Dietary Factors Influencing the Development of the Ruminant Gastrointestinal Tract

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The Investment of Raising Replacements

Feed Efficiency and Feed Costs by Age

$2,500 investment

Outline

I. Calf Management Trends
II. Pre-weaning
   I. Neonatal
   II. Feeding Plane
III. Weaning
   I. Strategy
   II. Post-weaning

Early Life Nutrition

- Dietary regimes in early life influence lifetime productivity
- 1kg of pre-weaning ADG = 1,540kg of milk in first lactation (Soberon et al., 2012)
Early Life Nutrition – Future Milk

<table>
<thead>
<tr>
<th>Study</th>
<th>Milk yield, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foldager and Krohn, 1991</td>
<td>1,405s</td>
</tr>
<tr>
<td>Bar-Peled et al., 1998</td>
<td>453s</td>
</tr>
<tr>
<td>Foldager et al., 1997</td>
<td>519s</td>
</tr>
<tr>
<td>Ballard et al., 2005 (@ 200 DIM)</td>
<td>700s</td>
</tr>
<tr>
<td>Shamay et al., 2005 (post-weaning protein)</td>
<td>981s</td>
</tr>
<tr>
<td>Davis-Rincker et al., 2011</td>
<td>416ns</td>
</tr>
<tr>
<td>Drackley et al., 2007</td>
<td>835s</td>
</tr>
<tr>
<td>Raith-Knight et al., 2009</td>
<td>718ts</td>
</tr>
<tr>
<td>Terre et al., 2009</td>
<td>624ns</td>
</tr>
<tr>
<td>Morrison et al., 2009 (no diff. calf growth)</td>
<td>0ns</td>
</tr>
<tr>
<td>Moallem et al., 2010 (post-weaning protein)</td>
<td>732s</td>
</tr>
<tr>
<td>Soberon et al., 2012</td>
<td>552s</td>
</tr>
</tbody>
</table>

Mortality by Age and Farm Size

- Over 50% of morbidity is related to scours (NAHMS, 2007)

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Gastrointestinal Development

- All compartments are formed by the third month (Warner, 1958)

Colostrum and Development

- Colostrum has a large collection of probiotics and prebiotics/oligosaccharides (Mills et al., 2011)

The Transition

Colostrum and Development

- Heat-treated colostrum increases *Bifidobacterium* and reduced the colonization of *E. coli* in the small intestine (Malmuthuge et al., 2015)

Colostrum management has been primarily focused on passive transfer of IgG (Hammon et al., 2000)

<table>
<thead>
<tr>
<th>Unit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Mature Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Matter (%)</td>
<td>24.5</td>
<td>19.0</td>
<td>16.0</td>
<td>15.5</td>
<td>15.3</td>
<td>12.2</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>6.4</td>
<td>5.6</td>
<td>4.6</td>
<td>5.0</td>
<td>5.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>13.3</td>
<td>8.5</td>
<td>6.2</td>
<td>5.4</td>
<td>4.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Essential Amino Acids Mmol/L</td>
<td>390</td>
<td>230</td>
<td>190</td>
<td>140</td>
<td>115</td>
<td>ND</td>
</tr>
<tr>
<td>Lactoferrin g/L</td>
<td>1.84</td>
<td>0.86</td>
<td>0.46</td>
<td>0.36</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Insulin µg/L</td>
<td>65</td>
<td>35</td>
<td>15</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Growth Hormone µg/L</td>
<td>1.5</td>
<td>0.5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Insulin-like growth factor I µg/L</td>
<td>310</td>
<td>195</td>
<td>105</td>
<td>62</td>
<td>49</td>
<td>ND</td>
</tr>
</tbody>
</table>
Gastrointestinal Development

- Colostrum components such as IGF-1 and insulin increase glucose uptake and metabolism in the duodenum in early life (Hammon et al., 2013)
- Colostrum feeding for the first three days of life increased:
  - Mucosal growth
  - Absorptive capacity of small intestine
  (Steinhoff-Wagner, 2014)

Intake Variation in Calves During First Week

- Calves consuming more milk in early-life have greater growth and health during the entire pre-weaning phase
  (Fujiwara et al., 2014)

Feeding Large Meals

- Calves typically nurse 12 time per day in the first weeks of life (Jensen, 2003)
- Larger meals fed less frequently increase the risk of milk over-flow into the rumen
  - Ruminal acidosis, decreased passage rate and digestion
- Larger meals may also be associated with reduced insulin sensitivity
  (Bach et al., 2013; Yunta et al., 2015)

Abomasal Emptying
Abomasal Emptying and Insulin Responsiveness

- Calves fed 8L/day vs 4L/day from birth had slower (41% reduction, \( P = 0.02 \)) abomasal emptying rates during the pre-weaning phase (MacPherson et al., 2015)

- No difference in insulin responsiveness determined by GTT

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Weaning Challenges

- A smooth transition from a monogastric to a ruminant
  - Decreases morbidity and mortality and increases gain (Khan et al., 2012)
  - Requires adequate size and function of the rumen (Baldwin, 2004)

- Elevated plane of nutrition pre-weaning makes weaning more challenging (Khan et al., 2011)
In both treatments, weaning increased (P<0.01) ruminal SCFA, blood BHBA and fecal starch.

Yet the differences between the week before and after weaning were greater (P<0.01) in calves weaned at six weeks.
Step-Down Weaning

Steele et al., 2015

Step-Down - Bodyweight

P < 0.05

Step-Down - Starter Intake

Intake (g/d)
**Dissection Results**

<table>
<thead>
<tr>
<th></th>
<th>Step-Down</th>
<th>Abrupt</th>
<th>SE</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross Anatomy (kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW</td>
<td>94.1</td>
<td>94.8</td>
<td>2.3</td>
<td>0.85</td>
</tr>
<tr>
<td>Forestomach</td>
<td>11.0</td>
<td>9.7</td>
<td>0.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Lower Gut</td>
<td>6.8</td>
<td>6.5</td>
<td>0.3</td>
<td>0.23</td>
</tr>
<tr>
<td>Rumen Full</td>
<td>8.2</td>
<td>7.0</td>
<td>0.4</td>
<td>0.03</td>
</tr>
<tr>
<td>Rumen Empty</td>
<td>1.7</td>
<td>1.5</td>
<td>0.1</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Rumen Morphology</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rumen Papillae Length (cm)</td>
<td>1.8</td>
<td>1.7</td>
<td>0.5</td>
<td>0.14</td>
</tr>
<tr>
<td>Rumen Papillae Width (cm)</td>
<td>0.4</td>
<td>0.4</td>
<td>0.1</td>
<td>0.24</td>
</tr>
<tr>
<td>Surface Area (mm²)</td>
<td>684</td>
<td>602</td>
<td>34.0</td>
<td>0.22</td>
</tr>
</tbody>
</table>

(Steele et al., 2015)
3D Morphology with Micro-CT

- No correlation between length or width and surface area
- Greater papillae size ≠ a greater surface area

(Steele et al., 2014)

Barrier Function at Weaning

- Elevated starch levels in fecal matter during weaning (Eckert et al., 2015; Steele et al., 2015- ADSA)
- Starter feeding in calves decreased the expression of tight junctions (Malmuthuge et al., 2013)

(Wood et al., 2015)

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Dry TMR - Dry Matter Intake

(Groen et al., 2015)
**Dry TMR – Average Daily Gain**

![Graph showing average daily gain in kg/day for different weeks of the experiment.]

- 1.75 ±0.08 kg/day
- 70% = 1.28 ±0.09 kg/day
- 85% = 1.69 ±0.07 kg/day

Week of Experiment (Groen et al., 2015)

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**Post-Weaning and Beyond**

- An area that has not been studied
- Need to integrate pre and post weaning planes of nutrition with lifetime performance

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**Take Home Messages**

- The prenatal and neonatal period is an area left undiscovered in calf nutrition
- Calves can drink large volumes of milk in early life and mediate abomasal emptying
- Weaning age and abruptness impact performance on high planes of nutrition
- Recent data suggest that weaning can impair gastrointestinal function
- Post-weaning nutrition is another topic left undiscovered in calf nutrition

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**Acknowledgements**

- Colleagues and students at the University of Alberta, Agricultural, Food and Nutritional Science
- My students and postdoc
Glucagon-Like Peptide-2 (GLP-2)

- GLP-2 injections have been shown to reduce nitrotyrosine staining of the mucosa of *E. bovis* infected calves (Connor et al., 2013)

- GLP-2 injections increased the mRNA and proteins of tight junctions in the calf during *E. bovis* infections (Connor et al., 2015)

Plane of Nutrition

- Graph showing milk feeding stage and post-weaning weight gain

Plane of Nutrition

- Graph showing solid feed intake (DMI) over time for different diets: ADL and RES

Plane of Nutrition

- Graph showing milk consumed and body weight over calf age for conventional and ad libitum feeding

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Reference:

Connor et al., 2013

Miller-Cushon et al., 2013

DeVries et al., 2013

Jasper and Weary, 2002
Conventional vs. Elevated

- Conventionally fed calves are limit fed milk at 10% of bodyweight
  - Cost
  - “Less diarrhea” – unfounded
- But, calves can consume up to 20% of bodyweight
  - Canadian Code of Practise recommends 20% of bodyweight

Molecular Rumen Development

- High-throughput transcriptomics uncovered putative mechanisms regulating development:
  - Peroxisome proliferator-activated receptor-α (PPARα)
  - Peroxisome proliferator-activated receptor-δ (PPARδ) (Naeem et al., 2012)
  - Estrogen-related receptor - α (ESRRα)
  - Transforming Growth Factor – β1 (TGFβ1)

Microbial Changes During Weaning

- High-throughput sequencing has uncovered changes between immature vs mature ruminants

- Weaning decreased the microbial diversity in rumen fluid (Li et al., 2014a)
- Weaning increased the microbial diversity in feces (Li et al., 2014b)
Rumen Papillae - Transition

Papillae Protrude from Polyps

Rumen Papillae - Transition

Rumen Papillae - Ruminant
Rapid Rumen Development

(Hodgson, 1974)