Asian-Aust. J. Anim. Sci.
Vol. 21, No. 5 : 640 - 647
May 2008
www.ajas.info

Growth- and Breed-related Changes of Fetal Development in Cattle*

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ABSTRACT : Breed differences in adult animals are determined during fetal development. If interventions are to be developed that influence growth of muscle and fat, it is important to know at which time during gestation breed differences appear and are fixed. The objective of this study was to characterize fetal development in cattle of different breeds. Pregnant cows of 4 cattle breeds with different growth impetus and muscularity were slaughtered under normal processing conditions and the fetuses were removed. German Angus, a typical beef cattle; Galloway, a smaller, environmentally resistant beef type; Holstein Friesian, a dairy type; and Belgian Blue, an extreme type for muscle growth were used. Fetuses of each breed were investigated at 3, 6, and 9 mo of gestation. Fetuses were weighed and dissected into carcass, organs, and muscles. Body fat weight was obtained using the Soxhlet extraction method. Fetal weight increased most rapidly in the third trimester of gestation mainly due to the accelerated muscle and fat deposition. The organ weight to body weight (BW) ratios decreased and the muscle and fat weight to BW ratios increased. At 3 mo of gestation, Galloway fetuses had the significantly smallest BW, half-carcass weight, leg weight, organ weight, muscle weight and shortest leg length. In contrast, Holstein fetuses had the significantly greatest BW, liver, kidney, and lung weights and significantly longest leg length among the 4 breeds, but no differences between Holstein Friesian and Belgian Blue were detected in half-carcass and leg weight. Indeed, Belgian Blue fetuses had the significantly greatest half-carcass weight, leg weight, and muscle weight at 9 mo of gestation, and Galloway had a significantly greater body fat to BW ratio than Holstein Friesian and Belgian Blue. These differences were not evident at 3 and 6 mo of gestation. These data show that the profound increase of tissue and organ weights occurred in later gestation in cattle fetuses even though breed differences were evident as early as 3 mo of gestation. Depending on the tissue of interest, impacting fetal growth likely needs to occur early in gestation before the appearance of breed-specific differences. (**Key Words :** Breed, Body Composition, Cattle, Fetal Growth, Gestation)

INTRODUCTION

Fetal growth and development is a complex process related to interactions among genetic potential, environmental factors, and nutrient supply. Fetal development essentially provides the template for postnatal growth characteristics of adult animal. Previously, Berg et al. (1978) studied the influence of genotype on growth patterns of muscle, fat, and bone in cattle fetuses, and found a distinct pattern of growth under appropriate nutrient supply and environmental conditions. Ferrell (1991) and Bellows et al. (1993) concluded that bovine fetal growth was primarily determined by genetic constraints imposed during fetal development but influenced by maternal factors.

Fetal body weight (BW) and its components, protein and fat, increase exponentially with gestational age in cattle (Prior and Laster, 1979; Robelin et al., 1991). Different growth patterns for BW, organs, muscles, and body fat, expressed relative to BW in cattle, were reported by Ferrel (1991) and Godfredson et al. (1991) and in sheep by Osgerby et al. (2002).

Any study in cattle concerning the effects on the embryo or fetus, must rely on the normal pattern of development as a basis for comparison. To understand the growth of cattle, especially the postnatal muscle and fat development, which influences the amount and quality of meat, a characterization of normal prenatal development of cattle is necessary. To date, extensive studies of fetal development in different cattle breeds have not been conducted. Differences in the development of organs and muscles in the fetus were expected between dairy and meat

* This study was supported by the Federal Ministry of Food, Agriculture, and Consumer Protection of Germany and the Agricultural Ministry of China (grant no. 26/2005-2006 “Adipogenesis”). The authors wish to thank Karola Marquardt for excellent technical assistance.
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Received May 22, 2007; Accepted November 11, 2007

Table 1. Number of samples per breed and age group

Breed	Month of gestation			
	3	6	9	Total
German Angus	5	5	6	16
Galloway	5	4	6	15
Holstein Friesian	5	6	6	17
Belgian Blue	6	5	7	18
Total	21	20	25	66

cattle. Furthermore, the muscle development in double muscled cattle compared with normal cattle is obvious at birth (Wegner et al., 2000). The exact time when these differences manifest themselves in development are not known. Therefore, the objective of the present study was to characterize the fetal growth of 4 different cattle breeds in the second and third trimester of gestation.

MATERIALS AND METHODS

Animals

All animals were reared and slaughtered according to German rules and regulations for animal care. The experiment was approved by the institutional authorities and by the responsible office of the County of Mecklenburg-Vorpommern, Germany. Sixty-six cows were artificially inseminated, fed and managed to meet their nutritional requirements. Fetuses of 4 cattle breeds with different muscle growth potential were used. The breeds represented German Angus, a typical beef cattle; Galloway, a smaller, environmentally resistant producer of beef; Holstein Friesian, a dairy type having significant beef characteristics; and Belgian Blue, an extreme type for muscle growth. Four to 7 fetuses of each breed were collected and studied at 3, 6, and 9 mo of gestation (Table 1).

Fetus dissection

Pregnant cows were slaughtered under normal processing conditions at 3 and 6 mo post-conception and fetuses were removed. Newborn calves were used for the 9 mo group. Fetuses were weighed and dissected into carcass, organs, muscles, and body fat. The fetal half-carcass was consistent to the half-carcass in slaughter animals, without head and tail. Body weight and the weights of half-carcass, fetal leg, liver, kidney, lung, heart, semitendinosus muscle, and biceps femoris muscle were recorded. Leg length was measured from the femoral head to the tarsal joint of the hind leg.

Body fat weight was defined as carcass fat, fat in organs, and fat in internal depots, and was determined individually after each respective tissue was ground and a sample of the ground tissue was analyzed in triplicate using the Soxhlet extraction method using petroleum ether as solvent and determined gravimetrically after evaporating the extracting solvent (AOAC, 2000). All weights of organs, muscles, and fat depots were related to BW (weight to BW ratio, %: W×100%/BW) to provide a weight independent comparison.

Statistics

Data were analyzed by ANOVA using the GLM procedure of SAS Windows (Version 8, 1999). Factors considered were gestational age and breed as well as gestational age×breed interaction. The test of significant differences was based on a significance level of p = 0.05. The used model was:

$$Y_{ijk} = \mu + B_i + A_j + BA_{ij} + e_{ijk}$$

where Y_{ijk} = dependent variable; μ = overall mean; B_i = effect of breed i (i = 1 to 4); A_j = effect of gestational age j (j = 1 to 3); BA_{ij} = effect of interaction; e_{ijk} = residual error. The least squares means were compared by use of the PDIFF statement. Differences between gestational age groups were not significant. The same appeared with the comparison between breeds for the small embryos. We assumed the variance differing between gestational age groups, naturally increasing with age. For the purpose of reducing this heteroscedasticity, we used single factor analyses and applied the logarithmic transformation to the independent variables for the comparison between gestational age groups.

RESULTS AND DISCUSSION

Body development

The BW, half-carcass, and leg weight showed a similar, continuous growth in all 4 breeds from 3 to 9 mo of gestation (Tables 2 and 3). The increase of body weight from 6 to 9 mo is about 3-fold greater than the increase from 3 to 6 mo. Previously, Prior and Laster (1979) reported that the growth of normally developing cattle fetus follows an exponential equation with a BW gain of 25 g/d up to 4 mo of gestation, and the maximal rate of BW gain of 352 g/d by 7.6 mo. The profound increases in fetal size and weight occur during the third trimester in cattle (Ferell, 1991; Orourke et al., 1991). McPherson et al. (2004) demonstrated that the growth of porcine fetuses and fetal tissues occurs at different rates during the gestation. Porcine fetus growth accelerates during late gestation. A similar result is also shown in ovine fetal growth by Osgerby et al. (2002).

In contrast to the other measured traits, the leg length increased linearly from 3 to 9 mo in all breeds studied (Table 3). Evans and Sack (1973) reported a linear increase of crown-rump length from 3 to 9 mo. Long bone and crown-anus length were considered the most predictable parameters for a given gestational age (Richardson et al.,

Table 2. Fetal body traits (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Body weight (kg) at gestation stage of				
German Angus	$0.22^{a,B}\pm0.04$	$8.70^{b}\pm1.41$	$34.17^{c,AB}\pm4.34$	14.36^{AB}
Galloway	$0.11^{a,A}\pm0.07$	$6.75^{b}\pm2.15$	$29.60^{c,A}\pm6.92$	12.15^{A}
Holstein Friesian	$0.32^{a,C}\pm0.03$	$8.81^{b}\pm1.05$	$41.00^{c,BC}\pm6.84$	16.71^{BC}
Belgian Blue	$0.24^{a,B}\pm0.05$	$8.39^{b}\pm1.55$	$46.34^{c,C}\pm6.28$	18.33^{C}
Total mean	0.22^{a}	8.16^{b}	37.78^{c}	
Half-carcass weight (kg) at gestation stage of				
German Angus	$0.06^{a,B}\pm0.01$	$2.77^{b,B}\pm0.45$	$8.51^{c,A}\pm1.06$	3.78^{AB}
Galloway	$0.03^{a,A}\pm0.02$	$1.98^{b,A}\pm0.73$	$8.38^{c,A}\pm2.21$	3.46^{A}
Holstein Friesian	$0.08^{a,C}\pm0.01$	$2.57^{b,AB}\pm0.36$	$11.17^{c,B}\pm2.27$	4.61^{B}
Belgian Blue	$0.07^{a,BC}\pm0.01$	$2.66^{b,AB}\pm0.57$	$14.01^{c,C}\pm2.64$	5.58^{C}
Total mean	0.06^{a}	2.49^{b}	10.52^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

Table 3. Fetal leg traits (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Leg weight (g) at gestation stage of				
German Angus	$12^{a,A}\pm3$	$874^{b,B}\pm141$	$3,099^{c,A}\pm459$	$1,328^{A}$
Galloway	$7^{a,A}\pm5$	$644^{b,A}\pm211$	$3,001^{c,A}\pm713$	$1,217^{A}$
Holstein Friesian	$19^{a,B}\pm4$	$851^{b,AB}\pm123$	$4,214^{c,B}\pm840$	$1,695^{B}$
Belgian Blue	$18^{a,B}\pm4$	$895^{b,B}\pm166$	$5,367^{c,C}\pm1,083$	$2,093^{C}$
Total mean	14^{a}	816^{b}	$3,920^{c}$	
Leg length (cm) at gestation stage of				
German Angus	$4.3^{a,B}\pm0.7$	$19.7^{b,BC}\pm1.4$	$32.7^{c,A}\pm1.9$	18.9^{AB}
Galloway	$3.2^{a,A}\pm0.8$	$17.1^{b,A}\pm1.6$	$33.3^{c,AB}\pm2.7$	17.9^{A}
Holstein Friesian	$5.6^{a,C}\pm0.7$	$21.3^{b,C}\pm1.7$	$38.5^{c,C}\pm3.3$	21.8^{C}
Belgian Blue	$4.6^{a,B}\pm0.6$	$19.2^{b,B}\pm1.1$	$36.4^{c,BC}\pm3.3$	20.1^{B}
Total mean	4.4^{a}	19.3^{b}	35.2^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

1991). Both leg and crown-rump lengths are measurements of bone growth, which is linear in cattle fetus. Different patterns between leg length and leg weight development implied that fetal weight and size are not coordinated during the gestation. A linear increase in fetal size suggests that the skeletal system and associated frame score of the animal is established early with development of bone.

Breed differences were noted for most body traits as early as 3 mo of gestation, yet more robustly at 9 mo (Tables 2 and 3). Galloway had the least BW, half carcass and leg weights and the significant shortest leg length at all gestational ages. At 3 mo, fetuses from Holstein Friesian had a significantly greater BW, half-carcass weight, leg weight, and leg length compared with German Angus and Galloway, respectively. Belgian Blue fetuses had significantly greater BW at 9 mo of gestation compared with German Angus and Galloway, respectively, but no significant difference was observed between Holstein Friesian and Belgian Blue. Before 6 mo of gestation, there were no significant differences in half-carcass weight and leg weight between Holstein Friesian and Belgian Blue, but fetuses from Belgian Blue had the significantly greatest half-carcass weight and leg weight among all investigated breeds at 9 mo of gestation. This result suggests that muscle tissue grew more rapidly in Belgian Blue than in the other breeds after 6 mo of gestation.

Our results support the findings of Reynolds et al. (1990), who reported that calves from large framed sire breeds had heavier BW at 6.5 mo of gestation and at birth than calves from medium-sized sire breeds. Also Ferrel (1991) showed that fetal weight of Brahman cattle at 7.7 mo was significantly smaller than Charolais. In contrast, Gore et al. (1994) reported that the BW of Angus and Chianina were not significantly different at 3.3 and 6.7 mo of gestation, and 1 mo after birth. In our study, cattle breeds with different postnatal growth impetus and muscularity had significant differences in body traits as early as 3 mo of gestation, and these differences were maintained at birth.

Organ development

Comparable to the body weights, the organ weights showed a similar, continuous growth pattern from 3 to 9 mo of gestation (Table 4). Increase of liver, lung, and heart weights from 6 to 9 mo was 2- to 3-fold greater than the increase from 3 to 6 mo. The kidney weight increased, in contrast to the other organs, linearly throughout the gestation from 3 to 9 mo. This is the first report of such data in cattle. Richardson et al. (1991) reported Jersey fetuses

Table 4. Fetal organ weights (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Liver weight (g) at gestation stage of				
German Angus	$8.5^{a,B}$±2.40	$251.0^{b,B}$±35.0	$642.2^{c,B}$±75.5	300.6^{B}
Galloway	$4.1^{a,A}$±2.6	$176.0^{b,A}$±45.9	$481.0^{c,A}$±86.1	220.4^{A}
Holstein Friesian	$11.6^{a,C}$±0.8	$256.8^{b,B}$±43.3	$832.7^{c,C}$±155.0	367.0^{C}
Belgian Blue	$8.6^{a,B}$±2.0	$251.4^{b,B}$±48.2	$831.3^{c,C}$±132.6	363.7^{BC}
Total mean	8.2^{a}	233.8^{b}	696.8^{c}	
Kidney weight (g) at gestation stage of				
German Angus	$2.4^{a,B}$±0.4	$61.6^{b,A}$±12.8	$118.3^{c,A}$±13.6	60.8^{B}
Galloway	$1.0^{a,A}$±0.7	$55.0^{b,A}$±12.7	$113.7^{c,A}$±15.8	56.6^{A}
Holstein Friesian	$3.2^{a,C}$±0.8	$84.5^{b,B}$±14.9	$161.8^{c,B}$±25.5	83.2^{C}
Belgian Blue	$2.4^{a,B}$±0.6	$73.8^{b,AB}$±22.4	$154.1^{c,B}$±16.9	76.8^{BC}
Total mean	2.3^{a}	68.7^{b}	137.0^{c}	
Lung weight (g) at gestation stage of				
German Angus	$7.0^{a,B}$±2.6	$217.4^{b,B}$±44.0	$950.5^{c,B}$±87.2	391.6^{C}
Galloway	$3.7^{a,A}$±2.0	$166.8^{b,A}$±34.9	$545.7^{c,A}$±184.5	238.7^{A}
Holstein Friesian	$11.5^{a,C}$±2.0	$235.3^{b,B}$±29.2	$706.2^{c,A}$±94.8	317.7^{B}
Belgian Blue	$7.9^{a,B}$±1.9	$210.6^{b,AB}$±33.1	$908.6^{c,B}$±178.7	375.7^{BC}
Total mean	7.5^{a}	207.5^{b}	777.7^{c}	
Heart weight (g) at gestation stage of				
German Angus	$1.7^{a,AB}$±0.6	$61.4^{b,AB}$±5.7	$216.8^{c,A}$±33.2	93.3^{AB}
Galloway	$1.0^{a,A}$±0.8	$52.0^{b,A}$±14.1	$204.7^{c,A}$±44.3	85.9^{A}
Holstein Friesian	$2.8^{a,C}$±0.5	$71.2^{b,B}$±13.3	$274.5^{c,B}$±25.8	116.1^{C}
Belgian Blue	$2.2^{a,BC}$±0.3	$59.4^{b,AB}$±8.5	$264.0^{c,B}$±38.8	108.5^{BC}
Total mean	1.9^{a}	61.0^{b}	240.0^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

had accelerated kidney growth after 4.7 mo, which is in conflict with our findings. Although the exact reason for this discrepancy is not known, the fact that we observed the same result in 4 different cattle breeds gives credence to our results.

For liver and heart growth, Godfredson et al. (1991) showed an accelerated growth in cattle fetus in the third stage of gestation, which agrees with our results. These findings for cattle were also similar to other livestock animals such as pig and sheep. In pig, McPherson et al. (2004) showed fetal liver, lung, heart, and kidney weights increased cubically with gestation. Similar results were reported by Osgerby et al. (2002) in ovine fetus.

Breed differences were found for liver, kidney, lung, and heart weights in all gestation stages (Table 4). Galloway had the significant smallest organ weights, and Holstein Friesian had the significant greatest organ weights at 3 mo of gestation. Galloway maintained small organ weights at all gestation stages. At 9 mo of gestation, Holstein Friesian and Belgian Blue had nearly double liver weights compared to Galloway. German Angus liver weights were significantly smaller than Holstein Friesian and Belgian Blue, but significantly greater than Galloway at 9 mo of gestation. Kidney and heart weights were significantly smaller in German Angus and Galloway than in Holstein Friesian and Belgian Blue at 9 mo of gestation.

Ferell (1991) observed significant differences in liver, lung, heart, and kidney weights between Brahman and Charolais fetuses at 7.6 and 9 mo of gestation. Gore et al. (1994) reported that most fetal organs weights were not different between Angus and Chianina at 3.3, 6.7 mo of gestation, and 1 mo after birth.

Generally, organ weight to BW ratios for all organs in this study significantly decreased with gestation (Table 5). Whereas the liver to BW ratios for all cattle breeds decreased continuously from 3 to 9 mo of gestation, the kidney weight to BW ratio remained constant in Galloway, Holstein Friesian, and Belgian Blue from 3 to 6 mo of gestation. This demonstrates a rapid growth of kidney during this period. Furthermore, the kidney weight to BW ratio significantly decreased in German Angus from 3 to 9 mo and in the other breeds from 6 to 9 mo of gestation. Heart weight to BW ratio in Belgian Blue decreased more rapidly than in the other 3 breeds from 3 to 6 mo, indicating that relative to fetal growth, heart development was different between breeds in early gestation. The lung weight to BW ratios significantly decreased in all breeds from 3 to 6 mo of gestation, except in Belgian Blue. In Galloway and Holstein, the lung weight to BW ratios significantly decreased also from 6 to 9 mo, but did not in German Angus. A continuous decrease of organ weight to BW ratios was also reported in different cattle breeds by Ferell (1991) and Gore et al. (1994). In pigs, McPherson et al. (2004) and Town et al. (2005) reported that fetal liver growth occurs

Table 5. Fetal organ weights to BW ratios (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Liver ratios (%) at gestation stage of				
German Angus	$3.89^{a,B}$±0.34	$2.90^{b,AB}$±0.14	$1.88^{c,AB}$±0.10	2.89^{B}
Galloway	$3.64^{a,AB}$±0.21	$2.64^{b,A}$±0.25	$1.68^{c,A}$±0.38	2.65^{A}
Holstein Friesian	$3.69^{a,AB}$±0.23	$2.90^{b,AB}$±0.18	$2.05^{c,B}$±0.35	2.88^{B}
Belgian Blue	$3.49^{a,A}$±0.08	$2.99^{b,B}$±0.17	$1.79^{c,A}$±0.10	2.76^{AB}
Total mean	3.68^{a}	2.85^{b}	1.85^{c}	
Kidney ratios (%) at gestation stage of				
German Angus	$1.12^{a,B}$±0.20	$0.71^{b,A}$±0.08	0.35^{c}±0.06	0.72
Galloway	$0.88^{a,A}$±0.28	$0.84^{a,AB}$±0.17	0.40^{b}±0.08	0.70
Holstein Friesian	$1.04^{a,AB}$±0.26	$0.96^{a,B}$±0.11	0.40^{b}±0.05	0.80
Belgian Blue	$0.98^{a,AB}$±0.12	$0.87^{a,AB}$±0.11	0.34^{b}±0.04	0.73
Total mean	1.00^{a}	0.84^{b}	0.37^{c}	
Lung ratios (%) at gestation stage of				
German Angus	3.18^{a}±0.65	2.49^{b}±0.23	$2.80^{ab,B}$±0.30	2.82
Galloway	3.32^{a}±0.52	2.53^{b}±0.23	$1.84^{c,A}$±0.37	2.56
Holstein Friesian	3.65^{a}±0.51	2.68^{b}±0.20	$1.75^{c,A}$±0.29	2.69
Belgian Blue	3.25^{a}±0.49	2.54^{a}±0.40	$2.00^{b,A}$±0.49	2.59
Total mean	3.35^{a}	2.56^{b}	2.10^{c}	
Heart ratios (%) at gestation stage of				
German Angus	$0.77^{a,A}$±0.13	0.72^{ab}±0.07	$0.64^{b,AB}$±0.06	0.71^{A}
Galloway	0.79^{A}±0.16	0.78±0.08	0.70^{B}±0.10	0.76^{AB}
Holstein Friesian	$0.87^{a,AB}$±0.11	0.80^{a}±0.63	$0.68^{b,AB}$±0.08	0.78^{B}
Belgian Blue	$0.91^{a,B}$±0.14	0.72^{b}±0.09	$0.57^{c,A}$±0.05	0.73^{AB}
Total mean	0.83^{a}	0.75^{b}	0.65^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

rapidly in the early stages of gestation and slows as fetal growth progresses. Rapid liver growth is most likely related to erythropoietic function within the liver during early gestation (Reece, 1997). In sheep, Osgerby et al. (2002) showed a different increase from 45 to 135 days in the liver, heart, lung, and kidney weight to BW ratios. Because comparison among different organs involves several different tissue types, coordinated organ growth cannot be expected, as observed for the other parts of body, such as muscle and bone (Gore et al., 1994).

Breed differences for the organ weight to BW ratios were rather small and not consistent during gestation. Liver weight to BW ratio in German Holstein at 9 mo of gestation was significantly greater than in Belgian Blue and Galloway, and similar in German Angus. No significant differences among the breeds were found for kidney at 9 mo, for lung at 3 and 6 mo, and for heart at 6 mo of gestation.

In the current study, different organ weights, occurred among certain breeds at 3 mo of gestation and maintained to birth. Regarding organ weight to BW ratios, the relationships among breeds show a large variation during gestation, indicating different growth patterns. These results were also found by Gore et al. (1994), who demonstrated that no clear relationship to breeds was observed for organ weight to BW ratios. Organ growth is influenced by breed, but interestingly not by the type of cattle (dairy or beef). The heavier liver in Holstein Friesian and Belgian Blue and the greater liver weight to BW ratio in Holstein Friesian indicate the higher metabolism of these high productivity breeds. According to that, Pfuhl et al. (2007) reported a greater weight of liver in adult Holstein Friesian compared to Charolais.

Muscle and fat development

Muscle weight increased between 214-fold in semitendinosus muscle of German Angus and 483-fold in biceps femoris muscle of Galloway from 3 to 9 mo of gestation (Table 6). Semitendinosus and biceps femoris muscle weights increased in the same manner as body traits and organs in this study. Fetal muscle growth was influenced by breed, gestational age, and their interaction during the fetus development. Galloway had the significantly smallest semitendinosus weight at 3 mo of gestation, and remained small at all gestation stages. Fetuses from Belgian Blue had the significantly greatest semitendinosus and biceps femoris muscle weights at 9 mo of gestation. Between Galloway and Belgian Blue differences remain significant from 3 to 9 mo of gestation. Deveaux et al. (2001) showed differences in semitendinosus muscle weight in Holstein Friesian and Belgian Blue fetuses on 3.3 mo of gestation. In our study no significant differences were found between the 2 breeds in semitendinosus muscle weight at 3 and 6 mo of gestation. Godfredson et al. (1991) reported similar weights for biceps

Table 6. Muscle weights (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Semitendinosus muscle weight (g) at gestation stage of				
German Angus	$0.5^{a,B}\pm0.1$	$31.2^{b,AB}\pm5.5$	$107.2^{c,AB}\pm24.4$	46.3^{A}
Galloway	$0.3^{a,A}\pm0.1$	$22.8^{b,A}\pm8.2$	$97.5^{c,A}\pm26.8$	40.2^{A}
Holstein Friesian	$0.7^{a,B}\pm0.1$	$29.7^{b,AB}\pm5.9$	$150.7^{c,B}\pm41.6$	60.3^{A}
Belgian Blue	$0.6^{a,B}\pm0.2$	$34.4^{b,B}\pm6.7$	$224.4^{c,C}\pm65.2$	86.5^{B}
Total mean	0.5^{a}	29.5^{b}	144.9^{c}	
Biceps femoris muscle weight (g) at gestation stage of				
German Angus	$1.3^{a,AB}\pm0.2$	$91.4^{b,AB}\pm17.7$	$324.8^{c,A}\pm56.3$	139.2^{A}
Galloway	$0.7^{a,A}\pm0.6$	$70.8^{b,A}\pm27.6$	$337.8^{c,A}\pm98.0$	136.4^{A}
Holstein Friesian	$1.9^{a,B}\pm0.4$	$87.8^{b,AB}\pm10.2$	$421.5^{c,A}\pm107.1$	170.4^{A}
Belgian Blue	$1.8^{a,B}\pm0.7$	$106.4^{b,B}\pm22.1$	$669.1^{c,B}\pm203.1$	259.1^{B}
Total mean	1.4^{a}	89.1^{b}	438.3^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

Table 7. Muscle weight to BW ratios (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Semitendinosus muscle ratios (%) at gestation stage of				
German Angus	$0.23^{a}\pm0.01$	$0.36^{b,AB}\pm0.02$	$0.31^{c,A}\pm0.04$	0.30^{A}
Galloway	$0.23^{a}\pm0.05$	$0.34^{b,A}\pm0.02$	$0.33^{b,A}\pm0.02$	0.30^{A}
Holstein Friesian	$0.21^{a}\pm0.01$	$0.33^{b,A}\pm0.03$	$0.36^{b,A}\pm0.05$	0.31^{A}
Belgian Blue	$0.26^{a}\pm0.03$	$0.41^{b,B}\pm0.02$	$0.48^{b,B}\pm0.11$	0.38^{B}
Total mean	0.23^{a}	0.36^{b}	0.37^{b}	
Biceps femoris muscle ratios (%) at gestation stage of				
German Angus	$0.59^{a}\pm0.02$	$1.05^{b,A}\pm0.11$	$0.95^{b,A}\pm0.08$	0.86^{A}
Galloway	$0.59^{a}\pm0.16$	$1.04^{b,A}\pm0.06$	$1.13^{b,B}\pm0.22$	0.92^{A}
Holstein Friesian	$0.60^{a}\pm0.09$	$1.00^{b,A}\pm0.03$	$1.02^{b,AB}\pm0.13$	0.87^{A}
Belgian Blue	$0.73^{a}\pm0.13$	$1.27^{b,B}\pm0.06$	$1.43^{b,C}\pm0.35$	1.14^{B}
Total mean	0.63^{a}	1.09^{b}	1.14^{b}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

femoris muscle in Hereford fetuses. Muscle development is related to the differentiation of muscle fibers in the fetus. Gerrard and Judge (1993) found greater muscle fiber number in the semitendinosus muscle of double muscled compared to normal muscled fetuses. In our former study (Wegner et al., 2000), the greater muscle fiber number was confirmed for newborn Belgian Blue in comparison to German Angus, Galloway, and Holstein Friesian. Fahey et al. (2005) reported that the majority of muscle fiber formation takes place after mid pregnancy in sheep. Results of this study indicate that muscle development in bovine fetuses is later than organs, and the increase in the muscle weight made a considerable contribution to the increase of BW in later gestation.

Muscle weight to BW ratios (Table 7) significantly increased from 3 to 6 mo, and remained constant from 6 to 9 mo of gestation. Muscle weight to BW ratios exhibited growth patterns different to those of organs. The semitendinosus and biceps femoris muscle weight to BW ratios were significantly greater in Belgian Blue at 6 and 9 mo compared to the other three breeds. At 3 mo of gestation no significant differences appeared among breeds in both muscles. Gore et al. (1994) reported greater muscle weight to BW ratios for late maturing type of cattle (Chianina) than for those early maturing types (Angus) at 3.3 and 6.7 mo of gestation and suggested that muscle growth patterns differ by genotype as early as 3.3 mo of gestation. In our study breed differences appeared from 6 mo of gestation onwards.

Body fat weight increased from 3 to 9 mo of gestation in the same manner observed for body traits, organs, and muscles in this study (Table 8). Fetal body fat weight at 3 mo of gestation was greatest in Holstein Friesian, but significant differences were not found at 6 or 9 mo in any cattle breed. In contrast to muscle weight to BW ratios, fat weight to BW ratios (Table 9) significantly increased throughout gestation. The continuous increase indicates that fat accretion in the fetus accelerates later in gestation. Until 6 mo of gestation, the body fat to BW ratios were not significantly different across breeds. At 9 mo of gestation, Galloway had significantly higher body fat to BW ratio than Holstein Friesian and Belgian Blue, respectively; and Belgian Blue also had significantly lower fat to BW ratio than German Angus. Previously, Prior and Laster (1979) reported that body fat weight increased exponentially with day of gestation, and fat accretion did not reach a maximal rate during the gestation period in cattle. In pigs, McPherson et al. (2004) reported fetal body fat gain was 0.06 g/d before 69 d of gestation and increased to 1.09 g/d

Table 8. Body fat weights (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Body fat weight (g) at gestation stage of				
German Angus	$0.4^{a,A}$±0.2	72.2^{b}±23.4	426.7^{c}±115.0	166.4
Galloway	$0.2^{a,A}$±0.2	56.3^{b}±34.1	406.7^{c}±192.5	154.4
Holstein Friesian	$0.7^{a,B}$±0.2	63.7^{b}±19.9	436.7^{c}±173.6	167.0
Belgian Blue	$0.3^{a,A}$±0.1	55.4^{b}±13.8	437.1^{c}±81.2	164.3
Total mean	0.4^{a}	61.9^{b}	426.8^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

Table 9. Body fat weight to BW ratios (LSM±SD) in cattle of different breeds during various stages of gestation

Breed	3 month	6 month	9 month	Total mean
Body fat ratios (%) at gestation stage of				
German Angus	0.19^{a}±0.08	0.84^{b}±0.24	$1.26^{c,BC}$±0.37	0.76^{B}
Galloway	0.15^{a}±0.09	0.79^{b}±0.21	$1.33^{c,C}$±0.41	0.76^{B}
Holstein Friesian	0.21^{a}±0.07	0.71^{b}±0.15	$1.05^{c,AB}$±0.34	0.66^{AB}
Belgian Blue	0.13^{a}±0.03	0.66^{b}±0.10	$0.95^{c,A}$±0.18	0.58^{A}
Total mean	0.17^{a}	0.75^{b}	1.15^{c}	

Values with different superscripts within a row (a-c) or column (A-C) differ significantly ($p<0.05$).

after 69 d of gestation. In present study, differences of fat weight to BW ratios at 9 mo indicate that during gestation the basis is established for the lower fat accretion in Belgian Blue, and the greater fat accretion in Galloway. No additional information exists in the literature regarding breed-related differences in fetal fat.

IMPLICATIONS

The results of the present study show breed differences in body weight, organ, muscle, and body fat weight in the second and third trimester of gestating cattle. Obviously, the greatest increase in all tissues and organs occurred in the third trimester. The weight to body weight ratios for organs decreased, while these of body fat increased continuously from 3 to 9 mo of gestation. Muscle weight to body weight ratios increased in the second trimester and remained constant during the third trimester. Cattle breeds with postnatal different growth impetus and muscularity show differences in fetal development, especially in muscle tissue deposition and development. Fetuses from large framed breeds had greater birth weights, which originated from greater muscle development already at 3 mo of gestation.

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