Heifers from Birth to 300 lb: How Important Is Rumen Development?

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Introduction

Consider the objectives of the heifer raiser: raise healthy, inexpensive, fast-growing replacements that will reach age at first calving **(AFC)** at the earliest time possible without sacrificing lifetime milk yield. Nowhere in current heifer raiser contracts is *rumen development* mentioned (Chester-Jones, 2005), and yet the heifer from birth to 300 lb has received a huge amount of research attention and management focus. Research topics include: immune status, altered/improved management schemes, new weight-for-age targets, and rumen development, mainly because of the perceived effect on AFC—where else can management attention have such an impact?

Changes Occurring during Weaning—What Needs to Happen?

From birth to 300 lb, calf nutrition changes from colostrum to milk and/or milk replacer, dry feed introduction, water, and eventually dry feed plus forage. Management milestones include: weaning, movement to group housing, and major nutritional transitions. All of these transitions should happen smoothly without health issues or death loss, and with concern for labor availability and cost-effectiveness. However, in the US, 11% of all heifer calves die before weaning, and an additional 2.4% die before calving (NAHMS, 1996).

The transition from preruminant to ruminant is not instantaneous—*adult* volatile fatty acid **(VFA)** and amino acid profiles develop over at least a week post weaning (Quigley et al., 1985), and rumen epithelial development and peripheral tissue ability to metabolize ketones takes 3-5 weeks (Warner, 1991). Dependence of the calf on glucose for energy gradually gives way to glucose plus circulating VFA's, as shown in Figure 1.

Weight-for-Age Targets

A 300 lb large breed heifer calf is not a commodity. In conventional rearing systems, she is approximately 4 months old, growing 1.77 lb per day, with a wither height of 39 inches (Chester-Jones, 2005). Accelerated programs can result in heifers reaching 300 lb by 3.5 months of age, thus reducing AFC by 2-4 weeks (Van Amburgh, 2004; Davis and Drackley, 1998). Typically, crude protein/metabolizable energy ratios **(CP/ME)** are adjusted to support the higher weight and structure gains of accelerated calves, so that a 110 lb calf growing 1.32 lb/day will consume approximately 1.6% of its bodyweight in dry matter, with ME = 3.49 Mcal/d and % CP = 26.6 (higher CP, lower ME than NRC, 2001). The physiological maturity of a 300 lb calf is obviously not a constant; depending on dietary history, mature body size, and age at weaning.

Factors Influencing Rumen Development

According to Warner (1991), characteristics of an adult (developed) rumen include: ability to subsist solely on forage/grain, microbial activity, volume (64% of the total stomach capacity in adults), papillary development, and nutrient absorption by the rumen wall. In addition, VFA concentrations increase, as does rumen microbial contribution to protein reaching the abomasum (Quigley et al., 1985).

Quigley (1997a; 1997b) describes five factors required for rumen development:

- Establishment of ruminal bacteria
- Liquid in the rumen
- Outflow from the rumen (muscularity)
- Absorptive ability of rumen epithelium
- Substrate

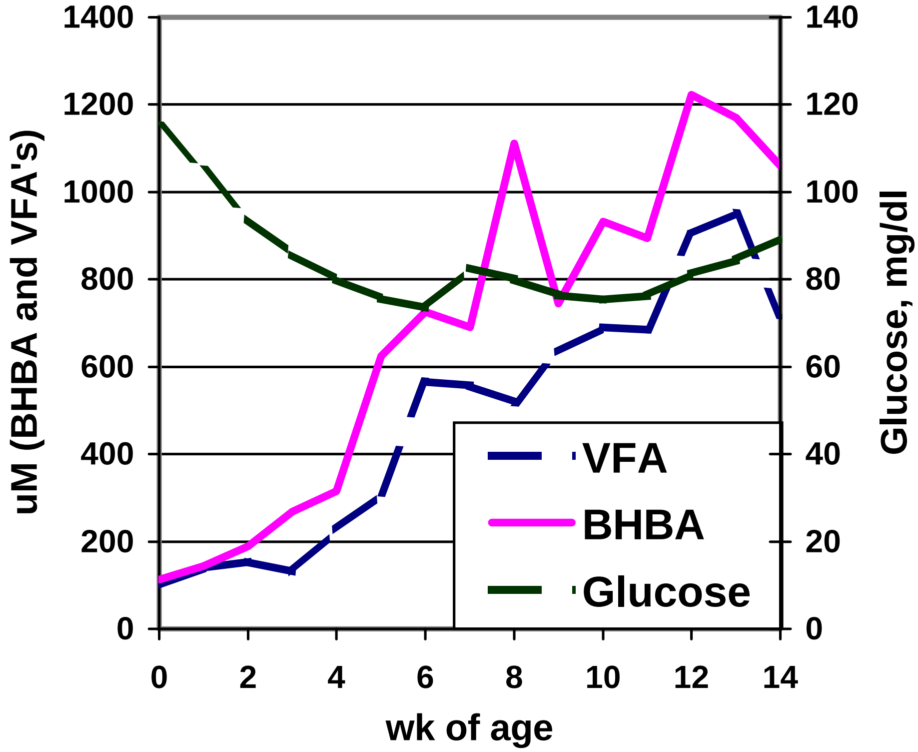
If these criteria are met, the rumen can grow 4-8 times faster than the calf from 3 to 8 weeks of age (Davis and Drackley, 1998).

Table 1. Physiological changes during weaning.

Indicator	Preruminant	Ruminant
Social/behavioral		
Feeding activity	Suckling	Chewing/ruminating
Esophageal groove	Functional	Non-functional
Liver enzymes[a]	Glycolytic/ketogenic	Gluconeogenic
Substrate/feed	Colostrum, milk	Water, starter
Bacterial protein[b]	<30% of total to abomasum	>50%
Rumen characteristic[c]		
Papillae	Short, narrow	Longer, wider
Muscularity	Low	Increasing
Volume	Low	Increasing
Blood metabolites[a]		
Energy Source	Glucose	Volatile fatty acids
β-Hydroxybutyrate (BHBA)	Low	Increasing
Mammary development[d]	More responsive to high protein	Less responsive to high protein

[a]Baldwin et al., 2004.
[b]Quigley et al., 1985.
[c]Beharka et al., 1998.
[d]Brown et al., 2005.

Figure 1. Blood metabolites by week of age (Quigley et al., 1991a; 1991b).



Bacteria

Although calves are born essentially sterile, bacterial inoculation occurs almost immediately through contact with other animals and the environment. Protozoa in isolated calves are often devoid until after weaning (Anderson et al., 1987), although flagellates may be observed as early as 3 weeks (Quigley et al., 1985). Researchers have investigated inoculating newborn calves with rumen fluid, finding even autoclaved samples to be effective in stimulating rumen development, average daily gain **(ADG)**, and health—there must be factors other than live microorganisms responsible (Muscato et al., 2002). As dry feed intake increases, numbers and types of bacteria change from aerobes to anaerobes and facultative anaerobes (Quigley, 1997a; Davis and Drackley, 1998), and *typical* adult populations, including cellulolytics, become established by 2-3 weeks after dry feed intake begins (Anderson et al., 1987).

Liquid in the Rumen

Free water intake is associated with starter intake, bypasses the esophageal groove, and obviously changes the reticulo-rumen to a more fermentative environment. Despite many lectures otherwise, producers often can't or don't offer water until 4 weeks of age or later; which can delay starter intake by several weeks (NAHMS, 1996).

Rumen Muscularity

Early researchers found that rumen muscularity can be stimulated by sponges and other inert materials, but that these don't stimulate epithelial development (Tamate et al., 1962). Earliest rumination (rumen wall contractions) has been observed in early-weaning trials, at 3 weeks of age (Quigley, 1997a), although cud-chewing has been observed as early as 7 days of age (Quigley, 1998).

VFA's

Propionate and butyrate stimulate rumen papillae development to a greater extent than do acetate and other VFA's (Tamate et al., 1962). A comprehensive review of *in vivo* and *in vitro* data suggests that additional factors such as gene expression and/or hormonal stimulation mediate the stimulatory effect of VFA's (Baldwin et al., 2004).

Scratch Factor/Particle Size

Scratch factor *per se* has been ruled out by many researchers as essential for rumen development (Warner, 1991). For example, calves dosed with plastic sponges or toothbrush bristles showed no papillary development (Warner, 1991). Because of the lack of effectiveness of scratch factor and interest in generating VFA's to stimulate epithelial development; most nutritionists have formulated calf starters to contain limited NDF, no forage, and finely ground grains to improve pellet quality. However, a growing body of research indicates that larger, more abrasive particles may stimulate rumen development in a desirable manner. Dry rolled corn stimulates intake and ADG versus finely ground corn (Lesmeister and Heinrichs, 2004). Table 2 shows that calves fed a coarse meal starter outperformed calves fed the same ration pelleted, in terms of intake and ADG; and that they ruminated 2.3 weeks earlier.

Researchers at KSU (Greenwood et al., 1997) developed an abrasiveness assay, and found that coarse diets (all diets contained 15% brome hay, either chopped or finely ground) decreased keratinization, length, and branching of papillae. The coarse diet also decreased BHBA initially. Coverdale et al. (2004) found that 7.5-15% ground grass hay (8-19 mm particle length) improved starter intake and ADG over coarse or ground grain rations. Others found morphological abnormalities (branched papillae), but no performance decline, in calves fed a diet of 25% alfalfa/75% grain mix ground to a mean theoretical particle size of 1 mm (Beharka et al., 1998). For feed manufacturers, coarseness adds cost and decreases pellet quality. As a rule, texturized starters have larger particle sizes and higher abrasiveness than complete pelleted starters (Waterman, 2005). Several researchers have recommended ground hay additions to starter for optimum rumen development (Beharka et al., 1998; Coverdale et al., 2004; Greenwood et al., 1997; Waterman, 2005).

Table 2. Effect of starter physical form on calf performance and rumen papillae (Warner, 1991). [1]

Variable	Physical Form	
	Pellet	Meal
NDF, %	23.6	23.0
Particle size (% > 1190 microns)	25.3	86.6
Starter intake, kg/d	0.85	1.09
ADG, kg/d	0.32	0.41
Age at first observed rumination (wk)	6	3.7
Papillae character	Clumped	Clean, leafy

[1]Results from low fiber; 19% NDF and high fiber 28% NDF starters combined; fiber sources were corn cobs, brewers grains, beet pulp.

Weaning Age

Despite management instructions to wean based on feed intake and not the calendar, 4-wk weaning is rare in practice (Quigley, 1998), with the US average remaining near 8 weeks (NAHMS, 1996). In 24 research trials, calves were weaned from 28-60 days of age, averaging 44 days (Kertz and Chester-Jones, 2004). Gains were highly variable (coefficient of variation = 43%), as were intakes (C.V. = 32%). Weaning age is determined by ability to *handle* dry feed and also current plane of nutrition—don't wean calves which are physiologically able to handle dry feed but are on a declining plane of nutrition due to stress or disease. Common rules of thumb are to wean after calves consume 2 lb of starter per day for 3 consecutive days to assure maintenance energy is being adequately provided (Davis and Drackley, 1998). Both abrupt or gradual weaning can be used. The drawback of gradual weaning may be excessively noisy calves (Quigley, 1998); whereas the advantage may be encouragement of starter intake, which saves feed and labor costs over the milk replacer ration (Davis and Drackley, 1998).

Starter Availability

There are two ways to limit substrate availability. One is to deny access to water and/or starter (NAHMS, 1996), the other is through increased availability or nutritional attractiveness of the liquid ration at the expense of starter, for example accelerated calves. Bar-Peled (1997) in a fascinating study suckled calves for six weeks with access to starter, hay, and water. The suckled calves were quite healthy, calved thirty days earlier and tended (P =0.08) to produce more milk in their first lactation. At weaning, the suckled calves lost 1400 g/d, and did not gain as fast as the controls for another 6 weeks. The suckled calves consumed up to 21.6 kg +/- 3.5 kg/d of milk (approximately 29% of their bodyweight, or 3 times the usual recommendation for milk replacer intake) and they consumed no hay or starter although starter was offered at birth.

Intensive Rearing Systems

Intensified calves often receive higher % CP/lower % fat milk replacers (up to 28/15 for Holsteins, 28/25 for Jerseys), fed at higher rates of powder per calf per day (Van Amburgh, 2004). Intensive rearing goals for a 90 lb birthweight Holstein would be: average daily gain 1.8-2.2 lb from birth until weaning at 6-8 weeks; weaning weight 180-200 lb at 7 weeks; feed efficiency, 1.5-1.7 lb feed/lb gain; and height gain, 6-8 inches. Although the extra protein cost of milk replacer and starter is higher than conventional programs, the cost of gain for intensively-reared calves is similar to conventional programs because of improved ADG and feed efficiency (Brown et al., 2005). Mammary parenchyma growth was 32% higher in calves fed higher protein milk replacer, and mammary growth was more responsive to protein prior to weaning (Brown et al., 2005; Van Amburgh, 2004).

Starter Intake Drives Rumen Development—RIGHT?

Right, but starter formula (forage, particle size, various additives, relation to milk replacer intake) can enhance or alter rumen development. Baldwin states: "gut growth is not simply a function of energy substrate supply or dietary chemical composition, but rather a plexus of nutritional and physiological inputs" (Baldwin et al., 2004). The uniqueness of rumen development is highlighted by the lack of similar developmental changes in the small intestine in response to weaning.

Recent Rumen Development Research

Several strategies have shown promise in stimulating rumen development and reducing the growth lag of weaning. Calves administered 8 ml/hd/d of untreated or autoclaved rumen fluid grew faster (6.9 kg gain vs. 3.6 in the first 2 weeks) and experienced less scours than untreated calves (Muscato et al., 2002). Researchers have investigated the effectiveness of various additives such as ionophores, soluble fiber sources, and butyrate salts. Lesmeister and Heinrichs (2005) found that including 12% molasses in a starter formula increased ruminal VFA's and butyrate; which resulted in increased papillae length and width, but decreased feed intake and performance.

Quigley et al. (1992) found that sodium bicarbonate at 3% increased rumen pH and acetate while decreasing propionate levels; but had no effect on intake or ADG. In the same experiment, a live-cell yeast additive fed at 0.2% of the ration tended to decrease ruminal lactate but did not influence gain or intake. Lesmeister et al. (2004) investigated the effects of yeast culture **(YC)** at 1 or 2% of the starter formulation and its response on starter intake, and weight and stature gains in weaned calves. The texturized starter consisted of roasted corn, cane molasses, oats, and a premix pellet, available from 2 days of age. YC calves tended to have longer and wider rumen papillae than controls. YC calves also showed significant benefits in starter intake and weight and stature gains, indicating that inclusion of YC could be used to promote rumen development and subsequent performance through the weaning period.

Field Issues with Inadequate Rumen Development

Frankly cases of inadequate rumen development are uncommon, and most researchers assume that the rumen will develop inevitably in response to dry feed intake, the timing is fairly elastic, and the process can either be advanced through early weaning or delayed. However, occasional field problems with inadequate rumen development have been observed (Hoffman, 2005):

1. Calves fed finely ground grain mix or pellets with inadequate NDF. This can cause temporary keratinization or impaction of rumen papillae, and can be alleviated with inclusion of chopped hay or coarse grains in the starter.

Table 3. Pre- and postweaning least square means for intake and bodyweight of calves receiving 0% (control), 1% (1YC), or 2% (2YC) supplemental yeast culture in a texturized calf starter (Lesmeister et al., 2004).

	Treatment			SEM
	Control	1YC	2YC	
ADG, g/d				
Wk 1 to 5	371	356	417	23
Wk 6	744[b]	920[a]	941[a]	65
Wk 1 to 6	437[b]	444[ab]	505[a]	22
DMI, g/d				
Milk replacer, wk 1 to 5	528	535	547	13
Starter				
Wk 1 to 5	282	291	324	18
Wk 6	1334[b]	1427[ab]	1538[a]	61
Wk 1 to 6	479[b]	511[ab]	555[a]	22
Total				
Wk 1 to 5	809[b]	826[ab]	871[a]	20
Wk 1 to 6	907[b]	944[ab]	997[a]	23

[a,b]Means within a row without common superscripts are different ($P < 0.05$).

Table 4. Least squares means for structural growth measurements (Lesmeister et al., 2004).

	Treatment			SEM
	Control	1YC	2YC	
Hip height				
Initial, cm	79.71	79.43	79.48	0.58
Final, cm	86.08	85.60	86.46	0.61
Change, cm/d	0.15[ab]	0.14[b]	0.17[a]	0.01
Hip width				
Initial, cm	18.09	17.91	18.06	0.16
Final, cm	20.27[b]	20.30[ab]	20.78[a]	0.18
Change, cm/d	0.05[b]	0.06[ab]	0.06[a]	<0.01
Heart girth				
Initial, cm	77.17	77.27	77.80	0.70
Final, cm	86.87[ab]	86.72[b]	88.93[a]	0.74
Change, cm/d	0.23	0.23	0.26	0.01

[a,b]Means within a row without common superscripts are different ($P < 0.05$).

2. Calves fed haylage at 7 weeks of age develop dark-colored diarrhea, due to excess soluble protein entering the lower gut, often misdiagnosed as coccidiosis. This problem can be cured by using an appropriate grain-based starter or by avoiding haylage entirely in young calves.

An excessive growth check or weight loss at weaning is a sign that rumen development has been delayed.

Conclusions

Weaning (conversion from preruminant to ruminant) is an important milestone in calves from birth to 300 lb, and the process of weaning and rumen development has been highly researched and characterized. Various strategies have been used to speed up the process including: increased scratch factor, added VFA's, supplemental bacteria, altered feeding schedules, additional nutrient sources, and particle size changes (Lesmeister et al., 2004; Muscato et al., 2002; Beharka et al., 1998). Strategies which lessen the lag or growth check at weaning lower costs, as labor and feed costs are lower for starter compared to milk replacer. Furthermore, programs to accelerate calf development depend on decreased AFC for economic advantage, and will increase the need for *lag-free* weaning.

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