WASHINGTON STATE UNIVERSITY EXTENSION

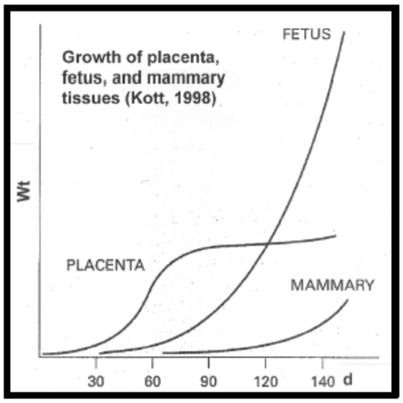
Importance of Fetal Programming in Sheep

By Sarah M. Smith[1], Min Du[2], Don Llewellyn[1], James K. Pru[2]
[1]Washington State University Extension, [2]Washington State University Department of Animal Sciences

Fetal programming is defined as material stimuli during pregnancy that can affect fetal development, as well as the growth, health, production, and reproduction of the offspring well after birth. This means that the way ewes are managed during pregnancy from the start of conception can have a significant effect on the growth, carcass quality, health, reproductive performance, and wool production of their offspring later in life as carcass lambs or as breeding sheep.

Fetal programming in cattle has received a lot of attention over the past few years, with great interest in getting cattle to perform better in feedlots (growth and carcass traits) or as retained heifers in the breeding herd (reproduction and performance). Much of the research to establish cattle and human fetal programming benchmarks was done with sheep as the model (Du et al., 2011 and Kenyon and Blair, 2013). Unfortunately, publication of this data to sheep producers and managers has not received as much attention as cattle. However, the information is just as important and might be even more critical to sheep producers because 1) the old mindset has been "Don't worry about the ewe nutrition during the first two trimesters, just be sure to increase nutrition in the third trimester when rapid fetal growth occur"; 2) the fact that sheep are seasonal breeders, most of the breeding of sheep flocks takes place in late summer and fall when pastures are mature and drying up, which has low nutritional quality and can result in nutrient deficiency for the pregnant ewe. However in spring calving herds, breeding of the cow takes place while the cow is still lactating and as spring pastures are coming on, resulting in better nutritional conditions for the early gestation cow than for the early gestation ewe; and 3) as we develop sheep to produce more pounds of heavy muscled lambs and wool (multiple births and more pounds per ewe) and as some flocks implement accelerated lambing schedules, we might be underestimating their nutritional requirements based on old scientific data. With genetic selection for higher producing animals (more muscle, greater growth, improved wool quantity and quality, etc.) it is possible, and likely that the ewe today has greater maintenance needs than the ewe did 50 years ago when nutrient requirement baselines were determined.

Sheep pregnancy typically lasts for 145-150 days and lambs are commonly harvested between 6 to 12 months of age. In other words, about one third of the total life of the lamb occurs inside the uterus and is greatly impacted by the management and care of the ewe during pregnancy. Also, all major developmental milestones; such as placental attachment and growth, and cell development, are accomplished during the fetal stage (Du et al., 2017). Therefore, it is important to manage the ewe to optimize fetus(es) potential at birth and later in life. From the physical evaluation of the ewe, there doesn't seem to be a lot going on for the first 100 days of pregnancy, however research has demonstrated that in addition to rapid placental growth in the first 15 weeks of gestation, there is also important and significant number of vital organ cells being developed (Vonnahme, 2007). The placenta is a temporary organ that nourishes and maintains the life of the fetus throughout gestation with nutrient, respiratory gases and waste exchange. Placental growth is rapid during the first part of gestation but slows during the last half of gestation (Figure 1; Kellems and Church, 2010). However, the function of the placenta increases dramatically in the last half of gestation, with blood flow increasing by three to four times the amount compared to early gestation (Vonnahme, 2007). In order for the fetus to effectively exchange nutrients, oxygen, and waste from the ewe, the placenta vascular system must be properly developed between the uterus and fetus, which occurs in early gestation. Research also has demonstrated that the blood flow can be reduced as much as 30% for nutrient restricted ewes in the mid to late gestation, resulting in decreased birth weights and weak lambs, resulting in increased lamb mortality (Vonnahme et al., 2013). Basically, the placenta is the lifeline of the fetus to the nutrition and management you provide the ewe throughout gestation.



It is well established, that cell development begins immediately with conceptions of the sperm and the egg and that fetal organ development occurs during early gestation. It is also, well understood by producers that rapid fetal growth in size, about 75% of size, occurs during the last 50 days, or third trimester, of gestation (Robinson et al., 1977). Poor nutrition during the 3rd trimester typically can result in small or weak lambs, with increased mortality or poor doing lambs; and ewes that are susceptible to ketosis, poor milking or have poor body condition. Traditionally, producers have typically increased protein and energy in the diet during the third trimester of the ewe to meet this rapid fetal growth and prevent weak and small lambs. However, the specific timeline of cell development and growth of various organs, skeletal muscles, and adipose (fat) cells of the fetus during gestation is not well recognized by producers and managers of sheep flocks, which could impact future growth performance, carcass quality and reproduction performance of the offspring (Vonnahme et al., 2013).

Current research has established that in sheep, the formation of skeletal muscle cells primarily occurs during the first two trimesters of gestation (Du et al., 2010a). Good balanced nutrition, particularly protein, during the early fetal stages of the first 1-3 months of gestation will enhance muscle fiber formation and development; enhancing lean growth (muscle growth) later in life (Du et al., 2017).

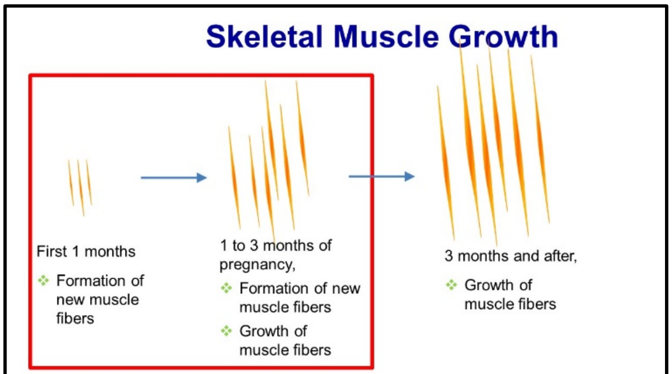


Figure 2. The formation of muscle cells occurs during early and mid gestation, while muscle growth occurs in late gestation and after lambing into maturity with proper nutrition.

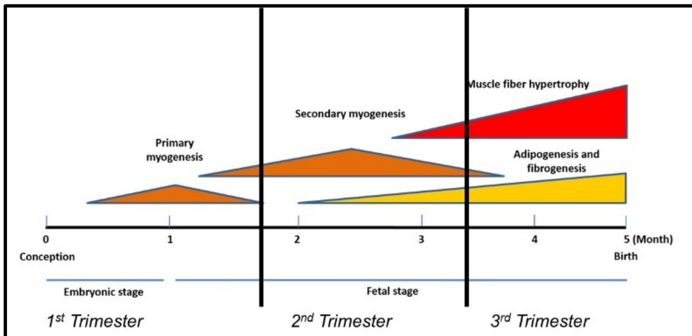


Figure 3. Compared to muscle cell formation that occurs primarily from early to mid gestation, adipose cells, also known as fat cells, being to develop from mid-gestation and continue through late gestation.

Basically, a lamb will be born with all the muscle cells it will ever have, which were primarily developed in the first three months of gestation (Figure 2). The development of the brain, heart, and liver will take priority over skeletal muscle development; therefore, muscle development will be compromised if nutrients are not optimally available (Du et. al, 2017). So, as a producer raising lambs, sheep cannot grow more muscle cells after birth even with good nutrition and good management. However, muscle size can be enhanced by increasing the diameter and length of existing muscle cells with good nutrition and management after birth. In contrast, fat cells in a lamb development starts in the second trimester through the third trimester and after birth (Figure 3; Du et al., 2010b). Even though intramuscular fat is not as critical in lamb meat palatability as it is for beef flavor and juiciness, the major formation of intramuscular adipocytes in lambs occurs after birth, during the typical weaning age of lambs as they are transitioning from a milk-based diet to forage or grain diet at approximately 60-120 days of age (Figure 4). Therefore, balanced nutrition during gestation is as important as good nutrition and management after birth and later into life. From a sheep producer's management perspective, it is not possible to make up for poor or limited nutrition during gestation by providing good nutrition later in the animals' life. Balanced nutrition for the ewe from the beginning of pregnancy is critical for future development and production of her offspring. It should also be noted, maternal milk quantity and composition is altered by the diet fed during late gestation and lactation. The development of fat cells and muscle fibers size growth of the offspring will be subsequently impacted by the maternal milk and supplemental creep feeding (Du et. al, 2017)

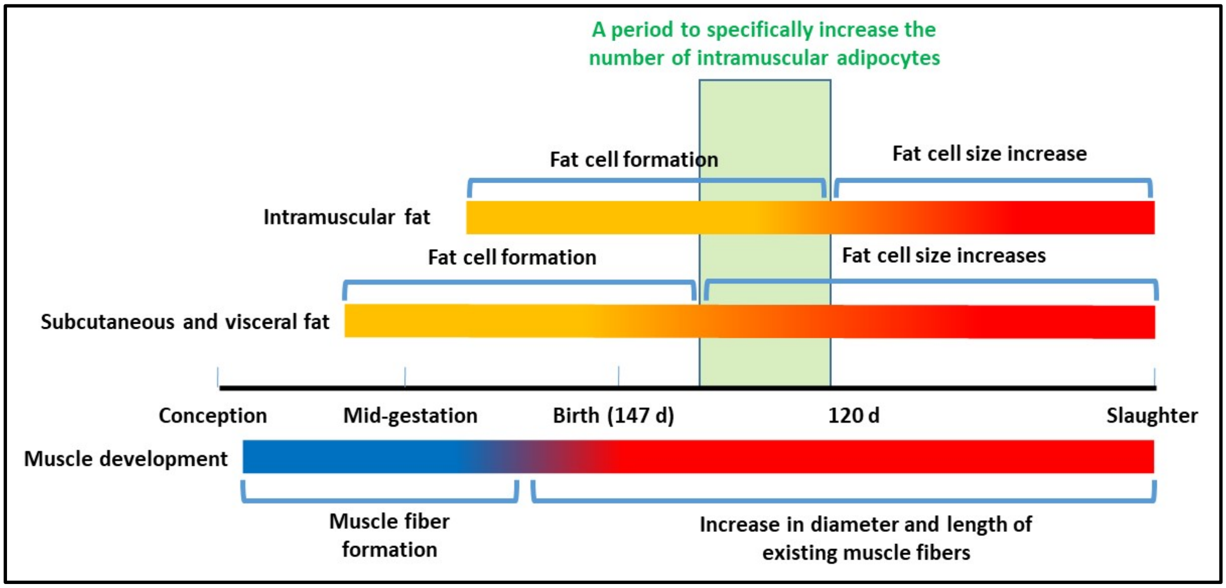


Figure 4. Skeletal cell formation occurs solely during gestation, primarily during early and mid-gestation. Subcutaneous and visceral fat cells form from mid-gestation and continuing until about 30 to 45 days after birth. Intramuscular cells, fat cells within the muscle, begin to form in mid-gestation and continue to about 90-120 days after birth.

Lambing percentage is calculated by the number of lambs born per ewe. However, this figure does not take into account the total number of embryos that may have been present during early gestation. Embryonic loss before the next heat cycle, typically 17 days, often goes unnoticed and is calculated as a "rebreed", or a "did not conceive," when actually it could be the result of embryonic loss (Menzies, 2018). Just as the complete pregnancy can be lost to early embryonic loss of all conceived embryo(s), it is possible that partial embryo loss may occur in a pregnancy that conceived multiple embryos, resulting in a successful pregnancy, but a decrease in lambing rate. It has been reported that early embryo loss can be relatively high, up to 30%, without a noticed problem during breeding or at lambing time because partial loss of pregnancy is more common than complete loss of multiple embryos (Dixon et al., 2007; Inskeep and Goodman, 2013). Numerous factors can influence embryonic loss such as congenital defects of the female reproductive axis, genetic mutations, and failure to properly establish a maternal recognition of pregnancy (hormone production and detection), as well as disease and stress related to handling and heat. Importantly, the nutritional status of the ewe prior to and immediately after conception can affect oocyte and embryo quality, early embryo development, the endocrine/hormone circuit that exists between the hypothalamus, pituitary and ovary that work together to regulate the estrous cycle, and the sophisticated bi-directional molecular communication that exists between the embryo and the uterus as pregnancy is being established (Mondal et al., 2015).

Current research also shows that maternal nutrition during various stages of gestation can also influence the offspring's future reproduction and wool production. Undernutrition of the ewe during early and mid-gestation resulted in delayed fetal ovarian development of the ewe lambs; these offspring also had lower ovulation rates than ewes that had adequate nutrition (Vonnahme et. al, 2013). Undernutrition of the ewe during gestation did affect the number of Sertoli cell numbers in the young male ram lamb's testicles, but that did not affect reproductive performance of the ram. In research projects, it has been observed that under nutrition during mid- and late gestation tend to reduce the number of wool follicles resulting in offspring that have lighter and coarser fleeces (Kenyon and Blair, 2013).

Feed typically is the single greatest cost in a sheep operation, especially during gestation and lactation for the ewe flock. To ensure flock profitability, producers have to manage their flock's nutritional needs, feed availability and supplementation requirements to optimize production with profitability. Unnecessary feed cost should be managed; however, the lowest cost ration may not be the most profitable if it compromises optimal production of the ewe and the future production of her offspring as either carcass animals or replacement breeding animals. Sheep are raised in a variety of conditions and with a variety of different feedstuffs depending upon the region and one's production system; such as dry lot housed ewes fed a specific formulate grain and hay diet delivered to a bunk feeder versus ewes raised on range or pasture foraging for feed. Each system will require producers to evaluate specific nutrient availability of feedstuffs and then manage supplementation if necessary, to the production stage and level of the flock. With the understanding of early nutrition on fetal programming, ewes bred on dormant fall pastures and ranges may need additional protein and energy during early gestation and especially during late gestations and lactation. Spring and early summer pastures are likely to have much higher energy and protein content than dormant feeds and may be able to meet the needs of the ewe's production requirement without supplementation. (Morrical, 2017). Ewes should be in a body condition score 3 at breeding and should increase to an average breeding score of 3.5 at lambing (Kott and Suber, 2019). The flock should have access to free-choice mineral and vitamin supplementation based on the requirements of the flock, mineral availability from feeds and local antagonistic effects that can impact mineral availability. For more detail on specific nutrient needs during different production stages and levels review the Sheep Production Handbook from the American Sheep Industry Association or consult your extension specialist or consulting nutritionist.

Ewes have important nutritional requirements, especially during gestation and lactation. Nutritional deficiency of the pregnant ewe can manifest in a variety of ways, including problems with growth, metabolism, reproduction and lactation of the ewe or weak and small lambs at birth. Nutritional deficiency in early gestation can also impair placenta development, impacting nutrient and waste exchange across the placenta between the dam and fetus, potentially impacting fetal development and growth. The development and growth of the lamb fetus is affected by the nutrition of the ewe during her entire pregnancy, and although some nutrient deficiencies may not be apparent at birth, they may be manifested later in life with offspring that lack muscle and fat deposition or retarded growth, health, reproduction, and wool quality. Since sheep are raised primarily for meat and secondarily for wool, it is important for producers to pay close attention to nutrition of the ewe flock going into the breeding season and through gestation to improve placental development and function, fetal muscle and adipose tissue development to improve offspring growth performance and carcass quality.

References

Du, M., J. Tong, J. Zhao, K.R. Underwood, M. Zhu, S. P. Ford, and P. W. Nathanielsz. 2010a. Fetal Programming of Skeletal Muscles Development in Ruminant Animals. J. Anim. Sci. 88:E51-60.

Du, M., J. Yin, and M. Zhu. 2010b. Cellular Signaling Pathway Regulating the Initial State of adipogenesis and marbling of Skeletal Muscle. Meat Science 86:103-109.

Du, M., J. Zhao, X. Yan, Y. Huang, L. Nicodemus, and M. J. Zhu. 2011. Fetal muscle development, mesenchuymal multipotent cell differentiation and associated signaling pathways. J. Anim Sci. 89:583-590.

Du, M., S. P. Ford, and M. Zhu. 2017. Optimizing livestock production efficiency through maternal nutritional management and fetal developmental programming. Animal Frontiers. 7(3):5-11.

Dixon, A. B., M. Knights, J.L. Winkler, D. J. Marsh, J. L. Pate, M. E. Wilson, R. A. Dailey, G. Seidel, and E. K. Inskeep. 2007. Patterns of late embryonic and feal mortality and associations with several factos in sheep. J. Anim. Sci. 85: 1274-1284.

Inskeep, E. K. and R. L. Goodman. 2013. Factos that Affect Prolificacy in Sheep. WERA-39-WSASA Sheep Symposium: Integrating Advanced Concepts into Traditional Practices, Montana State Univeristy. 67:15-20.

Kenyon, P. R. and H. T. Blair. 2013. Foetal programming in sheep – Effects on Production. Small Ruminant Research. 118:16-30.

Menzies, P. I. 2018. Prenatal Losses in Sheep. MSD Manual: Veterinary Manual. https://www.msdvetmanual.com/management-and-nutrition/management-of-reproduction-sheep/prenatal-losses-in-sheep

Mondal, S., I. J. Reddy, and A. Mor. 2015. Impact of nutritonal stress on early embryonic survival. Functional Foods in Health and Disease. 5(9):304-319.

Morrical, D. 2017. Increasing your lamb crop series: Optimal Nutrition. American Sheep Industry. https://lambresourcecenter.com/wp-content/uploads/2017/07/Optimum_Nutrition_LC_Fact_Sheet_05_25_20171.pdf

Robinson, J. J., I. McDonald, C. Fraser, and I. McHattie. 1977. Studies on reproduction in prolific ewes: I. Growth of the products of conception. J. Agri. Sci. Cambridge. 88:539-552.

Vonnahme, K. A. 2007. Nutrition during gestation and fetal programming. The Range Beef Cow Symposium XX (Proceedings). Fort Collins, CO.

Vonnahme, K. A., J. S. Caton, K. R. Maddock-Carlin, and C. S. Schauer. 2013. Maternal Environment Impacts Fetal and Offspring Outcomes In Sheep. WERA-39-WSASA Sheep Symposium: Integrating Advanced Concepts into Traditional Practices, Montana State Univeristy. 67:15-20.