Fetal Growth, Development, and Physiology

1) Fetal nutrition

♦ Severe maternal nutrition restriction ➞ maternal tissues mobilized to support fetus

♦ Diet (% of total diet)

• Glucose (1/2)
  ♦ Regulated by fetal insulin
  • Excess glucose: stored as glycogen, fructose, fats

• Lactate (1/4)
  ♦

• Amino acids (1/4)
  ♦

• Fructose: produced by placenta from glucose

  ♦ [High] amniotic fluid

• Oxygen
  ♦ Diffuses: maternal ➞ fetal
    • Limited by uterine blood flow

2) Fetal blood circulation

♦ Placental & fetal (single system w/ blood pumped by fetal heart)

• Blood shunted from lungs & liver (absent in postnatal)

  ♦ *Ductus venosus*: away from liver (absent in pigs & horses)

  ♦ *Foramen ovale*: from right atrium to left atrium

  ♦ *Ductus arteriosus*: away from lungs to descending aorta
• ↑ blood volume with ↑ placental/fetal weights

• Fetal heart rate > maternal heart rate
  - Sheep: 170 – 220 bpm
  - Cattle: 120 – 140 bpm
Gastrointestinal system: little function

Renal system: little function

Respiratory system

- Last ½ gestation, fetal breathing motions 1/3 time
  - ↑ fluid uptake ➔ lung distention; (+) lung growth?

Endocrine system: functional last ¼ of gestation

- Fetus modulates mineral metabolism
- (most farm animals)

3) Conceptus growth: general characteristics

- First: ____________________________________________________________
- Second: ______________________________________________________________________
  - ____________________________________________________________
  - ↑ efficiency of nutrient transfer

- Relationship between fetal weight & length with stage of gestation
  - Length ↑ early followed by ↑ mass
  - Skeleton ↑ before fetal mass ↑

<table>
<thead>
<tr>
<th>Fetus and Placental Membrane Size in the Bovine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gestation (days)</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>0 - 30</td>
</tr>
<tr>
<td>31 - 60</td>
</tr>
<tr>
<td>61 - 90</td>
</tr>
<tr>
<td>91 - 120</td>
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<td></td>
</tr>
<tr>
<td>121 - 150</td>
</tr>
<tr>
<td>151 - 180</td>
</tr>
<tr>
<td>181 - 210</td>
</tr>
<tr>
<td>211 - 240</td>
</tr>
<tr>
<td>241 - 270</td>
</tr>
<tr>
<td>271 - 300</td>
</tr>
</tbody>
</table>
Weight Changes During Early Bovine Gestation

Salisbury et al., 1978

Weight Changes During Mid to Late Bovine Gestation

Salisbury et al., 1978
Fetal weight, and protein, fat, and ash content of the bovine fetus by day of gestation (#1)

Total fetal growth increases exponentially

Growth rate of the bovine fetus and protein in the fetus by day of gestation (#3)

IGR for fetus is maximal 232 d, IGR protein maximal 242 d
4) Conceptus growth (Bovine model: specific to stage & length of gestation)

♦ Early growth (day 0-90)

- Cellular growth

- Tissue & organ development

- Minimal hypertrophic growth

- Eventual birth weight differences manifested by ↑ cell # at this stage

- Nutrition

- Initial placental attachment (> day 30)

- Fetus form complete (miniature)

- CNS, head, heart, limb buds, organs, cartilage skeleton

<table>
<thead>
<tr>
<th>Development (days)</th>
<th>Cattle</th>
<th>Horse</th>
<th>Sheep</th>
<th>Swine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blastocyst</td>
<td>7 - 8</td>
<td>6</td>
<td>6 - 7</td>
<td>5 - 6</td>
</tr>
<tr>
<td>Germ layer differentiation.</td>
<td>14</td>
<td>13 - 14</td>
<td>10 - 14</td>
<td>7 - 8</td>
</tr>
<tr>
<td>Elongation, trophoblast</td>
<td>16</td>
<td>50 - 60</td>
<td>13 - 14</td>
<td>9 - 12</td>
</tr>
<tr>
<td>Heart beat</td>
<td>22</td>
<td>24</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Forelimb bud</td>
<td>25</td>
<td>24</td>
<td>28 - 35</td>
<td>17 - 19</td>
</tr>
<tr>
<td>Hindlimb bud</td>
<td>27 - 28</td>
<td>24</td>
<td>28 - 35</td>
<td>17 - 19</td>
</tr>
<tr>
<td>Differentiation - digits</td>
<td>30 - 45</td>
<td>40</td>
<td>42 - 49</td>
<td>28+</td>
</tr>
<tr>
<td>Nostril/eye differentiation</td>
<td>30 - 45</td>
<td>40</td>
<td>42 - 49</td>
<td>21 - 28</td>
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<tr>
<td>Eyelids close</td>
<td>90</td>
<td>60</td>
<td>49 - 56</td>
<td>36 - 49</td>
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<tr>
<td>Hair follicles</td>
<td>90</td>
<td>38</td>
<td>42 - 49</td>
<td>28</td>
</tr>
<tr>
<td>Hair covering body</td>
<td>230</td>
<td>220</td>
<td>123</td>
<td>-</td>
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<tr>
<td>Gestation, d</td>
<td>280</td>
<td>340</td>
<td>150</td>
<td>113</td>
</tr>
</tbody>
</table>
Mid to late growth (day 90–180)

- Cellular growth

- Nutrition

- Absolute growth ⬆ exponentially but maximal late gestation

- Environment & nutrition: + & - effects

Late growth (day 180-280)

- Cellular growth: organ & tissue specific

  - Hypertrophy: ⬆ most tissues/organisms
    - Measured by protein to DNA ratios

  - Hyperplasia: ⬇ organs ⬆ tissues
    - Measured by DNA content as a % of tissue weight

### Developmental Characteristics of Fetal Sheep During Gestation

<table>
<thead>
<tr>
<th>Component</th>
<th>Day of gestation</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>70</td>
</tr>
<tr>
<td><strong>Brain</strong></td>
<td></td>
</tr>
<tr>
<td>Weight, g</td>
<td>3.9</td>
</tr>
<tr>
<td>DNA, mg</td>
<td>13.0</td>
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<tr>
<td>Protein/DNA, %</td>
<td>24.8</td>
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<tr>
<td><strong>Kidney</strong></td>
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<tr>
<td>Weight, g</td>
<td>.8</td>
</tr>
<tr>
<td>DNA, mg</td>
<td>3.6</td>
</tr>
<tr>
<td>Protein/DNA, %</td>
<td>27.7</td>
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<tr>
<td><strong>Heart</strong></td>
<td></td>
</tr>
<tr>
<td>Weight, g</td>
<td>1.2</td>
</tr>
<tr>
<td>DNA, mg</td>
<td>3.0</td>
</tr>
<tr>
<td>Protein/DNA, %</td>
<td>32.3</td>
</tr>
<tr>
<td><strong>Muscle</strong></td>
<td></td>
</tr>
<tr>
<td>Weight, g</td>
<td>.2</td>
</tr>
<tr>
<td>DNA, mg</td>
<td>.6</td>
</tr>
<tr>
<td>Protein/DNA, %</td>
<td>.9</td>
</tr>
</tbody>
</table>

Rattray et al., 1975
• Nutrition: optimal placental transfer
  ♦ 

• Fetal growth: maximal weight accumulation & protein deposition
  • Constraints & external stimuli - greatest effect on growth
  ♦ Nutrition
    • Severe maternal restriction (~40%), (-) effect on growth
      * 
  • Excess nutrient intake (~40%), (+) fetal weight
  ♦ Environment
    • Cold environments
      * 
      * 
      * 
      * 
    • Warm environments
      * 
      * 
      * 
      * 
  ♦ Fetal number (polytocous species model)
    • Interaction between fetal number & nutrition on growth
      * 
      * 

Weights of Single and Multiple Ovine Fetuses at Different Stages of Development and Nutrition

![Bar chart showing weights of single and multiple fetuses at different stages of gestation.]

Rattery et al., 1974

5) Fetal organ & tissue growth

♦ General order of tissue development during gestation
  - CNS > Bone > Muscle > Fat

♦ CNS
  - Head disproportionately large vs body (early development)

♦ Organs
  - Heart ⇔ relationship fetal body weight
    ♦ Maintains blood flow due to ↑ placental & fetal size
  - Lungs
    ♦ Minimal growth early but ↑ growth last half gestation
      • Oxygen from lungs only needed at birth
  - Liver
    ♦ Considerable development early and decreases late in gestation
♦ Tissues

- Skeletal
  - Initial development, cartilage miniatures
    - Replaced by bone later in gestation

- Muscle & skeletal groups exhibit differential growth
  - Lumbar region ⇔ relationship with rest of body
    - Spinal cord & CNS development

- Adipose (white)
  - Hyperplasia of preadipocytes significant
    - Hypertrophic growth minimal, little adipose tissue deposition

6) Factors influencing fetal growth

![Factors Influencing Fetal Growth Diagram]