Growth of the fetal calf and its arterial pressure, blood gases, and hematologic data

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Reeves, John T., Fuheid S. Daoud, and Michael Gentry. Growth of the fetal calf and its arterial pressure, blood gases, and hematologic data. J. Appl. Physiol. 32(2): 240-244. 1972.—Fetal growth, arterial pressure, arterial oxygen tensions, and hematologic data in 35 fetal calves were compared with similar data in fetal lambs. The data of the present report suggested that the fetal calf, its organs, and placenta had rates of growth which were similar to those in the lamb. The increasing arterial pressure during the last third of gestation was similar to that in the lamb and the higher arterial pressure achieved by the mature calf appeared to reflect merely its larger size. The fetal calf had a relatively high arterial oxygen tension which suggested there may be an efficient transport of oxygen across the placenta. The hemoglobin concentration was lower than that in the lamb and did not change during the last third of gestation. Thus the differences in oxygen transport in the fetal calf and lamb may reside primarily in the arterial oxygen tensions and the blood oxygen carrying capacities.

bovine; fetus; fetal growth; oxygen; hemoglobin concentration

MAMMALIAN FETUSES grow rapidly during the last third of gestation despite a relatively slow growth of the placenta (4). Data from the fetal lamb suggest that a progressive increase in arterial pressure increases placental blood flow during the period of rapid fetal growth (4). Increasing placental blood flow is probably a major mechanism providing an increased oxygen transport across the placenta to the fetus. Acute experiments in fetal lambs suggest there also may be an increase in the oxygen carrying capacity of the fetal blood during the last trimester of gestation (1, 4). One wonders how fetuses larger than the lamb utilize various mechanisms for oxygen transport at a time when growth of the fetus outstrips placental growth.

The fetal calf is large and may be conveniently studied (12). However, the growth curves of the fetal calf and its placenta are not available for the last third of gestation. A previous study of fetal calves in the 7th and 8th months of gestation suggested that the arterial pressures and oxygen tensions were higher than in fetal lambs (12). More complete data were needed for the fetal calf. The present study reports measurements of bovine fetal growth, arterial pressure, arterial blood gas values, and hemoglobin concentrations from 6 through 9 months of gestation.

METHODS

Methods of studying the live fetal calf. Thirty-five cesarean sections were performed under local anesthesia in Jersey cows (age 2-11 years) judged to be healthy by the consulting veterinarian. The handling of the mother cows and the surgical procedure have been described (12). The cows had been bred by artificial insemination and the ages of the fetuses varied between 163 and 281 days. The duration of gestation is approximately 281 days in the Jersey cow. In the first 12 experiments the fetuses were fully delivered onto a warm table. In subsequent experiments only the head (12 exp) or the foreleg (11 exp) was delivered from the uterus. After local anesthesia had been administered to the fetus a carotid artery or a brachial artery was exposed and intubated with polyethylene tubing. Fetal arterial pressure was recorded with a Sanborn 150 one-channel or an Electronics for Medicine four-channel recorder. Heart rates were counted at 1- to 2-min intervals from the pressure recording. Ten to thirty minutes after intubation of the fetal artery, and at a time when the fetal heart rate and arterial pressure were stable, simultaneous samples were drawn from catheters in the jugular vein (or systemic artery) of the mother and the artery of the fetus. Blood samples for hematologic study were placed in tubes containing sodium citrate. Arterial samples for blood gas analysis were drawn into heparinized glass syringes and placed on ice. The calves were then utilized for other experiments (12).

Weights of fetal calves and fetal organs. At the end of the experiment, the fetus was delivered, the cord tied, and the fetus weighed. After the last gasp, fetuses of 260 days or younger were dissected to obtain fetal organ weights. The skin, including the tail and the ears and excluding the hooves, was removed by sharp dissection and weighed while still wet. The two lungs were weighed together attached to a short portion of trachea. The heart was weighed unopened after the great vessels and pericardium had been removed. The kidneys were weighed after the fat was removed. The brain weight included the cerebral hemispheres, midbrain, cerebellum, and the medulla oblongata to the level of the foramen magnum. The weight of the “guts” included the stomach, intestines, bladder, and their contents, and the pancreas, mesenteric fat, adrenals, and ureters. A portion of the gastric contents was occasionally lost in the dissection. In 10 experiments the placenta was manually removed from each cotyledon. Although 2-4 hr were required to remove the placenta, removal was incomplete since a portion was retained within the depressions in the maternal cotyledons. The placenta weight (expressed as a percent of fetal weight) includes placenta, membranes, and a portion of the umbilical cord.
TABLE 1. Weights of the fetus: weights of fetal organs and placenta as percent of fetal weight

<table>
<thead>
<tr>
<th>Mean Fetal Wt, kg</th>
<th>Carcass, %</th>
<th>Skin, %</th>
<th>Guts, %</th>
<th>Liver, %</th>
<th>Lungs, %</th>
<th>Brain, %</th>
<th>Heart, %</th>
<th>Kidney, %</th>
<th>Spleen, %</th>
<th>Placenta, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.40 (163-187)</td>
<td>64.0 (2)</td>
<td>10.6 (2)</td>
<td>6.2 (4)</td>
<td>3.3 (4)</td>
<td>3.4 (4)</td>
<td>1.5 (4)</td>
<td>0.8 (4)</td>
<td>1.0 (4)</td>
<td>1.0 (4)</td>
<td>1.0 (4)</td>
</tr>
<tr>
<td>2.50 (200-216)</td>
<td>60.7 (3)</td>
<td>6.7 (5)</td>
<td>12.9 (6)</td>
<td>22.6 (6)</td>
<td>0.3 (6)</td>
<td>0.1 (6)</td>
<td>0.1 (6)</td>
<td>0.1 (6)</td>
<td>0.1 (6)</td>
<td>0.1 (6)</td>
</tr>
<tr>
<td>2.60 (225-238)</td>
<td>61.5 (7)</td>
<td>16.3 (7)</td>
<td>16.3 (7)</td>
<td>22.4 (7)</td>
<td>0.3 (7)</td>
<td>1.0 (7)</td>
<td>0.1 (7)</td>
<td>0.1 (7)</td>
<td>0.1 (7)</td>
<td>0.1 (7)</td>
</tr>
<tr>
<td>2.80 (242-260)</td>
<td>63.6 (5)</td>
<td>16.8 (5)</td>
<td>16.8 (5)</td>
<td>22.6 (5)</td>
<td>1.0 (5)</td>
<td>0.9 (5)</td>
<td>0.1 (5)</td>
<td>0.5 (5)</td>
<td>0.1 (5)</td>
<td>0.1 (5)</td>
</tr>
</tbody>
</table>

Values are means ±1 sd; number of observations is given in parentheses.

**FIG. 1.** Relationship of weight of fetal calves (●) to their gestational ages (80-281 days). Thirty-two fetuses are from this report and twenty-four were reported by other authors (7, 16). Curvilinear line drawn through the data was calculated from the equation, W^1/3 = 0.185 (T-47), shown in Fig. 2. T is the gestational age in days. Mean weights (±sd) of 18 spontaneously born calves on day of birth and 30 calves at 2, 4, and 9 weeks of age are shown (○).

**FIG. 2.** Relationship of fetal weight^1/3 to gestational age of 56 fetal calves (●) 80 days or older. Linear regression equation (-) indicated a slope of 0.135 and an intercept on absciss of 47 days and there was a high correlation coefficient (r = 0.98). Linear regression equation calculated by Huggett and Widdas (8) (---) from less complete data was similar. Linear regression equation for sheep (8) is shown (···). Photometer and the hematocrits were done by the micro-method. The total erythrocyte and leucocyte counts were done manually using an American Optical Bright Line hemocytometer.

**RESULTS**

**Weights of fetus and newborn calves (Table 1).** There was a rapid increase in the weight of the fetal calf (3.6-30 kg) with increasing gestational age (163-281 days) (Fig. 1). Weights have previously been reported in various breeds of fetal calves from age 1 to 7 months gestation (7, 16) and these have been included in Figs. 1 and 2 for comparison with the present data. The relationship of fetal weight to gestational age (Fig. 1) appeared to be curvilinear as has been reported for this and other species (1, 4, 7, 16). There was a linear relationship (r = 0.98) of fetal weight^1/3 and gestational age (Fig. 2) for fetuses older than 2 months (~56 days). The regression equation had a slope (0.135) and a calculated inter-
TABLE 2. Fetal brachial (or carotid) arterial blood gas data, arterial pressures, and heart rates

<table>
<thead>
<tr>
<th>Mean Gestational Age and Range, days</th>
<th>Mean Arterial Pressure, mm Hg</th>
<th>Heart Rate, beats/min</th>
<th>(p)-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\text{PO}_2), mm Hg</td>
<td>(\text{PO}_2), mm Hg</td>
<td>(\text{PHa})</td>
</tr>
<tr>
<td>176 (163–187)</td>
<td>35 ± 3</td>
<td>48 ± 8</td>
<td>7.27 ± 0.04</td>
</tr>
<tr>
<td>207 (200–217)</td>
<td>35 ± 5</td>
<td>45 ± 6</td>
<td>7.29 ± 0.04</td>
</tr>
<tr>
<td>233 (223–238)</td>
<td>32 ± 6</td>
<td>46 ± 3</td>
<td>7.28 ± 0.06</td>
</tr>
<tr>
<td>252 (242–260)</td>
<td>34 ± 6</td>
<td>49 ± 8</td>
<td>7.25 ± 0.04</td>
</tr>
<tr>
<td>273 (267–281)</td>
<td>29 ± 3</td>
<td>49 ± 3</td>
<td>7.32 ± 0.03</td>
</tr>
</tbody>
</table>

Values are means ±1 sd; number of observations is given in parentheses.

![Graph](image)

**Fig. 3.** Relation of mean arterial pressure to gestational age in 35 fetal calves. Regression equation, \(y = 0.33X - 8.8\), had a correlation coefficient \((r) = 0.7\).

TABLE 3. Hematologic data in fetal calves, newborn calves, and mothers

<table>
<thead>
<tr>
<th>Mean Age and Range, days</th>
<th>Hemoglobin, g/100 ml</th>
<th>Hematocrit, %</th>
<th>Erythrocytes, millions/mm(^3)</th>
<th>Leukocytes, thousands/mm(^3)</th>
<th>Neutrophils, %</th>
<th>Lymphocytes, %</th>
<th>Erythropoietin, ng/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>176 (163–185)</td>
<td>10.7</td>
<td>32 ± 26.8</td>
<td>6.4</td>
<td>16 ± 10</td>
<td>80 ± 19</td>
<td>4 ± 2</td>
<td>0</td>
</tr>
<tr>
<td>207 (200–217)</td>
<td>10.2 ± 1.7</td>
<td>32 ± 27.4</td>
<td>6.7 ± 2.4</td>
<td>19 ± 10</td>
<td>76 ± 10</td>
<td>2 ± 2</td>
<td>3 ± 2</td>
</tr>
<tr>
<td>233 (225–258)</td>
<td>9.9 ± 1.8</td>
<td>30 ± 57.9</td>
<td>6.8 ± 1.8</td>
<td>60 ± 14</td>
<td>72 ± 10</td>
<td>3 ± 3</td>
<td>3 ± 3</td>
</tr>
<tr>
<td>252 (242–260)</td>
<td>10.4 ± 1.4</td>
<td>33 ± 7.0</td>
<td>6.4 ± 2.1</td>
<td>20 ± 9</td>
<td>73 ± 10</td>
<td>2 ± 3</td>
<td>5 ± 3</td>
</tr>
<tr>
<td>273 (267–281)</td>
<td>10.5 ± 1.0</td>
<td>31 ± 27.8</td>
<td>7.9 ± 2.0</td>
<td>39 ± 10</td>
<td>57 ± 10</td>
<td>2 ± 2</td>
<td>2 ± 2</td>
</tr>
</tbody>
</table>

**Fetal calves**

| 2 | 10.2 ± 1.7 | 29.5 ± 9 | 7.3 ± 2.5 | 47.10 | 16.12 | 6.39 | 1 ± 1 |
| 19 | 11.5 ± 1.6 | 31 ± 3  | 6.5 ± 3.6 | 37 ± 8 | 60 ± 10 | 3 ± 2 | 0    |
| Mothers | 11.6 ± 1.3 | 33 ± 10 | 8.8 ± 3.0 | 41 ± 14 | 50 ± 16 | 3 ± 2 | 0    |

Values are means ±1 sd; number of observations is given in parentheses.

except on the abscissa (47 days) which were similar to those calculated by Huggett and Widdas (8) from less complete data.

Nine fetuses of mean age 273 days had an average weight of 20.5 ± 3.0 kg which was not different from the average weight of 18 spontaneously born calves weighed on the day of birth. However, the predicted weight of the term fetus (31.5 kg at 201 days) exceeded the weight of newborn calves by more than one standard deviation. The newborn calves had dry skins and had voided before suckling was established. When rapid growth of the Jersey calf resumed 2 weeks after birth, the growth rates of the mature fetus and the newborn were parallel (Fig. 1). In other species, the growth rate of the newborn is parallel to that of the fetus near the end of gestation (4). Fetal organ weights (Table 1). The increase in the relative weight of the skin as gestation advanced was probably related to the appearance of hair at about 200 days. The weights of the gut were variable, because the volume of their contents varied. The relative weight of liver, lung, brain, kidney, and spleen decreased from the youngest to the older fetuses, but the relative heart weight showed no consistent change. The placenta, expressed as a percent of fetal weight decreased during the last third of gestation, and the values obtained were similar to those reported in the lamb (1).

Arterial pressure, heart rate, and arterial blood gas data (Table 2). The arterial pressure increased with increasing gestational age \((r = 0.7, \text{Fig} \ 3)\) and increasing weight \((r = 0.65)\) but there were large variations between individuals. The heart rates were also variable but showed a decrease from younger to older fetuses.

The arterial blood gas values in 20 unanesthetized standing mother cows \((\text{PO}_2 = 95 ± 8 \text{ mm Hg}, \text{PCO}_2 = 38 ± 3, \text{and pH} 7.43 ± 0.05)\) did not change with advancing gestation. The mild respiratory alkalosis could represent either the normal values in pregnant cows or hypocapnia from excitement. The arterial oxygen tension was lower and the pH higher in the most mature fetuses; otherwise the blood gas values were unchanged during the last third of gestation.

Hematologic data in fetal and newborn calves and mother cows (Table 3). The hemoglobin concentrations did not change with advancing gestation in the fetuses examined (Fig. 4). The hemoglobin concentrations ranged from 7.2 to 12.8 g/100 ml and the average value for all fetuses \((10.2 ± 1.3 \text{ g/100 ml})\) did not differ from the values found by Ruo and Romijn (14) and by Gahlenbeck et al. (5). Of the seven fetal calves in the present study with hemoglobin concentrations less than 9.0 g/100 ml, only two \((\text{Hg} = 7.2, 8.0 \text{ g/100 ml})\) weighed less than average for their age group. In the 28 mother cows examined, the hemoglobin concentrations averaged 11.6 ± 1.3 g/100 ml which was greater \((P < 0.05)\) than the average hemoglobin concentration in the fetuses. There was no relationship between the maternal hemoglobin concentrations and the duration of gestation or the concentrations of hemoglobin in the fetuses. Erythrocyte counts were similar in mothers and fetuses.

The total leukocyte counts in the fetal calves ranged from 2,900 to 11,400/mm\(^3\), and there was no relationship of total counts to gestational age. There were no differences in total leukocyte counts between fetal and newborn calves. The
differential leukocyte counts showed the oldest fetuses had more neutrophils (36 ± 10 %) than did the 23 younger fetuses examined (24 ± 10 %). The newborn calves age 2 days had more neutrophils than did fetuses or did newborns at age 2 weeks. No data are available for leukocyte counts in fetal cows, but the counts in the newborn calves are within the normal range (15).

One mother cow had an elevated total leukocyte count of 18,000/mm³. However she was afebrile, there was no evidence of infection and she recovered well from the experiment. The other 27 mother cows had leukocyte counts of 4,500-14,000/mm³ which were within the normal range (15). The differential leukocyte counts were all within the normal range (15).

DISCUSSION

When the fetal weights from previous reports (7,16) are combined with the present data, the growth of the bovine fetus can be estimated throughout gestation (Figs. 1 and 2). The previously reported fetal weights were from larger breeds of cattle than the Jersey, but the differences in fetal weight between breeds should be small early in gestation. The good agreement of the present data with that previously reported, and the similar growth rates of the fetus near term and of the young calf older than two weeks suggest that the data are reliable.

The regression equation relating \( W^{1/3} \) to gestational age had an earlier intercept on the abscissa for the fetal lamb (37 days (8)) than for the fetal calf (47 days) (Fig. 1). If the intercept represents the approximate demarkation between embryonal and fetal growth rates (8) then the lamb enters upon the fetal growth phase a few days earlier than the calf. Thereafter the growth rates, i.e., the slopes of the regression line are approximately similar, but the calf has a longer gestation. The data in the calf agree with the general conclusion of Huggett and Widdas “that when the birth weight of the young is increased the mammal does not grow its young quicker, along a steeper slope, but must grow its foetus a longer time” (8). The fetal calf was also similar to the lamb in that there was little growth of the placenta during the last third of gestation while the fetus was rapidly increasing in weight.

In both the lamb and the calf the rapid growth of the heart compared to the other organs probably reflected cardiac hypertrophy secondary to increasing arterial pressure. There were large variations in arterial pressure between calves of similar age or size. The data suggest that normal growth of the fetal calf may occur within rather wide limits of mean arterial pressure. It would be of interest to measure the placental flows relative to the observed arterial pressures. The increasing arterial pressure during rapid growth late in gestation is reported for several mammalian species but the average pressures achieved at term vary with the species (4). The fetal calf at term weighs more and has higher arterial pressures than do fetuses (4) of sheep, man, rhesus monkey, dog, cat, rabbit, or rat. For these species there appeared to be a linear relationship between the mean arterial pressure at term and the logarithm of the term fetal weight (Fig. 5). The data for the fetal calf lay along an extension of the line suggesting that the calf’s arterial pressure was at a level expected for its large size.

In the present study, the values of arterial pH were lower than those reported for fetal calves (5), lambs (2, 3, 4, 11), and foals (3). It is possible that the surgical trauma to, and the manipulation of, mother and fetus altered the fetal state. However, the rather high arterial oxygen tensions, the absence of hypercapnia, and of tachycardia suggested the fetuses were otherwise in good condition. The fetal oxygen tensions were higher than those reported by Gahlenbeck et al. (5), a finding which probably reflected a higher maternal oxygen tension in the present study (95 vs. 70 mm Hg).

In the fetal calf the arterial oxygen tensions throughout the last third of gestation were higher than those in fetal lambs studied under either acute (4) or chronic experimental conditions (2, 3, 11). Rather the arterial oxygen tensions resembled those reported in the foal (3). Comline and Silver (3) suggested that the fetal arterial PO₂ was higher in the foal than in the lamb primarily because there was a smaller pressure gradient for oxygen across the placenta from mother to fetus (lamb 17 mm Hg, foal 4 mm Hg). It is possible that the fetal calf, like the foal, has a relatively “efficient” transfer of oxygen across the placental membranes.

Increases in hemoglobin concentrations that have been reported in mammalian fetuses approaching term (humans (1, 4), goats (9), lambs (1, 4), rabbits (18), rats (18), cats (18) and dogs (18)) are considered to reflect the stimulus of the hypoxic fetal environment on the hemopoietic system.
Indeed, hemoglobin concentration increases in the fetal lamb when the ewe is exposed for a few days to simulated high altitude (10). Further, relief of the fetal hypoxia after birth may account for the fall in hemoglobin concentration in the neonate (1, 4). Yet in the last third of gestation the hemoglobin concentration in the calf was lower than that in the lamb (1, 2, 4) and did not rise. Nor did it fall in the newborn period. Reticulocyte counts in newborn calves are low (< 1.4%) (15). It is difficult to attribute the absence of a rise in the fetal calf's hemoglobin concentration to immaturity of the hematopoietic system. Hemoglobin production was adequate to achieve and maintain a concentration of 10 g/100 ml during the period of rapid growth. Erythrocytes of the newborn calf, though small and numerous, do not show signs of immaturity (15). The low lymphocyte count in the newborn calf, though small and numerous, do not show signs of immaturity (15). However, even this interpretation may not be correct, because the differential lymphocyte count was particularly high in the fetus and only temporarily decreased to a minimum in the early newborn period. A poor or absent hematopoietic response to chronic hypoxia has been observed in young calves made chronically hypoxemic by a surgical right-to-left shunt (13) and in healthy steers taken for months to high altitude (6, 17). Possibly, the fetal calf, the young calf, and the mature bovine all have a diminished hematopoietic response to chronic hypoxemia. However, Meschia et al. (11) and Comline and Silver (2) have suggested that under normal conditions hemoglobin concentration in the fetal lamb may not increase near term. Serial observations utilizing indwelling catheters (2, 11) are needed to evaluate the role of chronic hypoxia as a hematopoietic stimulus to the healthy bovine fetus.

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