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Introduction

Fetal growth, as indicated by birth weight, has important influences on animal production. Birth weights lower than optimum are associated with reduced energy reserves, lowered thermoregulatory capability, and increased calf deaths at or near birth. In addition, low birth weights are related to low rates of growth after birth and decreased mature size. Conversely, birth weights greater than optimum are associated with greater calving difficulty. Primarily because of the increased calving difficulty, calf losses at birth and difficulties if rebreeding the cow are increased.

Fetal growth, hence birth weight, is influenced by numerous factors including number of fetuses, sex, parity or age of the cow, breed of sire, breed of dam, heat or cold stress, and nutrition. The importance of these and other effectors of fetal growth vary. In general, however, birth weight of each fetus decreases with increased numbers of fetuses, is greater for males than for females, and increases with age or parity of the cow. Birth weights are decreased by heat or inadequate nutrition, and increased by cold. Both the sire and dam contribute to differences in genetic potential for growth, but it is evident that the dam exerts an influence beyond her contribution to fetal genotype.

It is important to know what the factors are that affect fetal growth and their potential magnitude. In order to minimize adverse effects of factors influencing fetal growth, it is perhaps more important to understand how and why differences in fetal growth and birth weight occur. The following sections will summarize several experiments conducted to develop a better understanding of some of the major factors affecting fetal growth.

Experimental Procedures and Results

Experiment 1. The purpose of this study was, in part, to determine the influence of nutritional status of cows of different breeds on calf birth weight. Mature Angus, Braunvieh, Charolais, Gelbvieh, Hereford, Limousin, Pinzgauer, Red Poll, and Simmental cows were fed individually in dry lot for four years. Four cows of each breed were fed a ground alfalfa hay based diet at each of four feed levels (low=130, medium=170, high=210, and very high=250 kcal metabolizable energy per kilogram initial body size). Feed levels were adjusted upward during lactation to maintain body weight. Cows were bred to bulls of the same breed during a 90-day breeding season each year. Cows were calved on pasture and returned to the drylot barns within 14 days after calving. Calves were weighed within 24 hr after birth.

Calf birth weights differed substantially among the nine breeds of cattle (Table 1). Average weights were: Angus 76.2 lb, Braunvieh 111.7 lb, Charolais 104.2 lb, Gelbvieh 94.9 lb, Hereford 79.5 lb, Limousin 92.4 lb, Pinzgauer 102.8 lb, Red Poll 82.1 lb, and Simmental 106.2 lb. Observed birth weights were similar to those reported from the much larger Germplasm Utilization Project for these breeds of cows. Weights of calves from cows on the low feed level averaged 86.3 lb, whereas those from the medium, high, and very high averaged 96.9, 96.1, and 98.4 lb, respectively. Nutritional effects were much less than the breed effects and were, in general, larger in magnitude in breeds having larger calves. It is suggested that low levels of maternal nutrition may result in reduced birth weight, but nutritional levels above adequate result in no further increase.

Experiment 2. The purpose of this study was to determine rates of energy and nutrient use by the fetus and uteroplacenta (uterus + placenta) and to determine how these variables change as gestation advances. Mature Hereford cows were fed a corn silage based diet to maintain body weight and were bred to Simmental bulls. Catheters were surgically implanted in a uterine artery, a uterine vein, a fetal artery and vein, and an umbilical vein on 132, 176, 220, or 245 days after mating. Rate of maternal blood flow to the uterus (uterine blood flow) was determined four to six days after surgery. Concentrations of oxygen, glucose, lactate, and alpha-amino nitrogen (AAN, a measure of total amino acids) in samples from the uterine arterial (A) and venous (V), umbilical venous (v), and fetal arterial (a) catheters. Concentration differences (A-V and v-a) were calculated. Net uterine uptake of each metabolite was calculated as uterine blood flow X A-V and net fetal uptake was calculated as umbilical blood flow X v-a. Uteroplacental uptake was calculated as uterine-fetal uptake.

Uterine blood flow increased about 4.5-fold during the interval from 137 to 250 days, whereas umbilical blood flow increased 21-fold during this interval (Table 2). Neither metabolite concentrations nor concentration differences changed during this interval. It is important to note, however, that umbilical venous oxygen concentration was 67% of uterine arterial concentration (4.25 vs 6.36 mM), and umbilical glucose concentration was 48% of uterine arterial glucose. Conversely, umbilical AAN was 169% of uterine arterial concentrations. These results agree with data reported previously indicating oxygen and glucose are transported to the fetus by "facilitated diffusion." Amino acids are transported by active transport mechanisms. As a result, the fetus is less susceptible to changes in amino acids (protein) than to changes in oxygen or glucose.

Since neither metabolite concentrations nor concentration differences changed during gestation, changes in net uptake of those metabolites during gestation (Table 3) primarily reflect changes in uterine and umbilical blood flows. Net oxygen, glucose, and AAN uptakes by both the gravid uterus and fetus increased several fold during this interval of gestation, but fetal uptakes increased more rapidly than gravid uterine uptakes. Proportions used by the fetus generally increased over time, but the fetus used only 20 to 55% of oxygen, 3.5 to 17% of glucose, and 35 to 78% of AAN taken up by the gravid uterus. The difference was used by uteroplacental tissues. These results indicate a very high rate of nutrient and energy use by uterine and placental tissues, especially during earlier stages of gestation.

Experiment 3. This study was designed to evaluate the effects of chronic environmental heat stress on gravid uterine and fetal metabolism. Mature Hereford cows were bred to Simmental bulls, then assigned to control or heat stress treatments on day 100 of gestation. Control cows were maintained in a barn at 60 degrees and heated cows were maintained at 97 degrees, 50% relative humidity for 12 hr and 82 degrees, 50% relative humidity for 12 hours. All

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cows were fed a corn silage based diet to maintain maternal body weight. Catheters were surgically implanted (day 163) as described for Experiment 2. Uterine and umbilical blood flows and nutrient uptakes were determined as described on day 170. Fetuses were surgically removed on day 174.

Fetal weights (Table 4) were reduced 18% by the heat treatment. Uterine and umbilical blood flows were reduced 34% and 23%, respectively. Reduced uterine blood flows were likely a result of increased blood flow to the lungs and skin to facilitate heat dissipation. Neither metabolite concentrations nor concentration differences differed much between control and heated cows. Gravid uterine, fetal and uteroplacental uptakes of all metabolites (Table 5) were reduced in heated cows. The results indicated that metabolism of uteroplacental tissues was more adversely affected than was the fetus.

Experiment 4. The purpose of this study was to determine the effects of cow breed and number of fetuses on gravid uterine and fetal metabolism. Mature Charolais (bred to Charolais bulls) and Hereford cows (bred to Gelbvieh bulls) carrying either single or twin fetuses were used. Catheters were implanted (day 177) into each fetus and gravid uterine horn and measurements were made (day 183) as previously described.

Uterine blood flow was about 50% greater in Charolais (7.07 liter/min) than in Hereford (4.80 liter/min) cows (Table 6). Uterine blood flow per fetus was reduced about 20% in both Hereford cows carrying twin as compared to single fetuses. These findings indicated those breeds of cows responded similarly to twin pregnancies. They also showed that the difference due to cow breed was larger than the difference due to twins. Umbilical blood flows were similar in Charolais (1.17 liter/min) and Hereford (1.23 liter/min) cows. This result likely reflects similarity in fetal size at this stage of gestation. The ratio of umbilical to uterine blood flows for Hereford (.256) was greater than for Charolais (.166) cows. This observation indicates a greater potential for maternal constraint of fetal growth in late gestation in Hereford than in Charolais cows. Averaged across all cows, umbilical blood flow per twin fetus was reduced about 20% as compared to single fetuses, but the reduction appeared to be greater in Hereford cows. Other MARC data indicated birth weights of Charolais calves were about 24% heavier than Hereford calves. Calves born as singles were 16% heavier than calves born as twins, when weights were adjusted to equal gestation length, but the difference was about 24% when data were not adjusted. As in previous studies, net metabolite uptakes primarily reflected differences in blood flows (data not shown).

Experiment 5. The purpose of this study was to quantify maternal and paternal influences on rates of nutrient supply to uteroplacental tissues and the fetus. Mature, multiparous Gelbvieh and Pinzgauer cows mated to either Charolais or Longhorn bulls were used. Catheters were implanted (day 220) and measurements were made (days 227 and 241) as described for Experiment 2.

Both uterine (36%) and umbilical (26%) blood flows (Table 7) were greater in cows with Charolais-sired than in those with Longhorn-sired fetuses. Uterine blood flows were 18% greater in Pinzgauer than in Gelbvieh cows, but did not measurably change from 227 to 241 days. Umbilical blood flow was similar in Gelbvieh and Pinzgauer cows, but increased from 227 to 241 days. Oxygen uptakes by gravid uterine tissues were about 30% greater in Pinzgauer than in Gelbvieh, but fetal uptakes were similar. These data indicated greater rates of metabolism of uterine and placental tissues in Pinzgauer than in Gelbvieh cows. Uterine and fetal oxygen uptakes were greater in cows with Charolais-sired than in cows with Longhorn-sired fetuses. In total, these data indicated that uterine blood flow, hence nutrient to the gravid uterus and placental metabolic activity, was influenced by growth potential of the fetus as well as cow breed.

Experiment 6. Objectives of this experiment were to evaluate maternal and fetal influences on growth and metabolism of gravid uterine tissues of the cow. Brahman cows with Brahman or Charolais fetuses and Charolais cows with Brahman or Charolais fetuses (these combinations were produced by embryo transfer) were used. Catheters were surgically implanted in half of the cows at 220 days and measurements were taken at 227 days as described previously. Those cows were killed at 232 days of gestation. The other half of the cows were killed at 271 days after mating. Weights of fetuses and uteroplacental tissues were determined at slaughter.

Uterine blood flow in Brahman cows at 232 days was not affected by fetal breed (avg 4.8 liters/min, Table 8), even though Charolais fetuses weighed nearly twice as much as Brahman fetuses (Table 9). Uterine blood flow in Charolais cows was much greater than in Brahman cows. In addition, uterine blood flow in Charolais cows was greater (29%) when they were carrying Charolais fetuses than when they were carrying Brahman fetuses. These observations suggest that Brahman and Charolais cows responded differently to stimuli from the fetus or conceptus and that as a result, maternal perfusion of the uteroplacental tissues differed substantially. Umbilical blood flow was 68% greater for Charolais than for Brahman fetuses. This value was similar to the 77% difference in fetal weight. These results suggest that umbilical blood flow primarily reflected fetal weight.

Fetal oxygen uptakes paralleled fetal weight and umbilical blood flows. However, oxygen use by uteroplacental tissues did not reflect fetal, uterine or placentome weight. Further, the low oxygen use by uteroplacental tissues in Brahman cows with Charolais fetuses indicated oxidative metabolism by those tissues was substantially reduced in those groups. In contrast, glucose uptakes were greatest for Charolais fetuses in Charolais cows, intermediate for Charolais fetuses in Brahman cows, and least for Brahman fetuses. Uteroplacental glucose use was greater for Charolais than for Brahman fetuses, but not substantially altered by cow breed. These results may be interpreted to indicate that the fetus had higher priority for oxygen, but that the uteroplacenta had higher priority for glucose. The pattern of AAN use by fetuses was similar to that of glucose, but a much higher proportion was degraded for use as an energy substrate to compensate for the low glucose uptake by Charolais fetuses in Brahman cows (data not shown). Overall, the data indicated that both fetal and uteroplacental metabolism was altered a great deal, especially in the Brahman cows with Charolais fetuses, presumably to compensate for the low uterine blood flow and the resulting low rates of nutrient delivery to the gravid uterine tissues.

The influence of both cow and fetal breed on fetal growth is shown in Table 9. At 232 days, fetal weight was clearly affected by fetal breed but not by cow breed. During the ensuing 39 days, however, Charolais fetuses in Charolais cows gained 1.38 lb/day whereas fetuses of the same breed in Brahman cows gained only .58 lb/day. It is evident that in this comparison, fetal growth was constrained in the Brahman cow. Similarly, Brahman fetuses gained .99 lb/day in Charolais cows but .70 lb/day in Brahman cows. This result suggests that fetal growth may be limited by the maternal system, even in the "normal" situation.

Discussion

It is evident from the information presented, as well as from other information available, that the primary contributor to differences in fetal growth is fetal genotype, which consists of contributions from both the sire and dam. In essence, fetal genotype determines the maximum potential for fetal growth. However, it may be argued that the fetus rarely expresses its full genetic potential for growth. The cow, through her "uterine environment," may limit fetal growth to varying degrees as shown in Experiment 6. As a result, the cow's contributions to fetal growth and birth weight extend beyond her contribution to fetal genotype. Numerous other factors including maternal nutrition, number of fetuses, and environmental temperature may cause further limitation of fetal growth. These effects are most apparent during the latter stages of gestation when fetal growth rate and nutrient needs are the greatest.

The effects of many of the factors affecting fetal growth appear to be mediated, either directly or indirectly, through the nutritional status of the fetus. In this regard, nutrient availability to the fetus may be altered by nutritional status of the mother, or by other factors such as the maternal uterine environment, heat stress or increased numbers of fetuses. Uterine blood flow and function of the uterus and placental tissues appear to be major factors involved, because they are responsible for nutrient delivery to the gravid uterus and to the fetus. Uterine blood flow and function of the uterus and placenta are affected by various "external" factors such as environmental temperature; the amount of change depends on the nature, severity, duration, and timing of external stress. They are also affected by several "internal" factors such as the fetal genetic potential for growth, number of fetuses, and the cow's ability to respond to fetal needs. It is evident that the ability of the cow to respond to fetal stimuli is also under genetic control. What the primary signals from the fetus are and what mediates the cow's response to those signals are not known.

Table 1—Influence of breed and cow nutritional status on calf birth weight (lb)

	Nutritional level			
Breed	Low	Medium	High	Very high
Angus	71.4	78.3	80.7	74.3
Braunvieh	98.1	106.7	127.9	114.0
Charolais	82.0	105.6	106.3	122.8
Gelbvieh	86.6	98.8	95.7	98.5
Hereford	75.0	84.4	78.9	79.8
Limousin	86.6	93.5	94.8	94.8
Pinzgauer	100.3	113.8	93.7	103.4
Red Poll	79.8	86.4	81.4	80.7
Simmental	97.0	104.3	105.6	117.7

Table 2—Uterine and umbilical blood flows at different stages of gestation

	Day of gestation			
	137	180	226	250
Uterine blood flow, liter/min	2.92	4.78	8.75	13.18
Umbilical blood flow, liter/min	0.28	1.07	2.79	5.86

Table 3—Net uptakes of metabolites by the gravid uterus and fetus at different stages of gestation[a]

		Day of gestation			
		137	180	226	250
Oxygen	Gravid uterus	2.02	3.13	7.15	12.53
	Fetus0.40	1.50	4.18	6.92	
Glucose	Gravid uterus	0.57	0.84	1.38	2.60
	Fetus	0.02	0.10	0.24	0.42
AAN[b]	Gravid uterus	0.66	1.35	3.22	6.59
	Fetus	0.33	0.41	2.54	2.35

[a] mmol/min.
[b] AAN = alpha-amino nitrogen.

Table 4—Blood flow of the gravid uterus and fetus in control and heated cows

	Fetal	Total blood flow, liter/min	
Treatment	weight, lb	Uterine	Umbilical
Control	13.2	6.2	1.3
Heated	10.8	4.1	1.0

Table 5—Uptakes of metabolites by the gravid uterus, fetus, and uteroplacenta of control and heat stressed cows[a]

Metabolite	Treatment	Gravid uterus	Fetus	Uteroplacenta
Oxygen	Control	4.37	1.82	4.22
	Heated	3.59	1.42	2.16
Glucose	Control	1.20	0.17	1.52
	Heated	0.66	0.06	0.58
AAN[b]	Control	1.68	1.50	1.97
	Heated	-.22	0.61	-.54

[a] Mmol/min.
[b] AAN = alpha-amino nitrogen.

Table 6—Uterine and umbilical blood flows in Charolais and Hereford cows bearing single or twin fetuses

	Type of	Blood flows, liter/min/fetus	
Cow breed	pregnancy	Uterine	Umbilical
Charolais	Single	7.80	1.24
	Twin	6.34	1.18
Hereford	Single	5.51	1.40
	Twin	4.09	1.06

Table 7—Influence of dam and sire breed on uterine and umbilical blood flows

Dam breed	Sire breed	Blood flows, liter/min		Oxygen uptake, mmol/min	
		Uterine	Umbilical	Uterine	Fetal
Gelbvieh	Charolais	9.64	2.94	7.61	4.25
	Longhorn	7.18	2.22	5.79	3.34
Pinzgauer	Charolais	11.85	3.02	9.83	4.64
	Longhorn	8.34	2.34	7.80	3.66

Table 8—Maternal and fetal influences on blood flow and nutrient uptakes at 230 days of gestation

Breed of cow	Breed of fetus	Blood flow, l/min		Oxygen uptake, mmol/min		Glucose uptake, mmol/min	
		Uterine	Umbilical	Fetus	Uteroplacenta	Fetus	Uteroplacenta
Brahman	Brahman	5.01	2.71	2.32	3.48	.092	.61
	Charolais	4.66	3.65	3.89	1.57	.136	1.43
Charolais	Brahman	7.18	1.88	2.27	2.83	.098	.74
	Charolais	9.24	3.99	3.83	3.93	.215	1.82

Table 9—Maternal and fetal influences on growth of tissues of the gravid uterus

Breed of cow	Breed of fetus	Day of gestation	Weights, lbs			Fetal rate of gain[a]
			Fetus	Uterus	Placentomes	
Brahman	Brahman	232	29.1	9.92	6.34	
		271	56.2	14.48	7.91	0.70
	Charolais	232	52.2	13.51	10.27	
		271	74.7	16.49	10.93	0.58
Charolais	Brahman	232	28.4	12.35	6.28	
		271	67.0	17.86	9.24	0.99
	Charolais	232	49.4	19.11	12.26	
		271	103.4	24.60	14.19	1.38

[a] Rate of gain, lb/day, between 232 and 271 days of gestation.