Healthy Gut, Healthy Calf, Productive Future

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DAIRY at GUELPH
Healthy Gut, Healthy Calf, Productive Future

I. Calf Management Trends

II. Pre-weaning
   - Neonatal
   - Feeding Plane

III. Weaning
   - Strategy
   - Post-weaning
Dietary regimes in early life influence lifetime productivity

1 kg of pre-weaning ADG = 1,540 kgs of milk in first lactation

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

“...early adaptation to a stress or stimuli that permanently changes the physiology and metabolism of the organism and continues to be expressed even in the absence of the stimulus/stress that initiated them...”

(Patel and Srinivasan, 2002)
Gut Health and Dairy Calves

- 10% mortality and over 50% of morbidity is related to calf diarrhea (NAHMS, 2007)

- 19% of calves fail passive transfer of Ig and 24% of calves have calf diarrhea in the first month (NAHMS., 2007)

- Antibiotic use pre-weaning has been associated with decreased lifetime milk production (Soberon et al., 2012)
Pre and Post-Weaning

Pre-ruminant: Milk

Weaning Transition:

- 1 wk
- 4 wk
- 8 wk
- 12 wk

Ruminant: Solid Feed

Diagram showing the transition from pre-ruminant to ruminant stages, with details on the digestive system parts (Rumen, Esophagus, Reticulum, Abomasum) and their percentages at each stage.
Pre and Post-Weaning

- **Pre-ruminant**
  - Milk
- **Weaning Transition**
- **Ruminant**
  - Solid Feed

1 wk | 4 wk | 8 wk | 12 wk
Mixture of absorptive, goblet, paneth and neuroendocrine cells

Microbial richness and diversity increases through the lower gut

Cell junction proteins are expressed differentially (Malmuthuge et al., 2012)
Knowledge Gaps

Colostrum

Plane of Nutrition

Industry Concerns

Maternal

Antimicrobial
Colostrum Feeding Method

Bottle

Tube

(Sharifi et al., 2009)
Colostrum Feeding Method

IgG

Mean IgG Conc. (mg/ml)

Time Relative to Colostrum Feeding (minutes)

Acetaminophen

Concentration (mg/L)

Time Relative to Colostrum Feeding (minutes)

(Desjardins-Morrissette et al., 2018)
Delayed Colostrum Feeding

(Fischer et al., 2018)
Delayed Colostrum Feeding

- Delaying the first colostrum meal may delay the colonization of beneficial bacteria to the calf intestine

(Fischer et al., 2018)
Heat Treatment of Colostrum

- Heat-treated colostrum increases *Bifidobacterium* and reduced the colonization of *E. coli* in the small intestine

(Malmuthuge et al., 2015)
Heat Treatment of Colostrum

Heat-treatment may cleave prebiotic oligosaccharides from colostral proteins and lipids

(Fischer et al., 2018)
Bovine colostrum oligosaccharides (bCOs) produced in higher concentrations immediately after parturition (Fischer et al., 2018)
**From Colostrum to Milk**

<table>
<thead>
<tr>
<th></th>
<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>%</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>%</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>%</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</td>
<td>mM</td>
<td>390</td>
<td>230</td>
<td>190</td>
<td>140</td>
<td>115</td>
<td>ND</td>
</tr>
<tr>
<td>Lactoferrin</td>
<td>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</td>
<td>µg/L</td>
<td>65</td>
<td>35</td>
<td>16</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Growth Hormone</td>
<td>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</td>
<td>µg/L</td>
<td>310</td>
<td>195</td>
<td>105</td>
<td>62</td>
<td>49</td>
<td>ND</td>
</tr>
</tbody>
</table>

- Improved health status in calves fed transition milk milk
  (Conneely et al., 2014)
All calves fed one meal of colostrum followed by:
- Milk
- 50% milk/ 50% colostrum (Transition)
- Colostrum (Pyo et al., 2018)
From Colostrum to Milk

IgG mg/ml vs Hours after birth

- Milk
- 50%/50%
- Colostrum

First Meal
Second Meal

(Pletts et al., 2018)
Passive Transfer

- Trancytosis of immunoglobulins (Jochims et al., 1997)
- Receptor mediated and highly regulated
  - Trancytosis (to blood)
  - Recycling (back to lumen)
  - Metabolism (endosome)
- Regulation of these pathways in calves is unclear
Normal Pre-Weaning Milk Intake

d₄ of life

(de Passille et al., 2016)

(Jasper and Weary, 2002)
Automated Feeding
Feeding Large Meals

- Calves typically nurse 6-12 times per day in the first weeks of life (Jensen, 2004)

- Larger meals fed less frequently increase the risk of:
  - Abomasal inflammation & lesions
  - Milk overflow into the rumen
  - Ruminal acidosis, decreased passage rate and digestion (Berends et al., 2012; 2015)
Abomasal Capacity

- Young calves fed 2 litres of milk per meal (3 x)
- Offered ad libitum meal of milk with barium sulfate
- Most calves drank more than 5 litres with no evidence or ruminal overflow

(Ellingsen et al., 2016)
Larger Meal Size and Insulin Sensitivity

- Compared calves fed elevated (8L/d) vs low (4L/d) plane of milk 2x per day
  - No evidence of post-prandial hyperglycemia and hyperinsulinemia
  - No difference in glucose tolerance
  - Slower (41% reduction, $P = 0.02$) abomasal emptying rates during the pre-weaning phase

(MacPherson et al., 2016)
Gastric Emptying rate will influence glucose appearance in blood (Stahel et al., 2016)
Glucagon-like Peptides

1-2 hour postprandial

Gut motility
Gut Permeability
Proliferation
Blood flow
Nutrient absorption

Distal Small intestine

Endocrine L-cell

GLP-1
GLP-2

Nutrients

Glucagon-like Peptides

Gut motility
Gut Permeability
Proliferation
Blood flow
Nutrient absorption
Milk Replacer vs Whole Milk

- Most MR are high in lactose and osmolarity, low in fat compared with whole milk.

![Comparison chart showing the composition of milk and MR with percentages of protein, fat, ash, and other components.]

- 300 mOsm: whole milk/body fluid
- 400-600 mOsm: MR
Milk Replacer vs Whole Milk

- Area under the curve (AUC) and Cmax: LACTOSE > FAT
- Higher supply of lactose results increased gastric emptying and lower glucose tolerance in the first week of life

(Welboren et al., 2018)
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)
Pre and Post-Weaning

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<th>Pre-ruminant</th>
<th>Weaning Transition</th>
<th>Ruminant</th>
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<tr>
<td>Milk</td>
<td>Milk</td>
<td>Solid Feed</td>
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</table>

1 wk | 4 wk | 8 wk | 12 wk

**Diagram:**
- **1 wk:**
  - Abomasum: 60%
  - Rumen: 25%
  - Omasum: 10%
  - Reticulum: 5%
  - To intestines

- **4 wk:**
  - Abomasum: 80%
  - Rumen: 80%
  - Omasum: 7%
  - Reticulum: 5%

- **8 wk:**
  - Abomasum: 8%
  - Rumen: 80%
  - Omasum: 7%
  - Reticulum: 5%

- **12 wk:**
  - Abomasum: 8%
  - Rumen: 80%
  - Omasum: 7%
  - Reticulum: 5%
Rumen Papillae - Birth

300 µm
Papillae Protrude from Polyps
Rumen Papillae - Transition
Abnormal GIT Development

- Ruminal parakeratosis is common during weaning (Bush, 1965)

- Ruminal acidosis has been documented however to date, no research has linked it to impairment of gut health (Laarman et al., 2012)

- Is ruminal acidosis good or bad for the calf?
Ruminal pH During Weaning

(Kohler et al., 2017)
Ruminal pH During Weaning

(Kohler et al., 2017)
Ruminal pH During Weaning

(Kohler et al., 2017)
Ruminal Gene Expression

- Common genes are predominantly metabolic
  - Ketogenesis
  - Fatty acid metabolism

- It takes time for the genes involved in structural adaptations to change

(Kohler et al., 2017)
Early and Abrupt Weaning

Pre-ruminant | Transition | Ruminant
---|---|---
Milk | Solid Feed

Pre-ruminant | Ruminant
---|---
Milk | Solid Feed
Weaning Age

(Eckert et al., 2015)
Weaning Age - Bodyweight

(Eckert et al., 2015)

Early

6 week wean
Weaning Age - Bodyweight

Early

Late

8 week wean

* P<0.05

BW (kg)

Calf Age

6 week wean

(Eckert et al., 2015)
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.

(Eckert et al., 2015)
Weaning Strategy – Delayed Weaning
Impact on Ruminal Development

Wean

6 wk wean
8 wk wean

Pre-weaning
Post-weaning

PC1 Percent variation explained 24.2%
PC2 Percent variation explained 13.0%

(Meale et al., 2016)
Step-Down Weaning

(Steele et al., 2017)
Step-Down - Bodyweight

Weight (kg)

Calf Age (d)

P<0.05

Step-Down

Weaning

Step-Down

(Steele et al., 2017)
Step-Down - Bodyweight

$P<0.05$

Weight (kg)

Calf Age (d)

(Abrupt) (Step-Down) (Weaning)

(Step-Down) (Weaning)

(Steele et al., 2017)
Metabolizable Energy Intake

Intake (Mcal/d)

Calf Age (d)

Abrupt Step-Down

Weaning

Step-Down

(Steele et al., 2017)
Weaning Strategy – Abrupt Weaning Impact on Ruminal Development

Weaning Strategy – Abrupt Weaning Impact on Ruminal Development

Meale et al., 2016

Starter Intake (grams)

Calf Age (d)

30 36 42 48 54

Gradual
A abrupt

PCoA plot_weighted unifrac distance

PC1 Percent variation explained 9.1%

Abrupt_post-weaning
Abrupt_pre-weaning
Step-down_post-weaning
Step-down_pre-weaning

Pre-weaning
Post-weaning

PC1 Percent variation explained 17.8%

(Meale et al., 2016)
Pre and Post-Weaning

Pre-ruminant

Milk

Weaning Transition

Ruminant

Solid Feed

1 wk  4 wk  8 wk  12 wk
Fecal microbiota displayed more diversity post-weaning (Meale et al., 2015)

Abrupt Weaning – Delayed Weaning Impact on Hindgut

- Fecal starch %
  - 36
  - 48
  - 54

* $P = 0.04$
Diversity in Fecal Scores
Barrier Function at Weaning

- Starter feeding in calves decreased the expression of tight junctions (Malmuthuge et al., 2012)

(Wood et al., 2015)
Barrier Function at Weaning

- Weaning related changes of the gut epithelium (Pletts et al., 2016)

Rumen

Duodenum

Not-Weaned, d 42

Weaned, d 42
Endoscopic Biopsy
Post-Weaning and Beyond

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

(DMI (kg/d))

Week of Experiment

All 85% Concentrate
70% Concentrate
85% Concentrate
All Silage

(Groen et al., 2015)
DMI as % of BW

- 1.75 kg/day
- 70% = 1.28 kg/day
- 85% = 1.69 kg/day
- 1.05 kg/day

Week of Experiment

(Groen et al., 2015)
Take Home Messages

- There are still some basic concepts in calf biology and nutrition that we do not understand.
- No difference between tube vs. bottle feeding colostrum for passive transfer.
- Delaying colostrum by six hours can impact passive transfer and gut microbiology.
- Pasteurizing colostrum may help to improve calf gut health if managed properly.
Take Home Messages

- An abrupt transition from colostrum to milk can compromise gut development
- Elevated planes of milk can be fed early in life
- Elevated planes of milk can be fed with 2x/day feeding schemes
- Milk replacer formulations high in lactose may impact gut health and insulin sensitivity
Take Home Messages

- Weaning in dairy calves is one of the largest transformations of the gut in nature
- Milk feeding plane can have a large impact on weaning stress
- Weaning age and abruptness impact performance on high planes of milk nutrition
- Weaning is also associated with gut health problems
- Post-weaning nutrition is another area left undiscovered in calf nutrition
Industry Collaborators
Academic Collaborators
Thanks to my Team
Recruiting Starts Early

- Hazel Steele, Age: 4, Interests: Cows and Coloring
Early-life programming: Case Study
Early-life programming: Case Study
Questions