Growth, Health, and Blood Glucose Concentrations of Calves Fed High-Glucose or High-Fat Milk Replacers

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ABSTRACT

The influence of age, carbohydrate-fat ratios of milk replacers, and development of ruminal function on growth, health, and blood glucose concentrations were evaluated in calves. Colostrum-fed, 3-day-old Holstein bull calves were fed to 12 wk on one of three dietary treatments: 1) a high carbohydrate, low fat (60.5% glucose, 9.5% lactose, and 3% lard) milk replacer; 2) a low carbohydrate, high fat (23% glucose, 12.5% lactose, and 30% lard) milk replacer; and 3) weaning at 6 wk of age from high-fat replacer to a standard calf starter. The high fat milk replacer was superior to low fat milk replacer for total weight gains and efficiency of feed conversion. Rates of weight gain of starter calves were similar to those of calves fed low fat. Calves fed the diet with low fat had a high incidence of diarrhea, an occasional outbreak of a yeast-related ethanol intoxication syndrome, and high concentrations of glucose in urine. Irrespective of milk replacer composition or development of ruminal function, plasma and whole blood glucose concentrations declined rapidly in the first 6 wk. Corpuscular glucose declined steadily with age in all calves. This age-related decrease of blood glucose concentration of calves seems to be a constitutive phenomenon.

INTRODUCTION

Marked changes occur in the pattern of nutrients available for energy utilization and storage during development of ruminant animals through preruminant and functional ruminant stages (3, 16, 23). Essentially, high availability of fat in milk during the preruminant stage is followed by a predominant dependence upon volatile fatty acids after the animal is weaned and becomes a totally functional ruminant. Relatively little information exists on shifts of intermediary metabolism that may accompany changes of dietary and digestive tracts during these developmental stages in ruminant animals. An investigation was undertaken to evaluate the influence of age, dietary manipulation of carbohydrate and fat ratios in milk replacers, and development of rumen on lipid metabolism in young calves up to 12 wk of age. This paper reports growth, health, and changes of plasma, whole blood, and corpuscular glucose concentrations of experimental calves (33). Measurement of glucose concentrations was of interest because of lack of agreement (12, 13, 14, 26, 32, 36) as to whether age, diet, development of ruminal function, or other physiological events occurring simultaneously during growth and development are responsible for the decline of blood glucose from 90 to 100 mg/100 ml in the newborn calf to the relative hypoglycemia (40 to 60 mg/100 ml) characteristic of the ruminant adult.

MATERIALS AND METHODS

Animals

Twenty-nine, colostrum-fed, 3-day-old Holstein bull calves were obtained from the University herd or from a local dairy. Thirteen calves were assigned to a high carbohydrate, low fat (LF) milk replacer, and 16 calves were assigned to a low carbohydrate, high fat (HF) milk replacer. All calves fed the LF diet and nine calves fed the HF diet received milk replacer as the only feed source for the 12-wk study. Seven calves on the HF diet were weaned
at 6 wk of age to a calf starter (R), which was fed for an additional 6 wk. Calves were housed individually in elevated wire-floor cages in a well-ventilated, temperature-controlled (21°C) room. Calves losing much fluid in watery diarrhea and showing initial signs of dehydration and loss of vigor were given an electrolyte-glucose solution (Ion-Aid, Diamond Labs, Des Moines, IA) instead of diet for 2 to 3 days. Those requiring prolonged treatment (more than 5 days) were removed from the experiment.

**Feeds and Feeding**

Compositions of LF and HF milk replacers are in Table 1. The two milk replacers were fed on an isocaloric and isonitrogenous basis according to body weight. Digestible energy requirements of calves were based on National Research Council (NRC) (20) for body weights up to 50 kg and on (29) for body weights above 50 kg. The requirement for digestible protein was adapted from NRC (20).

Daily milk replacer for each calf was prepared each morning by dry feed mixed with warm water. To help dissolve the casein, 2.0% of its weight was added as KOH to the mixture. An equivalent amount of K was omitted from the mineral mixture. Minerals, linoleic acid, and vitamins were added in that order and mixed thoroughly to make a concentrated fluid. Nystatin was added (34) in equal dosages to the two milk replacers to prevent gastrointestinal yeast infections. One-third of the concentrate was diluted with warm water and offered to calves at 8, 13, and 18 h in nipple buckets. The pH of the as-fed milk replacers ranged between 6.1 and 6.6. Concentrate for second and third feedings was refrigerated until used. The daily total fluid intake was set at 11% of body weight in 40 kg calves and increased by .1% for each kg increase of body weight. Percentage dry matter was maintained at 15 and 12% for LF and HF milk replacers, respectively. Intake of milk replacer was recorded for each calf.

A pelleted calf starter containing ground alfalfa hay, barley, corn, cottonseed meal, soybean meal, bone meal, and trace-mineral salt (60, 15.4, 16, 4, 2, 2, and .4% by weight) was introduced to R calves at the beginning of the 3rd wk. The amount of liquid diet was reduced by one-half to three-fourths from the 5th to the 6th wk to encourage starter consumption, and calves were weaned by the end of the 6th wk. The calf starter and water were available to this group at all times after 3 wk. Weekly dry matter intake of calf starter was monitored between 6 to 12 wk of age. The R calves were identified as an independent group, beginning at 3 and 5 wk of age, respectively, for the measurements of blood glucose concentration and body weight.

**Body Weights**

Calves were weighed weekly before the

<table>
<thead>
<tr>
<th>TABLE 1. Composition of milk replacers.1,2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredients</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Lard3</td>
</tr>
<tr>
<td>Dextrose4</td>
</tr>
<tr>
<td>Lactose5</td>
</tr>
<tr>
<td>Casein6</td>
</tr>
<tr>
<td>Mineral mixture7</td>
</tr>
<tr>
<td>Digestible energy,8 kcal/kg</td>
</tr>
</tbody>
</table>

1 Vitamin mix was formulated to meet NRC (20) requirements with B vitamins increased according to Benevenga et al. (4). Equal amounts of the vitamin mix were added to diets as a 50% (wt:vol) solution in water, made by mixing for 30 s in a Waring blender.

2 Linoleic acid was added to milk replacers at 1 g/kg dry matter (15).

3 Lard product: homogenized (globule size, 3 to 4 μm) and spray-dried powder containing 60% lard: Calva Corp., Stockton, CA.

4 Dextrose: Cerelose 2001 regular; Corn Products, Englewood Cliffs, NJ.


6 Casein: Western Dairy Products, San Francisco, CA.

7 Mineral mixture formulated to meet NRC (20) requirements and with increases in the following (28, 29): Ca (.7 to .85%), P (.5 to .65%), Mg (.07 to .075%), and Fe (100 to 125 mg/kg). The minerals were mixed for 4 h in a ball mill, as a 25% (wt/wt) suspension in water, to produce a finely pulverized mix with no tendency to crystallize on storage (3 to 4 mo).

8 Calculated digestible energy based on (6) and (28).
morning feed. Those fed solid feed were fasted overnight prior to weighing.

**Sampling**

Jugular blood samples were collected from calves just prior to weekly measurements of body weight. Hematocrit was determined immediately. Urine samples voided before the morning feed and at hourly intervals for 3 h after feeding were collected from a representative number of calves on the three diets. Plasma, whole blood, and urine samples were stored frozen (−20°C). Ruminal fluid was sampled with a stomach tube from weaned calves at 7, 9, and 12 wk of age.

**Analysis**

Glucose concentration of plasma, whole blood, and urine was analyzed by the O-tolidine procedure (35) with an Auto-Analyzer (Technicon Instruments Corp., Tarrytown, NY). Corpuscular glucose concentration was calculated (13) from hematocrits and glucose concentrations in whole blood and plasma. Volatile fatty acids in ruminal fluid were determined in a gas chromatograph under standard procedures (7).

**RESULTS AND DISCUSSION**

**Growth**

Because colostrum was offered for the first 2 to 3 days after birth, weight gains for the 1st wk were not considered in evaluation of growth response. Growth of calves fed the HF diet was greater than for those on LF and R diets throughout the experimental period (Figure 1). The HF calves were superior to LF calves in total weight gains and feed conversion efficiency (Table 2). The lower weight gains of calves fed the LF diet can be attributed to continuous diarrhea, occasional outburst of a yeast-related ethanol intoxication syndrome, and excretion of considerable energy as glucose.
TABLE 2. Feed intake, weight gains, and conversion efficiencies of calves fed milk replacers

<table>
<thead>
<tr>
<th></th>
<th>Low fat milk replacer</th>
<th>High fat milk replacer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \bar{X} )</td>
<td>SE</td>
</tr>
<tr>
<td>Total dry matter intake, kg</td>
<td>76.40</td>
<td>4.53</td>
</tr>
<tr>
<td>Total weight gain, kg</td>
<td>24.00</td>
<td>2.34</td>
</tr>
<tr>
<td>Conversion rate, kg feed/kg gain</td>
<td>3.26</td>
<td>.14</td>
</tr>
</tbody>
</table>

\( ^1 \) Values from calves \( n = 7 \) between 2 to 12 wk of age.

\(* P < .05 \) (Student's t test).

\( ** P < .001 \) (Student's t test).

in urine. Average daily gains of weight with LF and HF calves were comparable to observations made by Adams et al. (1) with Holstein bull calves fed skim milk or lard-fortified skim milk.

The slow growth of the R group, which were similar to gains by the LF group, were unexpected because dry matter intake of calf starter ration (Table 3) seemed adequate for expected intakes (28). Body weights recorded for the 12-wk-old R calves were excessive but were due to gut fill from our inadvertently not withholding feed and water overnight prior to weighing these calves. The total weight gain and calculated feed conversion rate for R calves (Table 3) are, therefore, not accurate estimates.

Rumen Volatile Fatty Acids

Molar proportions of acetic (63.2%), propionic (18.4%), and butyric (15.8%) acid in ruminal fluid from R calves remained relatively stable between 7 to 12 wk of age and were similar to reports for adult ruminants (10). Thus, a functional ruminant status seemed to be achieved by the R group of calves at 7 wk of age.

Health

Diarrhea was common throughout the trial for all calves fed the LF milk replacer. Feces of these calves invariably became soft and semifluid within 2 to 4 days on the diet. The severity of diarrhea was enhanced at the beginning of each week when dry matter intakes were increased to meet requirements at new body weights. A greater incidence of diarrhea can be expected in calves fed milk replacers containing large amounts of glucose (19, 28), particularly when the amount of dietary fat is low (5). Diarrhea was nearly absent from calves raised on the HF milk replacer, except for a few minor cases in the first 2 wk. Beneficial effect of fat in preventing diarrhea has been recognized (2, 12).

During preliminary stages of the project one HF and four LF calves succumbed to a syndrome characterized by anorexia, unstable gait, depression, gradual distension of the abdomen, and an odor of alcohol in the breath. If untreated, such calves died within 4 to 5 h. A yeast infection in the gastrointestinal tract was

TABLE 3. Feed intake, weight gains, and conversion efficiency of calves fed calf starter

<table>
<thead>
<tr>
<th>Age (wk)</th>
<th>Dry matter intake/day (kg)</th>
<th>( \bar{X} )</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6–7</td>
<td>6.1</td>
<td>.61</td>
<td>.05</td>
</tr>
<tr>
<td>7–8</td>
<td>8.1</td>
<td>.81</td>
<td>.10</td>
</tr>
<tr>
<td>8–9</td>
<td>9.4</td>
<td>.94</td>
<td>.12</td>
</tr>
<tr>
<td>9–10</td>
<td>1.00</td>
<td>1.00</td>
<td>.11</td>
</tr>
<tr>
<td>10–11</td>
<td>1.32</td>
<td>1.32</td>
<td>.15</td>
</tr>
<tr>
<td>11–12</td>
<td>1.76</td>
<td>1.76</td>
<td>.10</td>
</tr>
<tr>
<td>8–12</td>
<td>15.65</td>
<td>15.65</td>
<td>2.12</td>
</tr>
<tr>
<td>Total weight gain (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8–12</td>
<td>2.26</td>
<td>2.26</td>
<td>.20</td>
</tr>
<tr>
<td>Conversion rate (kg feed/kg gain)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

\( ^1 n = 7. \)
identified as the causative agent, and details of
the syndrome and its prevention and treatment
are in (34). Nystatin, a gastrointestinal yeast
inhibitor (8, 11), was added daily to milk
replacers and proved to be an effective pre-
ventive measure. The high incidence of diarrhea
and alcohol intoxication problems necessitated
starting an excess of calves on the LF treatment
to maintain equal numbers of healthy calves for
treatments (Figure 1).

**Hematocrit**

Mean hematocrits ranged from 27 to 36%
and 28 to 35% for LF and HF calves between 1
to 12 wk of age and 28 to 40% for R calves
between 5 to 12 wk of age. Hematocrits were
relatively stable, and minor fluctuations with
age or diet were not statistically significant.

**Blood Glucose Concentrations**

Changes of the concentration of glucose in
plasma, whole blood, and corpuscles in rela-
tionship to age and dietary treatment are in
Figure 2. Data in Figure 2, analyzed by two-
way analysis of variance (30) in a repeated
measures model, indicated significant decline
with age ($P<.001$) of glucose concentration in
plasma, whole blood, and corpuscles in all
calves. Plasma and whole blood glucose concen-
trations in the HF and LF calves fell rapidly
between 1 to 6 wk of age toward characteristics
of adult ruminants. Regression analysis (30) of
data from calves fed milk replacer (Figure 2)
indicated negative linear ($P<.05$ or $P<.01$) and
positive quadratic ($P<.05$ or $P<.01$) relations-
ships between age and plasma or whole blood
glucose concentrations. Similar analysis of data
from all three dietary groups between 5 and 12
wk of age showed significant negative linear and
nonsignificant quadratic trends with age for
glucose concentrations in plasma ($P<.05$) and
whole blood ($P<.001$). Thus, observation of
Figure 2 and statistical analysis show that both

![Figure 2. Age-related changes in the concentration (mean and SE) of plasma, whole blood, and corpuscular glucose in calves receiving low fat (---) and high fat (-----) milk replacers or a calf starter (-----).](image-url)
glucose concentrations of plasma and of whole blood decrease with age irrespective of milk replacer composition or development of ruminal function. In previous studies, feeding of all milk diets orally (14, 36) or abomasally (22) and surgical removal of the rumen (18) failed to prevent the age related decrease of blood glucose concentration of calves. A decrease with age of the concentration of blood glucose also has been reported for gnotobiotic goats fed on high glucose-lactose diets (24, 25).

Corpuscular glucose concentration (Figure 2) declined steadily with age in calves of all three dietary groups. This observation was supported by regression analysis, which indicated significant negative linear relationship between age and corpuscular glucose concentration in HF (P<.01), LF (P<.01), and R (P<.001) calves. The progressive decline with age in corpuscular glucose, regardless of milk replacer composition or development of ruminal function, agrees with observations of calves fed whole milk (26, 36) and in weaned calves in which the rumen was functional (17, 21, 26).

Our study provides no explanation for the age-related decline of plasma, whole blood, and corpuscular glucose concentration in calves. It has been suggested (9, 26, 27) that the decline of corpuscular glucose may be responsible for the age-related decline of blood glucose concentration. However, this explanation does not account adequately for the concurrent decrease for plasma glucose content of calves. Some workers have related the decline of plasma glucose concentration to the diminishing intake of milk (3, 17, 27). This explanation does not hold in our study, because calves raised solely on increasing amounts of the two milk replacer diets up to 12 wk showed consistent decline of plasma glucose with age. In (36), plasma glucose declined with age regardless of changes of corpuscular glucose even when calves were limited to a diet of whole milk up to 15 wk of age. Glucose concentrations in plasma, whole blood, and corpuscles all decline with age toward characteristics of adult ruminants regardless of milk replacer composition or ruminal development. Based on similar observations, it has been suggested (13 24, 25, 26) that this age-related decrease of blood glucose concentration may be constitutive rather than an adaptive phenomenon. Our results tend to support such a concept.

Comparison of glucose concentrations between ages of 1 to 12 wk and 5 to 12 wk in calves on the three dietary treatments showed that both plasma and whole blood glucose concentrations were significantly greater (P<.05) in HF and R calves than in LF calves (Figure 2). An intraveous glucose load can cause a net decrease of gluconeogenic capacity and concomitant hyperinsulinaemia in lactating dairy cows (31). It is, therefore, possible that the greater dietary availability of glucose in LF calves may have caused greater release of insulin, which in turn resulted in maintenance of lower steady state or fasting plasma glucose concentrations in these calves.

**Urinary Glucose**

Quantitative assessment of glucose excretion in urine was not possible, because metabolism cages were not used. However, urinary glucose concentrations indicated in a qualitative manner that LF calves excreted much more glucose than did HF calves. No glucose was detected in urine of R calves. Urine samples voided before the morning feed ranged from 2.5 to 4.3 and from 0 to 3.0 mg/100 ml in LF and HF calves. Urine samples voided between 1 to 3 h after feeding ranged from 500 to 2800 and from 10 to 70 mg glucose/100 ml in LF and HF calves. The high concentrations voided following meals in the LF calves indicate that blood glucose concentrations exceeded the normal renal threshold (200 mg/ml), resulting in a spillover of glucose into the urine. Matthieu and de Tugny (19) reported high glucose in urine of calves fed glucose (6.9%) in partly skimmed milk (.5% fat). Such urinary losses relative to energy status of young calves may be of considerable importance.

**Summary**

Growth and feed efficiency of calves fed a low carbohydrate, high fat (HF) milk replacer were greater than those fed a high carbohydrate, low fat (LF) milk replacer. The slow gain for calves fed LF replacer was due to a high incidence of diarrhea, occasional problems with yeast-related ethanol intoxication, and excretion of energy in the form of glucose in urine. Plasma and whole blood glucose concentrations declined rapidly after birth in calves on both milk replacers toward characteristics of adult ruminants.
ruminants. The mechanism of control in the age related decline in blood glucose concentration of calves is not understood but seems to be a constitutive characteristic of the bovine and not under dietary regulation.

REFERENCES

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