**Volatile Fatty Acids (VFA)**

- Produced from the fermentation of pyruvate
  - Rumen and hind gut
  - Types/ratios depends on diet
- 3 major VFAs
  - Acetate: \( \text{CH}_3\text{COOH} \)
  - Propionate: \( \text{CH}_3\text{CH}_2\text{COOH} \)
  - Butyrate: \( \text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} \)

**Rumen Fermentation**

- Glucose → Pyruvate → Acetate + ATP + \( \text{H}_2\text{CO}_2 \)
- Cellulolytic bacteria
  - Energy source for rumen epithelium and muscle
  - Not utilized by liver

**Acetate**

- Pyruvate + Pi + ADP →
  Acetate + ATP + \( \text{H}_2\text{O} \) + \( \text{CO}_2 \)
- Cellulolytic bacteria
  - Energy source for rumen epithelium and muscle
  - Not utilized by liver

**Acetate utilization**

- Important as a precursor to de novo fatty acid synthesis
  - Adipose
  - Lactating mammary gland
- Oxidized via TCA
  - Activated to acetyl CoA
  - Used by skeletal muscle, kidneys, and heart for energy
  - Net gain of 10 ATP per mole of acetate
- Dependent upon
  - Energy balance
    - Generates \( \text{CO}_2 \) and \( \text{H}_2\text{O} \) (i.e., ATP) when in low energy balance
    - Used for fatty acid synthesis when animal is in high energy balance
  - Arterial concentration
    - Tissue uptake is directly related to rate of rumen fermentation [blood concentration]

**Propionate**

- Pyruvate + CoA + 4\( \text{H}^+ \) →
  Propionate + \( \text{H}_2\text{O} \)
- Amylolytic bacteria
- Utilized by rumen epithelium
  - Converted to lactate and pyruvate
- Important as a precursor for gluconeogenesis
Hepatic propionate metabolism

Glucose \[ \rightarrow \] OAA \[ \rightarrow \] TCA Cycle 
- Succinyl CoA 
- Methylmalonyl CoA 
- ATP + CoA + Biotin, Mg++ 
- Propionyl CoA 
- ATP + 2 Pi + CoA 

Propionate\[ \rightarrow \] Succinyl CoA
\[ \rightarrow \] Oxaloacetate (OAA)
\[ \rightarrow \] TCA Cycle

Butyrate

- Pyruvate + CoA \[ \rightarrow \] Acetyl-CoA + H2 + CO2
- 2 Acetyl-CoA + 4H+ \[ \rightarrow \] Butyrate + H2O + CoA
- Metabolized by rumen epithelium to ketone bodies (acetoacetate, β-hydroxybutyrate)
  - Later metabolized in liver
- Net ATP production is 25 per mole

Ruminal VFA absorption

<table>
<thead>
<tr>
<th>Rumen lumen</th>
<th>Rumen wall</th>
<th>Portal vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate 70</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Propionate 20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Butyrate 10</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Values are relative flux rates

Hepatic metabolism of VFA

<table>
<thead>
<tr>
<th>Rumen</th>
<th>Portal vein</th>
<th>Liver</th>
<th>Peripheral blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate 70</td>
<td>50</td>
<td>Glucose</td>
<td>Acetate</td>
</tr>
<tr>
<td>Propionate 20</td>
<td>10</td>
<td>Glucose</td>
<td>Glucose</td>
</tr>
<tr>
<td>Butyrate 10</td>
<td>1</td>
<td>3-OH butyrate</td>
<td>3-hydroxy Butyrate (BHBA)</td>
</tr>
</tbody>
</table>

Fermentation in the Rumen

Convert all available carbohydrates and some amino acids to volatile fatty acids (VFA)

<table>
<thead>
<tr>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Pectin</th>
<th>Starch</th>
<th>Sugars</th>
</tr>
</thead>
</table>

Bacterial fermentation

VFA, lactate and methane

Concentration of VFA in rumen = 50 to 125 µM/ml

<table>
<thead>
<tr>
<th>Diet</th>
<th>Acetate</th>
<th>Propionate</th>
<th>Butyrate</th>
<th>Ratio Acetate:Propionate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay</td>
<td>65</td>
<td>20</td>
<td>12</td>
<td>3:1</td>
</tr>
<tr>
<td>Grain</td>
<td>40</td>
<td>37</td>
<td>20</td>
<td>1:1</td>
</tr>
</tbody>
</table>
Amino Acid Fermentation in the Rumen

Deamination required
- Removal of the amino (NH$_2$) group
- Ammonia produced

Fermentation to
- Acetate
- Propionate
- branched chain volatile fatty acids
  - Isovalerate
  - Isobutyrate

Sources of energy leaving rumen:
- VFA 70%
- Microbial cells 10%
- Digestible unfermented feed 20%

No glucose available for the ruminant

Evaluating effective fiber and rumen health

Penn State Separator Box

Measure eNDF
Also available with 4 screens

Penn State Separator

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>Middle</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Silage (1/4)</td>
<td>&lt; 5</td>
<td>&gt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Corn Silage (1/2)</td>
<td>&lt; 5</td>
<td>&gt; 70</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Haylage</td>
<td>&gt; 20</td>
<td>&gt; 40</td>
<td>&lt; 40</td>
</tr>
<tr>
<td>TMR</td>
<td>&gt; 10</td>
<td>&gt; 30</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>

http://www.das.psu.edu/dairynutrition/documents/das0242.pdf
Applying the Results
Penn State Box

Effective NDF = 100 - (% in bottom box)

Example:
Alfalfa Haylage with 52% in the bottom box
Effective NDF = 100 - 52
= 48%

FIELD TOOLS

- Milk yield changes
- Milk component changes
- Signs of acidosis
  - Laminitis, sore feet
- Manure scores
- Free choice buffer use
- Grain in manure

Subclinical Ruminal Acidosis

↓ Rumen pH
△ Rumen motility
↓ Rumination
Variation in daily intake
Feces variable
- Firm ↔ diarrhea
- Undigested fiber & grain
- Gas bubbles
- Mucin/fibrin casts
↑ Fecal particle size

↓ Feed efficiency
↓ Production

Ruminal Acidosis

↑ Rapidly fermented CHO intake
↓ Total & effective NDF intake

↓ Reduced rumen mat
↓ Rumination & buffering with saliva

Ruminal acid concentration

↓ Ruminal pH
↓ Feed retention time in rumen
↓ Ruminal fiber and feed digestion

Figure from Karen Beauchemin

Ruminal fiber and feed digestion

Ruminal acid concentration

↓ Reduced rumen mat
↓ Rumination & buffering with saliva

↑ Rapidly fermented CHO intake
↓ Total & effective NDF intake

↓ Ruminal pH
↓ Feed retention time in rumen
↓ Ruminal fiber and feed digestion

Figure from Karen Beauchemin
A shift in the site of digestion changes nutrient supply & causes some of the symptoms of ruminal acidosis.
Effective fiber must be eaten to be effective.