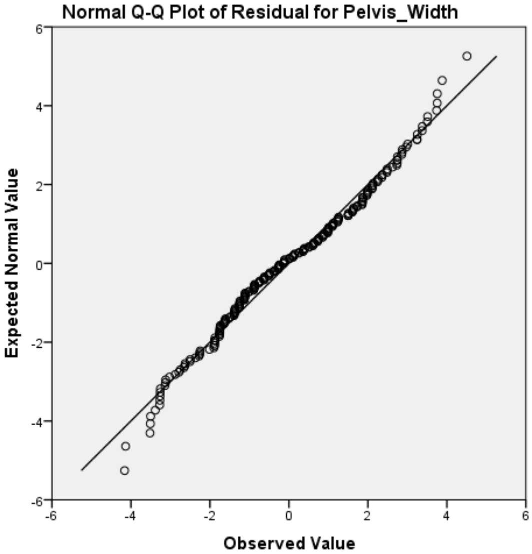
2.2.1. Scatterplot, Parameter estimates and q-q plots of Pelvis width & Body length.

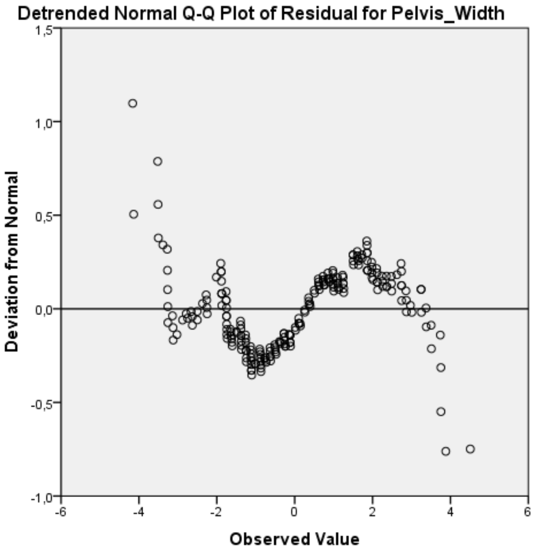


Parameter Estimates

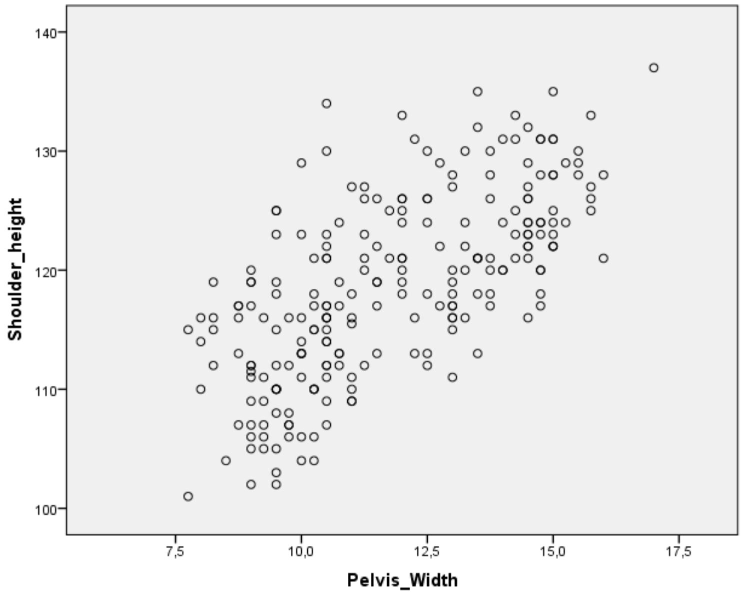
Dependent Variable: Pelvis_Width

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-3,026	1,558	-1,942	,053	-6,097	,044
Body_length	,126	,013	9,542	,000	,100	,152





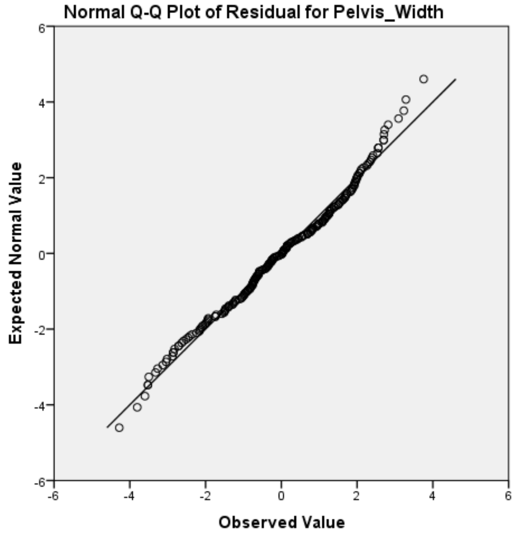
2.2.2. Scatterplot, Parameter estimates and q-q plots of Pelvis width & Shoulder height.

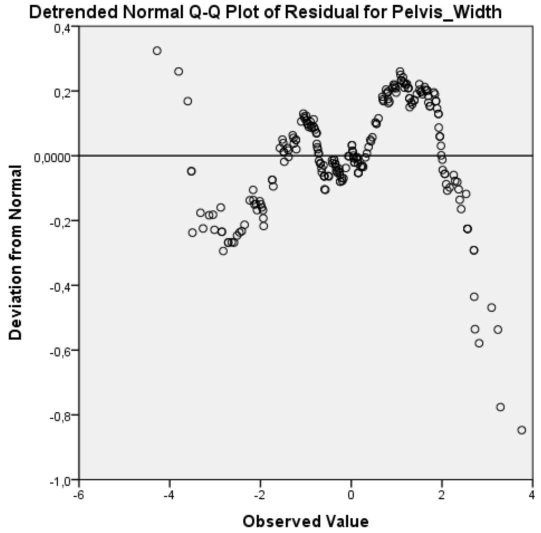


Parameter Estimates

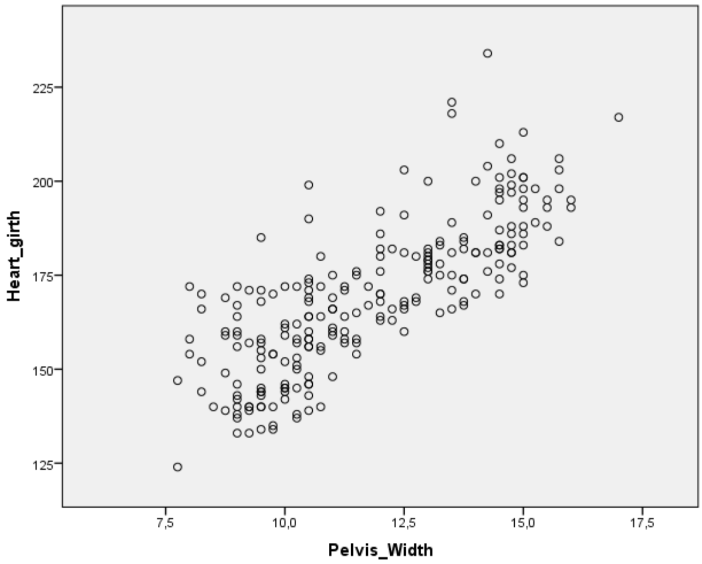
Dependent Variable: Pelvis_Width

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-11,379	1,694	-6,719	,000	-14,717	-8,042
Shoulder_height	,195	,014	13,710	,000	,167	,223





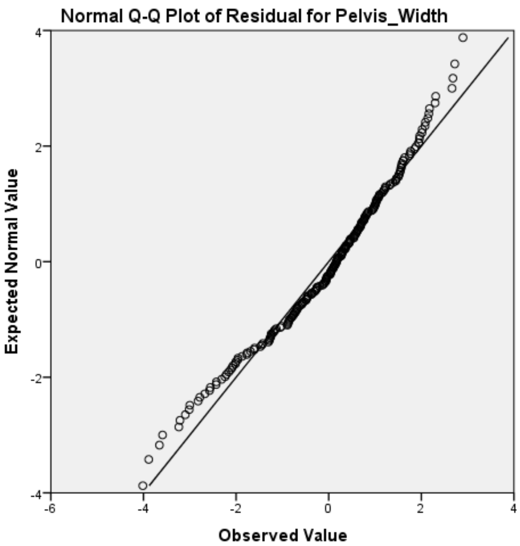
2.2.3. Scatterplot, Parameter estimates and q-q plots of Pelvis width & Heart girth.

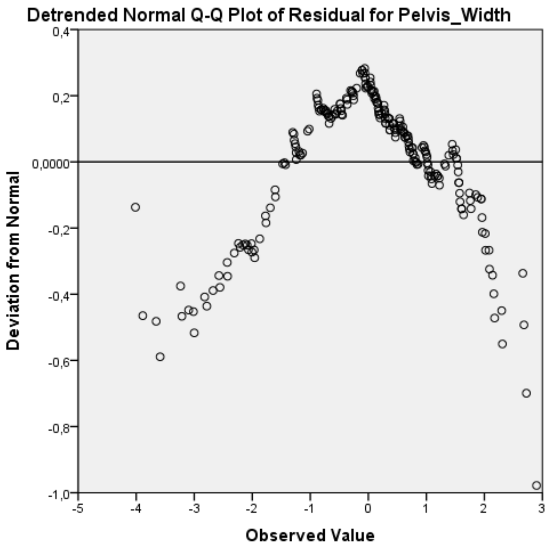


Parameter Estimates

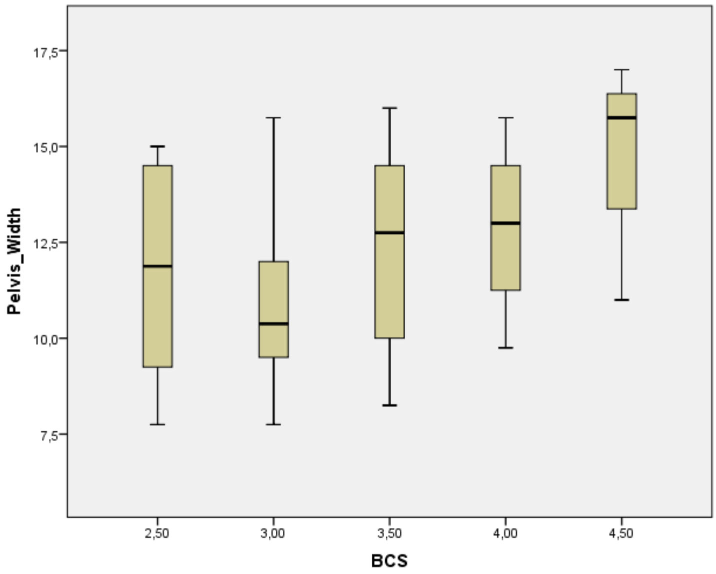
Dependent Variable: Pelvis_Width

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	-3,104	,792	-3,921	,000	-4,665	-1,544
Heart_girth	,088	,005	18,944	,000	,079	,097





2.2.4. Box plot, Parameter estimates and q-q plots of Pelvis width & BCS.

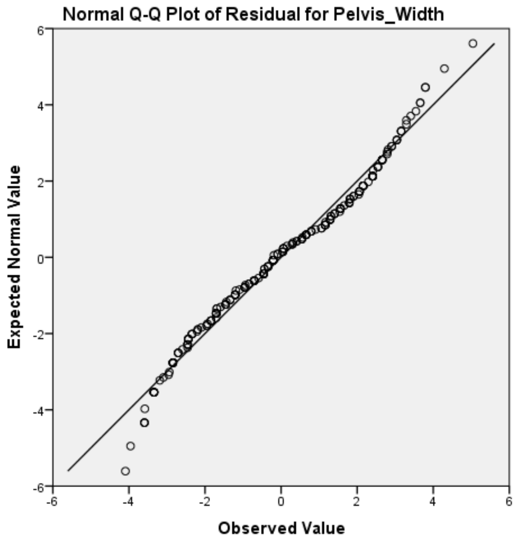


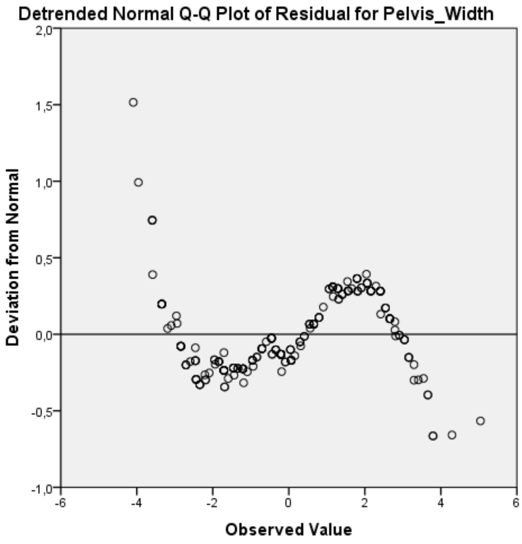
Parameter Estimates

Dependent Variable: Pelvis_Width

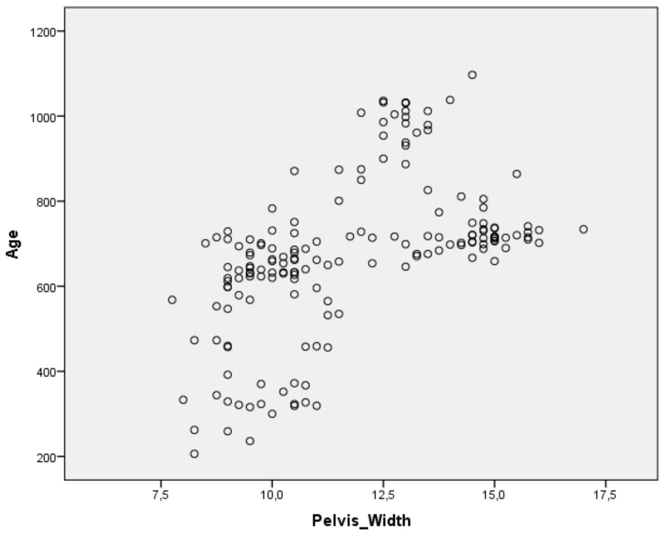
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	14,583	1,175	12,412	,000	12,268	16,899
[BCS3=2,50]	-2,875	1,439	-1,998	,047	-5,711	-,039
[BCS3=3,00]	-3,876	1,194	-3,247	,001	-6,228	-1,524
[BCS3=3,50]	-2,240	1,195	-1,874	,062	-4,596	,115
[BCS3=4,00]	-1,644	1,217	-1,351	,178	-4,043	,754
[BCS3=4,50]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





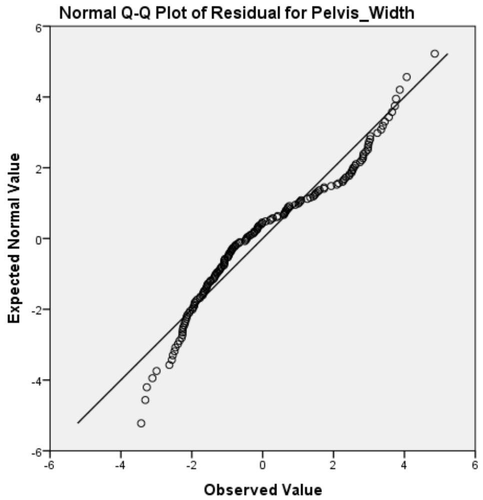
2.2.5. Scatterplot, Parameter estimates and q-q plots of Pelvis width & Age.

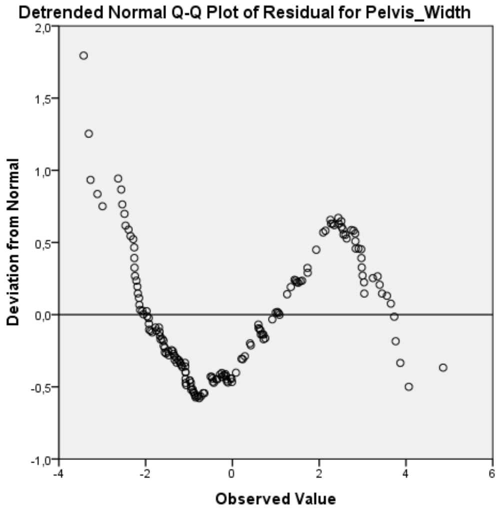


Parameter Estimates

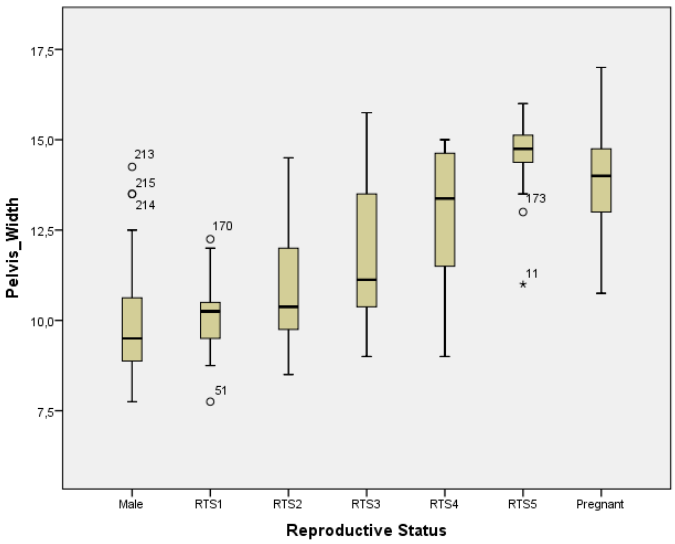
Dependent Variable: Pelvis_Width

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	7,356	,571	12,880	,000	6,229	8,484
Age	,007	,001	7,985	,000	,005	,008





2.2.6. Box plot, Parameter estimates and q-q plots of Pelvis width & Reproductive status.

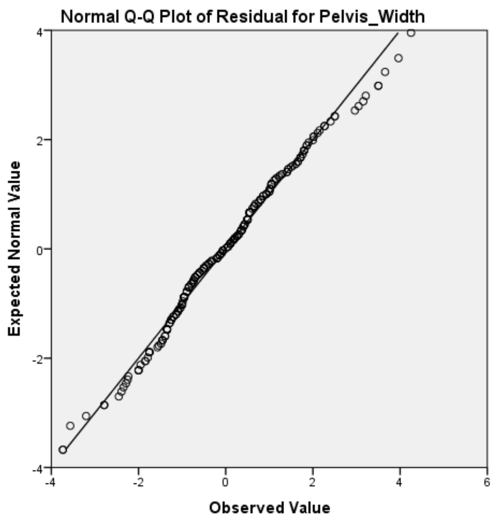


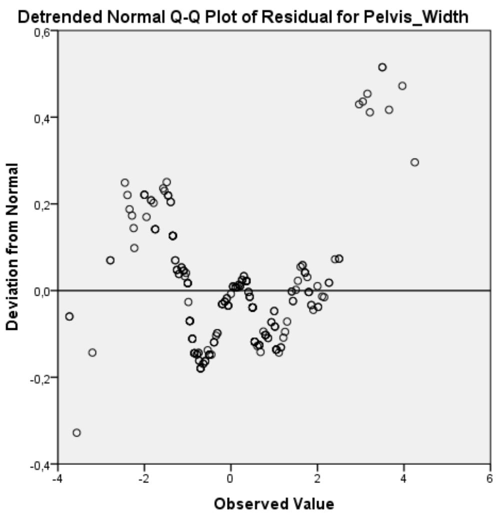
Parameter Estimates

Dependent Variable: Pelvis_Width

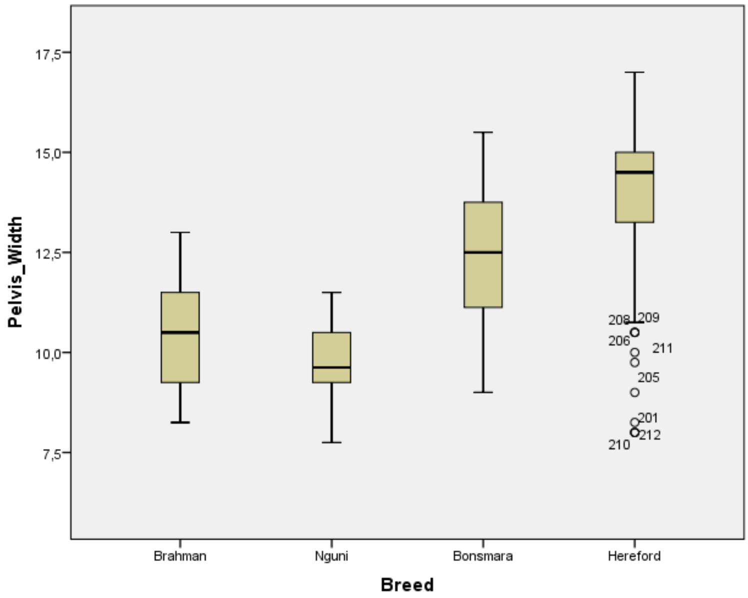
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	13,952	,200	69,812	,000	13,558	14,346
[RTS=0]	-3,952	,295	-13,387	,000	-4,534	-3,370
[RTS=1]	-3,810	,310	-12,292	,000	-4,421	-3,199
[RTS=2]	-3,107	,299	-10,391	,000	-3,696	-2,517
[RTS=3]	-2,164	,379	-5,708	,000	-2,912	-1,417
[RTS=4]	-1,218	,412	-2,955	,003	-2,029	-,406
[RTS=5]	,614	,386	1,589	,113	-,147	1,375
[RTS=6]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





2.2.7. Box plot, Parameter estimates and q-q plots of Pelvis width & Breed.

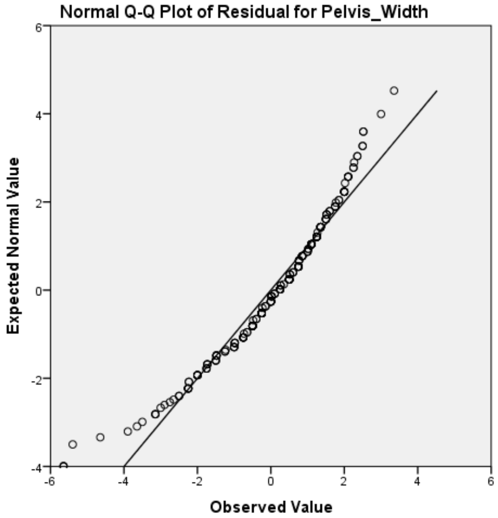


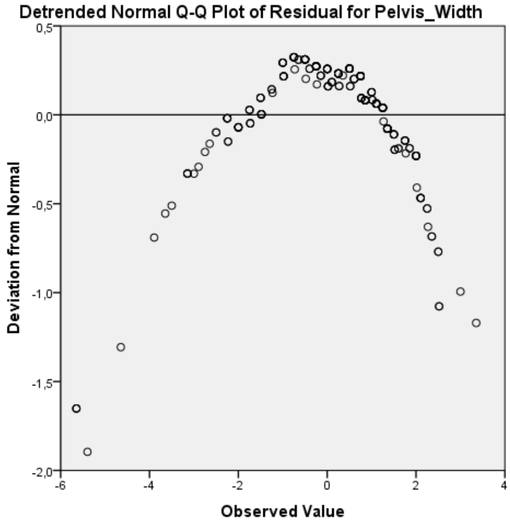
Parameter Estimates

Dependent Variable: Pelvis_Width

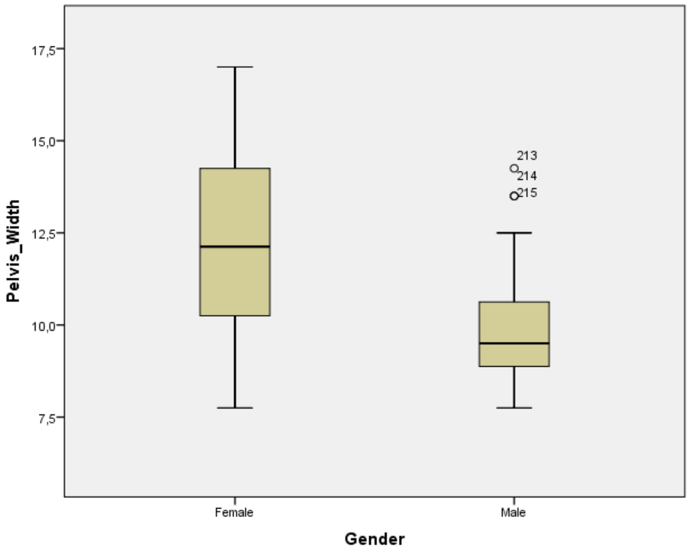
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	13,646	,211	64,525	,000	13,229	14,063
[Breed=1]	-3,164	,332	-9,533	,000	-3,818	-2,510
[Breed=2]	-3,896	,307	-12,679	,000	-4,501	-3,290
[Breed=3]	-1,146	,284	-4,038	,000	-1,705	-,587
[Breed=4]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





2.2.8. Box plot, Parameter estimates and q-q plots of Pelvis width & Gender.

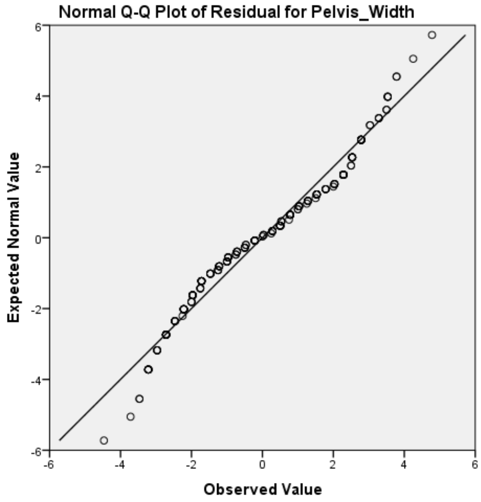


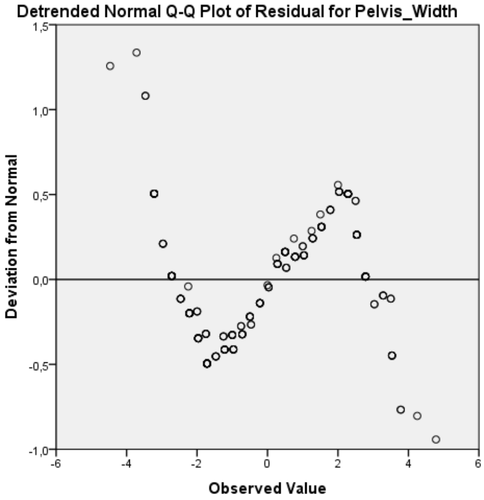
Parameter Estimates

Dependent Variable: Pelvis_Width

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	10,000	,311	32,146	,000	9,387	10,613
[Gender=0]	2,218	,346	6,411	,000	1,536	2,899
[Gender=1]	0[a]	.	.	.	.	.

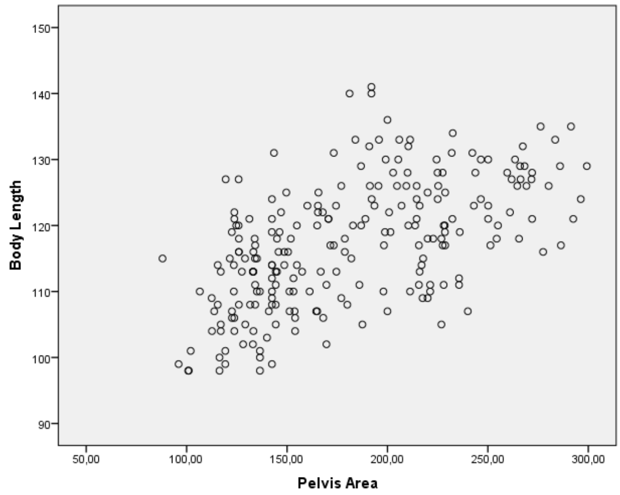
a. This parameter is set to zero because it is redundant.





2.3 Pelvis Area

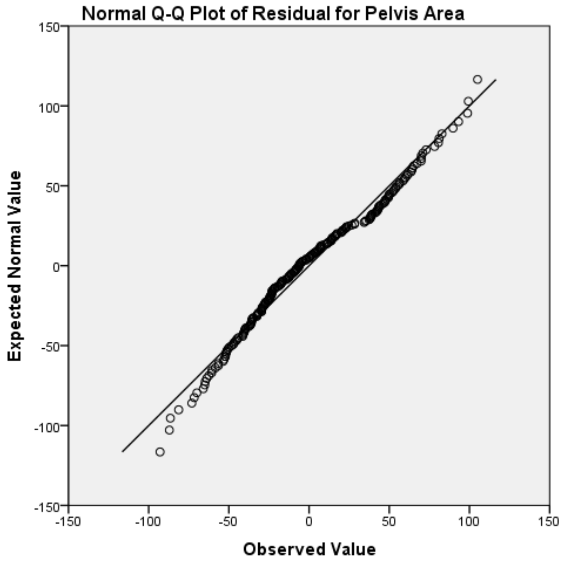
2.3.1. Scatterplot, Parameter estimates and q-q plots of Pelvis area & Body length.

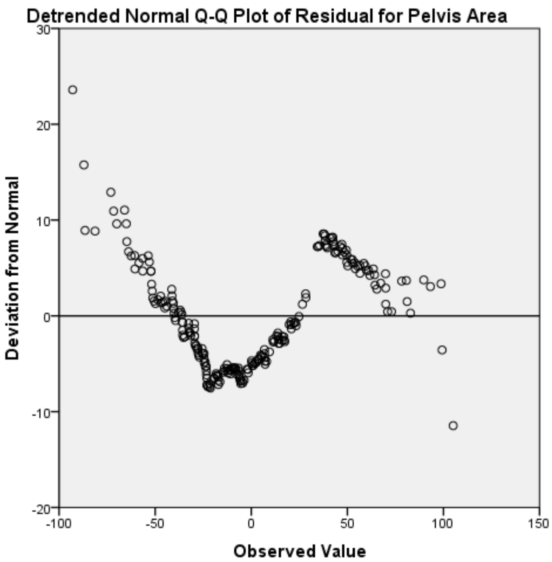


Parameter Estimates

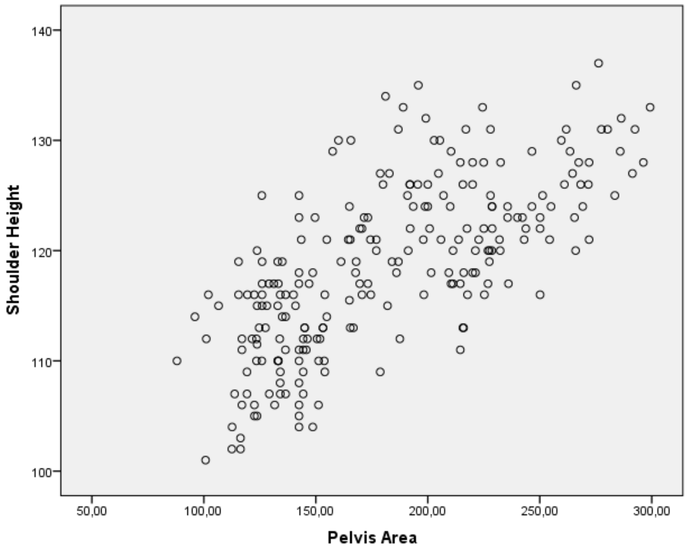
Dependent Variable: Pelvic_Area

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-182,060	34,534	-5,272	,000	-250,106	-114,013
Body_length	3,106	,293	10,584	,000	2,528	3,684





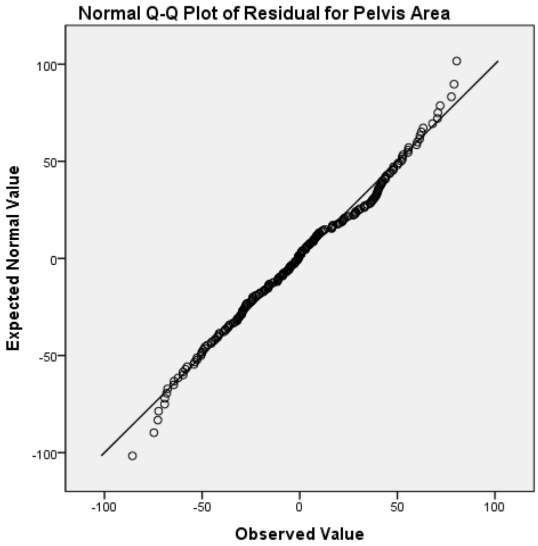
2.3.2. Scatterplot, Parameter estimates and q-q plots of Pelvis area & Shoulder height.

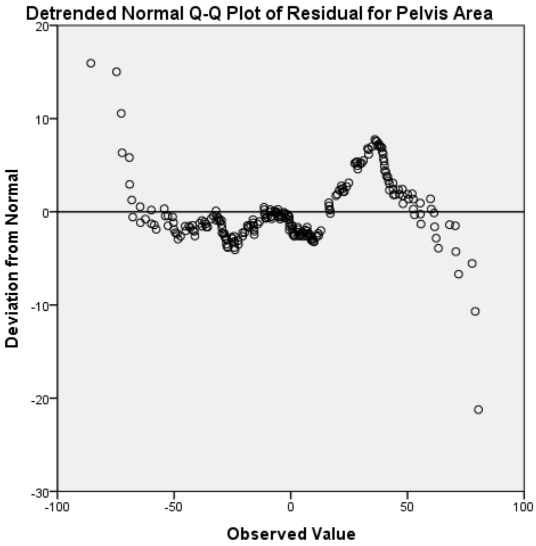


Parameter Estimates

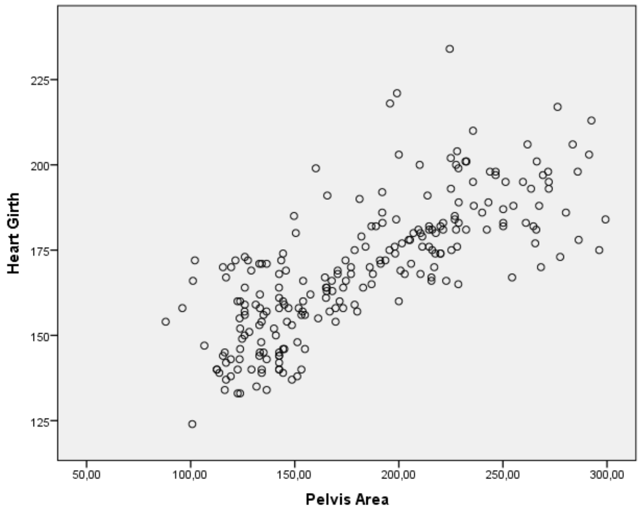
Dependent Variable: Pelvic_Area

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-369,720	37,387	-9,889	,000	-443,388	-296,051
Shoulder_height	4,650	,314	14,795	,000	4,031	5,270





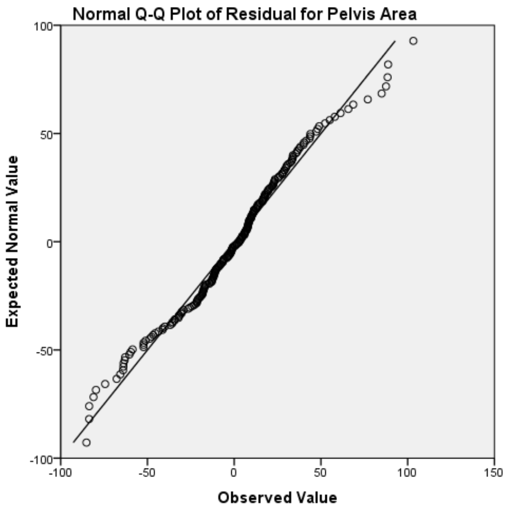
2.3.3. Scatterplot, Parameter estimates and q-q plots of Pelvis area & Heart girth.

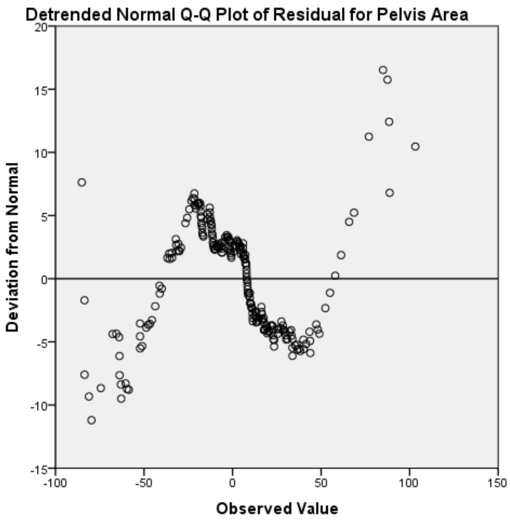


Parameter Estimates

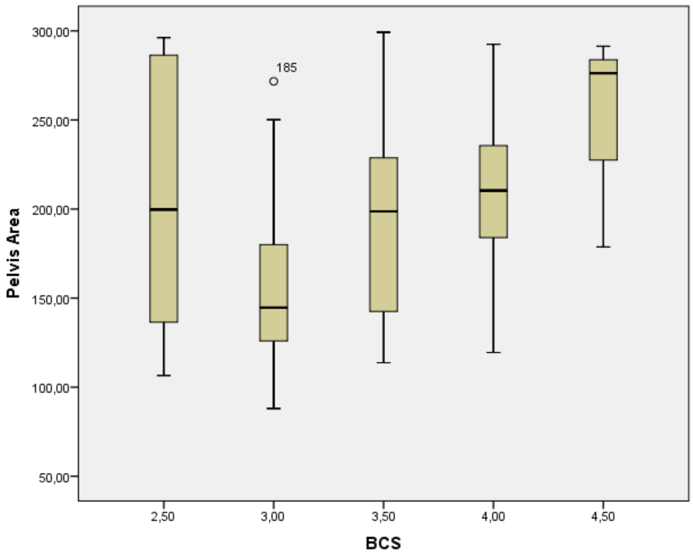
Dependent Variable: Pelvic_Area

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	-148,226	18,951	-7,822	,000	-185,567	-110,885
Heart_girth	1,950	,111	17,559	,000	1,731	2,169





2.3.4. Box plot, Parameter estimates and q-q plots of Pelvis area & BCS.

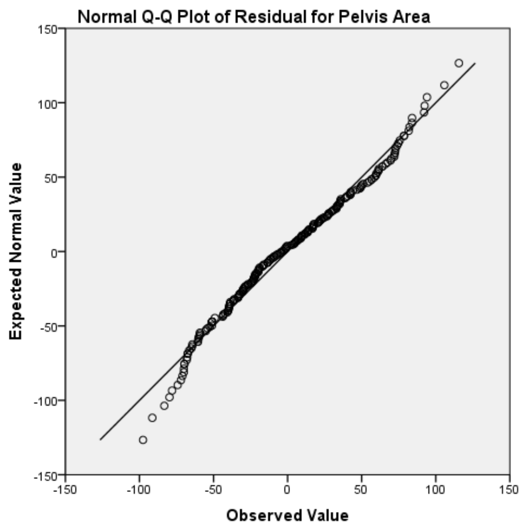


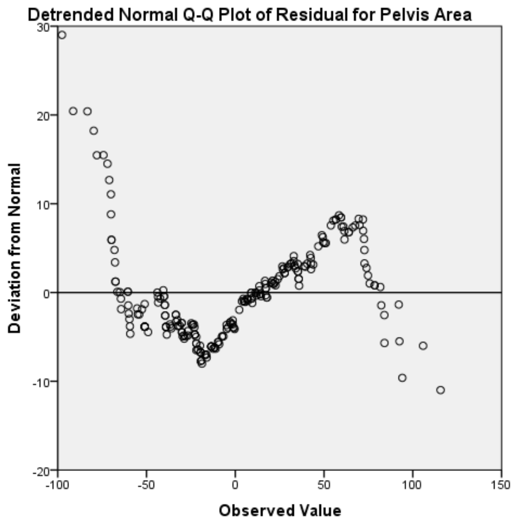
Parameter Estimates

Dependent Variable: Pelvic_Area

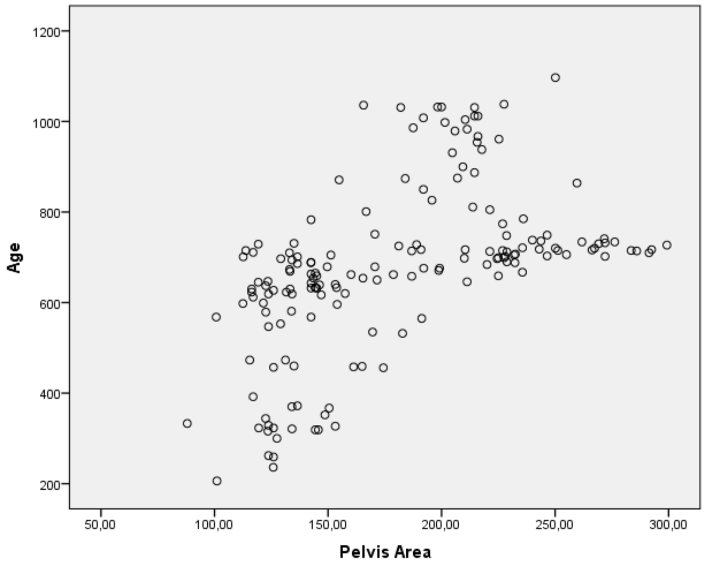
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	248,792	26,526	9,379	,000	196,521	301,062
[BCS3=2,50]	-44,625	32,487	-1,374	,171	-108,643	19,393
[BCS3=3,00]	-92,734	26,946	-3,442	,001	-145,833	-39,636
[BCS3=3,50]	-55,308	26,984	-2,050	,042	-108,483	-2,134
[BCS3=4,00]	-38,016	27,479	-1,383	,168	-92,165	16,134
[BCS3=4,50]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





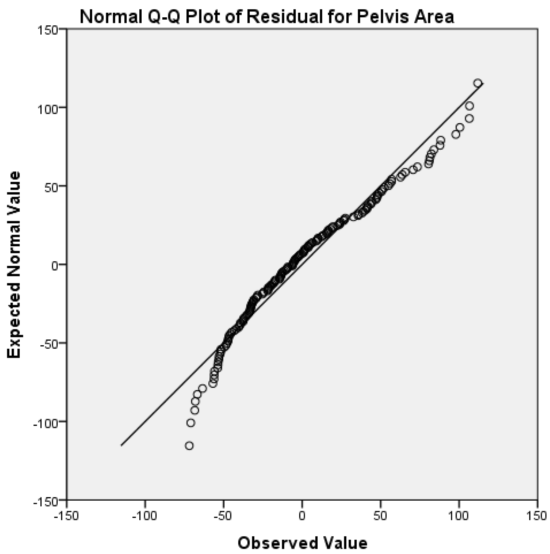
2.3.5. Scatterplot, Parameter estimates and q-q plots of Pelvis area & Age.

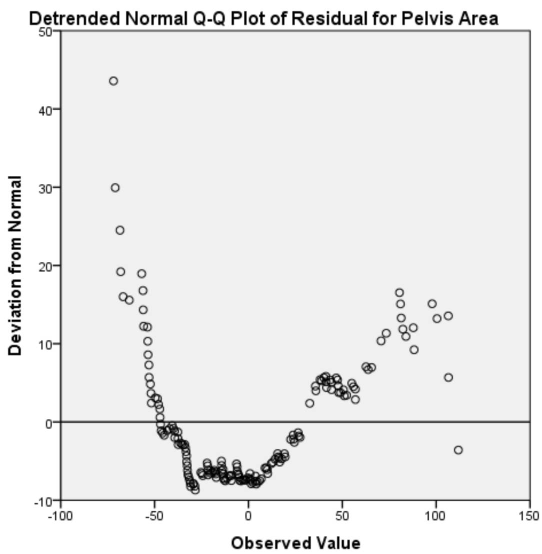


Parameter Estimates

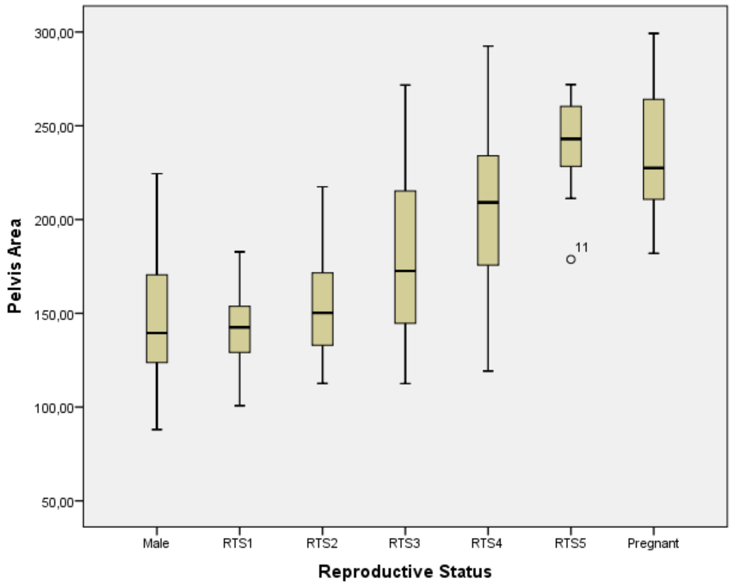
Dependent Variable: Pelvic_Area

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	81,484	12,625	6,454	,000	56,558	106,409
Age	,146	,018	8,067	,000	,110	,181





2.3.6. Box plot, Parameter estimates and q-q plots of Pelvis area & Reproductive status.

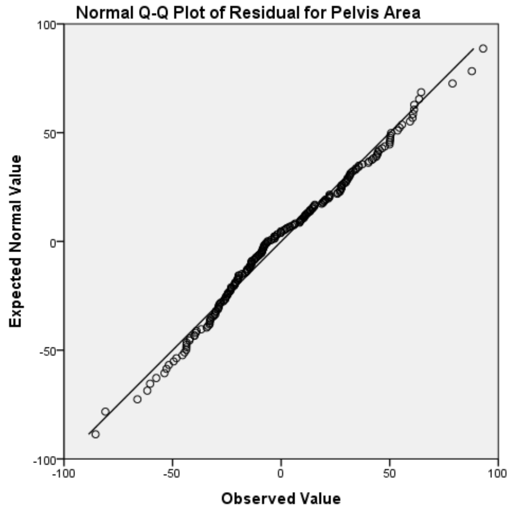


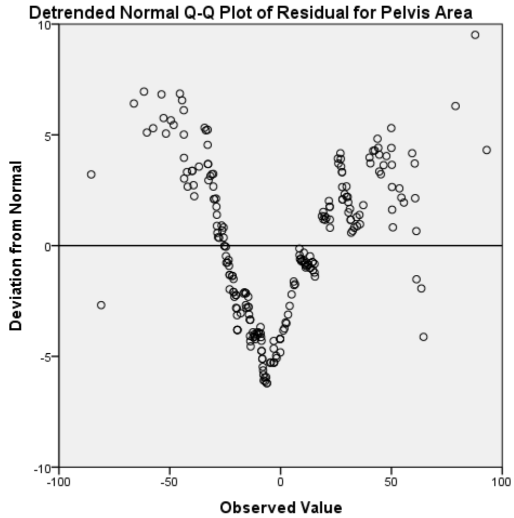
Parameter Estimates

Dependent Variable: Pelvic_Area

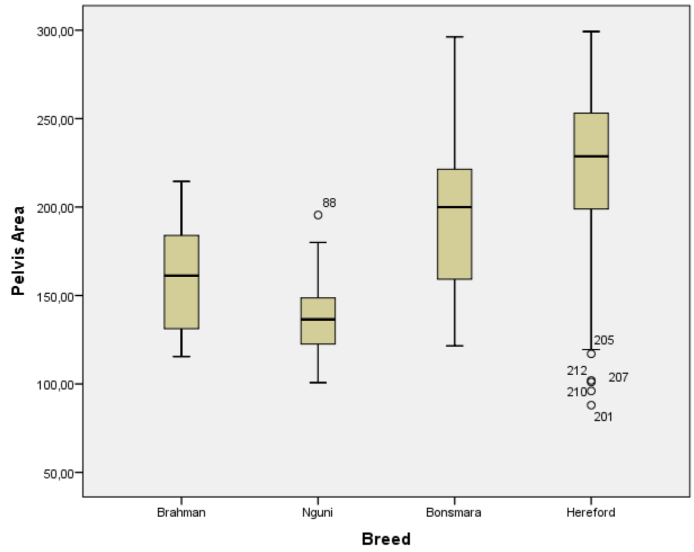
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	235,740	4,482	52,599	,000	226,908	244,573
[RTS=0]	-90,218	6,620	-13,628	,000	-103,264	-77,172
[RTS=1]	-93,031	6,951	-13,384	,000	-106,729	-79,333
[RTS=2]	-79,465	6,705	-11,852	,000	-92,678	-66,252
[RTS=3]	-57,044	8,504	-6,708	,000	-73,802	-40,285
[RTS=4]	-31,029	9,240	-3,358	,001	-49,238	-12,821
[RTS=5]	4,654	8,664	,537	,592	-12,419	21,728
[RTS=6]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





2.3.7. Box plot, Parameter estimates and q-q plots of Pelvis area & Breed.

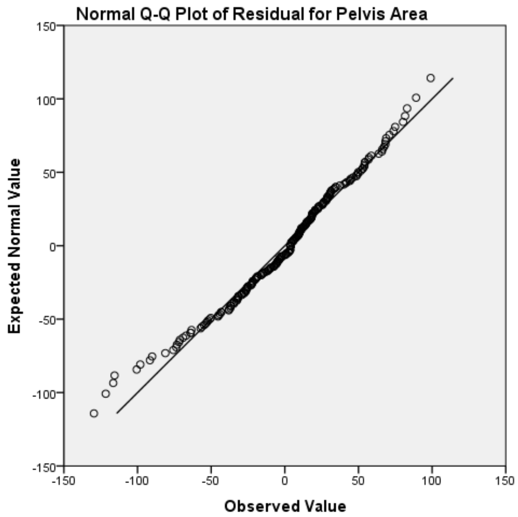


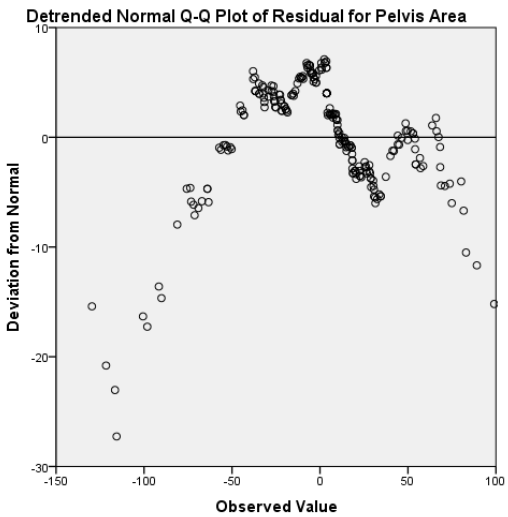
Parameter Estimates

Dependent Variable: Pelvic_Area

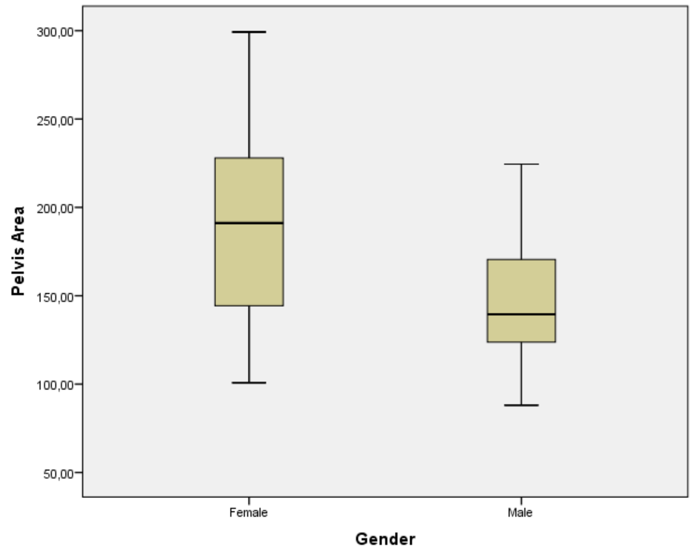
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	217,601	5,337	40,770	,000	207,084	228,118
[Breed=1]	-57,066	8,377	-6,812	,000	-73,573	-40,559
[Breed=2]	-78,887	7,755	-10,173	,000	-94,168	-63,606
[Breed=3]	-20,354	7,161	-2,842	,005	-34,464	-6,243
[Breed=4]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.





2.3.8. Box plot, Parameter estimates and q-q plots of Pelvis area & Gender.

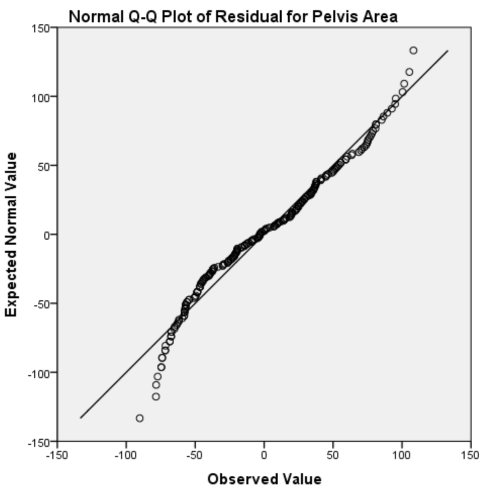


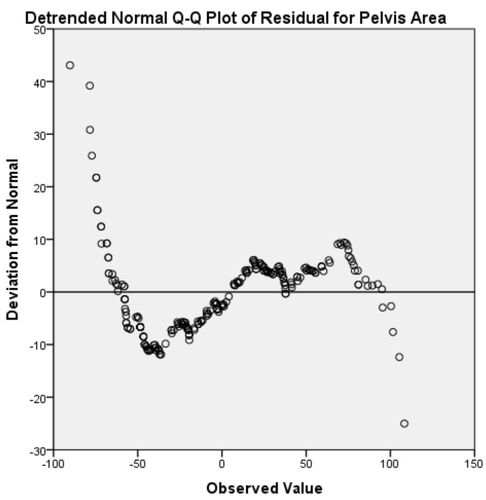
Parameter Estimates

Dependent Variable: Pelvic_Area

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	145,523	7,243	20,091	,000	131,250	159,795
[Gender=0]	45,440	8,055	5,642	,000	29,569	61,311
[Gender=1]	0[a]	.	.	.	.	.

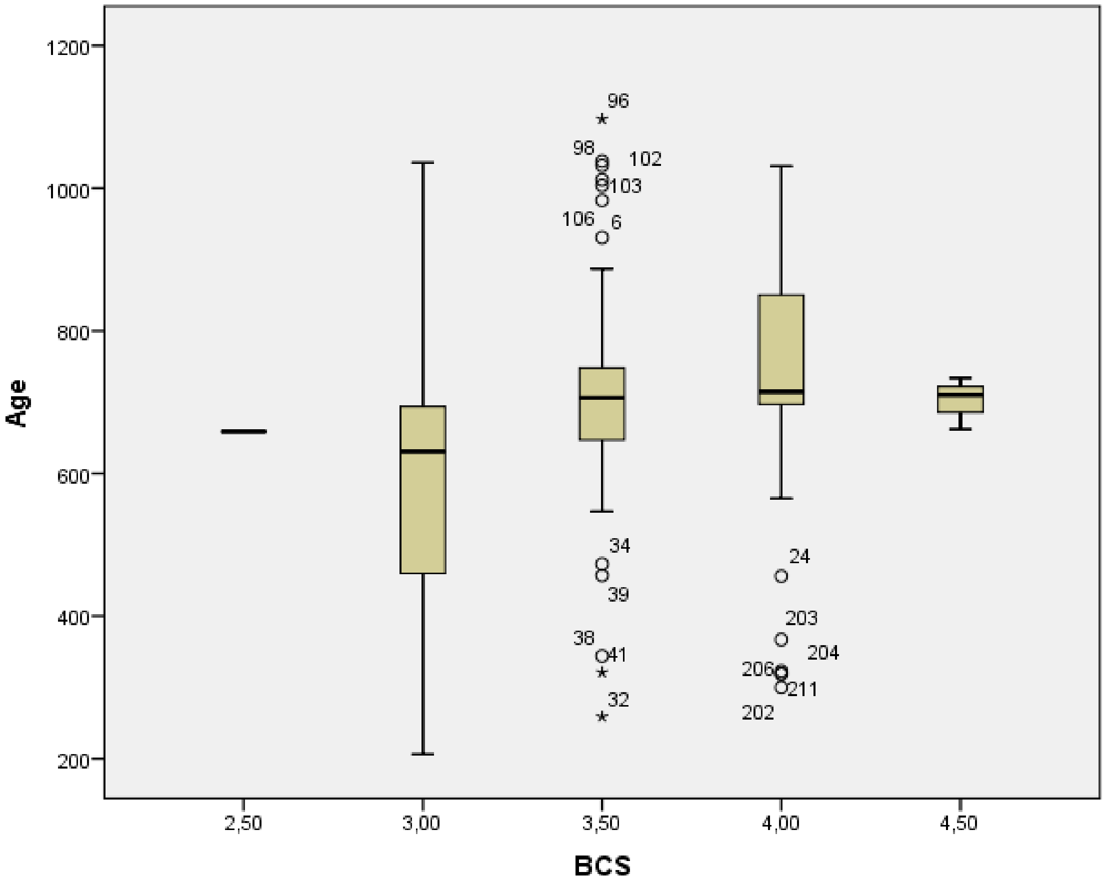
a. This parameter is set to zero because it is redundant.





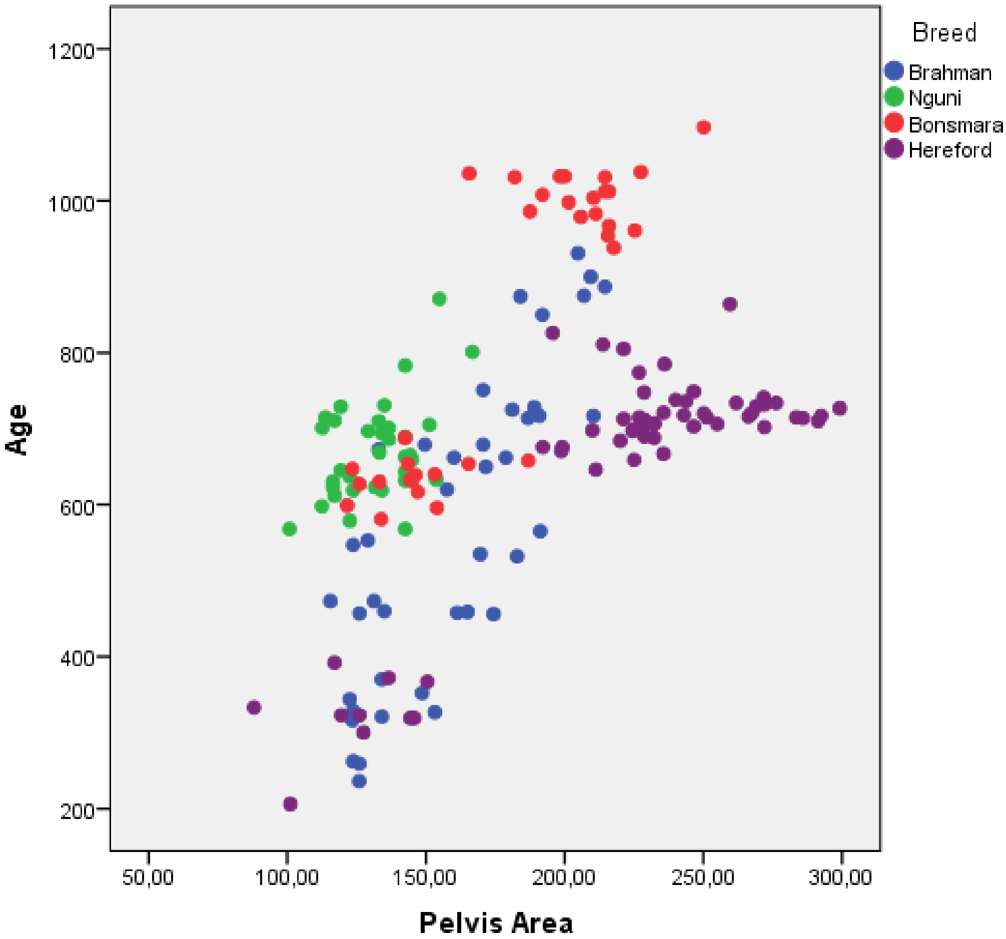
4. Figures concerning age data

Figure 1: Box plot of age against BCS in all breeds*



**Date of birth is unknown for 19 Nguni, 41 Bonsmara & 2 Hereford animals.*

Figure 2: Scatterplot of age against pelvis area with markers set for breeds*



**Date of birth is unknown for 19 Nguni, 41 Bonsmara & 2 Hereford animals.*