ANALYSIS OF NEWBORN CALF BODY MEASUREMENTS AND RELATIONSHIP OF CALF SHAPE TO SIRE BREEDING VALUES FOR BIRTH WEIGHT AND CALVING EASE

by

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REVIEW OF LITERATURE

INTRODUCTION

The need for the beef cattle industry to maximize efficiency of production requires that the total lifetime performance of individual cows be increased. Maximizing the total production of a cow requires she first calve at 2 yr of age. However, at this age she has not reached mature size and, consequently, calving difficulties are increased. This problem is compounded by the increased use of sires of large breeds in terminal crossbreeding schemes.

Difficult births in cattle can lead to increased perinatal calf death, which greatly reduces net calf crop (Wiltbank et al., 1961; Smith et al., 1976; Bellows et al., 1987; Patterson et al., 1987). Subsequent reproductive performance of the dam is also affected in beef and dairy females experiencing dystocia (Brinks et al., 1973; Laster et al., 1973; Philipsson, 1976e; McDaniel. 1981; Mangurkar et al., 1984; Djemali et al., 1987; Meacham and Notter, 1987). Anderson and Bellows (1967) reported that 79% of the calves lost at birth died due to difficult or delayed parturition. One estimate of the genetic correlation between calf livability and dystocia is .66 (Martinez et al., 1983; Holstein cattle). The culling rate also tends to be highest for heifers with dystocia at first calving (Philipsson, 1976e). The great financial impact of dystocia, or difficult birth, on the cattle industry (increased veterinary costs, stillbirths, retained placentas, extra work hours, calf deaths at or soon after birth, cow losses and decreased subsequent cow fertility) has necessitated an extensive research effort to identify causal factors and methods for minimizing occurrence of dystocia.

One of the earliest comprehensive studies of factors associated with calving difficulty was published by Bellows et al. (1969; 1971a). This study, conducted in 1966 and 1967, examined factors associated with calving difficulty and calf birth weight in 95 Hereford and 103 Angus primiparous heifers bred to either one Angus or one Hereford bull to produce reciprocal crossbred calves. Fourteen variables were hypothesized to be related to calving difficulty and(or) calf birth weight. These variables were divided into factors associated with the dam and those associated with the calf. Factors associated with the dam were: body weights at the end of the breeding season, mid-gestation and prior to calving; weight gains during these periods; and pre-calving measurements of fat thickness, body condition score and pelvic height, width and area. Factors attributed to the calf were: gestation length, sex and birth weight. Breed of sire and breed of dam were confounded in this study; thus breed comparisons were made only among factors that were attributed to the dam prior to the analysis.

Comparisons of least squares means revealed that pre-calving pelvic height in Angus dams was greater than that observed in Hereford dams. Conversely, pelvic width was greater for Hereford dams, such that no difference existed in pre-calving pelvic area (estimated as the product of pelvic width and pelvic height). Gestation lengths and birth weights of male Angus x Hereford calves were 1.9 d and 2.6 kg greater, respectively, than for females. These sex differences were not significant for Hereford x Angus calves.

More bull than heifer calves required assistance at birth within both calf breed groups. The frequency of assistance (calving score of 2 or greater) and calving difficulty score (1 = no assistance, 2 = hand pull, 3 = easy machine pull, 4 = hard machine pull or Caesarean section) for males exceeded that of females by 40.2% and .74 units and by 20.6% and .40 units for Angus x Hereford and Hereford x Angus calves, respectively. Weighted averages calculated over crossbred types revealed means of 64.6 and 30.3% for percent assisted and of 1.93 and 1.37 units for calving difficulty score for male and female calves, respectively.

Phenotypic correlations among the variables measured indicated positive relationships in Hereford dams between pelvic height and body weight at the three periods measured, weight gain during the first half of gestation and body condition score. Pelvic height in Angus dams was positively correlated with mid-gestation and pre-calving body weight and weight gain during the first half of gestation. Pelvic width was positively associated with body weight at the three periods in both Hereford and Angus dams. Hence, pelvic area was highly correlated with all three weights and with weight gain in the first half of gestation in both dam breeds.

These positive relationships indicate that larger dams, as measured by body weight, had greater pelvic dimensions and hence, larger pelvic areas. Larger pelvic areas were associated with greater weight gains early in gestation (first half), suggesting that larger pelvic size was associated with greater body growth of these heifers and may indicate that observed weight increases in the dams early in gestation represents body growth, while the weight gains observed later were due also to increasing conceptus size.

Calf birth weight was positively correlated with body weight of the dam (at all three periods) in both Hereford and Angus dams. There was also a positive relationship between birth weight and weight gain of the dam during the first half of gestation for Hereford and Angus dams. As expected, birth weight was positively correlated with gestation length in both dam breeds. A positive correlation between birth weight and pelvic height and area in Angus dams was also reported. These correlations indicated that larger females, as measured by body weight or pelvic area, tend to deliver heavier calves.

Partial regression coefficients (within breed of dam) from a model with calving difficulty score as the dependant variable revealed a negative effect of pelvic area in both dam breeds. Pelvic area of the dam was the most important factor attributable to the dam affecting calving score in Hereford dams. Pelvic area was the second most important cow effect influencing dystocia in Angus dams; precalving weight was first. Also, partial regression coefficients revealed that gestation length was not a significant source of variation in this model for either dam breed. Hence, gestation length had no effect on calving difficulty score independent of birth weight.

The effect of calf birth weight on calving difficulty score ranked first in importance among factors attributable to either the calf or the dam for both dam breeds. Calf sex ranked second in importance among calf factors influencing dystocia in both Angus and Hereford dams and indicated that some factor(s) associated with bull calves and not accounted for by gestation length or birth weight was present. Conformational and(or) hormonal influences were suggested by the authors. Coefficients of determination for the model describing calving score were .44 for Hereford dams and .46 for Angus dams.

Pre-calving body weight of the heifers was the most important factor affecting calf birth weight as indicated by a regression model with birth weight of the calf as the dependant variable. The effect of gestation length on birth weight was significant for both dam breeds, while calf sex affected birth weights in the Hereford dams only. The R^2 value for the model describing birth weight were .37 for Hereford and .22 for Angus dams.

The paper by Bellows et al. (1971a), reviewed in detail above, reported the results of one of the earliest attempts to identify factors affecting calving difficulty. The concept of attributing factors to the dam or calf and the large effect of birth weight and cow size (indicated by both body weight and pelvic size) on dystocia frequency were continually examined in subsequent research. The complexity of the direct effects and interactions among a multitude of factors influencing dystocia spurred research in many laboratories throughout the world. The examination of influences and interactions among these influences on calving difficulty within and across breeds were the subject of many studies attempting to model dystocia and identify factors that would allow prediction of the occurrence of calving difficulty with acceptable accuracy.

The coefficients of determination for the models used by Bellows et al. to describe dystocia score indicated an inability to correctly predict the likelihood of dystocia for a single mating. This inability to model dystocia provided the motivation for the vast amounts of scientific research into one or more factors associated with dystocia that have been published to date. The following is a review of research conducted in this area which attempted to refine our ability to model dystocia and predict the occurrence of an assisted birth. Most studies examine several factors (in either dairy cattle, beef cattle or crosses thereof), hence the easiest way to examine the results of these papers is by subdividing the factors into those attributed to the dam and calf and discussing each one in turn. In addition, other genetic and non-genetic factors influencing dystocia will be examined.

The terms calving score, calving difficulty score, calving ease score and dystocia score have been used in the literature to describe dystocia scoring systems such as the one used by Bellows et al. (1971a). Unless otherwise noted, the term calving score (or a synonym) as used in this review will refer to the scale described by Bellows et al. (1971a).

FACTORS AFFECTING CALVING DIFFICULTY

Factors Attributed to the Calf

Birth weight. Birth weight is generally accepted as the most important factor influencing dystocia in cattle. Several studies have identified the large influence of calf birth weight on incidence of dystocia (Nelson and Huber, 1971; Ward, 1971; Laster, 1974; Bellows et al., 1987). The frequency of calving difficulty (defined as dystocia score 1 or 2 = no difficulty, ≥3 = difficulty) increased 2.3±.21% for each kg increase in birth weight (after adjustment for dam age, calf sex and calf genotype) when Angus, Hereford, Jersey, South Devon, Limousin, Simmental and Charolais bulls were bred to 2-to-5-yr-old Hereford or Angus cows (Laster et al., 1973).

A similar regression coefficient of a 1.6±.2% increase in dystocia per kg increase in birth weight was reported by Smith et al. (1976). The magnitude of this effect depended upon age of dam. Subclass regressions revealed that dystocia increased by 3.3±.3, 1.5±.4, .9±.4 and .5±.3% per kg increase in birth weight for 2-, 3-, 4- and ≥5-yr-old cows, respectively. Calves experiencing dystocia averaged 2.2 kg heavier at birth than calves that were born unassisted. This difference was consistent among sire breeds and was not explained by differences in gestation length.

Notter et al. (1978) reported that crossbred cows which produced calves with heavier birth weights tended to have more dystocia at 2 and 3 yr of age, even though the cows were also larger and heavier at calving. This agrees with Laster (1974) who reported that calf birth weight increased with cow weight at a faster rate than did pelvic area. Frequency of dystocia tended to level off at birth weights below 35 kg in 3-yr-old crossbred cows, but not in 2-yr-olds (Notter et al., 1978).

When dystocia levels were adjusted for birth weight, variation among calf sire breeds was still highly significant in the study by Notter et al. (1978). Breeds with higher mean birth weights (Brahman, Holstein) still had higher mean dystocia levels. Thus, the within-sire-breed estimate of the rate of increase in dystocia with increasing birth weight underestimated the between-breed relationship. The total linear regression of dystocia level on birth weight was 4.8±.7% per kg in 2-yr-olds and 2.7±.9% per kg in 3-yr-olds. The linear regression of calf sire breed mean dystocia level on mean birth weight was 8.0±1.3% per kg in 2-yr-olds and 5.2±.7% per kg in 3-yr-olds. Apparently variation in birth weight within sire breeds was less closely associated with components of size and structure responsible for dystocia than was variation in birth weight among subclasses.

The simple correlation between birth weight and dystocia score in 2.5-yr-old first-calf heifers was .11 in Hereford, Angus and Charolais reciprocal crossed calves in a study conducted by Sagebiel et al. (1969). Birth weight was then expressed as a percentage of dam weight and a correlation coefficient was calculated between this ratio and dystocia score. The resulting coefficient for each cow breed was .41 for Angus, .30 for Hereford and .24 for Charolais, indicating that larger calves in relation to dam size experienced more difficult births.

Relative birth weight (calf birth weight/cow weight) and its effect on dystocia levels in 159 dairy females of Jersey, Swedish Red and White or Friesian breeding was studied for the first six parturitions by Berglund and Philipsson (1987). The Jersey breed had no dystocia among 100 parturitions and had absolute and relative birth weights that were lowest among the breeds compared. In general, relative birth weight decreased with parity (both birth weight and cow weight increased with parity) and accounted for the majority of observed breed differences. The repeatability of relative birth weight was rather high (.32 to .52).

Tong et al. (1988) found that correlations between sire means for birth weight and calving ease score (range from 100 = unassisted to 0 = Caesarean) ranged across breeds from -.77 to .08 with an overall average of -.27 for Beefmaster, Charolais, Simmental, Limousin, Red Angus and Chianina sires. The correlation between sire proofs for the two traits ranged from -.90 to .14 with an overall mean of -.41. Philipsson (1976c) estimated that the phenotypic correlation between birth weight and calving difficulty score was .25. The estimated genetic correlation was much higher (.9).

Pollak and Freeman (1976) estimated genetic correlations between dystocia and subjective calf size (range from 1 = very small to 5 = very large) in Holsteins at .89±.17 and .97±.07 for two locations. The genetic correlation between birth weight and calving difficulty score for Simmental-sired calves out of 2-yr-old, 3-yr-old and mature dams was .80±.12, .81±.21 and .48±.21, respectively (Burfening et al., 1979). The estimate of this correlation for data pooled across dam age group was .51±.11.

Correlations of sire expected progeny difference (EPD) for calving difficulty score (higher EPD indicated greater dystocia) of progeny from 2-yr-old dams with those of progeny from 3-yr-old, mature and all-age dams were .32, .04 and .78, respectively, for all sires and .46, .21 and .91, respectively for sires with 20 or more progeny (Burfening et al., 1979). Correlations of sire EPD for calving difficulty score with sire EPD for birth weight in 2-yr-old, 3-yr-old, mature and all-age dams were .53, .41, .33 and .42, respectively, for all sires and .74, .26, .63 and .58, respectively for sires with 20 or more progeny. The phenotypic correlations of calving difficulty score in 3-yr-old or older cows with birth weight were significant but low (.33 and .29). These data indicate that sire evaluations for calving difficulty in first-calf heifers should be based on data from first-calf heifers because of the low correlation between the sire EPD in 2-yr-olds with those in older cows. Correlations here indicate that birth weight may provide more information relating to calving difficulty in young cows than does calving ease in older cows. A threshold model approach to breeding value estimation for calving difficulty is appropriate for combining information on sires bred to different age females.

According to Thompson et al. (1981a), dystocia in dairy cattle in first and later parities do appear to represent similar traits (r_g = .84). Hence, information from heifers and mature cows should be combined. Modern sire summaries should incorporate calving information from second-calf and older females into the first-calf calving ease evaluation using the correlation between the traits. Ignoring information on a bull used on more mature females would result in the loss of the bulk of the field data available for sire evaluation. Because there is less dystocia among older females, however, differences in progeny performance tend to identify difficult calving bulls more readily than easy calvers. Thus, without information on calves out of first-calf heifers, bulls tend to be evaluated as average or below average for the first-calf calving ease EPD (ASA, 1990).

Tong et al. (1988) concluded that birth weight could be used to select indirectly to decrease calving difficulty. Reduction in birth weight via selection, however, would also tend to reduce weaning weights which could offset potential gains from reducing dystocia by this means ($r_g = .33 \pm .07$; Burfening et al., 1978a). Also, very low birth weights tend to reduce calf viability and can result in neonatal death (Bellows et al., 1987).

Makarechian and Berg (1983) report that dystocia can be reduced by using sires with below average birth weights. This resulted in production of calves with lower birth weights and lower calving difficulty compared with calves from bulls with above average birth weights. However, sire birth weight affected calving score of progeny only when birth weight of the calf was not adjusted for.

Identification of bulls with moderate birth weights and high growth potential should hold dystocia levels in check if extensive information on calving performance on a bull is not available. The close association of birth weight to dystocia renders it a good, easily measurable indicator of potential calving problems.

Sex. The magnitude of the sex effect on calving difficulty varies greatly from study to study. Usually an effect of calf sex is noted, however many times the effect is lost when data are adjusted for birth weight differences. Several studies report sex effects on dystocia levels without making an attempt to adjust all calves to a common birth weight.

Male calves were heavier at birth and experienced more dystocia (28.4±1.7 vs 17.0±1.7% for male and female calves, respectively) in the study reported by Laster et al. (1973). Nelson and Huber (1971) noted that males experienced more dystocia in matings of Angus, Brown Swiss, Charolais and Hereford sires to Hereford dams.

Generally, adjustments are made for birth weights of the calves before evaluation of sex effects. In a study done with 14 breed groups (Laster, 1974), calf sex did affect dystocia independent of birth weight. Significant effects of calf sex independent of birth weight were also reported by Smith et al. (1976) who used a data set that overlapped somewhat with that reported by Laster (1974). Sieber et al. (1989) noted similar results Holstein calves.

In approximately 21,000 calves sired by purebred Simmental bulls, Burfening et al. (1978a) found that 8% more bull calves required assistance at birth than heifers and that bulls had average dystocia scores of .11 units higher than heifer calves. These bull calves averaged 3.6 kg heavier at birth, and no effect of sex was seen after adjusting for this difference in birth weight.

Philipsson (1976b) found a difference in dystocia levels between bull and heifer calves after adjustment to common birth weights; bulls experienced 6.5% more dystocia. Male calves were 2 kg heavier and gestated .3 to 1.3 d longer than females.

Thomson and Wiltbank (1983) saw more hard pulls (calving score 3 or 4) in bull calves (35%) than heifer calves (14%) in calves with a heart girth greater than 76 cm. Hence, in this study a sex effect was seen only among calves with larger body sizes.

The sex effect on dystocia has also been reported to interact with cow age and breed of the calf. Dufour et al. (1981) found no differences due to sex (without birth weight adjustment) in dystocia levels at first parity, but at second parity cows calving bull calves had four times more assisted births than did those calving heifers. Male calves experienced more difficulty when born to 2-yr-old cows than when born to older cows (Nelson and Huber, 1971). Similar results were observed by Brinks et al. (1973) and Morris et al. (1986). According to Smith et al. (1976) the magnitude of this difference was more apparent for calves sired by breeds with higher birth weights (Charolais, Simmental, Limousin, South Devon) than for those sired by breeds with lower birth weights (Hereford, Angus, Jersey). Calving difficulty in parturitions involving male calves was 4.1±3.2% higher in reciprocal crosses than in straightbred calves, while in parturitions involving female calves, calving difficulty was 6.9±3.6% higher in the straightbred than in the reciprocal cross calves. The effect of calf sex was removed when birth weight was used as a covariable.

In the results reported by Smith et al. (1976) the sire breed x calf sex interaction was significant for birth weight, but explained less than 1% of the variation in birth weight. Dystocia levels were 12% less in heifer calves. This effect of sex was different among sire breeds and age of dam subclasses. The increased dystocia levels associated with males was greater in young cows and in sire breeds with higher mean dystocia scores. The difference in dystocia between males and females was 23% in 2-yr-old and 7% in mature cows, respectively.

Notter et al. (1978) reported that male calves from 2- and 3-yr-old cows had 28 and 16% more dystocia, respectively, than females. An interaction of sex with breed of sire of calf was present in this data set. Male and female calves by Hereford and Angus sires had similar levels of dystocia in 3-yr-old cows. However, male calves by Maine Anjou and Chianina sires had 31 and 37% more dystocia, respectively, than did female calves. Thus, the magnitude of the sex effect increased with average level of dystocia.

The effect of sex alone is thus not large, but may be significant in some cases. Philipsson (1976b) postulated that the effect of calf sex independent of birth weight may arise conformational or hormonal reasons. Generally, the effect is predominantly mediated through larger birth weights of the bull calves, frequently leading to increased dystocia.

Gestation length. The effects of birth weight on dystocia are in part tied to longer gestation lengths of bigger calves. Accordingly, several studies report the effects of gestation length on dystocia ignoring birth weight. Williamson and Humes (1985), however, found that gestation length differences across cow breed groups do not necessarily affect calf birth weights.

The regression of birth weight on gestation length, calculated on a within breed group basis, was .25 kg/d (Smith et al., 1976). Breed of sire had an effect on the size of this coefficient. However, gestation did not have a significant effect on observed dystocia levels independent of calf birth weight. Price and Wiltbank (1978b) report a correlation of .19 between gestation length and dystocia score in Angus, Angus x Hereford and Charolais heifers.

Using records from the American Simmental Association, Burfening et al. (1978c) found that the percentage of assisted births increased .7% per day increase in gestation length. Calving ease score increased .010 units per day increase in gestation length. The phenotypic correlations of gestation length with calving ease score and percent assisted births were both .06. When both gestation length and birth weight were included in the model as covariates, gestation length no longer had an effect on calving score or percent assisted births. This confirms that the effects of gestation length on calving ease appear to work predominantly through birth weight.

Kemp et al. (1988) used data from Canadian Simmentals with calving score as 100 = unassisted down to 0 = Caesarean to estimate the genetic correlation between calving ease and gestation length at -.6. The phenotypic correlation was -.06. This suggests that as gestation length increases, so will calving difficulty, but there are also large environmental influences. Interestingly, Anthony et al. (1986b) noted that genotypic affects on birth weight appeared to be manifested before 200 d of gestation because fetal growth rates after d 200 were equal between two genetic groups even though birth weights differed. Based on this information, selection on gestation length does not appear to be useful to control dystocia. Price and Wiltbank (1978a) provide a good review of the interaction of birth weight and gestation length with dystocia.

Calf shape. Because of significant calf sex effects on dystocia independent of birth weight and the structural sexual dimorphism in mature cattle, calf shape effects on dystocia (possibly associated with sex) have been investigated in several studies. However, identification of a consistent, repeatable effect of calf shape or any linear body measure indicative of some function of calf shape, has not been reported. Newborn calf body measurements have been related to calf birth weight, but effects on dystocia independent of birth weight are rarely found (Meijering, 1984).

Multiple correlation between five calf shape measures (shoulder width, hip width, chest depth, wither height and body length) and birth weight yielded a coefficient of .75, but calf shape independent of birth weight had no effect on dystocia (Laster, 1974). Ward (1973) reported that calf measures of chest depth, shoulder width, hook width and thigh width were correlated to birth weight, but had no effect on calving difficulty score.

Cadle et al. (1976) found that head width of the calf at birth (unadjusted for birth weight) was related to dystocia in Brangus and Hereford purebred and crossed heifers. The correlations of dystocia score with calf body length, hip width and birth weight in this study were .26, .36 and .44, respectively. The correlations of birth weight with body length and hip width were .46 and .43, respectively. Heritability estimates from these data were: .35 for body length; .42 for hip width; .28 for birth weight and .19 for both birth weight to body length and hip width ratios. Hence, shape or calf size appeared to be a heritable trait.

Dufour et al. (1974) reported that body measures (nose circumference, head circumference, heart girth and shoulder width) in Angus- and Limousin-sired calves out of dairy x beef heifers differed between calving difficulty groups (no difficulty vs difficulty). In another study by Dufour et al. (1981), circumference of head and nose, circumference and width at shoulder and hips, heart girth and cannon bone circumference were taken on crossbred calves out of beef x dairy females within 24 h after birth. Only circumference of the head and nose had significant effects on dystocia. However, these larger nose and head circumferences (unadjusted for birth weight, but adjusted for sex and sire breed) found in calves born with difficulty could have been caused by edema buildup due to prolonged parturition.

Thomson and Wiltbank (1983) reported that calves with a heart girth of at least 76 cm experienced 26% hard pulls (calving score 3 or 4) compared to only 12% for calves with a heart girth less than 72 cm. The correlation between calf heart girth and dystocia was low (.27), but significant.

The calf body measurements that were most closely correlated to calving performance in German Simmental cattle were calf weight (.38) and muscling of the shoulder (.31; Schlote and Hassig, 1979). Heart girth, chest depth, width of hips and muscling of hind quarters were less correlated with calving score (r = .26 for all traits).

In an attempt to quantify linear body measures into some aspect of calf shape, the ratio of calf birth weight to body length was calculated by Price and Wiltbank (1978b). This value was highly correlated with dystocia score in Angus x Hereford crossbred and Angus dams (.45). Pooled over Angus, Angus x Hereford and Charolais heifers, calf birth weight (.44) and calf density measures such as birth weight to body length ratio (.46) and birth weight to hip width ratio (.43) were similarly correlated to dystocia.

Body length to hip width ratio was correlated to dystocia scores when pooled over all breeds (-.18). All correlations were done without adjustment for calf birth weight. When Angus and Hereford sires were grouped according to observed dystocia levels for their calves in this study, those bulls with high levels of dystocia had calves that were larger with respect to all measures of calf size (body length, hip width and birth weight).

Several authors have quantified shape of cattle using multivariate methods, however rarely has this been done on calves. Further, multi-dimensional descriptions of shape in the calf have not been related to dystocia. Tanner and Burt (1954) used factor analysis to describe aspects of cow size and shape. Several others have also used multivariate procedures to quantify shape of cattle, usually with principal components (Carpenter et al., 1971, 1978; Brown et al., 1973, 1974; Hammack et al., 1986).

Though not shown to be extremely useful in predicting dystocia, factors affecting or related to linear body size measures of calves (collectively referred to as shape or shape measures throughout this review) have been examined by several researchers. Because this thesis deals heavily with calf shape, examination of some results of these studies is warranted.

Not surprisingly, bull calves generally have larger body measures than heifer calves. Wilson (1973) reported that cannon circumference, rump length and body length differed among bull and heifer calves by 5.6, 3.8 and 2.2%, respectively. Boyd and Hafs (1965) measured heart girth and head width on newborn Holstein or 1/2 Angus, 1/2 Holstein calves. Average heart girth and head width was larger for bull calves. Price and Wiltbank (1978b), Bellows et al. (1982) and Thomson and Wiltbank (1983) also noted sex effects on calf shape. These results are for shape measures unadjusted for calf birth weight.

Philipsson (1976d) found that chest girth, chest depth, chest width, hip width, thurl width and forehead width of 1-d-old calves were larger for bull calves. Only chest width showed sex differences after adjustment for birth weight. Hence sex differences on linear body measures generally occur because bull calves are bigger (weigh more) at birth. At the same birth weight, some (minor) differences in shape between the sexes may be present.

Gestation length and age of calf after birth can also alter the relative size of calf measurements. The regression coefficients of heart girth, head width and birth weight on gestation length reported by Boyd and Hafs (1965) were .12 cm/d, .08 cm/d and .13 kg/d , respectively. Price and Wiltbank (1978b) reported similar coefficients. Calf age (3 to 18 vs 60 to 72 hr; Wilson, 1973) affected all measures except cannon bone circumference. Heart girth, hook width, rump length and cannon length and circumference increased by 3.7, 1.9, 2.4, 2.7 and 1.1%, respectively, when a calf was measured at both ages. Russell (1975) reported that the estimated degree of maturity at birth ranged from about 25% for measures of width to 50% for measures of height, with body length intermediate at 40%. Braude and Walker (1949) measured several linear dimensions of calves at 2, 4, 6, 8, 10, 22 and 24 h after birth. No significant changes were observed except those due to errors associated with measurement. Hence, growth rates prepartum and postpartum are slightly different among the calf shape measures unadjusted for birth weight. Dam age effects on calf body measures were noted by Boyd and Hafs (1965), Wilson (1973), Russell (1975), Bellows et al., (1982) and Ali et al., (1984).

Gestation feed level can influence calf birth weight (see "Nutrition effects on dystocia", below) but does not appear to affect shape measures (Hodge and Stokoe, 1974; Laster, 1974; Bellows et al., 1982). Hence, increased calf birth weights (from increased feed levels) were apparently due to increased soft tissue rather than increased skeletal size. The shape measures in these studies were not altered by minor deviations from a normal gestation ration. Extreme malnutrition of the cow during gestation certainly could alter calf development and affect body dimensions.

Sire breed effects on calf body measures were noted by several researchers. Boyd and Hafs (1965) reported that average heart girth and head width was greater (3.81 and .25 cm, respectively) for Holstein- than Angus-sired calves. There were also within-breed differences among sires (measures not adjusted for birth weight) for calf shape measures. Bellows et al. (1982) noted differences due to sire of calf in head width, heart girth, thigh width, body length, and leg length. This may indicate that observed increases in birth weight due to sire effects were largely skeletal, which is opposite to what Laster (1974) reported.

Relationships between dam and calf shape measures also exist. Dam heart girth had phenotypic correlations of .26, .20 and .31 with calf heart girth, head width and birth weight, respectively (Boyd and Hafs 1965). Blackmore et al. (1958) took wither height, body length, paunch girth, chest depth, chest girth and body weight measures on Holstein heifers at 6 mo, 1 yr and 2 yr of age. The same measures were also taken on their calves. Correlations were computed within groups of daughters by the same sire. Phenotypic and genetic correlations between measures on a dam and daughter pair increased with age, indicating that shape of daughter dam pairs becomes more alike as the calf matures.

Wilson (1973) estimated heritability for several shape measures taken on newborn calves out of Angus-Holstein F_1 cows bred to Polled Hereford bulls. Estimates for each calf body measure before and after adjustment for birth weight were: .39±.11 for birth weight, .41±.11 and .17±.08 for heart girth, .55±.12 and .48±.12 for cannon bone circumference, .18±.08 and .19±.08 for hook width, .12±.07 and .03±.06 for rump length, .51±.12 and .27±.09 for body length, and .46±.11 and .35±.10 for cannon length. Hence, moderate sire effects exist for certain birth measures at constant birth weight. Blackmore et al. (1958) and Ali et al. (1984) also report significant heritability estimates for various body measurements in cattle.

As the heritability estimates for calf linear body measures indicate, selection for changes in calf shape should be somewhat successful. Some measures are more highly correlated to birth weight than others, indicating that changes in shape independent of birth weight could vary from measure to measure. Wilson (1973) reported that heart girth and hook width were highly correlated with body weight of the calf. Boyd and Hafs (1965) reported simple correlation coefficients of .85 and .69 between birth weight and calf heart girth and head width, respectively.

Schlote and Hassig, (1979) address the problem of measuring calves at different d postpartum (1 to 10), citing regression coefficients of calf measurement size per d of age. However, each calf was measured only once, numbers were low and reason for a calf being measured when it was is not discussed. These factors all combine to make their coefficients hard to interpret.

Factors Attributed to the Dam

Body size. Body size of the dam has often been thought to be related to her calving ability. Cow size as indicated by weight and external body measures will be discussed in this section. Cow size as indicated by pelvic dimensions is discussed below.

The simple correlation between cow weight and dystocia score in reciprocally crossed Hereford, Angus and Charolais calves was a significant -.24 (Sagebiel et al., 1969). However, breed of dam was confounded with cow weight in this analysis and no adjustment was made for birth weight of the calf.

Dam weight influenced dystocia levels in a study conducted by Singleton et al. (1973). Regression analysis indicated that for each 45.4 kg increase in dam weight, dystocia score (range from 1 = no assistance, live calf to 6 = assistance with mechanical puller, dead calf) decreased by .68.

Makarechian and Berg (1983) found that heifer weight at calving affects dystocia score. The regression of calving score on heifer weight was negative and significant (-.01±.004) even after adjustment of weight for hip height, pelvic area and condition score. The negative sign is probably due to the heifers being on a low plane of nutrition during gestation.

Thompson et al. (1983) found that smaller Holstein cows had more trouble at their first and second parities, but that cow size had no effect on dystocia in later parities. Thompson et al. (1981b) found that larger dairy breeds tended to have a higher incidence of dystocia. Belcher and Frahm (1979) and Nelson and Beavers (1982) found cow size had no effect on dystocia in dairy x beef cross heifers and cows bred to beef bulls.

Fagg et al. (1975) found that weight of dam at calving was the most important (over sire breed, sire breed of dam and pelvic area) pre-calving measure related to dystocia in several breed types of heifers. As heifer weight increased from 306.5 kg to 351.9 kg, dystocia score decreased from 2.79 to 2.14. These data were from heifers produced by mating Brown Swiss, Charolais, Angus and Hereford bulls to Hereford dams. The heifers were then bred to Angus and Charolais bulls.

Several studies have been reported where cow size was not a significant factor involved with dystocia. Dam weight had little effect on dystocia scores in over 1,000 calvings out of Angus, Angus x Hereford and Charolais heifers (Price and Wiltbank, 1978b). Heifer weight at breeding had a small correlation with dystocia (pooled r = -.10), while heifer weight at mid-gestation was not significantly related to dystocia.

Heavier Charolais cows had more dystocia in a study conducted by Willham (1970). Pollak and Freeman (1976) found that size of dam was a source of variation for calf size but not dystocia in Holsteins. Rice and Wiltbank (1972) found that weight of dam in Hereford heifers was correlated to pelvic area (.46) and birth weight (.40), but not dystocia. Morrison et al. (1989) found no effect of cow weight on dystocia levels independent of age, breed and pelvic area in cows of several breed crosses.

According to Singleton et al. (1973), dam body measures (height, weight, pelvic area, width at hooks and pins, distance from hooks to pins) in Brangus and Hereford straightbreds and reciprocal cross heifers suggest less dystocia for larger, heavier dams. Dam body weight, height, hook to pin length, width at hooks and pelvic area were all negatively correlated to dystocia levels.

Sieber et al. (1989) looked at the effects of cow body measures and weight on calf size and dystocia in Holsteins. Heart and paunch girths, wither height, chest depth, pelvic length (external distance from front of hook to back of pin), pelvic width (distance between left and right hooks) and body length were collected in this study. For first parity, all dam body traits had positive correlations with calf birth weight (range .10 to .21). Significance levels of correlations of cow body measures with calf birth weight varied with parity, but over all parities all traits had significant positive phenotypic correlations with birth weight (range .23 to .27). For individual parities, none of the dam body measures had significant correlations with calving assistance score (1 = easy to 10 = most difficult). Across all parities, however, correlations for dam body traits were all highly significant and negative (range -.24 to -.30). Correlations became significant across all parities because of the general increase in body size as a cow aged, which increased the range of measurements. Least squares analysis for calving score across parities showed that wither height had a small negative partial regression coefficient (-.04), indicating that shorter cows tended to have more dystocia.

According to Ali et al. (1984), the product-moment (simple) correlation for hip and pin width sire proof with sire proof for calving ease (sire of cow) was .16 and -.17, respectively, for Canadian Holstein-Friesian females (a sire with a positive proof for calving ease had daughters with above average difficulty). The conflict between the two widths may be due to the relatively small number of sires (n=51). The -.12 correlation between heart girth sire proof and calving ease sire proof indicates that as size goes up, calving ease increases. Correlations among other measure proofs and calving ease proof were low (<.15) and tended to be negative.

Multiple regression analysis (Ali et al., 1984) using sire (maternal grandsire of calf) proofs for calving ease as a dependant variable and proofs for body measurements as independent variables had an R^2 value of .44. Hence, in this data set body measures of the cow play an important role in determining rate of dystocia. Boldman and Famula (1985) published a similar study relating progeny linear type traits to sire dystocia transmitting ability.

Hip width, thurl width and rump length were measured after calving in dairy heifers by Berglund and Philipsson (1987), but the values had little predictive value for dystocia. Larger hip widths tended to increase calving difficulty score (r = .21; nonsignificant). Dam weight did not influence dystocia when effects of breed, cow, parity and calf sex were considered simultaneously.

Meijering and Postma (1984) used a stepwise linear discriminant analysis (more appropriate than multiple linear regression for categorical data) to identify cow size factors associated with dystocia. Holstein heifers calving with difficulty tended to have less body development as indicated by body weight, chest depth, heart girth and spiral girth. The opposite was observed in Dutch Red and White heifers; heifers with larger frame tended to have more difficulty. Makarechian et al. (1982) identified cow weight as the most important factor affecting dystocia (birth weight was second).

Heifer body measurement traits were low to moderately correlated to calving performance in German Simmental cattle (Schlote and Hassig, 1979). The highest correlations with calving score were for heart girth (.22), body length (.20) and width of chest (.19). Exterior pelvic measurements had low correlations with calving score.

Cow size relationships with calving difficulty are difficult to quantify, hence much of the literature is conflicting. The method used to quantify cow size affects conclusions as do differences in covariates (interactions and main effects among breed, age, etc. all influence size of calf and cow and dystocia) in models among various studies. Pelvic size and breed are two factors closely associated with cow size and dystocia. Both pelvic size and cow breed effects will be discussed in detail below.

Dam parity and dam age. Effects of age and parity of the dam on dystocia are generally confounded since heifers are bred to calve first as 2-yr-olds. Most, but not all, studies do not attempt to separate out these two effects, hence they will be discussed together in one section. Dam age(parity) effects on calving difficulty are usually strong in young females calving for the first or second time. Young, first-calf heifers are usually structurally small leading to disproportionate size between dam and calf. According to Morrison et al. (1989) younger cows tend to have higher birth weight/cow weight ratios .

Mean frequency of calving difficulty was 15.7% for heifers and 4.8% for cows in several Swedish herds (Philipsson, 1976b). Calves out of cows were also 3.1 kg heavier and were carried 1 d longer than those born at first calving. Among cows (2 parities or more), parity had no effect on gestation length, birth weight or calving score. Age of dam was a major source of variation associated with calving difficulty even after adjustment for calf birth weight in the studies reported by Laster et al. (1973) and Smith et al. (1976). Brinks et al. (1973) reported significant age effects in Hereford dams, however birth weights of calves were not recorded and could not be separated out from cow age effects. Dystocia in 2-yr-old cows was 36±3% higher than in 3-yr-old and 45±3% higher than in 4- and 5-yr-old females (Laster et al., 1973). There were 8.6±3.3% more difficult births in 3-yr-olds than 4- and 5-yr-old females. Smith et al. (1976) similarly reported that dystocia levels had plateaued by a cow age of 4 yr for all sire breeds studied except Charolais and Simmental.

Burfening et al. (1978a) reported that cow age had an effect on dystocia levels in Simmental-sired calves. Three-yr-old cows required more assistance than 4- and 5-to-8-yr-olds. Two-yr-old heifers required 2.5 times the assistance given the 3-yr-old cows at calving. These 2-yr-old heifers had .45 units higher average dystocia scores than the 3-yr-old cows. Willham (1970) reported dam age effects on dystocia in Charolais cows.

Burfening et al. (1978a) reported a significant age of dam x calf sex interaction whereby bull calves were born with more difficulty most frequently in 2-yr-old cows (as discussed above). The magnitude of the differences between the sexes in birth weight was smaller in young cows: average bull minus average heifer birth weight was 2.8, 3.2, 3.4 and 3.7 kg from 2-, 3-, 4- and 5-to-8-yr-old dams. There was also an age of dam x percentage Simmental interaction. Seventy-five percent Simmental calves required 13.7, 3.2 and 5.5% more assistance than 50% Simmental calves for 2-, 3- and 4-yr-old cows. For 2-yr-old females the percentage of assisted births increased 4.5% per kg increase in birth weight. For the other age groups, the percent assisted births did not increase until birth weights reached 30 to 35 kg indicating that older, larger cows tended to deliver calves unassisted unless birth weights were large.

Age of dam effects (in British crossbred females bred to Charolais bulls) indicated that dystocia scores for heifers exceeded those of cows despite the fact that calves from cows were 4.0 kg heavier (Bellows et al., 1982). The lower dystocia scores for cows was partially due to larger precalving pelvic measures resulting in less disproportionate size between calf and dam.

Rice and Wiltbank (1972) found no effect of age on dystocia within Angus heifers, but heifers in this study were extremely young (only 8 of 93 were 24 mo or older at calving) and high levels (83%) of dystocia were noted.

A few studies have attempted to study age effects independent of parity. Philipsson (1976b) separated out effects of parity and cow age on dystocia levels by examining age at calving for first calf heifers only. There was no effect of age on calving difficulty in one region studied (age range was 24 to 36 mo). However, another region showed more trouble in heifers outside a 26 to 33 mo age range. Birth weight increased linearly with age by about .1 kg/mo in this study. Age at first calving (22 to 45 mo) unadjusted for cow size had no effect on dystocia in Holstein dairy heifers (Thompson et al., 1983).

Notter et al. (1978) reported that cows first calving at 3 yr of age had more dystocia than cows that calved first at 2 yr (32±4% vs 23±2%). The effect of age at first calving on dystocia was, however, confounded with the effects of size and condition in this and probably most if not all of the studies reviewed in this section.

These results may indicate that increased cow age after 4 yr can be an advantage in crossing schemes utilizing large sire breeds. Heifers may not be physically big enough to deliver a calf unassisted, and thus comprise the majority of observed dystocia cases. Also, older heifers (within first parity females) may be fat or greater ossification and stiffness of the pelvis may be present. It appears advisable to select against the smaller virgin heifers as possible replacements regardless of age, because size of dam within parity and age does affect dystocia levels as indicated in the above section of this review.

Pelvic area. Pelvic area or some other expression of pelvic size is the most important factor attributed to the dam that influences calving difficulty. The majority of cow breed, age, parity and size effects on dystocia are mediated through pelvic area and how it interacts with the birth weight of the calf. Hence, several investigations into the relationship of pelvic size of heifers and cows with their calving performance have been conducted.

Generally, pelvic width and pelvic height are measured and the product of these two measures is referred to as pelvic area. Other mathematical variations have been used to better describe or approximate the true area of the bovine pelvic opening (see discussion in "Pelvic area as a selection criterion"), however the width x height product is by far the most common in the scientific literature. This definition will be used for pelvic area in this review unless otherwise noted.

After adjustment for calf birth weight, pelvic height affected calving difficulty in 2-yr-old cows of several breeds (Laster, 1974). In the same study, pelvic width influenced dystocia in straightbred Hereford and Angus cows. After adjustment to common cow weight, the effect was reduced but still significant. Sieber et al. (1989) found that the partial regression coefficient of dystocia score on pelvic length was -.12 (birth weight was in the model).

Heifers with dystocia were generally found to have a smaller pelvic area and smaller pelvic area to calf birth weight ratio (Philipsson, 1976d). However, as is the case with most factors affecting dystocia, conflicting results have been published. Morrison et al. (1989) reported that less dystocia was noted for Red Poll-, Charolais- and Gelbvieh-bred cows from Angus dams compared to Hereford dams and Brahman, Chianina or Maine Anjou sires, but Simmental x Angus cows experienced 9.45% dystocia (2- to 5-yr-old at calving) compared to 1.9% for the Simmental x Hereford cows. Birth weights of the calves were nearly identical, whereas pelvic areas of the Simmental x Angus cows were 17.2 cm^2 larger than those of the Simmental x Hereford cows.

Dufour (1981) found that among beef x dairy cows observed for their first two parities, those with two consecutive difficult calvings had smaller pelvic areas at their first breeding. Above-average birth weight calves from cows with below-average pelvic areas had the most dystocia. Also, cows with difficult first and second calvings were found to have a lower ratio of pelvic area to body weight. In 101 dairy x beef heifers, Dufour et al. (1974) found that the assistance percentage for heifers with below and above average pelvic areas were 25 and 12.5%, respectively, for those sired by Angus bulls and 37.5 and 18.8%, respectively, for those sired by Limousin bulls.

Pelvic area at calving was highly correlated to dystocia score in crossbred (-.34) and Charolais (-.47) dams (Price and Wiltbank, 1978b). Postbreeding pelvic area significantly affected dystocia score across all dam breeds (pooled r = -.22). Individual pelvic measures (i.e., length and width) were less correlated with dystocia score than was area. The pooled correlation estimate in this paper indicated that the vertical measure was more highly correlated with dystocia than was the horizontal measure; this was true in Angus and Angus x Hereford but not Charolais heifers. Without reference to calf size, heifers with smaller pelvic areas (< 181 cm^2) had more dystocia than heifers with larger pelves.

Results of other studies suggest a possible threshold relationship of pelvic area to dystocia. However, the apparent threshold varies with so many factors that its usefulness or even its definition is questionable at present. Ward (1971) found that 50% of Angus x Hereford heifers with pelvic areas less than 225 cm^2 experienced dystocia. Rice and Wiltbank (1970) observed dystocia in 68.7% of 2-yr-old Hereford dams with pelvic areas less than 200 cm^2 compared with only 28% dystocia for dams with larger areas.

Rice and Wiltbank (1972) found that Hereford heifers with a pelvic area less than 200 cm^2 had more dystocia (69%) than heifers with moderate (200 to 229 cm^2; 30%) or large (230 to 269 cm^2; 35%) pelvic areas. The regression of dystocia score on pelvic area was significant in range beef heifers according to Makarechian and Berg (1983). After adjustment for heifer weight, however, the significance was lost. Only 50% normal calvings were observed among heifers with pelvic areas less than 202 cm^2. Normal calvings occurred 76% of the time in heifers with larger pelves.

In 127 Holstein heifers, Thomson and Wiltbank (1983) found that the incidence of hard pulls was 11, 14, and 12% for heifers having a pelvic area less than 294, 294 to 332 and over 332 cm^2, respectively. Hence, there was no correlation between pelvic area and dystocia. The shape of the pelvis appeared to be related to calf size and dystocia. Twenty-eight percent of the heifers had a pelvis with a larger horizontal than vertical dimension. Seventeen percent of these heifers gave birth to calves with a heart girth less than 72 cm, compared to 35% for heifers who had a greater or equal vertical measure. The same type of relationship stood for assisted and for unassisted births. These researchers concluded that differences in dystocia levels between heifers with different shape pelves appeared to be the result of calf size differences rather than pelvic shape alone. This analysis tended to break measures into discrete groups which may not have been ideal, but their general conclusions that pelvic effects on dystocia depend upon the calf passing through that area were correct.

The conclusions of any study where pelvic area was investigated must take into account effects on calf size when discussing a possible threshold effect. Short et al.

(1979) concluded that the pelvic area to birth weight ratio must be greater than 8.4 to keep the incidence of dystocia to below 50% in range beef heifers. The factors affecting pelvic area in cattle and its use as a selection criterion will be discussed below.

Genotypic Effects

Sire and sire breed of calf. Many researchers have reported sire breed and sire within breed effects on dystocia levels. These effects predominantly occur through changes in birth weight of a calf from a particular female. Others have implicated sire effects on calf shape independent of birth weight (Smith et al., 1976; Comerford et al., 1987), however these authors have been unable to demonstrate such an effect.

Laster (1974) reported significant sire breed effects on calving difficulty independent of birth weight of the calf. Average levels of dystocia in this study were 22±6% for Angus, 39±8% for Hereford, 37±7% for South Devon, 65±8% for Holstein and 70±8% for Brahman-sired calves. Similar results are reported by Smith et al. (1976).

Sire line differences in dystocia scores of Hereford-sired calves was reported by Brinks et al. (1973), however no adjustment for birth weight was attempted. Sagebiel et al. (1969) reported significantly increased dystocia in crossbred calves sired by Charolais bulls compared with those sired by Hereford and Angus bulls.

O'Mary and Coonrad (1972) studied the effects of sire breed on calving difficulty in Charolais or Angus x mature Angus female matings. There was a breed of sire effect on birth weight (37.4 vs 31.6 kg) and on calving time (47 vs 29.7 min; time from appearance of the waterbag until the calf was on the ground) with the Charolais increasing weight and time. Times differed among sires within the Charolais breed (range 17 to 41.4 min). Correlation of birth weight and calving time was .45.

Comerford et al. (1987) found more dystocia among Brahman-sired calves in a four-breed diallel (others were Simmental, Limousin and Polled Hereford). Monteiro (1969) found that larger sire breeds tend to sire calves born with more incidence of dystocia. This result was also reported by Schaeffer and Wilton (1977).

Though not the usual conclusion, a few papers in the literature have reported no effect of sire breed upon dystocia levels. Nelson and Huber (1971) found no sire breed effects on dystocia levels in Angus-, Brown Swiss-, Charolais- and Hereford-sired calves. Joandet et al. (1973) found no sire breed effects on dystocia in over 2,000 progeny out of 18 sire breeds and Angus cows. Overall incidence of dystocia was low (4.3%) in this group of cattle, which could have made it difficult to distinguish among breeds. Finally, Williamson and Humes (1985) found no sire breed effect on percentage of assisted births in Brahman and European bulls bred to Angus and Hereford cows. However, these cows had calved at least once prior to this study, which again would have made detection of breed differences much more difficult due to a low overall percentage of assisted births.

Certainly, differences among sires within breeds on dystocia levels of their calves exist. This can readily be seen from any beef cattle sire summary which publishes both birth weight and calving ease breeding values. Not surprisingly, Willham (1970) found significant sire within breed differences in Charolais purebred calves. Philipsson (1976c) found large differences between both sires and maternal grandsires in calving difficulty at first calving but not at later calvings (Swedish Friesian cattle).

As with the other effects on dystocia, the interaction of many factors which result in the observed calving performance has led to the reporting of significant interaction effects involving sire breed of calf. Laster et al. (1973) reported that breed of sire influenced the percentage of difficult births in both female and male calves, but to a greater extent in male calves. Charolais-, Simmental-, Limousin- and South Devon-sired calves all experienced more difficulty than did those by Hereford, Angus and Jersey sires. Also, more difficulty was experienced by Hereford-sired calves compared to Jersey-sired calves. The range in percentage calving difficulty was from 6.1±5% for Jersey-sired bull calves to 44.3±4.1% for Simmental-sired bull calves and from 6.8±5% for Angus-sired heifer calves to 25.5±6.5% for South Devon-sired heifer calves. The significant effect of sire breed was removed when birth weight was added to the model as a covariate.

A highly significant sire breed x dam age interaction effect on dystocia was reported by Smith et al. (1976). Jersey cross calves from 2-yr-old dams had only 15% dystocia compared to the 66 to 74% observed in calves from large sire breeds such as Charolais, Simmental, Limousin and South Devon. These differences between large and small sire-breed calves were reduced in mature cows. After cow age differences were removed, variability among sires was still present, suggesting that other factors attributable to certain sires such as calf conformation are present.

Price and Wiltbank (1978b) reported high levels of dystocia (47%) in Charolais-sired calves out of Charolais heifers. Hereford- (41%) and Angus-sired calves (34.6%) out of Angus and Angus x Hereford crossbred heifers experienced lower levels of dystocia than did the Charolais heifers.

Sire effects on dystocia are certainly important, since the majority of genetic improvement in cattle can be made through proper selection of sires. Meijering (1986) concluded that identification of low-risk bulls for dystocia among selected bulls for preferential use on heifers has a favorable impact on returns from a breeding program in dairy cattle especially when initial levels of dystocia and calf prices are high. However, selection for direct and maternal influences on dystocia in a bull would reduce selection intensity in other economically important traits, generally causing lost revenue. Overall, dystocia in heifers especially could be reduced through the use of calving ease bulls or at least through the use of bulls known to sire calves with moderate birth weights.

Dam breed. Genotype of the cow certainly can influence her calving ability. Cow breed effects on pelvic area will be discussed in a later section, however a few studies have noted cow breed effects on dystocia without regard to pelvic size. Monteiro (1969) stated that larger dam breeds tend to have more dystocia. This was seen above when cow size effects on calving difficulty were discussed.

Hereford cows had more calving difficulty than Angus cows, especially as 2-yr-olds, in the study conducted by Laster et al. (1973; 34.8±3.2% for Hereford vs 27.0±3.1% for Angus). Differences in dystocia levels between Hereford and

Angus cows were similar for each calf sex. Birth weights averaged 37.7±3.4 kg in Hereford and 35.2±3.3 kg in Angus cows, but addition of calf birth weight to the model removed significant effects of dam breed on dystocia. Smith et al. (1976) reports similar results. Conversely, Sagebiel et al. (1969) reported that crossbred calves born to Angus cows had larger average dystocia scores than crossbred calves out of Hereford and Charolais cows.

Seventy-five percent Simmental calves required 7.6% more assistance than 50% Simmental calves, resulting in an increase in average dystocia score of .12 units in calves out of the one-half Simmental dams (Burfening et al., 1978a). The 75% calves were 2 kg heavier at birth which accounted for all observed differences in percentage Simmental on calving difficulty score, but not in percentage of assisted births.

Philipsson (1976a) noted smaller dam breed differences in dystocia levels for cows than heifers. This may be partly explained by selection, as heifers with the most difficult calvings are not bred again in many instances. Breed differences were also found for birth weight and gestation length. Breed differences in gestation length did not explain all the breed variation in birth weight.

Belcher and Frahm (1979) hypothesized that dairy x beef crossbred females have a biological advantage for calving ease over beef crossbreds such as less exterior fat, less muscling and a more flexible pelvic area. In their study, Brown Swiss x Hereford or x Angus heifers had calves averaging 30.6 and 30.3 kg, respectively at birth and experienced 28.2 and 18.2% difficulty. Angus x Hereford cross cows had lighter calves at birth (27.6 kg) but had 37.3% assisted births.

Maternal effects. Sire breed effects that have been discussed in a previous section of this review dealt with direct genetic effects only. Dam breed effects would have included direct genetic effects and maternal environmental effects on dystocia. Prior to selection of bulls that are expected to sire calves born more easily than average, maternal effects on dystocia need to be considered and studied. This would be especially important if a bull was going to be used to sire replacement females out of heifers.

A general perception of what might occur is that calving ease bulls should sire small birth weight calves, which are born easily. The small birth weight female calves should grow up to have smaller mature weights than average, and calve with more difficulty than average. However, as Monteiro (1969) stated, heavier dam breeds should have more difficulty due to their genes for birth weight causing a disproportion in size between dam pelvic area and calf birth weight. Based on estimates of the genetic correlation between direct and maternal components of calving ease and direct tests of the relationship between the two sources of variation, this idea is supported by some and refuted by others.

Philipsson (1976c) estimated the genetic correlation between direct and maternal effects on calving ease to be -.19. Thompson et al. (1981a) estimated the correlation between direct and maternal components of calving ease to be -.38 for heifers and -.25 for cows in a large Holstein data set (88,000 records from over 500 sires). Similarly, the estimate of this genetic correlation is -.27 for American Simmental cattle (Quaas et al., 1985; ASA, 1990).

The genetic correlation between direct and maternal traits for calving ease score (-.53) for Simmental cattle was also calculated by Burfening et al. (1981). The genetic correlations between direct and maternal effects for percent assisted births (-.55), birth weight (-.24) and gestation length (-.38) were also reported by Burfening et al. (1981).

Cue and Hayes (1985a) estimated the genetic correlation between direct and maternal effects for dystocia to be -.40 for heifers and .07 for cows. Trus and Wilton (1988) estimated the direct and maternal genetic correlation for calving ease to be -.43, -.15, -.32, -.74 and -.27 for Angus, Hereford, Shorthorn, Charolais and Simmental cattle, respectively, from Canadian sire evaluation records.

Pollak and Freeman (1976) found the rank correlation for calving ease between Holstein sires appearing in their data set as both grandsires and sires (n=39) to be .16. This correlation was not significant and indicated that dams sired by bulls whose calves are born easily do not experience more difficulty at calving than do other dams.

Thompson and Rege (1984) tested the theory of the negative correlation between direct and maternal effects on calving difficulty by breaking the relationships down into pieces and addressing each question in turn. Data were collected from California dairy herds. They wanted to see if small calves were born easily, grew up to be small cows and thus had more difficulty when they gave birth. First, small calves were born more easily as the positive regression of calving score on calf size indicated. Small calves did grow into small cows: the regression coefficient of daughter mature size on dam's average calf size corrected for sex of calf was .16. The regression of daughter mature cow size on calving score was .06. This indicated that dams with above average difficulty tended to have daughters with above average mature cow size and that small calves tended to grow into small cows.

Cow size affected only calving score at first or second parturition (bigger dams had less trouble); no effect of dam size on calving score was seen with all data taken into account. These results might explain why the direct-maternal correlation is greater for first than for later parities; cow size has its greatest effect at early parities. The regression of daughter difficulty score on dam difficulty score was positive. An increase of .12 units of daughter difficulty score per unit increase in dam score was seen. Hence, daughters of cows with above average calving difficulty also experience above average problems at calving. Thompson and Rege concluded that the hypothesis of a negative direct-maternal correlation for calving score may not be incorrect for early parturitions when the cow is still growing, but overall, the correlation is not a large negative and may be positive.

The hypothesis that low-risk bulls for dystocia sire small calves which develop into small heifers and tend to calve with more difficulty was also tested by Meijering and Postma (1985). These researchers used a two-way sire selection trial with Holstein, Dutch Red and White and Dutch Friesian cattle in pure breeding. Low-risk and high-risk bulls were used to sire replacement females out of heifers and cows. Within sire groups, replacement females were in turn bred to low-risk and high-risk sires. Only in the Dutch Red and White breed did sire selection yield a significant difference in calving score (easy = minor assistance; normal = easy pull; difficult = hard pull or Caesarean).

Replacement heifers were measured for wither height, chest depth and hip width at 3, 6, 9, 12, 15 and 25 mo of age. At 15 and 25 mo of age, heifer body weight but none of the size measures differed between sire groups. Heifers sired by low-risk bulls were 10.8±4.7 kg lighter at 25 mo of age (10 d after calving).

For ease of birth for the calves of replacement females, maternal grand-sire group interacted significantly with breed. Except for the Dutch-Friesian breed, the sign of contrasts between high- and low-risk bulls was the same as observed for sire groups in the F_1 calves. Sire group did not interact with maternal grandsire group so that direct genetic merit of one group of sires and maternal grandsire merit of a second group appear to behave additively. Hence from this data, it appeared safe to use low risk bulls on heifers in producing replacement females.

It may be important that genes for direct and maternal effects on the fetus size are to some extent antagonistic. In this way a genetic variation in calf characteristics will be moderated phenotypically by a maternal genetic influence (Philipsson, 1976c). This may favor a proper balance between the cow and the development of the fetus and may be a result of natural selection.

The effect of this antagonistic genetic relationship on production may not be large, as was seen in the studies published by Thompson and Rege (1984) and Meijering and Postma (1985). In fact, Meijering and Postma (1985) believe that the interpretation of the genetic correlation between direct and maternal components for calving ease is incorrect. It is not this correlation, according to the authors, but the regression of maternal grandsire merit on direct genetic merit that is relevant. This regression appears to be positive, though close to zero (Meijering and Postma, 1985). Further, after estimating the effects of selection for the direct and maternal components of calving ease, Balcerzak et al. (1989) concluded that selection for the direct component is not likely to cause any significant change in the maternal component for calving ease.

Heterosis and inbreeding. Few studies report significant heterotic effects on calving performance. Effects, when detected, are small and the results of many studies contradict. Also, little information exists on inbreeding effects on dystocia.

No heterosis effect on calving difficulty in Hereford and Angus reciprocal cross calves was reported by Laster et al. (1973) and Smith et al. (1976). Calving difficulty was 1.4±2.4% higher in births involving straightbred calves, despite the fact that calf birth weights were 1.6±.3 kg higher in the crossbreds (Laster et al., 1973). Comerford et al. (1987) found no heterosis for dystocia in calves from a Simmental, Limousin, Polled Hereford and Brahman four-breed diallel. Gotti et al. (1985) found no heterosis for calving ease in crosses among Angus, Santa Gertrudis and Gelbvieh cattle (no heterosis for birth weight was detected either, and percent dystocia overall was less than 5%).

Significant heterotic effects on dystocia levels were reported by Cundiff et al. (1974). Less dystocia was observed in Hereford x Shorthorn reciprocal cross females, especially in first-calf heifers. Opposite results were reported by Sagebiel et al. (1969) with reciprocally crossed Angus, Hereford and Charolais cattle. Crossbred female calves experienced more dystocia (effect was not significant with bull calves) when born out of Angus x Hereford and Angus x Charolais reciprocal crosses. This effect was most apparent in calves out of heifers. These crosses exhibited significant heterotic effects for birth weight, which probably accounts for at least part of this effect.

Levels of inbreeding of calf and dam affected the level of dystocia in purebred Hereford calves in Colorado (Brinks et al., 1973). Non-inbred calves and dams experienced 8.1 and 8.2% difficulty, respectively. Low levels of calf inbreeding (1 to 30%) and dam inbreeding (1 to 15%) were also associated with lower than average dystocia levels in this study (6.2 and 1.3%, respectively). Higher levels of inbreeding (31 to 46%) were associated with above average levels of dystocia. Age of dam x level of inbreeding interaction was significant, such that 2- and 3-yr-old highly inbred cows had much more difficulty than highly inbred, more mature cows.

Heritability. Estimates of heritability for calving ease, as with other reproductive traits, are generally low. Many estimates are published in the literature and results suggest that the trait may respond to selection, although environmental effects are expected to be large.

Calving difficulty as a trait of the calf using records from cows of several age classes yielded a heritability estimate of .069±.022. When only heifer records were used, heritability increased to .126±.109 (Brinks et al., 1973). Similar analyses considering calving difficulty as a trait of the dam yielded estimates of .134±.029 and -.003±.097 for all dams and 2-yr-old dams only, respectively. Hence, dams from some sires continue to experience difficulty at parturition, whereas 2-yr-old dams from different sires experience approximately equal amounts of difficulty.

Dr. P. J. Burfening and coworkers at Montana State University have published several estimates of heritability for calving ease and associated traits using field data obtained from the American Simmental Association in conjunction with their performance registration and sire evaluation program. Burfening et al. (1978b) reported estimates of heritability for calving ease in 50 and 75% Simmental calves out of dams ranging in age from 2 to 8 yr at .46±.05 and .28±.03 for bull and heifer calves respectively. These values did not change significantly when heritability was recalculated after adjustment for birth weight. Pooled over sex, heritability estimates for calving ease were .32±.02 and .30±.02 before and after adjustment for birth weight, respectively. Estimates for percent assisted births were .21±.02 and .20±.02 for unadjusted and birth weight adjusted records, respectively.

Burfening et al. (1979) found heritability estimates for Simmental-sired calves for calving ease to be .08±.03 for calves out of 2-yr-old dams, .02±.04 for 3-yr-old dams, .05±.04 for mature dams and .06±.01 for the pooled estimate. Burfening et al. (1981) calculated heritabilities for calving traits using only calves' data from 2-yr-old dams. Direct and maternal heritabilities of calving ease were quite low, .05±.01 and .20±.03, respectively. The same trend was seen for direct and maternal heritability estimates for percent assisted births, .04±.01 and .13±.03.

Several other estimates (range .09 to .33) for heritability of calving ease for several beef sire breeds have been published by Willham (1970), Schaeffer and Wilton

(1977) and Trus and Wilton (1988). Estimates in dairy cattle have ranged from .01 to .19 depending upon breed, location and whether calving ease is considered a trait of the cow or the calf (Philipsson, 1976c; Pollak and Freeman, 1976; Cue and Hayes, 1985b).

Cundiff et al. (1975) found the heritability of calving ease to be zero. More recently, however, calves out of Hereford and Angus cows sired by bulls of 14 Bos taurus breeds were evaluated for birth weight, gestation length and calving ease by Cundiff et al. (1986). Estimates of total heritability (.42) and within breed heritability (.21) were moderately large. Based on their estimates of heritability and genetic correlations among birth weight, gestation length and calving ease, these authors concluded that selection among or within breeds for reduced calving difficulty (or birth weight) should be effective and reduce birth weight (calving difficulty) and gestation length. However, selection for longer than a few generations, if unbalanced with other criteria, might reduce calf survival if average birth weights get too low.

Overall, additive genetic effects on dystocia appear very low. Genetic correlations and predicted correlated responses calculated by Burfening et al. (1978c) using Simmental cattle indicate that selection for calving ease would increase ease of calving, decrease gestation length and have little effect on birth weight or 205 d weight. Direct selection against large birth weights would not be as effective in increasing the ease of calving, and would shorten gestation lengths and decrease birth and 205 d weights. Hence, selection against high birth weight to decrease dystocia levels in beef cattle have the potential to be counterproductive unless done correctly.

Selection for calving ease would not potentially reduce economically important traits in dairy cattle as it might in beef cattle according to Thompson et al. (1980). Genetic correlations between dystocia score and four production traits (milk, fat, fat test and dollars) were zero or nearly so in this study. Conversely, selection on production traits alone in Holstein bulls should not increase dystocia.

Repeatability. In the absence of reproductive problems stemming from a difficult birth, the question arises as to whether a female should be culled after she has delivered a calf with dystocia because she may be liable to repeat this performance. Repeatability estimates measuring the correlation among first and subsequent calving performance in beef and dairy cattle are available in the literature to help answer this question.

Repeatability was .045 for dystocia in the paper published by Brinks et al. (1973). Of the 195 heifers which had no difficulty as 2-yr-olds, 7.2% had difficulty as 3-yr-olds. Of the 77 which had trouble at 2 yr of age, 11.7% had difficulty again at 3 yr of age. Willham (1970) calculated dystocia repeatability as .29 in Charolais females. Berglund and Philipsson (1987) estimated that repeatability between first and second calving performance was .10, among mature cow calvings was .06 and for all parturitions was .13.

Thompson and Rege (1984) investigated the repeatability of dam calving performance in data collected from California dairy operations. The average second parity difficulty scores increased from 1.1 for a score of 1 at first parity to an average of 1.51 for the most difficult first parity births. Repeatability of calving performance between first and second parity was .16. Repeatability between second and later parities was .10.

Hence, prior calving difficulty is not necessarily a good indicator of future performance, at least not in predicting the calving score of an individual female. The repeatability would be expected to be low due to low heritability estimates for calving ease, unless permanent environmental effects were high. The permanent deleterious environmental effects may be underestimated due to involuntary culling of females who experience severe, destructive dystocia. Also, the lower second and later parity repeatability estimates are expected since heritability of dystocia is usually lower in later calvings.

Environmental Effects

Abnormal presentation. Though not truly an environmental effect in the sense of region, nutrition or season, non-normal presentation of the calf occurs with low frequency and is of less concern in this review than are effects causing dystocia with normally presented calves.

Nearly all studies on factors influencing dystocia deal only with normal presentations. This allows a more unbiased assessment of factors causing dystocia in cattle independent of the positioning of the calf at birth. Abnormal presentation and thus dystocia caused by this problem are infrequent compared to the total numbers of calvings and assisted births as the work reviewed briefly below indicates.

Dystocia due to abnormal positioning or posture occurred in 4.6% of the births and accounted for 11.6% of the dystocias in over 1,000 calvings out of purebred and crossbred heifers (Price and Wiltbank, 1978b). Birth weights of these calves did not differ from those of other calves. Likewise, sex had no effect on incidence of abnormal presentation. These results agree with Laster et al. (1973) and indicate that prediction of dystocia due to abnormal presentation is not likely. This type of dystocia is of little consequence when compared to total dystocia incidence for heifers; frequency of dystocia due to abnormal presentation was .27% of all calvings according to Dreyer and Leipnitz (1971).

According to Philipsson (1976a), levels of abnormal presentations are low in Swedish cattle (around 3.5 to 6.5% of all calvings), but breed differences in frequency of occurrence do exist. Berglund and Philipsson (1987) also saw no sex effect on presentation of the calf in dairy cattle, but abnormal deliveries were more frequent in heifers than in mature cows. Calves born in an abnormal position tended to be heavier and have larger birth weights relative to their dam's weight.

Finally, Erb et al. (1981) state that malpresentation did not appear to be related to dam age, dam weight, gestation length, calf sex, birth weight, birth weight as a percent of dam weight or circulating prolactin, progesterone or estrogen levels in Holstein cattle.

The incidence and predictability (and most surely heritability and repeatability) of dystocia due to abnormal presentation are too low to pursue further at this time. When and if dystocia in normally born calves is understood and predictable, this may be an area for further research.

Thus, this subject will not be considered extensively here. For further information on the subject, Bellows et al. (1987) and Patterson et al. (1987) present well-written papers on abnormal presentations in range beef cattle.

Season. Whether physiologically real or managerially caused (especially in dairy cattle), several researchers have published findings of seasonal effects on observed dystocia levels. Pollak and Freeman (1976) and Bar-Anan et al. (1976) noted a seasonal effect on dystocia in dairy calves (more dystocia in winter months). Similar effects were seen by Sieber et al. (1989) for Holsteins. Cue and Hayes (1985a) reported more dystocia in winter in dairy heifers but not in mature cows.

Philipsson (1976b) found effects of month on gestation length and dystocia (even after adjustment for birth weight and gestation length) in field records collected on Swedish dairy heifers. Both traits exhibited lower levels in summer and early fall. Erb et al. (1981) found more dystocia in Holstein calves with low relative calf birth weights (representing physiological rather than anatomical dystocia; relative birth weight = calf birth weight/dam body weight) in December through February.

In beef cattle, Willham (1970) noted an increase in dystocia in fall vs spring born Charolais calves. Burfening et al. (1980) observed that calves born in the late spring had heavier birth weights, more calving difficulty and longer gestation lengths than those born in fall. The differences in dystocia were due to season independent of gestation length. Wilson and Willis (1976) reported higher dystocia in beef cattle in April to June in Britain, possibly due to differences in condition in the dam.

The higher levels of dystocia observed in winter could be attributed to either the better physical condition of females calving in early winter or to the fact that winter is a more likely time to observe cows experiencing difficult births (assuming cows are in a drylot or at least being given supplemental feed; all studies reviewed in this section dealt with field data with the exception of the Erb et al. [1981] study).

According to Philipsson (1976b) high dystocia levels correspond closely to the time of least daylight and when cows were generally kept indoors. Consequently, the best calving results were obtained during the pasture season and it may be plausible to suggest that increased daylight and exercise have a positive influence on calving performance. However, this hypothesis was not supported by Bellows (1979). The importance of daylight may be supported by the fact that the frequency of difficult calvings begins to decrease a few months before the heifers go out to pasture.

Region. Regional differences in dystocia levels have been reported. Hanford et al. (1985) reported significant differences between regions of the United States in calving difficulty and birth weight. No significant sire x region interaction was observed for direct (Burfening et al., 1982) or maternal effects (Hanford et al., 1985).

Nutrition. Producers have long thought that reduced feed levels during late gestation would reduce calf birth weight and thus reduce calving difficulty. The results of individual studies depend upon the experimental design, but the overall conclusions are similar. The literature clearly points to no beneficial and several detrimental effects of excessively low or high gestation feed levels for cattle. Effects of energy and then protein upon calving performance will be discussed.

Laster (1974) stated that increased levels of energy (4.9, 6.2, or 7.7 kg/hd/d) for a 90-d period before the calving season increased calf birth weights in straightbred Hereford and Angus 2-yr-olds, but did not affect the percentage of females requiring assistance at parturition.

Bellows and Short (1978) found that decreasing precalving feed level decreased pelvic area and calf birth weight (especially in heifers' calves) but had no effect on dystocia. There was no apparent beneficial effect of low pre-calving feed levels on dystocia and there were distinct detrimental effects on subsequent reproduction (Bellows and Short, 1978; Bellows et al., 1978; Bellows et al., 1982). Similar results in calf birth weight (decrease) and dystocia (no effect) were noted by Tudor (1972), Corah et al. (1975) and Makarechian and Berg (1983).

Absher and Hobbs (1968) found that average birth weights and mean calving difficulty scores were not influenced by pre-calving nutrition levels. Wiltbank and Remmenga (1982) fed Angus and Hereford heifers bred by either Angus or Hereford bulls either a high or low level of nutrition for the last 116 d of gestation. The level of dystocia did not differ between treatment groups in the first year (36 and 34%, respectively for high vs low nutrition level) but did differ in the second year (33 vs 16%). Over the 2 yr, calves born to heifers on the high nutrition level weighed 2.7 kg more.

According to Hodge et al. (1976), heifers that were fed poorly during the last 12 wk of pregnancy had more dystocia, even though calf size was similar from heifers fed at high, medium or low levels during this period. Birth weights were the same across treatments, even though heifer weights differed at the end of feeding. Hodge and Stokoe (1974) fed low levels of feed to heifers for 16 wk prior to calving and noted decreased unassisted births and pelvic areas, but no change in calf size or change in body weight or condition of the heifers.

Bellows et al. (1978) fed cows of Angus, Hereford and Charolais breeding isocaloric diets with either high (138%) or low (79%) levels of the 1976 NRC requirement for crude protein (NRC, 1976). Cows receiving high levels of protein had calves that tended to be heavier, but no differences in average dystocia score were noted. A similar study by Anthony et al. (1986a) found that calf birth weight and dystocia score were unaffected by varying protein levels in isocaloric diets.

In the studies that did find nutritional effects upon dystocia, explanations increased dystocia due to very fat or very thin females can be offered. Too much energy prepartum can cause fat deposition in the pelvic canal and this may reduce effective pelvic area and increase dystocia levels. Arnett et al. (1971) found that obese cows tend to require more assistance at calving than do normal cows. In animals fed a diet that is too low in energy prepartum, decreased calving endurance would appear to be a logical explanation for poor calving performance. Decreased growth, affecting pelvic size at calving, would also be a possibility if growth was greatly reduced.

Endocrine effects

Because birth is controlled by a whole physiological cascade of events (and their timing), it is conceivable that certain disorders (genetic or not) in the events could potentially lead to dystocia. Hence, a few researchers have attempted to quantify hormonal differences between cows experiencing dystocia and those with normal parturitions.

Twelve Holstein heifers from a herd having a high incidence of dystocia were bled from d 260 of gestation until parturition by O'Brien and Stott (1977). The concentrations of estradiol-17β were lower and the concentration of progesterone were higher during the prepartum period from -23 to -12d in animals experiencing dystocia (n=6). This result suggests that the timing in hormonal changes in preparation for parturition was delayed and not as pronounced in animals that required assistance at birth.

Erb et al. (1981) used calf birth weight percentage (calf birth weight x 100/dam weight) to divide dystocia cases (subjectively) into those caused by physiological and anatomical factors. Progesterone failed to drop to low concentrations peripartum in physiologically dystocial animals compared to anatomically dystocial and control calves. Physiologically dystocial calves appeared also to have higher estradiol-17α levels peripartum. The authors suggest the occurrence of hormonal defects which could be disrupting the entire physiological balance of parturition as a cause of physiological dystocia. Anthony et al. (1986a) report possible hormonal differences between cows experiencing different levels of dystocia also. Osinga (1978) has reported possible relationships between urinary estrogen levels and dystocia, however the conclusions are highly speculative.

Several attempts have been made to reduce dystocia through the administration of relaxin to prepartum females in order to increase pelvic area at the time of calving. Results have been contradictory. Musah et al. (1986) saw no dystocia in relaxin-treated heifers (0 assisted out of 31) compared to 2 of 16 cases of dystocia in control animals. The relaxin-treated animals calved an average of 3 d earlier. Musah et al. (1988) also noted that dystocia levels were reduced in cattle induced to calve with cloprostenol or dexamethasone when relaxin was given concurrently or nearly so. Significant increases in pelvic area and cervical dilation were noted within 48 h after relaxin treatment. However, Caldwell et al. (1989) and several others (R. A. Bellows, personal communication) have been unable to confirm these results. At this time, the usefulness of relaxin for prevention of dystocia is questionable.

Detailed explanation of physiological mechanisms associated with parturition and departures from these by dystocial females are outside the scope of this review. It is sufficient to say that hormonal disorders are probably associated with and may cause some cases of assisted calving. Until further research is completed, our ability to prevent this type of dystocia is questionable.

Prediction of dystocia

Many traits have been identified that influence dystocia levels. All interact to a large extent, making simple conclusions about, and prediction of, assisted births difficult. Several studies since Bellows et al. (1971a; reviewed in the introduction) have dealt with the statistical modelling and prediction of dystocia, but generally with little success.

The model of precalving traits used by Laster (1974) for several beef breeds explained only 26% of the subsequent variation in dystocia. The addition of postcalving measures of calf birth weight, sex and shape increased this value to 39%. A similar comparison in Hereford and Angus 2-yr-olds yielded R^2 values of .05 and .25 for pre- and post-calving models, respectively.

Multiple regression analysis (Price and Wiltbank, 1978b) revealed that calf size (birth weight to body length ratio) and pelvic area of the dam at breeding were the two variables most highly related to dystocia score (R^2 = .37; pooled over dam breed). This value increased to only .42 with the addition of other measures on the cow and calf. When birth weight was forced into the regression equation, it alone accounted for 19% of the variation in dystocia. Inclusion of pelvic area increased this value to .38. When pelvic area alone was forced into the regression, it accounted for 5% of the variation in dystocia score. Hence, birth weight is the single most important factor in prediction, but pelvic size can be helpful if birth weight is known or can be accurately approximated. Births out of very small pelves, regardless of birth weight, or very large calves, regardless of dam pelvic area, will be more likely to experience dystocia.

Data from 592 first-calf 2-yr-old beef heifers were analyzed in a multiple regression least squares analysis by Short et al. (1979). Calving difficulty was the dependant variable and birth weight, pelvic area, cow weight, precalving cow condition score and calf sex were used as independent variables with linear and quadratic relationships examined. Additionally, a cubic term for birth weight and pelvic area was used. Linear relationships of (birth weight)$^{.33}$ and (pelvic are)$^{.5}$ with dystocia were also examined.

Some function of birth weight was always the most important variable in the model, followed by some function of pelvic area (Short et al., 1979). When actual calving difficulty score was the dependant variable, birth weight and pelvic area accounted for 36% of the variation. Quadratic components (3%) and cow weight, condition score and calf sex (3%) added an additional .06 to the R^2. Cubic effects did not increase R^2. The attempt to account for nonlinear relationships by using the cube root of birth weight and square root of pelvic area did not change the R^2 value. Coding dystocia score as a binomial variable (unassisted vs assisted or unassisted and little difficulty vs extreme difficulty) decreased R^2 values by 10 to 13%.

Rutter et al. (1983) ran stepwise regression and discriminate analyses on calving data from approximately 500 Charolais heifers bred to either Charolais or Brahman bulls for their first and second calvings (cows experiencing severe dystocia at the first calving tended to be culled prior to the second calving, however). The analysis of variance results indicated that birth weight, calf sex and yearling weight of the cow affected calving difficulty at the first parity, while birth weight and the birth weight x sex interaction affected calving score at the second parity. Coefficients of variation for the first and second parity models were low (R^2 = .24 and .10, respectively). The majority of the variance in dystocia was explained by birth weight for both calvings, as expected.

The predictability of the model used by Rutter et al. (1983) with only precalving elements was low (R^2 = .10 for first parity and .02 for second parity) as was the model with all pre- and postcalving measures included (R^2 = .26 and .06). Measures taken were: yearling weight, dystocia score of cow's dam, grade of cow, dystocia score at first parity (for second parity model only), age of cow at first conception, breed of sire of calf, pelvic height of cow, sex and birth weight. The discriminant analysis model was very similar to the regression such that the predictive values of either method was very low even if birth weight was known.

Morrison et al. (1985a) used data from 131 calvings from 2- to 5-yr-old Chianina crossbred cows bred to Chianina bulls. Twenty one variables were measured and input into a comparison of the predictive value of discriminant analysis and multiple regression for dystocia. Measurements were: cow weight and pelvic width and height at breeding and calving, cow age and breed, gestation length, sire of calf, calf birth weight, sex, shoulder and hip width, chest depth, body length, wither height, heart girth and rump circumference. When just precalving variables were used, cow age and precalving pelvic height were identified by discriminant analysis to be the two most important factors differing in cows that calved with or without assistance.

Stepwise multiple regression identified prebreeding pelvic width and precalving pelvic height as the two most important variables ($R^2 = .315$). When cow age and precalving pelvic height were forced into the regression analysis as the only two variables, $R^2 = .312$. When all eleven variables were used in the regression, $R^2 = .372$. Hence, the two methods were comparable in predictive ability and two measures was almost as good as all. The discriminant analysis correctly classified 82.4% of the calvings as assisted or unassisted. However, the same data was used to develop and test the model so that results are biased upwards.

When Morrison et al. (1985a) included both pre- and postcalving measures, discriminant analysis correctly classified 87.4% of the calvings using birth weight, calf chest depth and height, precalving pelvic area and weight and cow age. However, only 16 of 25 cows that experienced dystocia were correctly predicted (64%). Regression analysis used prebreeding pelvic width, birth weight and calf shoulder width to predict dystocia ($R^2 = .399$). The regression model with all variables included explained 51.4% of the variation in dystocia.

Morrison et al. (1985b) reran the discriminant analysis as more data became available, this time withholding a portion of the data to validate their model. The analysis used only pelvic area and cow age and correctly classified 84.4% of all calvings as assisted or not. Only 57.1% of the assisted births were correctly classified (overall frequency of dystocia was 18.2% in the data used for verification). All misclassified cows in this study were at least 3 yr of age. Thus calf body measures may help to predict dystocia, but the accuracy, even with statistical procedures that may be more adequate for non-normal traits such as dystocia, is still too low to be of practical importance.

In 186 Hereford heifers, Johnson et al. (1988) found that calf birth weight and pelvic area accounted for most of the variation in calving score while external body measures (on the heifer) and pelvic angles did not explain any additional variation. Discriminant analysis correctly predicted 66.7% of the assisted and unassisted births using only prebreeding variables. Prediction (regression) equations explained 63 and 25% of the variation in calving score using all variables or pre-breeding variables, respectively.

In general, it appears that calf birth weight and dam pelvic area account for most of the explainable variation in dystocia and other measures add little additional predictive information.

Differences among evaluators of dystocia scores are a great source of variation which cannot be accounted for from study to study (Sieber et al., 1989), especially in field data where the manager may be familiar with the idea that obstetrical assistance, if used correctly, can improve subsequent reproductive potential as compared to allowing a cow experience extended labor (Bellows et al., 1988). If managers are aware of such information or unaware of when a cow needs to be aided, premature intervention can indeed be a problem (Hartigan, 1979). In fact, when Meijering and Postma (1984) measured the force required to extract a calf in addition to assignment of calving scores, their results indicated that scores representing no assistance and hand pulls with and without obstetrical chains were assigned more by subjectivity or chance than due to consistently greater extraction force associated with the latter. Thompson and Rege (1984) reported similar conclusions.

Short et al. (1979) concluded that an inability to accurately measure pelvic area or other body measures may also contribute to the low R^2 values for dystocia models. With small numbers of cattle (n=10), pelvic area measurement repeatability within technician was .87 to .92 and between technician was .73 to .86. With larger numbers of cattle (n=45), between technician values dropped to .61 to .87.

Conclusion

The major factor contributing to dystocia is disproportionate size of calf to size of dam. All other factors identified tend to have an effect upon dystocia levels through either dam (pelvic) size or calf size. Accuracy of prediction of dystocia from a single mating is poor. This accuracy would increase if we could better predict calf birth size prior to parturition. Selection against birth weight could decrease dystocia, but losses in weaning and yearling weights may counterbalance potential advantages.

The use of bulls who sire calves with moderate birth weights and high postnatal growth potential on heifers especially, appears to be the most practical method of controlling dystocia levels at this time. If high accuracy calving ease and growth trait breeding values are available on individual bulls, they should be useful. However, the efficacy of cattle breed association EPD for direct and maternal calving ease in a crossbreeding scheme has not been experimentally demonstrated.

PELVIC SIZE

Calf birth weight and cow pelvic area are the two measures that have the largest influence on dystocia levels. Due to genetic correlations with growth traits, long term selection against birth weight is not extremely practical for a beef producer. Recently, selection for increased pelvic size has been evaluated as a potential cure for dystocia problems. In order to evaluate the usefulness of selection for increased pelvic size, we must first investigate factors affecting pelvic size in cattle, the heritability of the trait, its correlations with other economically-important traits and then, finally, its overall potential for widespread measurement and use.

Factors affecting pelvic size

Many factors interact with and affect pelvic size of cattle, as is the case with dystocia. However, with calving difficulty, a clear cause and effect relationship with dystocia and the trait in question was usually apparent. This pattern is not so obvious with pelvic size, and rather than studying these traits as influential on pelvic area, they should rather be thought of as related to or interactive with pelvic area. Several researchers have investigated and reported on such measures in cattle.

Breed and body weight. Clearly, breed and body weight have a relationship with pelvic size. Because breed and body weight are somewhat confounded, many times these effects are not separated in the literature. Generally, within breed, bigger cattle (as measured by body weight) have larger pelvic areas. Across breeds, bigger cattle also tend to have bigger pelvic areas; however, at constant body size the bigger breeds have somewhat smaller pelvic areas.

In yearling heifers of 14 breed groups from phase I of the germ plasm evaluation program at Clay Center (Laster, 1974), pelvic area was influenced by breed of sire and breed of dam of the measured individual. These two factors accounted for only 18% of the variation in pelvic area. When pelvic area was adjusted for body weight, age, condition score and weight gain during the study, the breed of dam effect lost significance. Body weight was the largest source of variation in pelvic area both within and across breeds. Similar results were seen with 2-yr-old cows of the same breeding. A significant breed of dam x breed of sire heterotic effect on pelvic size was also observed. In straightbred Hereford and Angus 2-yr-olds, Angus cows had 21 cm^2 larger pelves than Herefords. Similar size differences were observed among Charolais x Angus and Charolais x Hereford crossbreds.

Neville et al. (1978a) studied pelvic measures in Angus, Polled Hereford, Simmental and Santa Gertrudis females at two locations (Tifton and Reidsville). Among animals at Tifton, pelvic width and area measures were greater for Polled Hereford than Angus. Simmental females had bigger pelves than both Polled Hereford and Angus females. At Reidsville, Polled Hereford pelves were again larger than those of Angus, and those of Santa Gertrudis were larger than both Angus and Polled Hereford. Differences between Angus and Polled Hereford in pelvic area at different locations were apparent. Clearly, taller breeds of cattle (Simmental, Santa Gertrudis) had smaller pelvic areas for a given hip height. Singleton and Nelson (1971), Singleton et al. (1973) and Green et al. (1988) also report among-breed variation in pelvic measures.

Since the effect of pelvic area on dystocia depends upon calf size, breed effects on calf birth weight relative to dam pelvic area may be more important than breed effects on pelvic size alone (Deutscher and Zerfoss, 1983). Morrison et al. (1989) bred Brahman, Chianina, Maine Anjou and Simmental bulls to either Angus or Hereford cows to produce F_1 females. These females were then bred to Red Poll bulls as yearlings and 2-yr-olds and to Charolais and Gelbvieh bulls as 2-, 3- and 4-yr-olds. Sire breed of cow had an effect on prebreeding pelvic area and on the ratio of calf birth weight to pelvic area. Prebreeding pelvic area was smaller for Simmental- than for Maine Anjou-sired cows.

No differences in daughter pelvic areas were found among the other three sire breeds.

Brahman-sired cows had smaller calf birth weight to pelvic area ratios than the other breeds studied. Chianina-sired cows had the largest birth weight to pelvic area ratio of all the cow types, yet no differences in dystocia levels between the Chianina-, Simmental- or Maine Anjou-sired cows was detected. Several unexplainable interactions were reported by Morrison et al. (1989), reflecting the complexity of these measures and breed effect on them. Cows from Angus dams and Chianina and Simmental sires had larger pelvic areas than those from Hereford dams; the reverse occurred for Brahman and Maine Anjou crosses. For cow weight/pelvic area ratio, cows from Maine Anjou and Simmental sires and Hereford dams were largest, whereas the reverse was true for Brahman and Chianina cow sire breeds.

Price and Wiltbank (1978b) reported that heavier heifers tended to have larger pelvic openings among females of three breed types. Pelvic area and heifer body weight in this study was greater for Charolais than Angus or crossbred heifers. Pooled over breed, pelvic area increased .38 cm/kg body weight.

Breed effects on pelvic shape. In addition to breed effects on pelvic size, pelvic shape differences in female cattle have been related to breed. According to Philipsson (1976d) differences between Swedish dairy heifers in pelvic area were more often due to differences in pelvic width than height. Generally, pelvic height is 33% greater than width (Taylor et al., 1975).

Fitzhugh et al. (1972) measured pelvic area in Angus, Brahman, Charolais, Hereford and Santa Gertrudis breeds and crosses. Horizontal and vertical pelvic measures were positively correlated except in Brahman crosses. A ratio of horizontal to vertical pelvic size was used as a measure of pelvic conformation. This value was lowest for Brahman-based breed types and was highest for Hereford and Charolais.

Significant pelvic shape differences were also detected among cow breed groups by Morrison et al. (1989). Brahman-sired cows had larger pelvic height and smaller pelvic width measures, indicative of more vertically oval shaped pelves than three other cow breed types. Additionally, Chianina cows had a higher mean value for height to width ratio than did Maine Anjou and Simmental-sired cows.

Breed differences in pelvic shape were also noted by Green et al. (1988b). Brangus pelves were larger in height relative to width than other breeds, while those of Simmental were more square. Neville et al. (1978b) reported that Simmental females tended to have more squarely shaped pelves as compared to Angus and Polled Hereford females.

Hence, pelvic shape differences do occur among breeds. Bellows et al. (1971b) found a phenotypic correlation of .32 between pelvic width and height in Hereford heifers. This low value is indicative of variation in pelvic shape within breeds. The usefulness of changing pelvic shape will be discussed below (see "Pelvic size as a selection criterion").

The results of studies on pelvic shape are probably influenced by the interaction of age and rate of pelvic growth. Taylor et al. (1975) stated that pelvic width and height grow at about the same rate relative to body weight. However, Nelsen et al. (1986; yearling Hereford bulls) and Green et al. (1988b; 1- to 15-yr-old females of several breeds) indicated that pelvic width matures more slowly than height. Increases in pelvic size of females are due to both growth and calving (Fitzhugh et al., 1972; Taylor et al., 1975; Brown et al., 1982). Neville et al. (1978a) noted that pelvic growth patterns vary with breed and management.

Relation of pelvic size to external body measures. Several researchers have attempted to relate external skeletal measures to pelvic area. Results indicate that pelvic area is indeed correlated to some external body measures, however, pelvic area must be measured directly and cannot be estimated accurately from external dimensions.

Philipsson (1976d) found a phenotypic correlation of .3 between pelvic height and general size in dairy heifers. Body size was based on external body measures (chest girth, wither height, hip height, hip width, thurl width, pin bone width, hip to thurl vertical and horizontal distance, hip to pin bone vertical and horizontal distance and sacrum to thurl vertical distance). Thomson and Wiltbank (1983) reported that the heart girth of Holstein heifers was moderately correlated to pelvic area (.45) and width (.54) but not as strongly with pelvic height (.28).

Bellows et al. (1971b), using 3-yr-old primiparous Hereford heifers, reported that phenotypic correlations among pelvic measures, body weight, hip width and rump length were all positive and highly significant (range .30 to .82). Thirty-six percent of the variability in pelvic area was accounted for by body weight, hip width and rump length. Similar correlations were published by Krahmer and Jahn (1971) and Ward (1973).

According to Neville et al. (1978b), the relationship between pelvic size and hip height depended upon breed. Pelvic width at constant hip height was similar for Hereford and Angus and smaller for Simmental and Santa Gertrudis. Santa Gertrudis had smaller pelvic width at a given hip height than Simmental females (these were young heifers measured from 9 to 40 mo of age). For pelvic height given hip height, again the British breeds were larger than the other two breeds. Pelvic area increased even after growth in hip height appeared to plateau at Tifton. Hence, growth patterns appeared to be different for pelvic area depending upon breed and management regime. Relative growth between height at hips and pelvic size was also affected by these factors.

Hormonal effects. Hormonal effects on pelvic area, especially at or just prior to onset of parturition, may certainly be tied to many of the factors affecting dystocia and pelvic area discussed in this review. However, there is little information available on this aspect of calving difficulty.

Henson et al. (1989) used 26 British crossbred multiparous cows bred to Red Poll bulls to study estrone concentrations in prepartum multiparous cows. Peripheral estrone concentrations were greater from -50 d until calving for cows bearing male fetuses. No differences were detected postpartum. Prepartum pelvic area was not influenced by fetal sex. However, postpartum pelvic area was greater for cows that gave birth to bull calves. There was no effect of sex on calf birth weight; all cows calved unassisted. Significant correlations between estrone levels and pelvic area from -50 d to 7 d postpartum were detected (r = .26). Calf birth weight was correlated with maternal estrone concentration from -10 d until parturition. The total percentage increase in estrone concentration measured from -50 d to calving was correlated (r = .75) with percentage pelvic area change. Larger placentas associated with larger calves may have accounted for differences in maternal serum estrogens. Estrogens are tied to relaxin release, which allows for greater pelvic expansion.

Musah et al. (1986) found an increase in the rate of pelvic expansion (width and height) in heifers given relaxin on d 278 of gestation. Rate of expansion was greater for a small-framed breed type, as was the increase in the rate of expansion after relaxin treatment. Rice and Wiltbank (1972) noted that the rate of pelvic expansion greatly increased during the 4 d prior to parturition and thus variability in rates of expansion could render pre-calving pelvic measures less useful in the prediction of assisted births. Thomson and Wiltbank (1983) estimated that pelvic area increased at a rate of .312 cm^2 per d of gestation (.01 cm/d for vertical and .008 cm/d for horizontal). However, according to Deutscher and Zerfoss (1983), precalving pelvic area had a phenotypic correlation of .79 with pelvic area measured at 18 mo of age. Hence, pelvic measures taken in the fall may be indicators of calving pelvic size.

Exogenous sources of hormones given early in life can also alter pelvic development. Twenty mg estradiol and 200 mg progesterone implants were put in 52±11 d old Hereford x Angus heifers to measure the effect upon body weight and pelvic area up until weaning (Lesmeister et al., 1972). Body weight gains in the next 124 d were greater for the implanted heifers. Pelvic area (adjusted and unadjusted for body weight) was larger in treated females. The difference in pelvic size between treatment groups tended to decrease with time, however.

Pelvic size as a selection criterion

Several attempts have been made to better quantify pelvic area, which is commonly assumed to be the area of a rectangle with dimensions pelvic width x pelvic height. Though the actual shape of the pelvic inlet is certainly not rectangular, the pelvic height x width expression is as heritable and explains at least as much variation in dystocia as other representations of this trait. Hence, other methods offer no advantage (and some may in fact be disadvantageous; Price and Wiltbank, 1978a) over the conventional method of calculation.

Rice and Wiltbank (1972) reported that the horizontal x vertical product was as good as expressing the pelvic area as an ellipse (diagonal measure/2 x horizontal measure/2 x π) in predicting dystocia, even though the latter provides a better approximation of the shape of the pelvis. Morrison et al. (1986) reported similar results. Other variations of describing pelvic size were attempted by Schlote (1984; {2x[height+width]}, pelvic circumference) and Price and Wiltbank (1978a; π[height + width]/4).

Several researchers have estimated heritabilities for pelvic measures of cattle (usually females) to determine whether the trait will respond to selection. Morrison et al. (1986) used data collected on 703 cows sired by Angus and Hereford bulls (1 to 14 yr of age) to obtain heritability estimates (pooled across cow age groups) for pelvic height, width, rectangular area, elliptical area and the ratio of height to width of .59±.15, .82±.16, .68±.15, .66±.15 and .70±.16, respectively.

Benyshek and Little (1982) studied three herds of Simmentals in Georgia, Virginia and Oregon. Their estimates of heritability were .53±.14 for pelvic area, .43±.13 for pelvic height and .58±.14 for pelvic width. Holzer and Schlote (1984) estimated heritabilities to be .29, .42, .36 and .36 for pelvic height, width, area and circumference (2x[height+width]) in 1,440 heifer daughters of 51 German Simmental bulls.

Neville et al. (1978b) estimated heritabilities for pelvic width, height and area in young females of three breeds. Estimates (pooled over breed) for two locations were .18±.34 and .22±.19, .10±.30 and .38±.18 and .04±.22

and .24±.12, respectively for pelvic width, height and area. The cattle at the first location were under more intensive selection for reproductive performance, which could have resulted in the lower heritability estimates.

Green et al. (1988b) reported estimates of heritability for pelvic measures that were quite high, even after adjustment for body weight or hip height (range .71 to .99; pooled over all ages). Estimates of heritability for width were high, but lower than those for height, opposite to what was seen by Benyshek and Little (1982), Holzer and Schlote (1984) and Morrison et al. (1986).

Nelsen et al. (1986) measured pelvic width and height on 427 Hereford bulls at 403 and 490 d of age. Paternal half-sib estimates of heritability at the two ages were .47 and .23 for pelvic height and .58 and .50 for pelvic width. Other estimates of heritability for pelvic measures in bulls of other breeds are not available from the literature.

The estimates of heritability for pelvic measures are generally moderate in size and indicate that the pelvis should respond to selection for changes in size. Genetic correlation estimates between pelvic height and width are generally also moderate in size (≈.4 to .45; Morrison et al., 1986; Nelsen et al., 1986; Green et al., 1988b), indicating that selection for changes in pelvic shape should be possible. However, correlations of pelvic measures with economically important traits such as weaning and yearling weights, birth weight and scrotal circumference need to be examined in order to further evaluate pelvic area as a selection criterion.

Several estimates of correlations between pelvic size and body weight are available. Benyshek and Little (1982) estimated the genetic correlation between pelvic area and weaning (.30±.22) and yearling(.65±.17) weights. These values indicated that direct selection for pelvic area would increase post- and pre-weaning growth. Phenotypic correlations between pelvic measures and growth generally were lower. Low (<.45) environmental correlations indicated that environmental effects on pelvic area and growth were not similar. A possible reason for low environmental and phenotypic correlations is that growth measured by weight includes fat, protein and bone deposition, whereas pelvic area is influenced mostly by bone. The genetic correlations reported by Morrison et al. (1986) between pelvic height, width and area and cow weight were moderate (.38 to .47) but had large standard errors (.50 to .64).

In Hereford bulls measured at 403 d of age, genetic correlations (Nelsen et al., 1986) between yearling weight and pelvic width and area were .48±.31 (paternal half-sibs) and .43±.16 (sire-son regression) and .46±.20 and .24±.19, respectively. The corresponding genetic correlations for pelvic height and yearling weight were .36±.25 and -.52±.67. At 490 d of age, correlations with yearling weight were -.13±.36 and -.25±.37 for height, .30±.23 and .67±.23 for width and .20±.29 and .50±.38 for area for each of the two methods, respectively. Phenotypic correlations were generally lower. As expected, positive correlations between pelvic size and body size exist. The correlations are generally moderate in size, although those reported by Nelsen et al. (1986) for pelvic height are rather odd and the reason for the negative sign is unknown. Generally these values indicate that selection for increased pelvic size would result in a correlated increase in body size.

Estimates for correlations between pelvic measures and birth weight have been inconsistent. The genetic correlation between pelvic area and birth weight reported by Benyshek and Little (1982; .73±.25) was larger than that reported by Deutscher and Johnson (1986; .072). Genetic correlations estimated from the Hereford bull data by Nelsen et al. (1986) tended to be low and negative (range -.13 to -.32), although the sire-son regression estimate was .48. Conclusions are hard to draw from these studies. The correlation between pelvic size and mature body weight indicate that a positive correlation between pelvic area and birth weight should exist.

Selection for bull pelvic area and its effect on fertility as measured through scrotal circumference has been addressed in two papers. Deutscher and Johnson (1986) reported that pelvic area was positively correlated with scrotal circumference (.26). However, genetic correlations between scrotal circumference (Nelsen et al., 1986) and pelvic height were -.37 and -.79 at 403 d but were -.10 and .35 at 490 d. Genetic correlations for scrotal circumference and width were 0 and -.01 at 403 d but -.24 and .18 at 490 d. Again, the estimates from the Hereford bulls were highly variable and inconsistent with other estimates.

Overall, available correlation estimates indicate that body size is probably positively related with pelvic area. The relationships among pelvic size and birth weight and fertility are not clear. The relative size between pelvic height and width (i.e., shape) could theoretically be altered. However, the effects of altering pelvic shape are not known. As with many other factors associated with dystocia, pelvic shape explains such a small amount of the variation in calving difficulty that selection to improve this trait is not economically feasible.

The significant genetic (additive) variation in pelvic measures and careful choice of correlations in the literature has led some to recommend selection for increased pelvic area as an answer to dystocia. The potential for some improvement exists, but selection must be approached correctly. Overemphasis of the trait or simple selection for cattle with large pelves is not the answer.

Selection for pelvic area, because of its moderate heritability, would result in positive genetic change; however, some of the potential benefit from larger pelvic areas may be negated by correlated increases in birth weight. According to Laster (1974), the regression of pelvic area on cow weight indicates that larger cows have larger pelvic openings and that this trend is quite similar regardless of breed. The regression of calf birth weight on cow weight was larger than the regression of pelvic area on cow weight such that heavier 2-yr-old cows had larger pelves but had proportionately even larger calves (b = .099% for pelvic area vs b = .292% for birth weight per 1% increase in cow weight).

Similarly, Price and Wiltbank (1978b) concluded that as heifer weight and pelvic area increased, so did the mean birth weight of their calves. There was an average increase of .06 kg in birth weight for each kg increase in heifer body weight. There was also a .08 kg increase in birth weight associated with every cm^2 increase in pelvic area. Thus selection for increased pelvic area would increase cow size, calf birth weights and probably dystocia. Correct selection for increased pelvic area necessitates a control of birth weight and cow size.

According to Taylor et al. (1975), the ratio of pelvic width or height to (body weight)$^{.4}$ may be an appropriate selection index against calving difficulty for any breed and degree of maturity since (dam weight)$^{.4}$ estimates pelvic size (Monteiro, 1969). Thus the ratio of calf weight to pelvic height or width (or their geometric mean but not their product) should also serve as an index of calving difficulty. Dystocia would then depend upon the ratio of calf birth weight to a linear dimension which of necessity increases very much more slowly than body weight, so that calving difficulties must be expected to be greater for larger breeds (in agreement with Laster, [1974] and Price and Wiltbank [1978b]).

Selection to decrease dystocia might therefore aim to increase the ratio of pelvic size to calf birth weight. An alternative would be to use pelvic size relative to body weight in the form (pelvic size)/(body weight)$^{.4}$ or with separate exponents (from Taylor et al., 1975) for height and width. This index should be useful regardless of age or breed with a 10% correction for the effect of a previous parturition. This method could lead to a decrease in cow body size such that a restricted selection index may be needed to prevent decreases in body weight. A study testing

Taylor et al.'s method and other strategies for pelvic area selection and its total economic impact would be extremely useful.

The fairly low phenotypic correlations among pelvic measures and cow weight reported by Morrison et al. (1986; range from .26 to .40) indicated that selection for females with large pelvic area does not necessarily involve selection for those with potential for large mature weight. Expected response to direct selection for increased pelvic area was calculated by these authors and an increase of 12.2 cm^2 per generation was estimated. A correlated response of 12.5 kg in cow weight would also be expected, however. A restricted selection index holding cow weight constant yielded an increase of 11 cm^2, which was still 90% as effective at increasing pelvic size.

The low phenotypic correlations between pelvic measures and growth published by Benyshek and Little (1982) suggest that retention of the faster growing, heavier animals as replacements would not necessarily involve the selection of those animals with large pelvic areas. However, the moderate to high genetic correlations suggest that the faster growing individuals would indeed possess genes for larger pelvic areas even though the phenotype for larger pelves may not be exhibited.

If selection based on pelvic area in females did appear useful, the next step would be to investigate the selection of bulls for maternal calving ease based (at least partly) upon their pelvic size. Green et al. (1988a) estimated genetic correlations among pelvic measures to be moderate to high (range .24 to .83) among half-sib groups of heifers and bulls. This indicates that male pelvic height is a good indicator of pelvic width, height and area of his half sisters (r_g range .63 to .83). Phenotypically, bull pelvic areas are generally much smaller than heifer pelvic areas (Deutscher and Johnson, 1986).

If done correctly, selection for pelvic area may be useful. However, caution must be used when bulls from a herd under selection for pelvic area are sold to herds in which animals are not selected in the same way. The relationship between sire and daughter pelvic area also still warrants research. A better definition of shape effects, threshold nature of pelvic area on dystocia and more consistent estimates of genetic correlations with economically important traits are needed. Since pelvic area interacts so closely with calf birth weight, a meaningful threshold value may not be attainable. Large non-genetic variation in dystocia levels and our inability to predict calf birth weight certainly make the definition of minimum acceptable pelvic areas extremely difficult.

ANALYSIS OF BODY MEASUREMENTS IN NEWBORN ANGUS- AND POLLED HEREFORD-SIRED CALVES AND RELATIONSHIP OF CALF SHAPE TO POLLED HEREFORD SIRE BREEDING VALUES FOR BIRTH WEIGHT AND CALVING EASE

INTRODUCTION

Maximizing the total production of a beef cow requires that she first calve at 2 yr of age. However, at this age she has not yet reached mature size and, consequently, calving difficulties are increased. Difficult births can lead to increased perinatal calf death, with correspondingly reduced net calf crop (Wiltbank et al., 1961; Bellows et al., 1987). Subsequent reproductive performance is also affected in females experiencing dystocia (Brinks et al., 1973; Meacham and Notter, 1987).

Several factors associated with calving difficulty have been studied. Calf birth weight and dam pelvic size are the two most important factors identified to date (Price and Wiltbank, 1978a; Meijering, 1984). Predictability of calving performance for a single mating is still quite low, however (Price and Wiltbank, 1978b; Short et al., 1979; Morrison et al., 1985a). Several researchers have suggested that calf shape should influence dystocia, but consistent, repeatable calf body measures that are associated with dystocia have not been reported. Newborn calf body measurements have been related to calf birth weight (Laster, 1974), but relationships between body measures and dystocia, independent of birth weight, have rarely been reported (Meijering, 1984; Morrison 1985a).

Several authors (Tanner and Burt, 1954; Carpenter et al., 1971, 1978; Brown et al., 1973, 1974; Hammack et al., 1986) have quantified shape in cattle using multivariate statistical methods, but rarely has this been done with calves. Further, multidimensional descriptions of shape in the calf have not been related to observed dystocia levels or sire breeding values for calving ease. The objectives of this study were to quantify newborn calf shape in Polled Hereford- and Angus-sired calves and further, to relate aspects of Polled Hereford-sired calf shape to sire expected progeny differences (EPD) for first-calf calving ease and birth weight. Calf body measures that have a significant relationship to sire calving ease EPD and are independent of birth weight may be useful in prediction of dystocia.

MATERIALS AND METHODS

Animals.

Data were collected on calves born at the Virginia Polytechnic Institute and State University (VPI) Catawba Research Station and at the Shenandoah Valley Agricultural

Experiment Station, Steeles Tavern, Virginia. At both locations, cows were maintained on predominantly fescue pastures throughout the year. Supplemental fescue hay, corn silage and(or) whole shelled corn was given in winter; water was provided ad libitum.

At Catawba, calves were produced from artificial and natural matings of Angus bulls to either grade Angus; 7/8-Angus, 1/8-Holstein; 3/4-Angus, 1/4-Holstein; or 1/2-Angus 1/2-Holstein cows (n = 183). Cow age ranged from 2 to 12 yr. Calvings occurred in spring of 1982 through 1985 (n = 194) and in fall of 1986 through 1988 (n = 180). Hence, year and season effects were completely confounded. Seventeen Angus sires generally selected to be above average for growth and daughter maternal performance were used. Semen for artificial breeding was obtained from AI studs, while bulls used for natural service were obtained from the VPI purebred Angus herd.

At Steeles Tavern, calves resulted from artificial breeding of 49 Polled Hereford bulls to 157 grade Angus cows of two age groups: one hundred four grade Angus cows born in 1976 had been obtained as weanling heifers from 6 Virginia locations; the other 53 grade Angus cows were purchased as weanling heifers from a single source in fall, 1982. Calvings (n = 438) occurred in spring from 1983 through 1988. Polled Hereford bulls from the American

Polled Hereford Association Sire Summary (APHA, 1982-1986) were selected divergently in a 2 x 2 factorial design for high or low yearling weight EPD and high or low maternal weaning weight EPD. A more complete description of these bulls and of the matings has been given by Mahrt et al. (1990).

At approximately 24 h postpartum, calf sex, birth weight and the following linear measurements on the calf were recorded to the nearest .5 cm: head circumference (measured around parietal bone and mandible just anterior to orbits), shoulder width (distance between the left and right lateral tuberosity of humerus), heart girth (just posterior to foreleg), hip width (distance between the left and right trochanter major), cannon bone circumference (narrowest point of metacarpus), cannon bone length (distance between metacarpal tuberosity and condyles) and body length (distance along vertebral column from scapula to tuber ischii). Calves were suspended vertically from the hind legs for all measures (except heart girth) to minimize variation in measures among calves due to different body positions and to approximate the posture of a calf passing through the birth canal. All measures except hip and shoulder width were taken with a flexible tape. Width measures were taken with wooden calipers specifically designed for that purpose. Measures were taken by a different technician at each location such that differences due to location and(or) breed were confounded with technician. This design was not optimal, but was unavoidable due to the distance (160 km) between farms.

Statistical analysis.

Data were initially analyzed using the general linear models procedure of SAS (1985). Independent variables in all models included effects of year, calf sex, cow age group (representing dams born in the same year-season) and all two-way interactions. The percentage of Holstein breeding in the dams bred at Catawba affected ($P < .05$) birth weight, head circumference, hip width, body length and heart girth, and was included as an independant categorical variable in all models involving Angus-sired calves.

Dependent variables included birth weight, head circumference, shoulder width, heart girth, hip width, cannon bone circumference and length, and body length; the latter seven measures will be collectively referred to as calf shape measures. Birth weight also was used as a covariate in several models as was gestation length for Polled Hereford-sired calves. Sire effects were tested for both groups of calves, but sire EPD for birth weight and(or) first-calf calving ease (APHA, 1989) were added to the analysis (as covariables) only for Polled Hereford-sired calves. Relationships among calf body measures and EPD were also investigated by multiple regression of sire EPD on fixed-effect, birth weight (FE-BW) adjusted residuals of the seven calf-shape measures of the Polled Hereford-sired calves. Due to the use of mature females, the incidence of dystocia was low (4.6% assisted births). For this reason, and because of the small calf numbers per sire, observed calving performance (assisted or unassisted) for each calf was not considered in the analysis.

Fixed effects (FE) residuals of the seven shape measures after adjustment for birth weight using intrasire regression coefficients were subsequently analyzed via factor analysis with orthogonal rotation of resulting factors (SAS, 1985). Similar to principal components analysis, factor analysis defines underlying relationships among correlated variables in terms of a smaller number of sequentially extracted, independent empirical factors. Unlike principal components, however, factor analysis determines relationships among variables using a reduced correlation matrix, the diagonal elements being the squared multiple correlation of each measure with the other variables (Hair et al., 1987). Each factor was a unitless, weighted linear combination of the original shape variables and was used to calculate a factor score for each calf. Factor scores (representing independent aspects of shape for each calf) were then analyzed to determine differences in calf shape among half-sib groups and the relationship between body shape and sire EPD. Measures were adjusted for differences in birth weight prior to factor analysis to assess the potential usefulness of calf shape as a selection criterion for reducing dystocia in addition to (independent of) birth weight. Testing for differences between residual (co)variance matrices of shape measures for the two groups of calves was conducted using a generalization of the Bartlett test for homogeneity of variances (Morrison, 1976).

Repeatability of cow effects on calf shape was estimated for each measure. Mixed-model least squares procedures were used to estimate error (σ^2_e) and dam (σ^2_d) variance components (Harvey, 1982). Sire effect was simultaneously fitted for Polled Hereford-sired calves, but due to insufficient cross-classification, sire could not be fitted for Angus-sired calves. Repeatability was calculated as: $\sigma^2_d/(\sigma^2_d + \sigma^2_e)$. The expectation for σ^2_d under an additive genetic model (in the absence of epistasis) was $1/4\sigma^2_A + \sigma^2_{AM} + \sigma^2_{EM} + \sigma_{AAM}$ where σ^2_A, σ^2_{AM} and σ^2_{EM} were variance due to direct and maternal genetic effects and permanent maternal environmental effects, respectively and σ_{AAM} was direct and maternal covariance (Dickerson, 1969). Thus, repeatability in the present study was not an estimate of the upper limit of heritability. Standard errors for repeatability estimates were calculated according to Swiger et al. (1964).

RESULTS

Angus-sired calves.

Overall means and FE residual standard deviations for calf measures are presented in Table 1. Sire differences ($P < .05$) were present for all body measures except hip and shoulder width, cannon bone length and heart girth. Residual correlations among shape measures ranged from .08 to .79 (Table 2), and regression coefficients of the seven body measures on birth weight ranged from .09±.01 to .74±.04 cm/kg ($P < .01$; Table 3). After adjustment for birth weight, only cannon bone circumference still differed ($P < .05$) among paternal half-sib groups. Correlations among FE-BW residual calf measures ranged from -.06 to .63 (Table 2).

The first three factors in the initial factor pattern accounted for 60.3, 34.2 and 5.4%, respectively, of the variance in the original shape variables that was explained by the factor pattern. Thus only these three factors were retained for subsequent orthogonal rotation (Hair et al., 1987). Rotated factors for the seven body measures are presented in Table 4. The factor loadings (i.e., within factor coefficients for each residual shape measure) represent the correlation between the original variables and the factors.

The first factor (factor 1) contained high loadings for both hip and shoulder width residuals. The underlying dimension of shape represented by factor 1 appeared to be skeletal or structural width. The second factor loaded highly for head and cannon bone circumferences and heart girth. A smaller negative loading for cannon bone length also existed. Scores calculated for factor 2 tended to differentiate between structurally thicker and to a small extent, shorter calves and more narrow and somewhat longer calves. The third factor loaded highest for body length and, to a lesser extent, head circumference. This factor may have differentiated between long and short bodied calves, however, loadings were small and interpretation was not straightforward. Final communality estimates for shape variables are listed in table 5. These values indicated the proportion of variance in each shape measure that was accounted for by the three factors together.

Subsequent analysis of factor scores revealed differences among sires in calf thickness (factor score 2; $P < .01$) and length (factor score 3; $P < .05$). Hence, linear combinations of body measurements adjusted for birth weight and representing two independent aspects of newborn Angus calf body shape differed among paternal half-sib groups.

Calf birth year and sex and dam birth year and breed group effects were removed prior to estimation of σ^2_e and σ^2_d. Repeatability estimates were .19±.07 for birth weight and .16±.07 for cannon length, .21±.07 for heart girth, -.02±.07 for head circumference, -.02±.07 for hip width, .02±.07 for shoulder width, .03±.07 for body length and -.01±.07 for cannon circumference. After further adjustment of measures for birth weight, repeatabilities were nonsignificant for all measures.

Polled Hereford-sired calves.

Overall means and FE-residual standard deviations for body measures of Polled Hereford-sired calves are presented in Table 1. Sire effects were significant ($P < .05$) for all seven shape measures and for birth weight. Regression of FE-residual shape measures on birth weight yielded significant ($P < .01$) coefficients ranging from .08±.01 to .75±.04 cm/kg (Table 3). When residuals were also adjusted for birth weight, only hip width, body length, cannon bone circumference and heart girth differed ($P < .05$) among paternal half-sib groups. Half-sib groups still differed for hip width and cannon circumference (both $P < .05$) and body length and heart girth (both $P \leq .07$) after gestation length was added as a covariate. Fixed-effect residual correlations ranged from .21 to .61; after adjustment for birth weight, correlations among the residuals ranged from -.07 to .40 (Table 6).

The relationships of birth weight EPD and first-calf calving ease EPD to calf measures were investigated by regressing FE shape residuals on calf sire EPD. Birth weight EPD was positively associated ($P <.05$) with all shape measures, and the regression of calf birth weight on sire birth weight EPD was 1.1±.2 kg/kg. After adjustment of shape measures for phenotypic differences in birth weight, a positive relationship of birth weight EPD with head ($P <.05$; $b = .18 \pm .08$ cm/kg) and cannon bone ($P <.01$; $b = .19 \pm .03$ cm/kg) circumference remained; inclusion of gestation length as a covariate did not alter the relationship between birth weight EPD and head and cannon circumference.

Calving ease EPD was negatively related ($P <.05$) with birth weight and all FE residual shape measures except shoulder width ($P = .12$). Adjustment for birth weight removed the relationship between calving eased EPD and all shape measures except cannon bone circumference ($P < .01$). The correlation between the FE-BW residual for cannon bone circumference and calving ease EPD was -.16. When birth weight EPD was inserted into the model as a covariate along with phenotypic birth weight, the relationship between cannon bone circumference and calving ease EPD was non-significant ($P = .16$).

The partial regression coefficient for the FE-BW residual for cannon bone circumference with birth weight EPD as the dependent variable was significant (b = .4±.1 kg/cm; P < .01). Regression coefficients for the other measures were not significant (P > .17). The FE-residual coefficient of determination was .09. The same analysis with calving ease EPD as the dependent variable revealed a .5±.2% decrease in calving ease EPD/cm cannon bone circumference (P < .01). Regression coefficients for the other measures were not significant (P > .30). Residual R^2 for this model was .04.

Three factors accounted for all of the variance in the FE-BW-adjusted shape measures that was accounted for by the factor pattern. The rotated factor pattern is presented in table 7. The final communality estimates are presented in table 5. The first factor contained high loadings for hip and shoulder width residuals. Much of the variation in factor 1 scores could again be accounted for by differences in skeletal width.

The second factor loaded highly for cannon bone length and circumference, body length and to a lesser extent, head circumference. This factor appeared to discriminate between large and small framed calves (at the same birth weight). The third factor loaded highly for heart girth and head circumference and appeared to discriminate between thicker, larger and thinner, smaller calves.

Analysis of factor scores revealed sire differences for factor 2 ($P < .01$) and, perhaps, also factors 1 and 3 (both $P = .07$). Significant ($P < .01$) correlations with birth weight EPD (.21) and calving ease EPD (-.13) existed for factor 2 only. The correlation between factor 2 and calving ease EPD became nonsignificant after birth weight EPD was included in the model as a covariate.

The Chi-square test for homogeneity of residual (co)variance matrices of calf measures indicated that relationships among measures differed between the two breeds of calves ($P < .01$). The differences could have been due to variation between breed, location (including technician) or some other source.

Repeatability was calculated after removal of cow age group, year, calf sex and calf sire effects. Estimates were .22±.06 for birth weight, .33±.06 for hip width, .22±.06 for shoulder width, .27±.06 for body length, .27±.06 for cannon length, .16±.06 for heart girth, .03±.06 for head circumference and .01±.06 for cannon circumference. After removal of birth weight effects, repeatabilities became nonsignificant for all measures except for cannon and body length (.22±.06 and .19±.06, respectively) and hip width (.17±.06).

DISCUSSION

Sire effects on individual measures.

Sire differences for all measures were present in Polled Hereford-sired calves, but sire differences were not detected in the Angus-sired calves for hip and shoulder width, cannon length and heart girth. Due to the high positive relationship between birth weight and shape measures, the divergent selection of Polled Hereford bulls for high or low yearling weight EPD (and the observed correlated selection for high or low birth weight; Mahrt et al., 1990) may have exaggerated sire effects for body measures in these calves.

Differences in method of sire selection may also have contributed to expression of sire differences at constant birth weight in hip width, body length, heart girth and cannon circumference in Polled Hereford-sired calves but only in cannon circumference in Angus-sired calves. Differences in components of calf shape at constant birth weight were clearly observed, and were in part attributable to sire. Bellows et al. (1982) noted differences due to sire of calf in head width, heart girth, thigh width, body length and leg length. Wilson (1973) noted significant paternal half-sib heritability estimates after adjustment for birth weight in calf heart girth, hook width, body length and cannon circumference and length.

Correlations.

Comparison of FE residual correlation matrices for body measures revealed large correlations between shape measures and birth weight for both breeds of calves. Laster (1974) reported a large multiple correlation between five calf body measures and birth weight. In the current study, some independence among body measures was present, however, as indicated by some low to moderate correlations. After adjustment to common birth weight, correlations decreased in magnitude, indicating that a large portion of the relationships among the seven body measures was mediated through birth weight or general size of the calf. Wilson (1973) reported FE residual correlations of from .33 to .82 for several calf body measures including birth weight.

Fixed-effect residual correlations among measures were generally similar for the two breeds except for those involving cannon length (above diagonal, Tables 2 and 6). The independence of cannon length from the other measures was greater for Angus-sired calves. Due to the similar variability for this measure between the two breeds (Table 1), technician inconsistency should not have contributed to this discrepancy.

After adjustment for birth weight, inconsistency between breeds in correlations involving cannon length remained, and increased for body length and heart girth.

Fixed-effect, birth weight-adjusted residual correlations of body length and heart girth with other shape measures again were lower for Angus-sired calves. This could be indicative of inherent shape relationship differences between calves of the two breeds.

Regression of individual measures on sire EPD.

The positive relationship between sire birth weight EPD and all body measures including birth weight was expected due to the high correlations among the measures and the significant positive relationship between actual birth weight and birth weight EPD. After removal of birth weight effects by linear regression, a positive relationship remained between birth weight EPD and head and cannon bone circumference. Hence, calves from sires with genetic potential for large birth weights tended to have larger head and cannon circumferences compared to calves of the same birth weight out of sires with lower genetic potential for birth weight. When comparing calves of equal birth weight, one would expect larger framed calves from sires with larger birth weight EPD. This effect was not due to differences in gestation length.

Calving ease EPD tended to be negatively related to birth weight and other calf body measures. Several studies (Laster, 1974; Notter et al., 1978; Bellows et al., 1987) have reported a positive association between birth weight and incidence of dystocia. Dufour et al. (1974) and Cadle et al. (1976) found similar relationships between calf body measures (unadjusted for birth weight) and observed calving difficulty. Relationships between calf body measures and dystocia are usually considered to be mediated through birth weight. Significant relationships between calf body measures and observed dystocia independent of birth weight have rarely been reported (Meijering, 1984).

In the present study, cannon circumference was correlated with sire calving ease EPD even after adjustment for observed birth weight. Though the low correlation (r = -.16) indicates that the relationship was small, calves of the same birth weight tended to have smaller cannon circumferences if they were from high calving ease EPD sires. Calving ease EPD explained 2.6% of the variation in the FE-BW residuals for cannon circumference and 1.7% of the variation in factor 2. Multiple regression of calving ease EPD on shape measures yielded an R^2 of 4%. Thus, the relationship (independent of birth weight) between shape and calving ease EPD was quite low and the relationship of calving ease EPD and cannon circumference was almost as large as the relationship between calving ease EPD and linear combinations of several shape measures.

Dufour et al. (1981) reported no relationship between cannon bone circumference of crossbred calves and observed dystocia levels. Schlote and Hassig (1979) noted a correlation between calf cannon circumference and calving difficulty of .25 in German Simmental cattle. In that study, cannon circumference was not useful in prediction of dystocia in a forward regression procedure involving birth weight and several other body measures on the calf, dam and sire.

In the present study, cannon bone circumference was not related to calving ease EPD after adjustment for sire birth weight EPD. Thus for the Polled Hereford-sired calves, no calf body measure was significantly related to calving ease EPD above that which could be attributed to phenotypic and genetic (EPD) relationships with birth weight.

Factor patterns.

In general, visual inspection of factor patterns for each breed revealed basic similarities in calf shape factors. Tanner and Burt (1954) also reported agreement between mature dairy Shorthorn and Ayrshire cows in the relative factor loadings for several body measures.

An underlying width dimension dominated the first factor for both breeds (Tables 4 and 7). The high loadings for both hip and shoulder width indicated that the first factor discriminated among wide and narrow bodied calves of the same birth weight. All other body measures had smaller (≤.18) loadings in the first factor. Tanner and Burt (1954) reported that width measures loaded highly together in an analysis of body measures taken on mature dairy cows. Comparison with their specific results was difficult due to lack of inclusion of or adjustment for body weight. Brown et al. (1973) reported a second principal component with large coefficients for shoulder and hip width for body measures on young Hereford and Angus bulls. Body weight was included as a measure in their study and thus the first principal component contained large positive coefficients for all measures and described overall body size. Differences in the number and type of body measures used in these other multivariate statistical studies of shape in cattle makes comparison to our results beyond the first factor difficult.

The second factor for the Angus-sired calves discriminated between calves on the basis of structural thickness and, to a small extent, height. The second factor for Polled Hereford-sired calves differentiated structurally long and thick vs thin and short calves. The second factor from the Polled Hereford-sired calves may represent skeletal size or general frame.

Most of the variance in measures of Angus-sired calves that was accounted for by factor analysis was explained by the first two factors. Therefore, loadings in the third factor were quite low except for body length (.28). The third factor for Polled Hereford-sired calves loaded highly for heart girth and head circumference, again suggesting that there were some differences in calf shape relationships between the breeds. This result was confirmed by the significant heterogeneity of the two (co)variance matrices.

Final communality estimates (Table 5) indicate that generally less than 50% of the variance for any one measure was accounted for by three factors. This result was in part due to low correlations among the FE-BW residuals. Further, only factors contributing to the variance of at least two variables are considered in factor analysis; variance unique to a single shape measure was not accounted for.

Sire effects on factor scores and relationship to EPD.

Across both calf breeds, all factor scores except those for the first factor in Angus-sired calves differed among sires ($P < .08$). Thus, differences in calf shape that were independent of birth weight were present in both breeds and have at least a partial genetic origin. Morrison et al. (1985a) reported results from a stepwise multiple regression that indicated a positive relationship between observed calving ease and calf shoulder width independent of birth weight. Results of analyses of factor score 1 were inconsistent with that finding. The significant correlations of factor score 2 (frame) with both birth weight EPD (.21) and calving ease (-.13) EPD in Polled

Hereford-sired calves was consistent with the analysis involving cannon bone circumference alone. Cannon circumference loaded highly in the second factor and thus should heavily influence results of analyses involving factor score 2.

The correlations between the EPD and factor score 2 are small and as with cannon circumference, factor score 2 was not related to calving ease EPD independent of birth weight EPD. Cannon bone circumference appears to be a good measure of skeletal size and probably has an indirect relationship to calving ease EPD. Cannon circumference was also the only measure that was significantly associated with both EPD in the multiple regression analysis.

Repeatability of calf shape.

Calf birth weight repeatability was estimated at .19 and .22 for Angus- and Polled Hereford-sired calves, respectively. Slightly larger birth weight repeatability estimates of .28 for Hereford and .29 for Angus calves can be derived from variance components given by Wilson et al. (1986). Repeatabilities for heart girth and cannon length were significant for both breeds, but this was in part mediated through general calf size (birth weight). The estimates of repeatability of calf shape measures independent of birth weight were inconsistent between the two breeds, however inclusion of sire in the model for

Angus-sired calves would have reduced within cow variation (σ^2_e) and increased repeatability estimates. Generally, body shape of a cow's progeny, independent of birth weight, was not highly repeatable.

CONCLUSIONS

Differences in calf body measures at constant birth weight were observed among sires of both breeds, however interrelationships among measures differed between the two breeds. A skeletal width component of calf shape was especially apparent, but was not related to calving ease EPD. Cannon bone circumference was related to both birth weight EPD and calving ease EPD independent of birth weight, and appeared be an indicator of skeletal size.

Overall, the relationship of linear body measures to sire first-calf calving ease EPD in newborn Polled Hereford-sired calves was not large enough to warrant selection for calf shape independent of birth weight in order to reduce dystocia. Although a significant relationship between calving ease EPD and actual calving performance has not been reported in the literature, conclusions in this study assume that sire calving ease EPD is correlated to dystocia levels experienced in crossbred progeny. Birth weight EPD was a good predictor of actual birth weight in crossbred calves (Mahrt et al., 1990) and the results of this study indicate that calf shape adds no additional information for prediction of dystocia to that provided by birth weight EPD.

IMPLICATIONS

Expected progeny differences of sires for first-calf calving ease and birth weight were related to linear body measures on their newborn progeny that were independent of observed birth weight. Calf shape differences at birth existed and were in part influenced by genotype. Differences in calf skeletal size at constant birth weight were negatively related to sire calving ease expected progeny difference. However, selection to change calf shape independent of birth weight in order to reduce dystocia levels is not recommended.

TABLE 1. MEANS AND FIXED-EFFECT RESIDUAL STANDARD DEVIATIONS FOR CALF MEASURES

	Sire breed			
	Angus		Polled Hereford	
Body measure[a]	Mean	SD[b]	Mean	SD[b]
Birth weight (BW)	35.4	3.8	35.2	4.6
Head circumference (HC)	48.4	2.0	47.8	1.0
Hip width (HW)	19.9	1.1	19.2	.8
Shoulder width (SW)	18.4	1.2	17.9	.7
Body length (BL)	52.0	3.5	52.5	1.7
Cannon circumference (CC)	11.7	.7	11.7	.4
Cannon length (CL)	16.6	1.3	14.4	.6
Heart girth (HG)	75.1	3.8	73.3	2.2

[a] All measures expressed in cm except birth weight (kg).

[b] Fixed effects include cow age group, calf sex, year and cow breed group (Angus-sired calves only).

TABLE 2. FIXED-EFFECT RESIDUAL CORRELATIONS AMONG BODY MEASURES FOR ANGUS-SIRED CALVES[a,b,c]

Body measure[d]	HC	HW	SW	BL	CC	CL	HG
BW	.58	.65	.64	.44	.45	.31	.74
HC		.43	.41	.33	.52	.08	.50
HW	.09		.79	.28	.33	.26	.47
SW	.05	.63		.22	.35	.21	.47
BL	.10	-.01	-.10		.25	.11	.29
CC	.36	.05	.08	.06		.08	.43
CL	-.14	.08	.02	-.04	-.07		.21
HG	.13	0	-.01	-.06	.15	-.03	

[a] Fixed effects include cow age group, cow breed group, calf sex and year.

[b] Correlations below diagonal were based on data that were adjusted for birth weight.

[c] Correlation coefficients ≥ .10 are significant ($P \leq .05$).

[d] See Table 1 for abbreviations of body measures.

TABLE 3. COEFFICIENTS AND STANDARD ERRORS FROM REGRESSION OF CALF BODY MEASURES ON BIRTH WEIGHT[a]

	Sire breed	
Body measure	Angus	Polled Hereford
Head circumference	.31±.02	.31±.02
Hip width	.19±.01	.22±.01
Shoulder width	.21±.01	.19±.01
Body length	.41±.05	.41±.04
Cannon circumference	.09±.01	.08±.01
Cannon length	.11±.02	.13±.01
Heart girth	.74±.04	.75±.04

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[a] Coefficients and SE are expressed in cm/kg.

TABLE 4. ROTATED FACTOR PATTERN OF RESIDUAL SHAPE MEASURES FOR ANGUS-SIRED CALVES[a]

Body measure	Factor 1	Factor 2	Factor 3
Head circumference	.09	.48	.20
Hip width	.72	.02	-.04
Shoulder width	.72	.04	-.10
Body length	-.04	.04	.28
Cannon circumference	.09	.48	.13
Cannon length	.06	-.18	-.12
Heart girth	-.02	.29	-.10

[a] Measures are adjusted for cow age group, cow breed group, calf sex, year and birth weight.

TABLE 5. FINAL COMMUNALITY ESTIMATES FOR FACTOR ANALYSES OF CALF BODY MEASURES

Body measure	Sire breed	
	Angus	Polled Hereford
Head circumference	.28	.27
Hip width	.53	.30
Shoulder width	.53	.30
Body length	.08	.18
Cannon circumference	.25	.17
Cannon length	.05	.26
Heart girth	.09	.21

TABLE 6. FIXED-EFFECT RESIDUAL CORRELATIONS AMONG BODY MEASURES FOR POLLED HEREFORD-SIRED CALVES[a,b,c]

Body measure[d]	HC	HW	SW	BL	CC	CL	HG
BW	.63	.60	.57	.50	.43	.46	.73
HC		.49	.41	.42	.43	.43	.62
HW	.19		.60	.36	.30	.27	.49
SW	.09	.40		.25	.31	.21	.47
BL	.16	.09	-.04		.33	.44	.42
CC	.22	.06	.09	.16		.36	.31
CL	.20	0	-.07	.28	.21		.45
HG	.30	.10	.10	.11	.01	.20	

[a] Fixed effects include cow age group, calf sex and year.

[b] Correlations below diagonal were based on data that were adjusted for birth weight.

[c] Correlation coefficients $\geq .10$ are significant ($P \leq .05$).

[d] See Table 1 for abbreviations of body measures.

TABLE 7. ROTATED FACTOR PATTERN OF RESIDUAL SHAPE MEASURES FOR POLLED HEREFORD-SIRED CALVES[a]

Body measure	Factor 1	Factor 2	Factor 3
Head circumference	.18	.31	.37
Hip width	.53	.07	.12
Shoulder width	.54	-.02	.05
Body length	-.01	.39	.15
Cannon circumference	.10	.40	.04
Cannon length	-.10	.44	.24
Heart girth	.10	.13	.43

[a] Measures are adjusted for cow age group, calf sex, year and birth weight.

ANALYSIS OF BODY MEASUREMENTS OF CROSSBRED CALVES SIRED BY SIMMENTAL BULLS DIVERGENTLY SELECTED FOR PROGENY FIRST-CALF CALVING EASE IN RELATION TO BIRTH WEIGHT

INTRODUCTION

Calf birth weight and dam pelvic area are the two most important factors associated with dystocia (Meijering, 1984). However, less than 50% of the variation in dystocia score generally is accounted for by these two variables (Price and Wiltbank, 1979b; Short et al., 1979; Morrison et al., 1985a). Several researchers have suggested that body shape of the calf may influence ease of birth (Philipsson, 1976b; Smith et al., 1976; Comerford et al., 1987). Linear body measures taken on newborn calves are clearly related to birth weight, however, a relationship between calf body measures and observed calving difficulty that is independent of birth weight has rarely been demonstrated (Laster, 1974; Meijering, 1984; Morrison 1985a).

Nugent et al. (1990) reported that after adjustment of calf body measures for phenotypic effects of birth weight, a significant relationship remained between calf shape and sire expected progeny differences (EPD) for both birth weight and first-calf calving ease in calves sired by Polled Hereford bulls. However, no relationship between shape and calving ease EPD remained after adjustment of shape for sire birth weight EPD. Progeny shape measures, independent of birth weight, and sire genetic potential for calving difficulty had no association in addition to the relationship mediated through sire genetic value for birth weight. The objective of this study was to utilize Simmental bulls whose EPD for birth weight and calving ease indicated that their progeny experienced more or less dystocia than anticipated from the birth weight EPD of their sire to further investigate calf body shape factors associated with calving ease.

MATERIALS AND METHODS

Animals.

Data were collected on calves born at the Shenandoah Valley Agricultural Experiment Station, Steeles Tavern, Virginia. Calves resulted from artificial breeding of 27 Simmental bulls to 161 Polled Hereford x Angus 1- and 2-yr-old females for their first and second calvings. Calvings (n = 204) occurred in spring of 1987 through 1989 (Table 8). Polled Hereford maternal grandsires had been selected divergently in a 2 x 2 factorial design for high or low yearling weight EPD and high or low maternal weaning weight EPD (Mahrt et al., 1990).

Simmental bulls were selected from the 1986 and 1987 Simmental Sire Summaries (ASA, 1986, 1987). Initially, the linear regression of first-calf calving ease EPD (CEEPD) on birth weight EPD (BWTEPD) was estimated in each year using all bulls with an accuracy (BIF, 1986) for BWTEPD of at least .78 and an accuracy for CEEPD of at least .49 in 1986 (n = 99) or .59 in 1987 (n = 117). Regression coefficients were -4.72±.39 and -4.76±.35 %/kg for 1986 and 1987, respectively, with corresponding coefficients of determination (R^2) of .60 and .62.

Bulls with large positive and negative CEEPD residual deviations from the regression line were primary candidates for selection and usually represented the top and bottom 15% of all bulls used in the analysis. These bulls appeared to sire calves born with either much less or much greater calving ease than that predicted from their BWTEPD. Semen from many potential sires was not available, however, so semen from bulls with similar CEEPD residuals but lower EPD accuracies than those used in the regression analysis was occasionally used. Approximately equal numbers of "hard calving" (negative CEEPD residual) and "easy calving" (positive CEEPD residual) bulls were used. The only constraint placed on sire use was that bulls with BWTEPD greater than .68 kg were not bred to yearling heifers.

Sire EPD and accuracies in the year of selection and in the most current sire summary (ASA, 1990) are listed in Tables 9 and 10. The regression coefficient of CEEPD on BWTEPD using bulls from the 1990 Simmental Sire Summary (ASA, 1990) with an accuracy of at least .6 and .8, respectively, for CEEPD and BWTEPD was -4.30±.28 %/kg (R^2 = .65). Residuals for CEEPD in the year of selection and in 1990 are listed in tables 11 and 12.

Cows were maintained on predominantly fescue pasture throughout the year with supplemental fescue hay, broiler litter, corn silage and(or) whole shelled corn given in winter. Cows were examined several times daily as parturition approached and were assisted at calving if necessary. Obstetrical assistance was generally given if cows in the second stage of labor (Beal, 1982) failed to make progress toward expulsion of the calf for longer than approximately 45 min. Calving score was recorded as 1 = no difficulty; 2 = minor assistance (hand pull); 3 = assistance with mechanical puller; 4 = major assistance with mechanical puller; 5 = Caesarean; 6 = abnormal presentation.

At approximately 24 h postpartum, calf sex was recorded and birth weight, head circumference, shoulder width, heart girth, hip width, cannon bone circumference, cannon length and body length were measured as described by Nugent et al. (1990). Calves were suspended vertically for all measures except heart girth. At weaning [mean (SD) age of 230 (22) d], body weight, hip height, shoulder width and hip width were recorded on the standing calves. Heart girth was also measured at weaning in 1988 and 1989. All linear body measures were recorded to the nearest .5 cm. At birth, each calf was measured by one of two technicians; at weaning each calf measurement was made by the same technician. Newborn body measures also had been recorded on the Polled Hereford x Angus dams of these calves when they were born in 1984 through 1987 (Nugent et al., 1990).

Statistical analysis.

Data were initially analyzed using the general linear models procedure of SAS (1985). Dependent variables included head circumference, cannon circumference, cannon length and body length at birth and shoulder width, hip width, heart girth and body weight at both birth and weaning. Independent variables in all models included (fixed) effects of year, calf sex, cow age and all two-way interactions as well as maternal grandam group (Nugent et al., 1990) and maternal grandsire group (Mahrt et al., 1990). Sire effects were tested or BWTEPD and(or) CEEPD were added as covariates to several models in addition to fixed effects.

To test relationships of calf body measures independent of body weight or age, birth weight, gestation length, weaning weight or age was added as a covariate in some models. The linear combination of body measures most associated with each EPD was estimated by multiple regression of CEEPD and BWTEPD on fixed-effect, birth weight-adjusted residuals of body measures.

Observed calving performance was categorized as unassisted (calving score 1 and 2; Short et al., 1979; Meijering and Postma, 1984) or assisted (calving score 3, 4 and 5) for use as an independent variable to relate observed calving performance to individual body measures, calf shape and birth weight. Consistent with evaluations of field data (Burfening et al., 1978a; Quaas et al., 1985), calves born via abnormal presentation were deleted from analyses involving observed calving score. The effect of interaction between cow age and calving score on body measures was tested in preliminary models, found to be nonsignificant and deleted from final models. An overall difference between assisted and unassisted calves in body measures was tested with Wilks' lambda criterion, a multivariate statistic (Hair et al., 1987). Low calf numbers per sire and differences in the range of BWTEPD for sires bred to 1- and 2-yr-old females did not allow for the relationship between observed calving performance and sire EPD to be accurately evaluated.

Fixed-effect (FE) residuals of newborn calf body measures were also adjusted for birth weight using intrasire regression coefficients and subsequently analyzed via factor analysis (SAS, 1985; Nugent et al., 1990). Factor analysis described underlying dimensions of variables and assigned numerical (factor) scores to each calf based on the underlying dimensions (Hair et al., 1987). Factor scores were then related to calving performance and used to determine sire effects on newborn calf shape and relationships of shape to sire CEEPD and BWTEPD.

Relationships among residuals for dam and calf birth measures and for calf birth and weaning measures were tested before and after adjustment for body weight. Correlation between dam and calf body measures at birth was accomplished by pairing each calf with its dam. Thus, dam measures were repeated for females that had two calves during the study.

RESULTS

Calf birth traits.

Overall means and FE-residual standard deviations for newborn calf measures are presented in Table 13. Sire effects were present for cannon bone circumference ($P = .01$) and length ($P < .05$) and head circumference ($P < .09$), but not for birth weight or any other skeletal measure. Regressions of body measures on birth weight were significant for all measures (Table 13). Fixed-effect residual correlations among calf measures ranged from .21 to .79; after adjustment for birth weight, correlations ranged from -.07 to .55 (Table 14). Differences among half-sib groups in cannon circumference ($P < .01$) and length ($P < .05$) remained after adjustment for birth weight. These sire effects were not removed by addition of gestation length as a covariate.

Relationships of BWTEPD and CEEPD to calf measures were investigated by regressing FE-residual body measures on calf sire EPD. Birth weight EPD was positively associated with birth weight, head circumference, shoulder width, cannon circumference (all $P < .01$) and hip width ($P = .06$). The regression of birth weight on BWTEPD was 1.0±.4 kg/kg. The regression of fixed-effect, birth weight-adjusted (FE-BW) residuals on BWTEPD was positive for cannon circumference ($b = .13 \pm .06$ cm/kg; $P < .05$) and head circumference ($b = .22 \pm .12$ cm/kg; $P = .08$). Inclusion of gestation length in the model did not remove effects of BWTEPD on head and cannon circumference.

No relationship ($P > .11$) existed between CEEPD and FE residuals for birth weight and body measures. Further, no relationship ($P > .14$) between FE-BW residuals of body measures and CEEPD was observed. However, when FE-BW residuals were also adjusted for BWTEPD, there was a significant correlation (r; $P < .05$) between CEEPD and both cannon circumference ($r = .12$) and cannon length ($r = .17$). This relationship between body measures and CEEPD also was not affected by gestation length.

Multiple regression of BWTEPD on FE-BW residual newborn calf measures revealed a positive relationship ($P < .05$)

between BWTEPD and residual cannon circumference. Partial regression coefficients for the other residual measures were not significant ($P > .16$). After adjustment for fixed effects, the coefficient of determination was .06. When CEEPD was used as the dependent variable in the same analysis, there was a negative relationship between CEEPD and residual head circumference ($P < .10$); the residual R^2 was .05.

Results of factor analysis indicated that three factors accounted for all of the variance in the FE-BW adjusted body measures that was accounted for by the factor pattern; factors 1, 2 and 3 explained 51, 41 and 8% of the variance, respectively. The rotated factor pattern (Nugent et al., 1990) is presented in Table 15, as is the amount of variation in the FE-BW residuals accounted for by each factor (i.e., the final communality estimates). The first factor contained high loadings for hip and shoulder width residuals. Body length had a moderate loading (.26) in the first factor. The second factor loaded highly for cannon length, head circumference and cannon circumference. The final factor loaded highest for heart girth. Factor scores 1, 2 and 3 appeared to discriminate among calves based on skeletal width, frame and thickness, respectively.

Analysis of factor scores revealed sire differences for factor 2 ($P = .01$) and a positive correlation between BWTEPD and factor 2 ($r = .14$; $P = .06$). No relationship between factor scores and CEEPD existed. However, after adjustment of factor scores for BWTEPD, a correlation between factor score 2 and CEEPD was observed ($r = .15$; $P < .05$).

Table 8 lists the percentage of assisted and unassisted births by dam age and year. Observed calving performance was related ($P < .01$) to FE residuals of birth weight and all linear newborn calf body measures except cannon bone length (Table 16). All measures except cannon length were smaller for calves born unassisted. Accordingly, Wilks' criterion was significant ($P < .01$), indicating an overall difference in assisted and unassisted calves in body measures. The fixed-effect, birth weight-adjusted residuals for newborn hip width were smaller ($P < .10$) in calves born unassisted. However, Wilks' criterion ($P = .27$) indicated no overall difference in body measures independent of birth weight between calves born assisted and unassisted.

Weaning traits.

Means and age-adjusted, FE-residual standard deviations for weaning body measures are presented in Table 17. Sire effects were significant only for heart girth ($P < .05$). After adjustment of FE residuals for weaning weight, sire effects existed for heart girth ($P < .05$) and shoulder width ($P = .08$).

Correlations between birth and weaning body measures were calculated after adjustment for fixed effects and with or without additional adjustment for body weight (Tables 18 and 19). Prior to adjustment for weight, residual correlations of birth measures with age-adjusted weaning measures ranged from -.08 to .30; after adjustment to common weight, correlations ranged from -.32 to .16.

Dam birth traits.

Analysis of newborn body measures taken on the Polled Hereford x Angus dams of the calves has been reported by Nugent et al. (1990). Residual correlations between dam body measures at birth adjusted for year and calf body measures at birth adjusted for year, dam age, calf sex and sire ranged from -.03 to .34 (Table 20). When dam and calf residuals were further adjusted for birth weight, correlations ranged from -.17 to .14 (Table 21).

Heritability was estimated for each measure as twice the coefficient of regression of offspring on dam (Dickerson, 1969). Heritability estimates were .52±.14 for birth weight, .26±.12 for head circumference, .34±.12 for shoulder width, .24±.10 for hip width, .30±.12 for cannon circumference (all $P \le .01$), .28±.12 for heart girth ($P < .05$), .16±.10 for body length ($P < .10$) and .14±.12 for cannon length ($P = .2$). After adjustment for birth weight, coefficients were reduced and nonsignificant except for heart girth (b = -.13±.06; $P < .05$).

DISCUSSION

Sire residuals for CEEPD listed in Tables 11 and 12 indicated that residuals for many bulls decreased in magnitude from the year of selection to 1990. Bulls selected as hard calving sires still had negative CEEPD residuals in 1990 and all but two easy calving sires still had positive residuals in 1990. Thus, these bulls still appeared to be divergent for calving ease relative to birth weight.

Sire differences for newborn calf cannon bone circumference and length and possibly head circumference indicated that skeletal size and shape, even at constant birth weight, is in part under genetic control. Wilson (1973), Bellows et al. (1982) and Nugent et al. (1990) drew similar conclusions. Smith et al. (1976) and others have reported sire effects on calf birth weight. Large standard errors for sire means for birth weight, resulting from small numbers of calves per sire, may have been responsible for lack of significance of sire effects on birth weight in the present study. Nevertheless, the significant relationship between birth weight and BWTEPD indicated that sire differences did, in fact, influence progeny birth weight.

Newborn body measures were all positively related to birth weight, and generally exhibited positive, significant correlations among measures (Table 14). Boyd and Hafs (1965) and Wilson (1973) also noted moderate to large correlations among calf body measures. After adjustment for birth weight, residual correlations were lower. Thus, relationships among body measures were to a large extent mediated through general calf size, as reflected by birth weight.

Large correlations among body measures and birth weight were partially responsible for the positive relationship of BWTEPD to head and cannon circumference and to shoulder and hip width. However, even after removal of phenotypic birth weight effects, head and cannon circumference tended to be larger in calves sired by bulls with larger BWTEPD. This result was supported by the multiple regression of BWTEPD on FE-BW residuals. In a group of Polled Hereford x Angus calves which included the dams of the calves in the present study, a positive relationship between head and cannon circumference and BWTEPD was also present (Nugent et al., 1990). The propensity for large skeletal size at constant birth weight in calves sired by bulls with larger BWTEPD was not mediated through differences in gestation length in either study. A positive relationship was present between calf skeletal size and sire genetic merit for birth weight independent of phenotypic birth weight and length of gestation. Burfening et al. (1978c) reported that gestation length had no effect on calving score independent of birth weight.

No relationship between CEEPD and any body measure was observed in the present study, which was inconsistent with results of Nugent et al. (1990). This discrepancy may have resulted from the mode of selection of Simmental bulls. Among bulls from the Simmental Sire Summary used to estimate the regression of CEEPD on BWTEPD, the simple correlation between the two EPD was approximately -.79. Among selected bulls, this correlation was -.57. The lower correlation between CEEPD and BWTEPD among selected sires may have reduced the relationship between CEEPD and body measures that was mediated through birth weight or general calf size. The multiple regression of CEEPD on FE-BW residuals confirmed the lack of a strong relationship between the body measures independent of birth weight and CEEPD. Burfening et al. (1979) reported a phenotypic correlation of .74 between sire EPD for calving score (range of 1 = unassisted to 4 = Caesarean) and sire birth weight EPD for bulls with 20 or more progeny out of first-calf heifers. Tong et al. (1988) reported a correlation of -.45 between sire proofs for calving score (range of 100 = unassisted to 0 = Caesarean) and birth weight for 44 Simmental bulls.

After adjustment for fixed effects, birth weight and BWTEPD, there was a positive correlation between both cannon measures and CEEPD. Thus, at constant BWTEPD and birth weight, calves from higher CEEPD sires tended to have longer and thicker cannon bones. This effect was also not mediated through differences among sires in gestation length, but may have been detectable due to the expanded range (relative to that for bulls selected at random) in CEEPD at constant BWTEPD that was present in the selected sires. The correlation of CEEPD to FE-BW, BWTEPD-adjusted cannon measure residuals may not reflect a causal relationship between cannon circumference and calving ease, but rather a relationship of CEEPD to structural size that is reflected by cannon bone size.

Results of factor analysis indicated that factor 1 contained high loadings for both hip and shoulder width, similar to those observed in Angus- and Polled Hereford-sired calves by Nugent et al. (1990). These two skeletal width measures were highly correlated, even at constant birth weight, and scores based on factor 1 would discriminate among calves based on structural width. Tanner and Burt (1954) and Brown et al. (1973) reported large loadings of skeletal width measures in factor and principal components analyses, respectively.

The second factor loaded highly for head and cannon circumference, similar to the second factor in both Angus- and Polled Hereford-sired calves (Nugent et al., 1990). The Simmental- and Polled Hereford-sired calves also had a large factor 2 loading for cannon length, but the magnitude of loadings for body length and heart girth were quite different between the two sire breeds. Factor 3 loaded highly for heart girth, similar to the result observed with Polled Hereford-sired calves, but this factor contributed only 8% of the variation explained by the factors. The factors indicated that at constant birth weight, inherent independent skeletal width and frame dimensions did exist and greatly determined common elements of calf shape for three sire breeds.

Analysis of factor scores confirmed that differences in skeletal size independent of birth weight were in part due to sire effects. However, factor scores were not related to CEEPD, again indicating that calf shape, independent of size, was not related to sire genetic potential for dystocia. The relationship between one element of frame (factor 2) and CEEPD at constant BWTEPD was significant, however, but again may have been specific to these selected sires. Nugent et al. (1990) found no relationship between

CEEPD and factor scores independent of BWTEPD in Polled Hereford-sired calves.

Several researchers have compared body measures of calves born unassisted and assisted in an attempt to identify a body measure, in addition to birth weight, that could be easily measured and readily used as a selection criterion against dystocia. Rarely has such a measure been identified. Laster (1974) reported a multiple correlation between five calf body measures and birth weight of .75, but measures were unrelated to dystocia independent of birth weight. The calf body measurements that were most closely correlated to calving performance in German Simmental cattle were calf weight (.38) and muscling of shoulder (.31; Schlote and Hassig, 1979). However, after adjustment for birth weight, muscling of shoulder explained only .2% of the variation in calving performance. Morrison et al. (1985a) found a significant relationship between calf shoulder width and calving ease that was independent of birth weight.

In the present study, calves born unassisted were smaller in weight and all other body measures except cannon length. Bellows et al. (1971a, 1982) and Smith et al. (1976) have discussed the effect of birth weight on dystocia. Dufour et al. (1974) and Cadle et al. (1976) have reported a relationship between calf body measures unadjusted for birth weight and dystocia. At constant birth weight, hip width tended to be smaller in calves born unassisted. The effect approached significance, but was not large, however, and overall shape did not differ between calves born assisted and unassisted.

Weaning body measurements were recorded to test the relationship among birth and weaning body measures and to test if newborn calf shape is related to shape in older animals. Birth weight and newborn heart girth were lowly to moderately correlated to all weaning measures. Newborn skeletal measures, primarily widths and cannon circumference, were lowly correlated to all weaning measures except heart girth (no correlation). Thus body size and shape measures in a newborn calf were partially indicative of weanling calf size. Brown et al. (1973) reported that size (based on the first principal component of several body measures including weight) in 4-mo-old bulls was highly correlated to size at 8 and 12 mo of age. However, when body measures were adjusted for weight, correlations were greatly reduced, indicating that calf shape independent of birth weight was not related to weight-adjusted body measures in weanling calves.

The correlations between newborn body measures in the dam and her calf's birth weight, hip and shoulder width and heart girth were low to moderate. Dam hip and shoulder width and cannon circumference were low to moderately correlated to all calf measures except cannon length. Boyd and Hafs (1965) reported correlations of .26, .20 and .31 for calf heart girth, head width and birth weight, respectively, with mature dam heart girth in Holsteins. Blackmore et al. (1958) reported low to moderate correlations between Holstein dams and daughters for several body measures taken at 6 mo of age.

Based on FE-residual correlations, hip and shoulder width and cannon circumference were indicators of skeletal size in successive generations. The heritability estimates indicated that calf size should respond to selection, however changing calf shape independent of body weight would be difficult. Wilson (1973) reported large significant heritability estimates for birth weight (.39), heart girth (.41), cannon circumference (.55), body length (.51) and cannon length (.46) in newborn crossbred (1/2 Polled Hereford, 1/4 Angus, 1/4 Holstein) calves. Wilson also reported significant heritability estimates in these measures after adjustment for calf birth weight. Cadle et al. (1976) reported heritability estimates of .28 for birth weight, .35 for calf body length and .42 for calf hip width. Blackmore et al. (1958) reported heritability estimates of .17 for body length and .18 for chest girth in 6 mo-old Holsteins; no standard errors for these estimates were reported, however. Ali et al. (1984) reported significant heritability estimates of body measures in mature dairy cattle.

CONCLUSIONS

Body shape differences at constant birth weight existed in crossbred beef calves sired by bulls selected for large differences in genetic potential for dystocia independent of genetic potential for birth weight. The shape differences, however, were not strongly related to observed dystocia nor CEEPD. Underlying dimensions of skeletal size that were positively associated with sire BWTEPD at constant phenotypic birth weight were defined by hip and shoulder width and, independently, cannon circumference. These measures were related to dam body measures and weanling body measures, but only through a general relationship to calf size. Selection for calf shape based on one or more body measures to reduce calving difficulty independent of birth weight does not appear useful.

IMPLICATIONS

Sire birth weight expected progeny difference was related to calf shape independent of birth weight. However, increases in skeletal dimensions (best estimated by hip or shoulder width and cannon circumference) were not related to observed calving difficulty or sire expected progeny difference for first-calf calving ease independent of the effect of birth weight. Selection for reduced calving difficulty should not be based on parent or offspring body shape.

TABLE 8. NUMBER OF CALVES BORN AND PERCENT ASSISTED BIRTHS BY YEAR OF CALVING AND DAM AGE

		Dam age at calving (yr)				
		2		3		
Year	Calving group[a]	n	(%)	n	(%)	Total
1987	Unassisted	10	(23)	34	(81)	
	Assisted	32	(75)	7	(17)	
	Abnormal	1	(2)	1	(2)	
	Subtotal	43		42		85
1988	Unassisted	11	(30)	25	(86)	
	Assisted	26	(70)	3	(10)	
	Abnormal	0	(0)	1	(4)	
	Subtotal	37		29		66
1989	Unassisted	12	(48)	22	(78)	
	Assisted	13	(52)	5	(18)	
	Abnormal	0	(0)	1	(4)	
	Subtotal	25		28		53
	Total	105		99		204

[a] Unassisted = calving score 1 and 2; assisted = calving score 3, 4 and 5; abnormal = calving score 6.

TABLE 9. EXPECTED PROGENY DIFFERENCES AND ACCURACY VALUES FOR CALVING EASE AND BIRTH WEIGHT FOR BULLS SELECTED IN 1986

Bull	1986 CEEPD,%[a]	1986 BWTEPD,kg[a]	1990 CEEPD,%[b]	1990 BWTEPD,kg[b]	Year Used[c]
		Hard calving sires[d]			
77	89.3(.34)[e]	.09(.74)	95.2(.63)	.23(.90)	1
78	90.8(.63)	-.27(.86)	94.2(.65)	-.27(.91)	1
79	85.7(.75)	.82(.89)	84.2(.80)	.73(.93)	1,3
80	92.9(.47)	.68(.81)	92.2(.71)	.77(.91)	1
81	98.8(.79)	-.36(.90)	97.6(.83)	-.46(.95)	1
82	97.3(.26)	-.86(.49)	98.6(.60)	-.91(.89)	1,3
85	89.7(.73)	.68(.84)	91.6(.75)	.86(.90)	1
		Easy calving sires[f]			
74	107.3(.57)	-.18(.79)	104.7(.63)	-.50(.88)	1,3
75	103.4(.24)	.09(.64)	97.3(.65)	.32(.91)	1
76	104.4(.73)	-.05(.89)	102.6(.79)	-.05(.94)	1
83	110.2(.21)	-.91(.56)	100.6(.48)	-.73(.85)	1
84	97.0(.19)	1.09(.52)	93.8(.36)	.91(.84)	1,3
86	92.1(.33)	2.68(.57)	88.5(.44)	2.96(.74)	1

[a] EPDs published in 1986 (ASA, 1986).

[b] EPDs published in 1990 (ASA, 1990).

[c] Year of study when bull was bred to cows; 1 = 1986, 3 = 1988.

[d] Lower CEEPD than predicted from linear regression on BWTEPD

[e] Number in parenthesis is accuracy of EPD.

[f] Higher CEEPD than predicted from linear regression on BWTEPD.

TABLE 10. EXPECTED PROGENY DIFFERENCES AND ACCURACY VALUES FOR CALVING EASE AND BIRTH WEIGHT FOR BULLS SELECTED IN 1987

Bull	1987 CEEPD,%[a]	1987 BWTEPD,kg[a]	1990 CEEPD,%[b]	1990 BWTEPD,kg[b]	Year Used[c]
			Hard calving sires[d]		
87	95.8(.64)[e]	-.36(.85)	95.7(.66)	-.27(.91)	2
88	90.7(.52)	-.82(.76)	93.3(.53)	-.86(.84)	2
89	91.1(.47)	.09(.81)	92.2(.51)	-.05(.88)	2,3
92	87.5(.68)	1.41(.86)	87.8(.68)	1.55(.91)	2
94	91.0(.91)	.55(.95)	91.3(.92)	.55(.97)	2
118	96.2(.42)	-.36(.74)	99.0(.46)	-.46(.84)	3
			Easy calving sires[f]		
90	107.3(.58)	-.73(.77)	105.9(.65)	-.91(.88)	2,3
91	102.7(.63)	.09(.79)	103.1(.65)	.00(.86)	2,3
93	100.5(.54)	1.32(.68)	101.3(.63)	1.23(.79)	2
95	100.2(.84)	.36(.92)	98.1(.87)	.27(.96)	2
114	96.0(.66)	1.09(.80)	95.5(.68)	1.14(.87)	3
115	99.6(.55)	.59(.86)	97.5(.62)	.64(.91)	3
116	101.6(.68)	.14(.86)	100.1(.70)	.18(.91)	3
117	99.7(.56)	.64(.76)	94.5(.66)	.82(.89)	3

[a] EPDs published in 1987 (ASA, 1987).

[b] EPDs published in 1990 (ASA, 1990).

[c] Year of study when bull was bred to cows; 2 = 1987, 3 = 1988.

[d] Lower CEEPD than predicted from linear regression on BWTEPD.

[e] Number in parenthesis is accuracy of EPD.

[f] Higher CEEPD than predicted from linear regression on BWTEPD.

TABLE 11. RESIDUAL FIRST CALF CALVING EASE EXPECTED PROGENY DIFFERENCE VALUES FOR BULLS SELECTED IN 1986

Bull	1986 Residual CEEPD,%[a]	1990 Residual CEEPD,%[b]	Cow Age[c]
	Hard calving sires[d]		
77	-7.85	-1.67	1
78	-8.07	-4.82	1
79	-8.02	-10.52	2
80	-1.46	-2.32	2
81	-0.49	-2.21	2
82	-4.35	-3.16	1,2
85	-4.66	-2.53	1
Mean	-4.99	-3.89	
	Easy calving sires[d]		
74	8.86	4.70	1,2
75	6.25	0.82	1
76	6.61	4.56	1
83	8.33	-0.38	1,2
84	4.57	-0.14	2
86	7.18	3.34	2
Mean	6.97	2.15	

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[a] Difference between actual and predicted 1986 first-calf calving ease expected progeny difference (ASA, 1986).

[b] Difference between actual and predicted 1990 first-calf calving ease expected progeny difference (ASA, 1990).

[c] Age of cows to which bull was bred.

[d] See Table 8 for definition.

TABLE 12. RESIDUAL FIRST CALF CALVING EASE EXPECTED PROGENY DIFFERENCE VALUES FOR BULLS SELECTED IN 1987

Bull	1987 Residual CEEPD,%[a]	1990 Residual CEEPD,%[b]	Cow Age[c]
	Hard calving sires[c]		
87	-3.71	-3.32	1
88	-10.98	-8.27	1,2
89	-6.25	-5.84	1,2
92	-3.58	-3.40	2
94	-4.19	-4.20	2
118	-3.31	-0.81	1
Mean	-5.34	-4.31	
	Easy calving sires[c]		
90	6.06	4.14	1,2
91	5.35	5.25	1
93	8.99	8.73	2
95	4.15	1.43	2
114	3.41	2.54	2
115	4.63	2.39	2
116	4.47	3.03	1
117	4.94	0.17	2
Mean	5.25	3.46	

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[a] Difference between actual and predicted 1987 first-calf calving ease expected progeny difference (ASA, 1987).

[b] Difference between actual and predicted 1990 first-calf calving ease expected progeny difference (ASA, 1990).

[c] Age of cows to which bull was bred.

[d] See Table 8 for definition.

TABLE 13. NEWBORN CALF BODY MEASURE MEANS, FIXED-EFFECT RESIDUAL STANDARD DEVIATIONS AND COEFFICIENTS OF REGRESSION OF BODY MEASURES ON BIRTH WEIGHT

Body measure[a]	Mean	SD[b]	b[c]
Birth weight (BW)	37.3	4.2	
Head circumference (HC)	48.1	1.9	.31±.02
Hip width (HW)	19.6	1.1	.18±.01
Shoulder width (SW)	18.0	1.2	.20±.01
Body length (BL)	51.8	2.6	.38±.04
Cannon circumference (CC)	12.0	.8	.10±.01
Cannon length (CL)	15.5	1.1	.09±.02
Heart girth (HG)	72.5	3.8	.61±.05

[a] All measures expressed in cm except birth weight (kg).

[b] Fixed effects include maternal grandam and grandsire groups, dam age, calf sex and year.

[c] Regression coefficient (±SE), cm/kg.

TABLE 14. RESIDUAL CORRELATIONS AMONG BODY MEASURES ON NEWBORN CALVES[a,b]

Body measure[c]	HC	HW	SW	BL	CC	CL	HG
BW	.70	.72	.73	.61	.53	.34	.68
HC		.55	.49	.50	.52	.46	.47
HW	.09		.79	.52	.42	.32	.47
SW	-.03	.55		.57	.38	.21	.53
BL	.13	.15	.22		.36	.32	.42
CC	.25	.08	-.01	.06		.39	.31
CL	.33	.12	-.05	.16	.27		.31
HG	0	-.03	.08	.02	-.07	.12	

[a] Correlations above the diagonal were adjusted for maternal grandam and grandsire groups, dam age, calf sex and year; correlations below diagonal were additionally adjusted for birth weight.

[b] Correlation coefficients ≥.14 are significant ($P \leq .05$).

[c] See Table 13 for abbreviations of body measures.

TABLE 15. ROTATED FACTOR PATTERN AND FINAL COMMUNALITY ESTIMATES OF RESIDUAL BODY MEASURES FOR NEWBORN CALVES[a]

Body measure[b]	Factor 1	Factor 2	Factor 3	Communality Estimate
HC	.04	.50	.03	.25
HW	.66	.11	-.04	.44
SW	.69	-.08	.06	.49
BL	.26	.19	.11	.12
CC	.04	.43	-.10	.20
CL	.04	.54	.15	.32
HG	.03	.01	.31	.10

[a] Measures are adjusted for maternal grandam and grandsire groups, dam age, calf sex and year.

[b] See Table 13 for abbreviations of body measures.

TABLE 16. DIFFERENCE IN BODY MEASURES AND FACTOR SCORES BETWEEN CALVES BORN UNASSISTED AND ASSISTED[a,b]

Body measure	FE adjusted[c]	FE-BW adjusted[d]
Birth weight	-3.1**	
Head circumference	-1.1**	-.1
Hip width	-.8**	-.2†
Shoulder width	-.8**	-.2
Body length	-1.1*	.2
Cannon circumference	-.4**	-.1
Cannon length	0	.3
Heart girth	-1.5*	.5
Factor 1		-.2
Factor 2		.1
Factor 3		.1

$^{**}P \leq .01$ $^{*}P \leq .05$ $^{\dagger}P \leq .10$

[a] Expressed as unassisted - assisted.

[b] All differences in cm except for birth weight (kg) and factors (unitless).

[c] Fixed effects (FE) include maternal grandam and grandsire groups, dam age, calf sex and year.

[d] Adjusted for birth weight.

TABLE 17. MEANS AND AGE-ADJUSTED, FIXED-EFFECT RESIDUAL STANDARD DEVIATIONS FOR WEANLING CALF BODY MEASURES[a,b]

Body measure[c]	Mean	SD
Weaning weight (WWT)	183.6	23.0
Hip width (WHW)	31.3	1.8
Shoulder width (WSW)	31.2	1.8
Hip height (WHH)	40.5	1.6
Heart girth (WHG)	130.8	6.5

[a] Fixed effects include maternal grandam and grandsire groups, dam age, calf sex and year.

[b] Mean (SD) age at weaning was 230 (22) d.

[c] All measures expressed in cm except weaning weight (kg).

TABLE 18. AGE-ADJUSTED, FIXED-EFFECT RESIDUAL CORRELATIONS AMONG BODY MEASURES TAKEN AT BIRTH AND WEANING[a,b,c]

Birth measures[e]	Weaning measures[d]				
	WWT	WHW	WSW	WHH	WHG
BW	.26	.30	.20	.30	.28
HC	.11	.16	.07	.14	0
HW	.18	.22	.18	.22	.12
SW	.18	.22	.18	.18	.09
BL	.09	.13	.04	.14	-.01
CC	.20	.16	.21	.29	.13
CL	-.03	.04	-.08	.11	0
HG	.25	.30	.19	.29	.23

[a] Fixed effects include maternal grandam and grandsire groups, dam age, calf sex and year.

[b] Correlation coefficients >.15 are significant ($P < .05$).

[c] Mean (SD) age at weaning was 230 (22) d.

[d] See Table 17 for abbreviations of weaning measures.

[e] See Table 13 for abbreviations of birth measures.

TABLE 19. WEIGHT-ADJUSTED, FIXED-EFFECT RESIDUAL CORRELATIONS AMONG BODY MEASURES TAKEN AT BIRTH AND WEANING[a,b,c]

Birth measures[e]	Weaning measures[d]			
	WHW	WSW	WHH	WHG
HC	.08	-.04	-.04	-.06
HW	.03	.09	.03	-.17
SW	-.01	.09	-.04	-.32
BL	-.03	-.05	.03	-.11
CC	.02	.09	.16	-.04
CL	-.05	-.07	.15	-.11
HG	.13	-.02	.05	.04

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[a] Fixed effects include maternal grandam and grandsire groups, dam age, calf sex and year.

[b] Correlation coefficients >.18 are significant (P < .05).

[c] Mean (SD) age at weaning was 230 (22) d.

[d] See Table 17 for abbreviations of weaning measures.

[e] See Table 13 for abbreviations of birth measures.

TABLE 20. RESIDUAL CORRELATIONS AMONG NEWBORN BODY MEASURES FOR CALVES AND DAMS[a,b]

	Dam measure[c]							
Calf measure[c]	BW	HC	HW	SW	BL	CC	CL	HG
BW	.27	.19	.26	.29	.20	.22	.16	.22
HC	.19	.16	.19	.28	.04	.18	-.03	.13
HW	.21	.16	.19	.20	.18	.16	.15	.24
SW	.23	.16	.23	.21	.16	.21	.12	.23
BL	.24	.11	.18	.18	.13	.20	.09	.11
CC	.10	.12	.16	.22	.09	.18	.05	.01
CL	.09	.07	.04	.08	.16	.03	.09	.04
HG	.34	.22	.28	.32	.17	.17	.16	.17

[a] Calf measures adjusted for dam age, calf sex, year and sire; dam measures adjusted for year.

[b] Correlation coefficients >.14 are significant ($P < .05$).

[c] See Table 13 for abbreviations of body measures.

TABLE 21. RESIDUAL CORRELATIONS AMONG NEWBORN BODY MEASURES FOR CALVES AND DAMS ADJUSTED FOR BIRTH WEIGHT[a,b]

	Dam measure[c]						
Calf measure[c]	HC	HW	SW	BL	CC	CL	HG
HC	.05	.01	.14	-.14	.05	-.19	-.04
HW	.02	-.01	-.03	.04	-.01	.06	.14
SW	0	.05	-.04	0	.06	-.01	.08
BL	-.08	-.04	-.08	-.05	.04	-.05	-.14
CC	.05	.05	.12	-.01	.10	-.02	-.13
CL	.01	-.06	-.03	.11	-.05	.05	-.05
HG	0	.02	.05	-.06	-.07	-.02	-.17

[a] Calf measures adjusted for dam age, calf sex, year, sire and birth weight; dam measures adjusted for year and birth weight.

[b] Correlation coefficients >.14 are significant (P < .05).

[c] See Table 13 for abbreviations of body measures.

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VITA

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ANALYSIS OF NEWBORN CALF BODY MEASUREMENTS AND RELATIONSHIP OF CALF SHAPE TO SIRE BREEDING VALUES FOR BIRTH WEIGHT AND CALVING EASE

by

Russell A. Nugent III

(ABSTRACT)

These studies were conducted to define calf body shape, to test for relationships between calf shape and sire expected progeny differences for birth weight (BWTEPD) and first-calf calving ease (CEEPD) and to evaluate the efficacy of calf shape as a selection criterion for reduction of calving difficulty. Birth weight (BW), head circumference (HC), hip width (HW), shoulder width, body length (BL), cannon circumference (CC), cannon length (CL) and heart girth (HG) were measured at birth on 1,016 calves sired by Angus, Polled Hereford and Simmental bulls.

In the Angus- and Polled Hereford-sired calves, sire effects were present for BW-adjusted residuals of CC. Additionally, HW, BL and HG residuals differed among half-sib groups for the Polled Hereford-sired calves. Thus, calf body measure differences independent of BW were in part attributable to sire. Multivariate factor analysis was used to identify underlying skeletal width and frame dimensions of calf shape in both breeds.

After adjustment of body measures for differences in BW, a positive relationship of BWTEPD with HC and CC and a

negative relationship between CEEPD and CC existed. Further adjustment for BWTEPD removed effects of CEEPD on CC. Thus, BWTEPD influenced calf shape independent of BW, but shape was not related to CEEPD independent of BWTEPD.

Simmental bulls were divergently selected on CEEPD relative to BWTEPD so that body measures of calves from sires whose progeny tended to be born with more or with less dystocia than expected from BWTEPD could be obtained. Differences in CL and CC at constant BW were in part attributable to sire. Underlying shape factors were similar to those of the other breeds. Sire BWTEPD was positively related to CC and HC independent of BW. However, a relationship between body measures and CEEPD existed only at constant BW and BWTEPD. Calf shape independent of BW was also not different among calves born unassisted and assisted.

Estimates of heritability, repeatability and birth to weaning relationships for each BW-residual body measure were generally not significant. Overall, sire BWTEPD was related to calf shape independent of BW. However, increases in skeletal dimensions were not related to either observed calving difficulty nor sire CEEPD independent of BW. Selection for reduced calving difficulty should not be based on calf body shape.