*Animal* (2010), **4:5**, pp 661–671 © The Animal Consortium 2009
doi:10.1017/S1751731109991558

animal

# Analysis of body measurements of newborn purebred Belgian Blue calves

I. Kolkman[1,2†], G. Opsomer[2], S. Aerts[1], G. Hoflack[2], H. Laevens[1] and D. Lips[1]

[1]*Department of Agro- and Biotechnology, KaHo Sint-Lieven, Hospitaalstraat 23, B-9100 Sint Niklaas, Belgium;* [2]*Faculty of Veterinary Medicine, Department of Reproduction, Obstetrics and Herd Health, Ghent University, Salisburylaan 133, B-9820 Merelbeke, Belgium*

(Received 28 April 2009; Accepted 29 October 2009; First published online 22 December 2009)

*At calving, purebred animals of the Belgian Blue (BB) breed are compromised by the incompatibility in size and shape of the dam and her calf, resulting in a very high incidence of dystocia problems. To clarify which body parts of the calf are of decisive importance to allow natural delivery and to investigate both the mean value as well as the variation among these body sizes within this breed (variation being an important condition for selection), measurements of nine body parts (body weight at birth (BW), body length (BL), length of the head (LH), shoulder width (SW), hip width (HW), heart girth (HG), withers height (WH) and the circumference of the fetlock of both the front (CFF) and the hind leg (CFH)) were assessed in 147 newborn purebred BB calves on 17 farms. Simple and partial correlations were assessed and we examined whether environmental factors (gender of the calf, parity of the cow, type of calving, season of birth and time of measurement after birth) were significantly associated with these specific calf measurements. The mean BW was 49.2 ± 7.1 kg. The average BL was 56.4 ± 4.5 cm and the mean LH was 24.4 ± 2.3 cm. Measurements obtained for SW and HW were 22.4 ± 2.2 and 22.9 ± 2.1 cm, respectively, whereas the mean WH was 71.1 ± 4.7 cm. Measurements of circumferences revealed a CFF of 17.9 ± 1.1 cm, a CFH of 18.0 ± 1.0 cm and a mean HG of 78.0 ± 5.4 cm. Partial correlations of the BW with eight body measurements were significant ($P < 0.01$) and ranged between 0.17 and 0.85; 0.42 and 0.88; and 0.24 and 0.88 when corrected for gender, parity and type of calving, respectively. BL ($P < 0.01$) and the CFF and CFH ($P < 0.001$) are larger in bull calves than in heifer calves. Calves born through caesarean section had broader SW ($P < 0.01$) and HW ($P < 0.01$) when compared with calves born after natural calving (defined as born* per vaginam *without assistance or with slight traction). Sizes of calves born out of multiparous cows were generally larger than of calves born out of heifers (SW: $P < 0.001$; HW: $P < 0.05$). As SW and HW are the broadest points of a BB calf, they are both candidates for being the limiting measures for calving ease, but the difference between HW and SW for the total data set was not different from zero ($P > 0.05$). In contrast to male calves in which no significant difference (between HW and SW) could be found, female calves show the difference between HW and SW that was significantly different from zero ($P < 0.001$); thus, in female calves, the HW is the most limiting factor of the calf's body. The significant variation in some body measures between the calves and the strong correlation within these sizes raises the possibility of selection towards smaller calves aiming to limit the dystocia problem in the BB breed. Furthermore, on the basis of our results, we were able to build equations for the farmer to use at the moment of calving containing the LH, the CF and the calf's gender to estimate SW and HW, the limiting body parts of the calf to be born naturally. Together with the knowledge of the pelvic size of the dam, this information gives the obstetrician or the farmer a more accurate prediction of the probability of natural calving at parturition.*

**Keywords:** Belgian Blue calves, body measurements, calving ability

## Implications

In the double-muscled the Belgian Blue breed, dystocia is caused by incompatibility between the size of the calf and its mother's pelvis. Therefore, calving has to be carried out through caesarean section, which poses ethical questions that limit the use of this breed for beef production to a large extent. It is known that calf birth weight and size account for most of the variation in calving difficulty; hence measurements were performed to clarify which body parts are of decisive importance to allow natural delivery in this breed. This information should give the obstetrician a more accurate prediction of the probability of natural calving.

† E-mail: iris.kolkman@kahosl.be; iris.kolkman@ugent.be

## Introduction

In cattle, dystocia is most frequently due to fetomaternal, or more specifically fetopelvic disproportion (Mee, 2008). Generally, there is a close correlation between the calf's birth weight (BW) and the probability of dystocia (Bellows *et al*., 1971a and 1971b; Laster, 1974; Anderson and Bullock, 2000; Wang *et al*., 2000; Zollinger and Hansen, 2003), as it explains around 50% of the variability in the frequency of difficult calvings (Meijering, 1984; Freking, 2000). Johanson and Berger (2003) demonstrated that the odds of dystocia increased by 13% by every kilogram increase of BW. Other factors that have been reported to influence the incidence of dystocia are the calf's body conformation (Morrison *et al*., 1985) and gender, its sire, the dam's age and pelvic area (Laster, 1974; Bellows and Short, 1978), her weight and body condition (Berry *et al*., 2007), and finally, some environmental effects such as the ambient temperature (Brinks *et al*., 1973; Anderson, 1990; Colburn *et al*., 1997). In addition, inadequate heifer growth and development, abnormalities in hormone profiles during pregnancy and at parturition or abnormal position of the calf at the time of birth will also cause dystocia (Berger *et al*., 1992; Anderson and Bullock, 2000). The importance of the BW as well as the body conformation of the calf has also been suggested as significantly contributing to the ease of calving. In the study of McGuirk *et al*. (1998), an increase in dystocia was associated with larger calves and calves with a better conformation (more developed muscles). More specifically among body measurements, the calf's head circumference and shoulder width (SW) appeared to be the most important predictors of the likely severity of dystocia (Colburn *et al*., 1997). In addition, the dimension of the calf's heart girth (HG) seemed to have a significant association with dystocia (Thomson and Wiltbank, 1983). Hindson (1978) indicated that in this context, specific measurements of the size of the foetal thorax would possibly be a better predictor than foetal BW.

In a study by Arthur *et al*. (1988), which was performed in double-muscled cattle breeds, no significant association between the BW of the calf and of the weight and body condition score of the dam, and the incidence of dystocia could be shown. As the muscular hypertrophy significantly increases the width of the fore and hindquarters of the double-muscled calves, these authors suggested that this typical conformation significantly contributes to the incidence of dystocia, maybe even more than BW. Furthermore, the latter was supported by the fact that the incidence of dystocia increases when double-muscled animals are mated to produce calves with muscular hypertrophy. At parturition, dystocia in purebred Belgian Blues (BBs) is mainly due to fetomaternal disproportion mostly caused by the double-muscled phenotype of the calf, originating from a deletion in the *mh* gene (Grobet *et al*., 1997 and 1998; Kambadur *et al*., 1997; McPherron and Lee, 1997; Karim *et al*., 2000). This *mh* gene – which is responsible for the regulation of muscular growth – is blocked in its function, resulting in enhanced muscular development of mostly shoulder, loin and hindquarter regions, resulting in animals with an excellent carcass conformation, but with the disadvantage of a significantly increased incidence of dystocia (Olivier and Cartwright, 1968). Cases of severe dystocia requiring a caesarian operation are usually those caused by a disproportion between shoulders, hip or rump of the foetus and the anterior pelvic canal or pelvic opening of the double-muscled dam (Ménissier and Foulley, 1979).

According to the opinions of skilled herdsmen and veterinarians in Belgium, attempts to deliver purebred BB calves *per vaginam* frequently results in dystocia due to the so-called 'hip lock' and the subsequent death of a valuable calf, and in some cases also of the dam. As a consequence, in general, veterinary practice, elective caesarean operations (CSs) are performed in 95% to 99% of purebred BB calvings, without any attempt to deliver *per vaginam* in the purebred BB in Belgium at calving (Kolkman *et al*., 2007), sire selection based on calving score index cannot be done as the tools for constructing such indices in the BB breed do not yet exist. According to the veterinary practioners who attend such calvings, the so-called 'hip-lock', mainly occur at the birth of purebred female BB calves, as these calves are said to have relatively smaller fore, and a significantly larger hindquarters. Only a very limited number of studies on body measurements and BW of purebred BB calves have been described (West, 1997; Fiems *et al*., 2001; Coopman *et al*., 2004). As the routine use of elective CS has prevented the selection of sires and dams for ease-of-calving, improvements in the numbers of normal calvings can only be achieved by attempting to reduce the BW and size of the calf, and the selection of dams with a larger than normal pelvis.

The aim of this study was to investigate the weight and the body size of newborn purebred BB calves to determine whether there is enough variation within the population to still select for a smaller calf at birth. In addition, we aimed to find associations between several environmental factors (gender, parity of the cow, type of calving, season of birth and time of measurement after birth) and the body sizes measured, and to calculate simple and partial correlations between these body measurements. All these analyses were performed to search for a model to assess the most limiting body sizes of the calf at the moment of parturition using both obtainable body measurements of the calf (such as fetlock circumference) as well as environmental factors (age of the dam, gender of the calf (can be determined by ultrasound during gestation)) that are available at the moment of parturition. In the field, this model can then be used at the moment of parturition to estimate the size of the calf. Together with information of the pelvic area of the particular dam, this model will give the farmer or veterinarian a more accurate estimation of the possibility of natural calving. Finally, a model to predict the likelihood of calving naturally using the circumference of the fetlock (the only body part accessible at parturition) was tested on our data set.

## Material and methods

*Animals and housing*

During the all the months of the autumn, winter and spring of 2006 to 2007, body dimensions of 155 BB calves, were recorded on 15 commercial farms, one experimental farm and at the Department of Reproduction, Obstetrics and Herd Health of the Faculty of Veterinary Medicine (FVM) of the Ghent University (Belgium). Data from 147 calves (120 born by CS and 27 *per vaginam*) were found to be suitable for further analysis. The other eight calves were removed as five of them were dead at or within hour after birth and three were not 100% double-muscled BB calves. Eighty calves (54.4%) were male and sixty-seven (45.6%) were female. There were no twins included in the study, and all the calves were full term at birth. The calves were delivered from 27 heifers and 120 multiparous cows. Only one heifer calved naturally. Two technicians performed the measurements: one on the commercial farms, and the other in the FVM and on the experimental farm. Both technicians got a training period before starting their measurements.

The BB is managed very intensively with minor variations in nutrition during winter and summer. As a breed with a relatively short intestinal system compared to other breeds, it has to be fed with a very high energy and protein diet to reach the levels for maintenance and growth. Normally, animals remain inside until the first calving at around the age of 24–26 months. Older animals do go out on the pasture but are also fed with maize silage en concentrates. In our study, the animals were housed inside during the whole period of the study, fed by a mixture of maize and grass silage. The husbandry differed between farms. In the experimental farm, the animals are housed in loose housing systems until a couple of days before parturition. For better observation, they were moved to a tie stable. In 14 of the commercial farms, the animals were housed in loose housing systems until the parturition started. In the other commercial farm, the animals were housed in a tie stall during the whole winter period. At the FVM, the animals arrived a couple of day before partition and were tethered. In four commercial farms and at the FVM, the calves were allowed to suckle until weaning at 3 months of age, whereas in the other 11 commercial farms and in the experimental farm, the calves were separated from their mother immediately after birth and fed with milk replacers. In 14 farms, the calves were born following natural mating, whereas in one farm all cows were artificially inseminated. In two other farms, both artificial and natural breeding were used. In all the farms, except one, CS was used systematically as a management policy without performing trial traction. In five of these farms, calves were born naturally occasionally, defined by born *per vaginam* without assistance or with slight traction.

*Measurements*

The BW, body length (BL), length of the head (LH), SW, hip width (HW), HG, withers height (WH) and the circumference of the fetlock of both the right front (CFF) and hind leg (CFH) of the calves were recorded within 72 h after birth, but not before the calf had stood without assistance to standardize our measurements (Figure 1). As a calibrated balance was only available in the experimental farm and in the FVM, the BW was only recorded in 45 calves. The calves were weighed immediately after birth, before being completely dry. All the measurements took place on the calf standing on a concrete floor. The BL was defined as the linear distance along the vertebral column from the cranial edge of the lateral *tuberosity* of the *humerus* to the first coccygeal vertebra. The LH was measured as the distance from the mucocutaneous junction of the *planum nasolabiale* to the caudal border of the *os frontalis*. For both these measurements, a flexible measuring tape was used. With the calf standing, the SW was measured as the linear distance between the lateral *tuberosity* of the left and right *humerus*. The HW was measured as the linear distance between the *trochanter major* of the left and right *femur*. Both these conformational traits were measured with a pair of callipers, specially designed and calibrated for this use, which were placed on the shoulder or hip area and pressed as hard as possible. As the animals of the BB breed are double-muscled, it is important to mention that it is not possible to measure from bone to bone and that the muscles have been included especially when measuring the SW and the HW. The HG was assessed as the circumference around the chest measured just caudally to the front legs using a measuring tape. The WH was defined as the linear distance from the dorsal end of the scapula to the floor. The fetlock circumference was determined by placing the measuring tape around the fetlock of the right fore (CFF) and hind leg (CFH), respectively. All measurements were made to the nearest 0.5 cm and performed thrice on the same animal. The calculated average was used for further analyses.

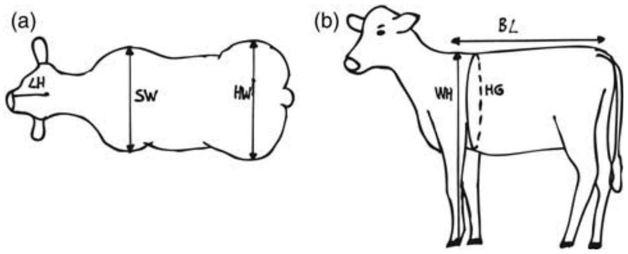


**Figure 1** Diagram of the performed body measurements. (a) Dorsal view from a calf with the length of the head (LH), the shoulder width (SW) and the hip width (HB); (b) lateral view from a calf with the body length (BL), the withers height (WH) and the heart girth (HG).

*Statistics*

The data were checked for errors and the records of eight calves were removed (five calves were dead at or within hour after birth and three of them were not 100% double-muscled BB calves) leaving data from 147 calves for further analysis using SPSS 16.0 to explore and check the data for normality by the use of the Kolmogorov–Smirnov test and

Q–Q plots. In all the statistical analyses, the technician was taken into account.

Simple correlations between the body measurements on the total data set as well partial correlations correcting for gender, parity and type of calving were calculated per factor. Next, the data set was divided per factor in a male and female data set, in a heifer and cow data set and in a CS and natural delivery data set, and individual correlations for the different classes (male–female, heifer cow and CS–natural delivery) were calculated by the Pearson correlation coefficient.

To look for associations between the body measures and some environmental factors (gender of the calf, parity of the dam (heifer *v.* multiparous cow), type of calving (CS *v.* natural delivery), season of calving (autumn, winter and spring), and time of measurement after birth (days 1, 2 and 3)), a multivariate mixed ANOVA was used with herd as random effect (SAS 9_2). The body measures were inserted as dependent variables and the environmental factors as independent variables, and a type III model was used.

An assessment was made to see which body part was the limiting factor for calving, so which was the most critical to pass the birth canal. Biologically seen, the shoulder and hip width are both candidates for being the most critical. A *t*-test was used to look whether the 'HW−SW' difference was significantly different from zero and therefore statistically prove which of the two is the most limiting. Also, it was examined whether this difference (from zero) differed between male and female calves, between calves born from heifers or cows and between CS or naturally delivered calves. Whenever the confidence intervai (CI) spans 1, this difference was significant. In both analyses, herd was included as random effect.

A model to predict the size of the two most detrimental body parts for calving ease (SH and HW) was constructed by the use of a generalized linear mixed assessment (herd was included as random effect). This model contained parameters that are easily measurable at parturition, that is, CF (CFF and CFH) and LH. The only two environmental factors that can be known at the moment of parturition are the gender of the calf (assessed by pregnancy diagnoses after 60 days) and the parity of the dam. Because of the specific management characteristics (i.e. using a breeding bull), there was no information available in this study concerning the moment of mating and hence concerning the length of gestation. The latter resembles practice, as this is the case in most of the current BB herds in Belgium. The dependent variables SW or HW, the covariances LH and CFF/CFH and the fixed variables gender and parity were inserted all together in the model to see which of the parameters had an influence on SW or HW. Parameters with $P > 0.05$ were eliminated from the model. This was repeated until all the parameters' leftover had significant influence on the dependent variables (SW and HW).

Finally, generalized estimating equation methods of SPSS were used to estimate the likelihood of natural calving by the use of CFF and CFH. A binary logistic model was chosen within the generalized linear models with herd as a subject and type of calving as response. The predictor within this model was the CFF or the CFH. Afterwards, a scatterplot was made with the predicted value of mean, the lower and upper bound of the CI for mean of CFF or CFH to visualize the probability of natural calving.

## Results

More than 20% of the calves (34) were born in autumn, almost 50% (72) in winter and the rest (41) of the calves in spring. The measurements were made within $25.6 \pm 17.7$ h of birth. Table 1 shows the descriptive statistics for all the body measures.

Most simple correlations, partial correlations and correlations per class between the nine body dimensions were significant and moderate-to-high (Tables 2, 3 and 4 for gender, parity and type of calving, respectively). Male calves showed higher correlation between BW and other body measures, whereas in female calves it was lower. For the other body dimensions, the individual male and female correlation showed a variation (different directions for the different measurements) in comparison with the simple correlations of the total data set (Table 2). Higher correlations between the body dimensions (excluding BW) were also seen in heifers and multiparous cows, in contrast with the simple correlations (Table 3). Body measurements of calves delivered *per vaginam* showed a much higher correlation compared to the simple correlations, but this was not the case for body dimensions of calves born after CS (Table 4).

Body measurements and BW presented by gender, parity of the cow and type of calving are shown in Table 5. From all the assessed environmental factors, the multivariate mixed ANOVA confirmed a significant association between the calf's gender and its BL ($P < 0.01$), and the CF of both its front and hind leg ($P < 0.001$; Table 5). All the above-mentioned body parts were larger in bull calves in comparison to heifer calves (Table 5). Both SW and HW showed a significant association with the type of calving and parity. Calves born by CS had broader shoulders ($P < 0.01$) and hips ($P < 0.01$) compared to calves born after natural

**Table 1** *The mean values, the standard deviation, the minimum and the maximum values of body measurements and birth weight of 147 Belgian Blue newborn purebred calves*

| Body measurements | *n* | Mean | s.d. | Min. | Max. |
|---|---|---|---|---|---|
| Body weight at birth (kg) | 45 | 49.2 | 7.1 | 35.0 | 65.0 |
| Body length (cm) | 147 | 56.4 | 4.5 | 44.3 | 67.8 |
| Length of the head (cm) | 147 | 24.4 | 2.3 | 18.7 | 33.3 |
| Shoulder width (cm) | 147 | 22.4 | 2.2 | 16.0 | 28.8 |
| Hip width (cm) | 147 | 22.9 | 2.1 | 17.0 | 28.7 |
| Circumference of the front fetlock (cm) | 147 | 17.9 | 1.1 | 14.5 | 20.3 |
| Circumference of the hind fetlock (cm) | 147 | 18.0 | 1.0 | 15.5 | 20.5 |
| Heart girth (cm) | 147 | 78.0 | 5.4 | 57.0 | 94.3 |
| Withers height (cm) | 146 | 71.0 | 4.7 | 58.7 | 81.8 |

Min. = minimum; Max. = maximum.

**Table 2** *Simple correlations (diagonally above), partial correlations adjusted for gender (diagonally below) and correlations per class (male–female; diagonally below) between the nine body measurements (the body weight at birth, the body length, the length of the head), the shoulder width, the hip width, the circumference of the fetlock of both the right front and hind leg, the heart girth and the withers height*

| Gender | | BW | BL | LH | SW | HW | CFF | CFH | HG | WH |
|---|---|---|---|---|---|---|---|---|---|---|
| BW | Partial | 1.000 | 0.456** | 0.286 | 0.560** | 0.561** | 0.323** | 0.491** | 0.312* | 0.457** |
| | Male | | | | | | | | | |
| | Female | | | | | | | | | |
| BL | Partial | 0.458** | 1.000 | −0.017 | 0.313** | 0.005 | 0.467** | 0.490** | 0.364** | 0.618** |
| | Male | 0.520* | | | | | | | | |
| | Female | 0.337 | | | | | | | | |
| LH | Partial | 0.284** | −0.032 | 1.000 | 0.410** | 0.554** | 0.268** | 0.314** | 0.181* | −0.116 |
| | Male | 0.345 | 0.007 | | | | | | | |
| | Female | 0.203 | −0.087 | | | | | | | |
| SW | Partial | 0.564** | 0.291** | 0.402** | 1.000 | 0.731** | 0.615** | 0.616** | 0.604** | 0.301** |
| | Male | 0.709** | 0.399** | 0.357** | | | | | | |
| | Female | 0.355 | 0.140 | 0.462** | | | | | | |
| HW | Partial | 0.561** | −0.005 | 0.552** | 0.734** | 1.000 | 0.414** | 0.484** | 0.533** | 0.085 |
| | Male | 0.683** | 0.013 | 0.490** | 0.693** | | | | | |
| | Female | 0.481* | −0.025 | 0.625** | 0.784** | | | | | |
| CFF | Partial | 0.356* | 0.448** | 0.262** | 0.618** | 0.445** | 1.000 | 0.414** | 0.484** | 0.533** |
| | Male | 0.439** | 0.457** | 0.229* | 0.644** | 0.377** | | | | |
| | Female | 0.286 | 0.430** | 0.297* | 0.605** | 0.519** | | | | |
| CFH | Partial | 0.531** | 0.469** | 0.310** | 0.608** | 0.510** | 0.849** | 1.000 | 0.541** | 0.498** |
| | Male | 0.577** | 0.462** | 0.255* | 0.598** | 0.458** | 0.819** | | | |
| | Female | 0.485* | 0.469** | 0.373** | 0.630** | 0.573** | 0.882** | | | |
| HG | Partial | 0.311* | 0.349** | 0.171* | 0.595** | 0.530** | 0.533** | 0.541** | 1.000 | 0.428** |
| | Male | 0.455** | 0.398** | 0.054 | 0.656** | 0.544** | 0.515** | 0.583** | | |
| | Female | 0.106 | 0.283* | 0.324** | 0.516** | 0.519** | 0.563** | 0.496** | | |
| WH | Partial | 0.457** | 0.610** | −0.128 | 0.285** | 0.078 | 0.513** | 0.495** | 0.417** | 1.000 |
| | Male | 0.505** | 0.598** | −0.154 | 0.358** | 0.094 | 0.529** | 0.541** | 0.411** | |
| | Female | 0.380 | 0.628** | −0.092 | 0.178 | 0.061 | 0.511** | 0.444** | 0.427** | |

BW = the body weight at birth; BL = body length; LH = length of the head; SW = shoulder width; HW = hip width; CFF = circumference of the fetlock of the front leg; CFH = circumference of the fetlock of hind leg; HG = heart girth; WH = withers height.
*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

delivery (Table 5). Measures from calves born out of multiparous cows were larger than from calves born out of heifers (SW: $P < 0.001$; HW: $P < 0.05$; Table 5). None of the nine body measurements were significantly associated with the season of birth or with the moment in which the measurement was done relative to birth (data not shown).

As SW and HW are the broadest points of a BB calf, they are both candidates for being the limiting measures for calving ease. On the basis of the data set of this study, the difference between HW and SW for the total data set was not different from zero ($P > 0.05$), thus the body part being the most detrimental factor concerning calving ease could not be assessed for the total data set. The difference between HW and SW was significantly different between male and female calves, whereas this difference between HW and SW was not significantly different between heifers and cows and between naturally calving animals and animals that were delivered by CS, respectively (Table 6). Within classes, in female calves, the statistical analysis showed that the difference between the HW and SW was significantly different from zero (Table 6; 95% CI (0.157 to 1.283)), suggesting the HW being the limiting factor at least in the female calves. In male calves, this difference was not significant (Table 6; 95% CI (−0.392 to 0.697)). For calves that were born naturally, the difference between HW and SW was also significantly different from zero, in contrast with calves born by CS (Table 6; 95% CI = (0.120 to 1.559) and (−0.303 to 0.820) for naturally and by CS, respectively).

Models to predict these limiting measures for calving, HW for female calves and SW and HW for male calves, at the time of parturition are described by the equations shown in Table 7. Both for SW as for HW, these models are assessed for posterior and anterior positions of the calf taking the CFF and the CFH, respectively, into account.

Figures 2 and 3 show the probability of natural calving by the use of the CFF and CFH. With the minimum circumference of 14.5 cm for CFF in this data set, the probability for natural calving was estimated to be 47% (95% CI: 23% to 74%), whereas with the maximum measured CFF (20.3 cm), the probability for natural calving was reduced to 5% (2% to 13%). The mean CFF of this data set (17.9 cm) corresponded with a chance of natural calving of 14.5% (7% to 27%). For the CFH, the minimum (15.5 cm) and maximum (20.5 cm) measured circumference gave a

**Table 3** *Simple correlations (diagonally above), partial correlations adjusted for parity (diagonally below) and correlations per class (heifer – cow; diagonally below) between the nine body measurements (the body weight at birth, the body length, the length of the head, the shoulder width, the hip width, the circumference of the fetlock of both the right front and hind leg, the heart girth and the withers height)*

| Parity of cow | | BW | BL | LH | SW | HW | CFF | CFH | HG | WH |
|---|---|---|---|---|---|---|---|---|---|---|
| BW | Partial | 1.000 | 0.456** | 0.286 | 0.560** | 0.561** | 0.323** | 0.491** | 0.312* | 0.457** |
| | Heifer | | | | | | | | | |
| | Cow | | | | | | | | | |
| BL | Partial | 0.301 | 1.000 | −0.017 | 0.313** | 0.005 | 0.467** | 0.490** | 0.364** | 0.618** |
| | Heifer[a] | | | | | | | | | |
| | Cow | 0.149 | | | | | | | | |
| LH | Partial | −0.265 | 0.437 | 1.000 | 0.410** | 0.554** | 0.268** | 0.314** | 0.181* | −0.116 |
| | Heifer | | 0.324 | | | | | | | |
| | Cow | −0.316 | 0.499** | | | | | | | |
| SW | Partial | −0.087 | 0.482* | 0.350 | 1.000 | 0.731** | 0.615** | 0.616** | 0.604** | 0.301** |
| | Heifer | | 0.576** | 0.302 | | | | | | |
| | Cow | −0.083 | 0.468** | 0.367** | | | | | | |
| HW | Partial | 0.201 | 0.454* | 0.296 | 0.714** | 1.000 | 0.414** | 0.484** | 0.533** | 0.085 |
| | Heifer | | 0.429* | 0.282 | 0.716** | | | | | |
| | Cow | 0.261 | 0.486** | 0.346** | 0.711** | | | | | |
| CFF | Partial | −0.087 | 0.453** | 0.457* | 0.604** | 0.666* | 1.000 | 0.414** | 0.484** | 0.533** |
| | Heifer | | 0.568** | 0.507** | 0.619** | 0.657** | | | | |
| | Cow | −0.087 | 0.602** | 0.454** | 0.676** | 0.641** | | | | |
| CFH | Partial | −0.139 | 0.654** | 0.422* | 0.605** | 0.658** | 0.916** | 1.000 | 0.541** | 0.498** |
| | Heifer | | 0.677** | 0.438* | 0.632** | 0.638** | 0.933** | | | |
| | Cow | −0.139 | 0.633** | 0.417** | 0.644** | 0.664** | 0.910** | | | |
| HG | Partial | 0.281 | 0.633* | 0.324 | 0.746** | 0.802** | 0.624** | 0.606** | 1.000 | 0.428** |
| | Heifer | | 0.626** | 0.265 | 0.759** | 0.834** | 0.557** | 0.606** | | |
| | Cow | 0.210 | 0.672** | 0.529** | 0.703** | 0.785** | 0.642** | 0.607** | | |
| WH | Partial | 0.217 | 0.471 | 0.355 | 0.555** | 0.721* | 0.658* | 0.601** | 0.697** | 1.000 |
| | Heifer | | 0.463* | 0.262 | 0.414* | 0.711** | 0.644** | 0.589** | 0.624** | |
| | Cow | 0.277 | 0.586** | 0.473** | 0.603** | 0.759** | 0.686** | 0.661** | 0.746** | |

BW = the body weight at birth; BL = body length; LH = length of the head; SW = shoulder width; HW = hip width; CFF = circumference of the fetlock of the front leg; CFH = circumference of the fetlock of hind leg; HG = heart girth; WH = withers height.
[a]Cannot be computed because at least one of the variables is constant.
*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

probability of natural calving of 38 (16% to 66%) respectively 5% (1% to 14%). With the mean CFH (18.1 cm) of this data set, the probability of natural calving was 14.2% (6% to 25%).

## Discussion

In this study, the mean ± s.d. of the BW and eight other body dimensions of newborn double-muscled BB calves were obtained. BW data were similar to those reported by Fiems *et al*. (2001), but lower for male and higher for female calves when compared to the data of West (1997) and Coopman *et al*. (2004). Comparison of our measurements with those obtained by Coopman *et al*. (2004), also revealed a decrease of SW, HW, HG and WH. The inclusion of (smaller) calves born *per vaginam* in our study – whereas Coopman *et al*. (2004) only measured calves born by CS – is probably not responsible for this difference, as the calves born by CS in our study were also smaller than the ones measured by Coopman *et al*. (2004). Another explanation might be the apparent decrease in WH of the BB animals over the last decade(s), which has been stated to be the result of the high selection for conformation (muscularity) (Hanset, 2004 and 2005). As dam size is correlated with calf size (Laster, 1974), it is possible that BB calves are smaller in 2006 to 2007, than in 1995 till 2001, when the studies of Coopman *et al*. (2004) were performed. Furthermore, within the BB breed, a trend for selection in favour of smaller, and hence more viable, calves has been noticeable over the past years, as heavy calves in the BB generally have greater difficulties in suckling. The publication of bull genetic indices for calf viability at birth and willingness to suckle has indirectly accelerated selection for calves with lighter BW (Berger *et al*., 1992; HBBBB, 2008).

The limiting dimension for ease of calving of BB female calves seems to be the HW. This is in agreement with the reports of veterinarians in the field attempting *per vaginam* deliver of the calf, in that the so called 'hip lock' is a common occurrence with female calves. Difficulties during *per vaginam* delivery of bull calves often occurs early in the expulsive phase of calving, as male calves have relatively wide shoulders. Equations to calculate SW and HW were

**Table 4** *Simple correlations (diagonally above), partial correlations adjusted for type of calving (diagonally below) and correlations per class (CS – Nat; diagonally below) between the nine body measurements (the body weight at birth, the body length, the length of the head), the shoulder width the hip width, the circumference of the fetlock of both the right front and hind leg, the heart girth and the withers height)*

| Type of calving | | BW | BL | LH | SW | HW | CFF | CFH | HG | WH |
|---|---|---|---|---|---|---|---|---|---|---|
| BW | Partial | 1.000 | 0.456** | 0.286 | 0.560** | 0.561** | 0.323** | 0.491** | 0.312* | 0.457** |
| | CS | | | | | | | | | |
| | Nat | | | | | | | | | |
| BL | Partial | 0.456** | 1.000 | −0.017 | 0.313** | 0.005 | 0.467** | 0.490** | 0.364** | 0.618** |
| | CS | 0.462** | | | | | | | | |
| | Nat | | | | | | | | | |
| LH | Partial | 0.299* | −0.012 | 1.000 | 0.410** | 0.554** | 0.268** | 0.314** | 0.181* | −0.116 |
| | CS | 0.313* | −0.071 | | | | | | | |
| | Nat | | 0.522** | | | | | | | |
| SW | Partial | 0.594** | 0.334** | 0.372** | 1.000 | 0.731** | 0.615** | 0.616** | 0.604** | 0.301** |
| | CS | 0.623** | 0.315** | 0.366** | | | | | | |
| | Nat | | 0.461* | 0.477* | | | | | | |
| HW | Partial | 0.595** | 0.013 | 0.527** | 0.707** | 1.000 | 0.414** | 0.484** | 0.533** | 0.085 |
| | CS | 0.627** | −0.072 | 0.530** | 0.699** | | | | | |
| | Nat | | 0.669** | 0.495* | 0.788** | | | | | |
| CFF | Partial | 0.336* | 0.482** | 0.236** | 0.594** | 0.380** | 1.000 | 0.414** | 0.484** | 0.533** |
| | CS | 0.397* | 0.423** | 0.194* | 0.585** | 0.326** | | | | |
| | Nat | | 0.751** | 0.653** | 0.677** | 0.799** | | | | |
| CFH | Partial | 0.505** | 0.503** | 0.287** | 0.598** | 0.458** | 0.876** | 1.000 | 0.541** | 0.498** |
| | CS | 0.564** | 0.438** | 0.249** | 0.579** | 0.408** | 0.863** | | | |
| | Nat | | 0.806** | 0.676** | 0.741** | 0.853** | 0.935** | | | |
| HG | Partial | 0.321* | 0.372** | 0.154 | 0.592** | 0.516** | 0.510** | 0.528** | 1.000 | 0.428** |
| | CS | 0.323* | 0.327** | 0.166 | 0.584** | 0.483** | 0.470** | 0.482** | | |
| | Nat | | 0.709** | 0.643** | 0.657** | 0.855** | 0.808** | 0.864** | | |
| WH | Partial | 0.456** | 0.618** | −0.106 | 0.333** | 0.106 | 0.528** | 0.518** | 0.443** | 1.000 |
| | CS | 0.472** | 0.609** | −0.165 | 0.302** | 0.029 | 0.482** | 0.470** | 0.401** | |
| | Nat | | 0.680** | 0.554** | 0.567** | 0.802** | 0.809** | 0.807** | 0.789** | |

BW = the body weight at birth; BL = body length; LH = length of the head; SW = shoulder width; HW = hip width; CFF = circumference of the fetlock of the front leg; CFH = circumference of the fetlock of hind leg; HG = heart girth; WH = withers height; CS = caesarean operation; Nat = natural.
[a]Cannot be computed because at least one of the variables is constant.
*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

**Table 5** *Body measurements divided in gender, parity of cow and type of calving (mean ± s.d.) and the significant differences between these body measurements within these classes (by multivariate mixed ANOVA)*

| | Gender | | Parity | | Type of calving | |
|---|---|---|---|---|---|---|
| Measurement | Male ($n = 80$) | Female ($n = 67$) | Heifer ($n = 27$) | Cow ($n = 120$) | CS ($n = 120$) | Nat ($n = 27$) |
| Body weight at birth (kg) | 49.4 ± 7.9 | 49.0 ± 6.4 | 48.0 ± 5.0 | 49.2 ± 6.7 | 49.2 ± 7.4 | 47.8 ± 4.0 |
| Body length (cm) | 57.1 ± 4.6 | 55.5 ± 4.1**[a] | 57.0 ± 3.6 | 58.2 ± 4.3 | 56.3 ± 4.5 | 56.6 ± 4.4 |
| Length of the head (cm) | 23.6 ± 2.4 | 23.2 ± 2.2 | 22.1 ± 1.4 | 22.4 ± 1.5 | 23.6 ± 2.4 | 22.3 ± 1.3 |
| Shoulder width (cm) | 22.7 ± 2.2 | 21.9 ± 2.1 | 21.5 ± 1.8 | 22.1 ± 1.8** | 22.6 ± 2.1 | 21.0 ± 1.8*** |
| Hip width (cm) | 23.0 ± 2.0 | 22.7 ± 2.3 | 21.4 ± 1.0 | 22.0 ± 1.3** | 23.1 ± 2.1* | 21.5 ± 1.5* |
| Circumference of the front fetlock (cm) | 18.4 ± 0.9 | 17.3 ± 1.0*** | 17.5 ± 1.1 | 18.0 ± 1.2 | 18.0 ± 1.1 | 17.4 ± 1.2 |
| Circumference of the hind fetlock (cm) | 18.4 ± 0.9 | 17.5 ± 1.0*** | 17.6 ± 1.0 | 18.1 ± 1.0 | 18.1 ± 1.0 | 17.6 ± 1.1 |
| Heart girth (cm) | 78.6 ± 5.4 | 77.2 ± 5.2 | 75.6 ± 4.0 | 78.1 ± 4.4 | 78.3 ± 5.5 | 76.1 ± 4.1*** |
| Withers height (cm) | 71.6 ± 5.0 | 70.4 ± 4.3 | 71.6 ± 3.4 | 73.3 ± 3.9 | 71.0 ± 4.9 | 71.7 ± 4.1 |

CS = caesarean operation; Nat = natural.
[a]results of the multivariate mixed ANOVA, the significancy is within row within class
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

evaluated in this study, to enable the farmer and the veterinarian to predict the size of the calf at the beginning of the expulsive stage of parturition. This together with the knowledge of the pelvic size of the dam should enable a more accurate prediction of the possibility of natural calving being possible. However, the generalized estimating equations are most likely an underestimation as CS is performed on a routine basis without attempts to deliver the calf naturally. With evaluating selection towards natural calving, these generalized estimating equations should be adjusted as the likelihood for natural calving increases.

It is generally known that at birth, bull calves are heavier than heifer calves (Thomson and Wiltbank, 1983; Houghton and Corah, 1989; Echternkamp, 1993; Zollinger and Hansen, 2003); so, in non-double-muscled breeds of cattle, they probably also have larger body dimensions. This can partly be explained by the fact that bull calves generally have a 1- to 2-day longer gestation length, during which time they continue to grow. (Houghton and Corah, 1989) and McGuirk *et al*. (1998) showed that the frequency of seriously difficult calvings was greater in male calves, which were larger, and had a better conformation (for subsequent rearing) than heifer calves. In a study by Burfening *et al*. (1978a), bull calves of the Simmental breed had gestation lengths of about 1 day longer, and were 3.0 kg heavier at birth; their birth was associated with a 0.23 U lesser calving ease score, and required 12.7% more assistance. The effect of the calf's gender on the incidence of assisted births and on calving ease was greater in young than in older cows (Laster *et al*., 1973; Burfening *et al*., 1978b). Our results correspond well with the data on other breeds in the fact that bull calves were heavier compared to female calves.

**Table 6** *Estimated marginal means, standard errors and 95% confidence intervals of the difference between hip width (HW) and shoulder width (SW) between the different classes of gender, parity and type of calving as well as the difference between HW and SW within one class*

| | | | 95% Confidence interval | |
|---|---|---|---|---|
| Parameter | Estimate | s.e. | Lower bound | Upper bound |
| Gender[a] | 0.567 | 0.228 | 0.117 | 1.017 |
| Male[b] | 0.152 | 0.263 | −0.392 | 0.697 |
| Female[b] | 0.720 | 0.273 | 0.157 | 1.283 |
| Parity[a] | −0.065 | 0.285 | −0.632 | 0.502 |
| Heifer[b] | −0.074 | 0.249 | −0.590 | 0.442 |
| Cow[b] | −0.009 | 0.166 | −0.467 | 0.450 |
| Type of calving[a] | 0.581 | 0.339 | −0.088 | 1.250 |
| CS[b] | 0.259 | 0.268 | −0.303 | 0.820 |
| Nat[b] | 0.839 | 0.359 | 0.120 | 1.559 |

CS = caesarean operation; Nat = natural.
[a]Assessment of the differences between the classes for the difference between HW and SW.
[b]Assessment to see whether the difference between HW and SW is different from zero within a class.

Parity and age of the dam are also known to significantly influence BW (Nelson and Beavers, 1982). Dawson *et al*. (1947) showed that BW of calves tended to increase per month parallel with the increase in age of the dam until 6 years of age, and that the weight of the dam was related to BW to the same extent as the age of the dam. However, in our study involving double-muscled BB cows, there was no association between the parity of the dam and the BW of the calf, although some body dimensions of calves born from multiparous cows were larger than those of calves born from heifers.

The season of birth appeared to have no influence on the BW, or the eight other body dimensions. In contrast, Wilson and Rossi (2006) found that calves born in the fall weighed less than calves born in the winter and spring months, which is most likely caused by a higher nutrient intake due to supplementary feeding of the cow. Deutscher *et al*. (1999) concluded that calf BW increased 1 pound, and calving difficulty was increased by 2.6% for each degree Fahrenheit and the average winter temperature is reduced. Colburn *et al*. (1996) also showed an influence of temperature on BW, resulting in larger BWs and more calving difficulties following winter temperatures which were below average. Compared to the extensively managed breeds described in these latter studies (all on cattle without double muscling), the BB is managed very intensively with minor variations in nutrition during winter and summer. Besides this, the BB breed is also known for its excellent feed conversion, which

**Table 7** *Equations to predict shoulder width and hip width at the time of parturition for posterior and anterior position*

| Limiting factor | Position of the calf | Parameter | Estimate | s.e. | d.f. | *t* | *P* |
|---|---|---|---|---|---|---|---|
| SW | Anterior | Intercept | −5.89 | 2.72 | 139.37 | −2.17 | 0.032 |
| | | Gender | 0.79 | 0.31 | 137.78 | 2.57 | 0.011 |
| | | LH | 0.22 | 0.07 | 22.42 | 3.22 | 0.004 |
| | | CFF | 1.27 | 0.15 | 140.35 | 8.67 | <0.001 |
| | Posterior | Intercept | −0.51 | 2.46 | 142.61 | −0.21 | 0.837 |
| | | CFH | 1.26 | 0.14 | 142.67 | 9.27 | <0.001 |
| HW | Anterior | Intercept | 3.92 | 2.21 | 139.09 | 1.77 | 0.078 |
| | | Gender | 1.05 | 0.26 | 135.43 | 1.07 | <0.001 |
| | | CFF | 1.00 | 0.12 | 136.38 | 8.37 | <0.001 |
| | Posterior | Intercept | 3.36 | 2.26 | 139.29 | 1.49 | 0.140 |
| | | Gender | 0.85 | 0.25 | 134.94 | 3.43 | 0.001 |
| | | CFH | 1.03 | 0.12 | 136.88 | 8.43 | <0.001 |

SW = shoulder width; HW = hip width; LH = length of the head; CFF = circumference of the fetlock of the front leg; CFH = circumference of the fetlock of hind leg.

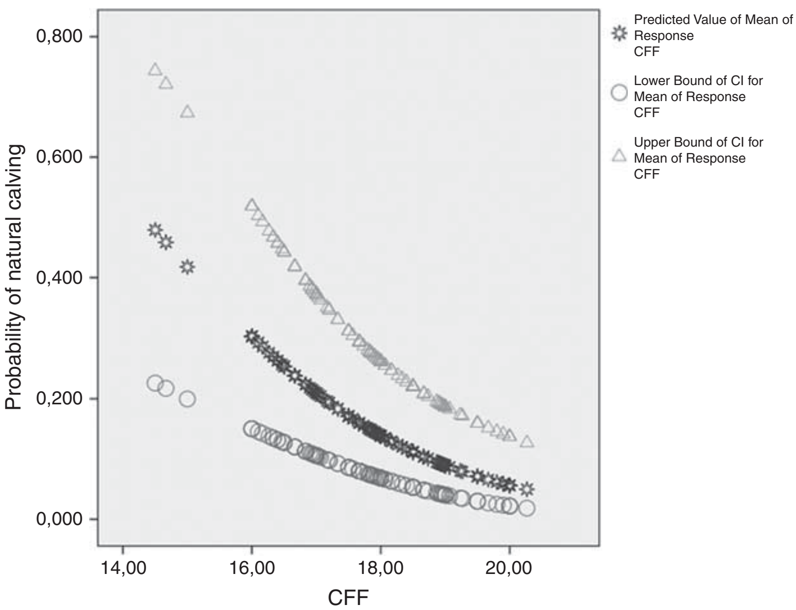


**Figure 2** Probability of natural calving based on the circumference of the front fetlock (CFF; bounds of 95% CI).

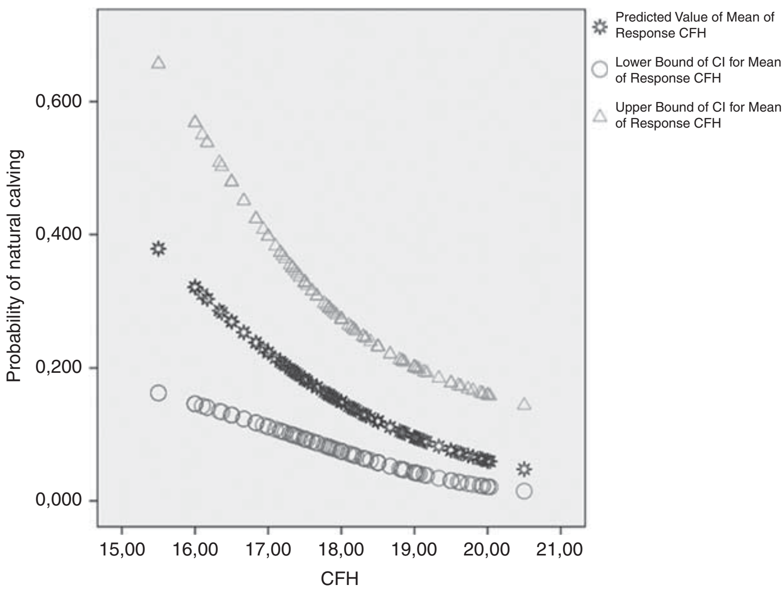


**Figure 3** Probability of natural calving based on the circumference of the hind fetlock (CFH; bounds of 95% CI).

enables the dams to maintain adequate body reserves at all times. Hence, this may be a reason for the absence of any influence of the season of the year on BW and body dimensions in the BB breed.

The data presented in this study show significant differences between body sizes (only SW and HW) of calves born by CS and calves delivered *per vaginam*. Unfortunately, it is very difficult to correctly assess the validity of this observation in relation to the incidence of dystocia as in BB cows, as CSs are performed electively in Belgium. As mentioned above, this will probably underestimate the predictive value for a natural calving by the use of the CFF and CFH. Nevertheless, the results of our study show that the few BB calves that are not born by elective CS, but *per vaginam*, have smaller SW, HW and HG measurements, which suggests an influence of the calf's body conformation on the incidence of dystocia. Although BB calves born by CS are heavier, the difference in BW between BB calves born *per vaginam* and by CS was not significant, and BW does not correlate with type of calving. Casas *et al*. (1999) indicated that in double-muscled animals, the BW of the calf has a significant effect on calving difficulty, as their results showed an increase of 0.7% in calving difficulty per kilogram increase in BW; however, only the homozygous double-muscled calves had a greater calving difficulty. Coopman *et al*. (2004) measured WH, SW, HW and HG in double-muscled BB calves, and found that all four dimensions were positively and significantly correlated with BW, which was confirmed in our study. Consequently, the smaller SW and HW in BB calves born *per vaginam*, as encountered in our study, might be responsible for the lower BW in these calves, which may further contribute to the fact that they were born *per vaginam*.

Although the correlation of body dimensions with the risk of dystocia is much lower than BW with dystocia (West, 1997), BW has been shown to be highly correlated with calf conformation and body measurements; the correlations ranging from 0.60 to 0.85 (Freking, 2000). Although these correlations are lower in the BB breed (shown in this study; Coopman *et al*., 2004), these correlations are still significant, and hence influence BW and possibly but indirectly, also dystocia. However, selection for smaller dimensions and lower BW should not be too great, as the viability of the calf decreases with excessive decrease of the birth weight. Furthermore, light calves need to have the potential to grow into large cows, so that on turn, they are able to calve naturally. The latter suggests that in attempting to reduce frequency of elective CS, the selection for lower BW and shorter gestation length (Norman *et al*., 2009) should be performed simultaneously with selection for an increase in pelvic dimensions of the adult cows.

## Acknowledgements

We greatly acknowledge Professor Noakes for reviewing the manuscript carefully and giving his comments.

## References

Anderson P 1990. Minimizing calving difficulty in beef cattle. Proceedings Minnesota Beef Cattle Improvement, Association Annual Beef Cattle Conference, MN, USA, 21, 1–15.

Anderson LH and Bullock KD 2000. Pelvic measurements and calving difficulty. Cooperative Extension Service Bulletin, University of Kentucky, KY, USA, 1–3.

Arthur PF, Makarechian M and Price MA 1988. Incidence of dystocia and perinatal calf mortality resulting from reciprocal crossing of double-muscled and normal cattle. The Canadian Veterinarian Journal 29, 163–167.

Bellows RA, Gibson RB, Anderson DC and Short RE 1971a. Precalving body size and pelvic area relationships in Hereford heifers. Journal of Animal Science 33, 455–457.

Bellows RA and Short RE 1978. Effects of precalving feed level on birth weight, calving difficulty and subsequent fertility. Journal of Animal Science 46, 1522–1528.

Bellows RA, Short RE, Anderson DC, Knapp BW and Pahnish OF 1971b. Cause and effect relationships associated with calving difficulty and calf birth weight. Journal of Animal Science 33, 407–415.

Berger PJ, Cubas AC, Koehler KJ and Healey MH 1992. Factors affecting dystocia and early calf mortality in Angus cows and heifers. Journal of Animal Science 70, 1775–1786.

Berry DP, Lee JM, MacDonald KA and Roche JR 2007. Body condition score and body weight effects on dystocia and stillbirths and consequent effects on postcalving performance. Journal of Dairy Science 90, 4201–4211.

Brinks JS, Olson JE and Carroll EJ 1973. Calving difficulty and its association with subsequent productivity in Herefords. Journal of Animal Science 36, 11–17.

Burfening PJ, Kress DD, Friedrich RL and Vaniman DD 1978a. Phenotypic and genetic relationships between calving ease; gestation length, birth weight and preweaning growth. Journal of Animal Science 47, 595–600.

Burfening PJ, Kress DD, Friedrich RL and Vaniman DD 1978b. Calving ease and growth rate of Simmental-sired calves. I. Factors affecting calving ease and growth rate. Journal of Animal Science 46, 922–929.

Casas E, Keele JW, Fahrenkrug SC, Smith TPL, Cundiff LV and Stone RT 1999. Quantitative analysis of birth, weaning, and yearling weights and calving difficulty in Piedmontese Crossbreds segregating an inactive myostatine allele. Journal of Animal Science 77, 1686–1692.

Colburn D, Deutscher G, Nielsen M, Adams D and Olson P 1997. Effects of sire EPD, dam traits and calf traits on calving difficulty and subsequent reproduction of two-year-old heifers. Nebraska Beef Cattle Report, Lincoln, CA, USA, 20–23.

Colburn D, Deutscher G and Olson P 1996. Winter temperatures may affect calf birth weights. Nebraska Beef Cattle Report, Lincoln, CA, USA, 23–25.

Coopman F, Gengler N, Groen AF, de Smet S and Van Zeveren A 2004. Comparison of external morphological traits of newborns to inner morphological traits of the dam in the double muscled Belgian Blue Beef Breed. Journal of Animal Breeding Genetics 121, 128–134.

Dawson WM, Phillips RW and Black WH 1947. Birth weight as a criterion of selection in beef cattle. Journal of Animal Science 6, 247–257.

Deutscher GH, Colburn D and Davis R 1999. Climate affects birth weight and calving difficulty. Nebraska Beef Cattle Report, Lincoln, CA, USA, 7–9.

Echternkamp SE 1993. Relationship between placental development and calf birth weight in beef cattle. Animal Reproduction Science 32, 1–13.

Fiems LO, de Campeneere S, van Caelenbergh W and Boucqué ChW 2001. Relationship between dam and calf characteristics with regard to dystocia in Belgian Blue double-muscled cows. Animal Science 72, 389–394.

Freking B 2000. Heifer Management. Beef Progress Report-1. Kerr Center for sustainable Agriculture, OK, USA, 1–9.

Grobet L, Poncelet D, Royo Martin LJ, Brouwers B, Pirottin D, Michaux C, Ménissier F, Zanotti M, Dunner S and Georges M 1998. Molecular definition of an allelic series of mutations disrupting the myostatin function and causing double muscling in cattle. Mammalian Genome 9, 210–213.

Grobet L, Royo Martin LJ, Poncelet D, Pirottin D, Brouwers B, Riquet J, Schoeberlein A, Dunner S, Ménissier F, Massabanda J, Fries R, Hanset R and Georges M 1997. A deletion in the myostatin gene causes double muscling in cattle. Nature Genetics 17, 71–74.

Hanset R 2004. Genetisch trends in witblauw: toename van bespiering, maar verlies aan gestalte gaat onverminderd door. VeeteeltVlees 6, 18–19.

Hanset R 2005. Evolutie vleesproductiekenmerken: trendanalyse in BWB wijst op constante toename uitval. VeeteeltVlees 1, 26–27.

Herd Book Blanc Bleu Belge (HBBBB) 2008. Functional and zootechnical indexes (1st and 2nd visits) and Linear score. Retrieved from http://www.hbbbb.be/pdf/publication_index_2008_site.pdf

Hindson JC 1978. Quantification of obstetric traction. The Veterinary Record 15, 327–332.

Houghton PL and Corah LR 1989. Calving difficulty in beef cattle: a review. Cooperative Extension Service Kansas State University, Manhattan, Kansas State, 1–9. http://www.oznet.ksu.edu

Johanson JM and Berger PJ 2003. Birth weight as a predictor of calving ease and perinatal mortality in Holstein cattle. Journal of Dairy Science 86, 3745–3755.

Kambadur R, Sharma M, Smith TPL and Bass JJ 1997. Mutations in myostatin (GDF8) in double muscled Belgian Blue Cattle. Genome Research 7, 910–916.

Karim L, Coppieters W, Grobet L, Valentini A and Georges M 2000. Convenient genotyping of six myostatin mutations causing double muscling in cattle using a multiplex oligonucleotide ligation assay. Animal Genetics 31, 369–399.

Kolkman I, De Vliegher S, Hoflack G, Van Aert M, Laureyns J, Lips D, de Kruif A and Opsomer G 2007. Protocol of the caesarean section as performed in daily bovine practice in Belgium. Reproduction of Domestic Animals 42, 583–589.

Laster DB 1974. Factors affecting pelvic size and dystocia in beef cattle. Journal of Animal Science 38, 496–503.

Laster DB, Glimp HA, Cundiff LV and Gregory KE 1973. Factors affecting dystocia and the effects of dystocia on subsequent reproduction in beef cattle. Journal of Animal Science 36, 695–705.

McGuirk BJ, Going I and Gilmour AR 1998. The genetic evaluation of beef sires used for crossing with dairy cows in the UK. 2. Genetic parameters and sire merit predictions for calving survey traits. Animal Science 66, 47–54.

McPherron AC and Lee SJ 1997. Double muscling in cattle due to mutations in the myostatin gene. Proceedings of the National Academy of Sciences, USA 94, 12457–12461.

Mee JF 2008. Prevalence and risk factors for dystocia in dairy cattle: A review. The Veterinary Journal 176, 93–101.

Meijering A 1984. Dystocia and stillbirth in cattle: a review of causes, relations and implications. Livestock Production Science 11, 143–177.

Ménissier F and Foulley JL 1979. Present situation of calving problems in the EEC: Incidence of calving difficulties and early calf mortality in beef herds. In Calving Problems and Early Viability of the Calf (ed. B Hofmann, IL Mason and J Schmidt), pp. 30–85. Martinus Nijhoff, The Hague, The Netherlands.

Morrison DG, Humes PE, Keith NK and Godke RA 1985. Discriminant analysis for predicting dystocia in beef cattle. I. Comparison with regression analysis. Journal of Animal Science 60, 608–616.

Nelson LA and Beavers GD 1982. Beef × beef and dairy × beef females mated to Angus and Charalois sires. I. Pregnancy rate, dystocia and birth weight. Journal of Animal Science 54, 1138–1149.

Norman HD, Wright JR, Kuhn MT, Hubbard SM, Cole JB and VanRaden PM 2009. Genetic and environmental factors that affect gestation length in dairy cattle. Journal of Diary Science 92, 2259–2269.

Olivier WM and Cartwright TC 1968. Double muscling in cattle, a review of expression, genetics and economic implication. Technical Report 12, Department of Animal Science, Texas A&M University, TX, USA.

Thomson DB and Wiltbank JN 1983. Dystocia in relationship to size and shape of pelvic opening in Holstein heifers. Theriogenology 20, 683–692.

Wang Y, Miller SP, Wilton JW, Sullivan P and Banks LR 2000. The relationship between birth weight and calving ease in a beef herd. Ontario Beef Research Update 14–17.

West HJ 1997. Dimensions and weight of Belgian Blue and crossbred calves and the pelvic size of the dam. The Veterinary Journal 153, 225–228.

Wilson TW and Rossi J 2006. Factors affecting calving difficulty. Bulletin 943 Cooperative Extension, University of Georgia, GA, USA, 1–4.

Zollinger B and Hansen D 2003. Calving school handbook. Animal Sciences Publication 110, 13–22.