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Calvin L. Ferrell
U.S. Meat Animal Research Center

Lawrence P. Reynolds
U.S. Meat Animal Research Center, lawrence.p.reynolds@me.com

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Introduction

Early reports suggested fetal growth is an energetically efficient process; however, more recent reports have suggested fetal growth to be a relatively inefficient process. These latter reports were based on indirect estimates obtained by the use of indirect calorimetry or comparative slaughter approaches, whereas the earlier data resulted from acute *in vivo* and *in vitro* approaches. Methodologies have been developed to directly measure rates of oxidative metabolism of tissues of the gravid uterus of cows using chronic preparations. The objective of this study was to quantify rates of oxidative metabolism of gravid uterine, fetal and utero-placental tissues of the pregnant cow and to determine how these variables change with stage of gestation.

Procedure

Mature (3 to 11 yr), multiparous Hereford cows were mated to Simmental bulls. Cows were fed a corn silage based diet (10.6 MJ metabolizable energy, 120 g crude protein per kg) at approximately maintenance. Surgery was performed on cows at about 132 (12 head), 176 (8 head), 220 (11 head), and 245 (7 head) days after mating. At surgery, indwelling catheters were placed in a uterine artery, uterine vein, umbilical vein, fetal femoral artery, and fetal femoral vein of cows at 176 and 220 days of gestation. Similar procedures were followed in surgeries performed on cows at 132 and 245 days of gestation, except catheters were placed in a placental artery and two placental veins rather than in the fetal femoral vessels and umbilical vein. Tips of the catheters were placed close to the umbilical vessels.

All measurements were taken at approximately five days after surgery. Uterine and umbilical blood flows were determined by diffusion equilibrium procedures by the use of deuterium oxide (D_2O) as the marker substance. Samples of blood were collected into heparinized blood collecting tubes for subsequent oxygen determinations and into test tubes containing ethylenediamine tetraacetate (EDTA) for subsequent D_2O, glucose, and lactate determinations. Oxygen, D_2O, and lactate concentrations in blood and glucose concentrations in plasma were determined.

Results

Uterine blood flow increased about 4.5 fold during the interval of gestation encompassed by this study, whereas umbilical blood flow increased about 21 fold during this interval (Table 1). Relationships of uterine and umbilical blood flow to day of gestation (t) were as follows:

uterine blood flow, l/min = $.479e^{.0129t}$ SE = .18, R^2 = .91, N = 31
umbilical blood flow, l/min = $.011e^{.0245t}$ SE = .24, R^2 = .94, N = 24

These regressions show that umbilical blood flow was lower initially but increased at a rate about twice as great as that of uterine blood flow. This finding is consistent with the more rapid rate of fetal growth compared to growth of other gravid uterine tissues.

Concentrations of oxygen, glucose, and lactate in samples from the uterine artery or umbilical vein remained constant across stage of gestation (Table 1). Uterine artery-uterine vein and umbilical vein-umbilical artery concentration differences likewise remained constant across stages of gestation, except that uterine artery-uterine vein oxygen concentration difference increased during the latter stages. Mean concentration differences were similar to those observed in previous studies. Since concentration differences changed little, uterine and fetal uptake changes primarily reflected changes in uterine and umbilical blood flows. These data indicate, as do those reported previously, net uptakes of oxygen and glucose by the gravid uterus, fetus, and utero-placenta of pregnant cows and a net loss of lactate from the utero-placenta to both the fetus and maternal circulations. Fetal glucose uptake was 3.3, 11.1, 15.9, and 16.2 percent of gravid uterine glucose uptake at 137, 180, 226, and 250 days of gestation, and fetal oxygen uptake was 19.9, 48.6, 58.5, and 55.2 percent of gravid uterine oxygen uptake at those stages, respectively. Estimates of fetal respiratory quotients (RQ) suggest that glucose and lactate uptakes, if entirely oxidized, could account for about 33 and 26 percent of fetal oxidative metabolism, respectively. These data indirectly show that although glucose and lactate are important energy substances, other substances must be important sources of energy for the bovine fetus.

The data are also indicative of a high rate of oxidative metabolism of utero-placental tissues as compared to that of the fetus. Oxygen uptake of the fetus was 26, 94, 141, and 176 percent of that of the utero-placenta at 137, 180, 226, and 250 days of gestation, respectively; however weights of these tissues vary greatly during this interval. When expressed relative to weight of tissue, oxygen uptake of the fetus was relatively constant (255 μmole/kg/min). Oxygen uptake by the utero-placenta (460 μmole/ kg/min) was nearly two fold greater than that of the fetus.

Total heat production of the gravid uterus, calculated from the data presented in Table 1, assuming 21.1 kJ/liter O_2, was 1.37, 2.12, 4.87, and 8.57 MJ/day at 137, 180, 226, and 250 days of gestation. The heat increment of gestation (the total increase in heat production of pregnant over non-pregnant cows) is about 2.69, 7.36, 12.34, and 14.95 MJ/day at these times. Thus, heat production of gravid uterine tissues appear to account for about 44 percent of 8.57 MJ/day at 137, 180, 226, and 250 days of gestation. Thus, heat production of gravid uterine tissues appear to account for about 44 percent of heat increment of gestation. These results are in concert with early reports which suggested maternal energy expenditure increased during pregnancy in addition to that utilized by gravid uterine tissues.

Rates of energy accretion in the gravid uterus, fetus, and utero-placenta may be calculated. Gross efficiency of energy accretion of each of these tissues can then be calculated as energy accretion divided by the sum of energy accretion and heat production. The resulting gross efficiency of energy accretion in gravid uterine, fetal, and utero-placental tissues were 27, 39, and 15 percent, respectively. These results suggest that fetal growth *per se* is a relatively efficient process. However, the efficiency of fetal growth is not readily observable because of the relatively low efficiency of energy accretion in the utero-placental tissues which are required to support fetal growth directly and because of the apparent increase in maternal metabolism, which may be required to support fetal growth less directly.

[1]Ferrell is a research animal scientist and Reynolds is a postdoctoral research associate, Nutrition Unit, MARC.

Table 1.—Some components of oxidative metabolism of gravid uterine tissues of the cow

Variable[a]	Day of gestation				SE
	137	180	226	250	
Uterine blood flow	2.93	4.78	8.75	13.21	.29
Umbilical blood flow	.28	1.07	2.79	5.87	.25
Uterine arterial oxygen	6.121	6.558	6.263	6.371	.008
Umbilical venous oxygen	4.200	4.140	4.242	4.257	.075
Uterine arterial glucose	4.588	4.526	4.502	4.831	.109
Umbilical venous glucose	2.531	2.162	2.679	2.097	.084
Uterine arterial lactate	.639	.484	.580	.560	.043
Umbilical venous lactate	1.721	1.582	2.243	2.223	.140
Uterine A-V oxygen	.684	.663	.830	.968	.039
Umbilical v-a oxygen	1.520	1.409	1.500	1.291	.045
Uterine A-V glucose	.279	.260	.219	.284	.026
Umbilical v-a glucose	.098	.127	.109	.117	.014
Uterine A-V lactate	−.054	−.063	−.054	−.081	.012
Umbilical v-a lactate	.123	.085	.134	.088	.030
Uterine oxygen uptake	2.01	3.11	7.15	12.58	.28
Fetal oxygen uptake	.40	1.51	4.18	6.95	.24
Utero-placental oxygen uptake	1.51	1.60	2.97	3.97	.24
Uterine glucose uptake	.58	.84	1.32	2.61	.14
Fetal glucose uptake	.019	.093	.210	.424	.026
Utero-placental glucose uptake	.40	.66	1.11	2.51	.16
Uterine lactate uptake	−.142	−.289	−.581	−1.125	.079
Fetal lactate uptake	.047	.091	.326	.625	.051
Utero-placental lactate uptake	−.19	−.38	−.91	−1.67	.12

[a]Blood flows are liters/min, metabolite concentrations and arterial-venous (A-V) veno-arterial (v-a) concentration differences are millimoles/liter and millimoles/min. Glucose concentrations were determined in plasma; lactate concentrations were determined in whole blood.