Transitional Nutrition for Small Ruminants

Robert J. Van Saun, *DVM, MS, PhD, Diplomate, ACT and ACVN*
Department of Veterinary and Biomedical Sciences, Pennsylvania State University, University Park, PA 16802

Abstract

The time around parturition is the single most stressful event in a doe's or ewe's reproductive life cycle. Nutritional insults prior to and following parturition can result in exacerbation of key metabolic changes necessary to make the physiologic transition from pregnancy to lactation, resulting in a myriad of metabolic diseases. Current perceptions tend to focus attention on the lactating female and nutritional support of milk production; however, nutrition and management of the late pregnant female has more significant impact on her productive efficiency, both reproductive and lactational. Veterinarians can play an important role in their client's small ruminant transition program through nutritional monitoring of body condition score, forage quality and metabolic parameters of energy balance and protein status.

Résumé

La période qui entoure la mise bas est l'événement le plus stressant du cycle reproductif d'une chèvre ou d'une brebis. Tout déséquilibre nutritionnel avant et après la parturition peut exacerber les changements métaboliques nécessaires à la transition physiologique de la gestation à la lactation, provoquant ainsi une myriade de troubles métaboliques. La tendance actuelle veut que l'on mette l'accent sur la femelle en lactation et sur le soutien nutritionnel de sa production de lait. Toutefois, l'alimentation et la régie de la femelle en fin de gestation ont plus d'impact sur son efficacité à la fois reproductive et de lactation. Les vétérinaires peuvent améliorer de façon importante la transition des petits ruminants de leurs clients, en surveillant la condition corporelle des animaux, la qualité de leur fourrage et les paramètres métaboliques de leur équilibre énergétique et protéinique.

Introduction

There has been much interest over the past two decades regarding pregnancy nutrition and its impact on animal health, reproduction and lactational performance. As a result the pregnant, non-lactating animal has often become the most scrutinized animal on the farm. In the not-so-distant past and probably still presently on many farms, management of the pregnant animal was by benign neglect. Everything was focused on the animal at the time of parturition and later as a result of the perceived importance of the lactating animal. The sheep and goat producer, as well as the supporting veterinarian, can take a lesson from their dairy colleagues in placing a renewed emphasis on the nutritional management of the pregnant animal. As profit margins continue to decrease, more effort should be placed on maximizing neonate viability and milk production. The objective of this presentation is to describe critical maternal and fetal metabolic processes and how nutritional management influences occurrence of metabolic disease and neonate viability problems.

Metabolic Challenges of the Transition Period

An appreciation of the exquisite metabolic adaptation the doe or ewe must undergo to achieve a successful transition from pregnancy into lactation is key to understanding the critical role of nutrition on metabolic disease and reproductive performance. Minimal data are available regarding pregnant doe, metabolism and nutrition. Given the similarity in metabolic responses observed with dairy cattle and sheep, current research concepts regarding physiologic alterations associated with the transition from pregnancy to lactation can be extrapolated from these species.

An exponential fetal growth pattern places the greatest nutritional burden of pregnancy on the late pregnant ewe and doe, with greater than 60% of fetal growth occurring in the final month of gestation (Figure 1).[14,25] Glucose is the primary nutrient required by

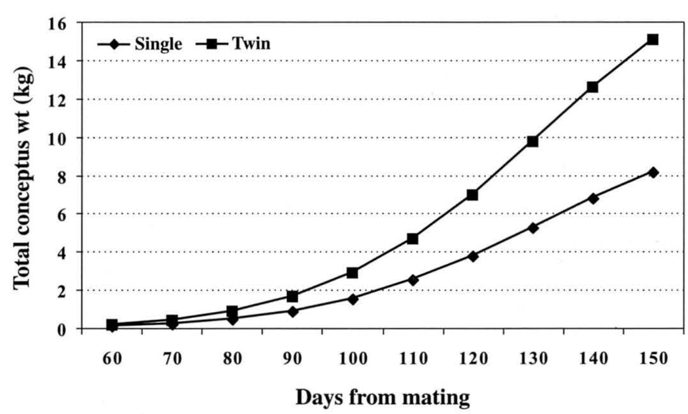

Figure 1. Cumulative fetal growth in goats for single or twin pregnancy.

both mammary gland and gravid uterus for metabolism.[4] The mammary gland converts glucose to lactose, while the gravid uterus oxidizes glucose as its primary metabolic fuel. Most energy derived by the gravid uterus comes from oxidation of glucose, lactate and amino acids.[1,4] Other potential energy substrates for the ewe or doe include acetate, fatty acids and ketone bodies. These substrates, however, are not appreciably oxidized for energy by the gravid uterus as a result of their failure to be significantly transported across the placenta from maternal circulation.[1] Complete oxidation of glucose and lactate can only account for 60 to 70% of the total fetal caloric requirement.[2] This suggests amino acids account for 32 to 40% of the total conceptus caloric requirement, in addition to providing the necessary substrate to support substantial protein synthesis activity.[3,8]

In periods of maternal undernutrition, the fetus has little flexibility in terms of available alternative metabolic fuels. Fetal glucose and acetate concentrations and utilization decline, a direct result of declining maternal concentrations. In contrast, fetal amino acid uptake is essentially unaffected by maternal nutrient status, suggesting a greater role for amino acids in fetal energy production.[1,4] A study using pregnant sheep showed amino acid oxidation, based on urea synthesis rates, to increase from 32 to 60% of total fetal oxygen consumption for diets either maintaining or restricting maternal nutrient intake throughout gestation, respectively.[8] These data clearly demonstrate that amino acids are essential fetal energy substrates, especially during periods of maternal undernutrition, and place an additional protein utilization burden on the dam.

In contrast, fatty acids and ketone bodies can contribute to energy for the mammary gland and milk fat production, but cannot provide precursors for lactose synthesis; hence, milk yield will be substantially reduced in the face of maternal glucose deficiency. Excessive fat mobilization and ketone production resulting from maternal negative energy balance will contribute to a greater risk of metabolic derangement, resulting in ketosis and hepatic lipidosis.

Prepartum Nutrition Effects on Fetal Growth and Survival

Data from cattle and sheep suggest nutrition of the dam at all stages of gestation can influence neonate viability and productivity. In reviewing factors responsible for contributing to prepartum and partum calf[32] or lamb[6,26] losses, nutritional deficiencies and toxicities influenced all factors. Similar contributing factors can be reasonably assumed for goats. Fetal growth pattern is influenced by a variety of interrelated factors including fetal genotype and sex, maternal uterine environment, ambient environment and breed of sire.[2] However, the primary determinant of fetal growth is the availability of nutrients.

Birth weight is the single most important factor determining postnatal survival. Extremely heavy birth weight is more associated with dystocia, while lighter birth weight kids, typical of twins and triplets, have higher mortality rates.[30] Dynamic *in vivo* measures of fetal sheep crown-to-rump length found fetal growth to be deterred or completely stopped during periods of induced maternal hypoglycemia during late pregnancy.[18] Twin-bearing ewes fed an 8% crude protein (CP) diet gave birth to lambs that were 20% lighter than lambs born to similar ewes fed isocaloric diets with either 11 or 15% CP.[15] In contrast, additional protein feeding (11.8% CP) to singleton-bearing ewes resulted in larger lambs (10.8 vs 9.5 lb; 4.9 vs 4.3 kg) with greater birthing difficulty and higher mortality rate, compared to ewes fed to requirement (8.7% CP).[23] Besides differing in using twin or singleton pregnant ewes, dietary treatments were initiated at 110[15] and 85[23] days of gestation for these two studies.

Maternal dietary influence on fetal growth is more complicated than simply addressing under or over-feeding relative to requirement. Maternal body condition score and dietary nutrient status relative to period of fetal and placental growth are confounding variables.[5] Fat ewes partition more nutrients to the gravid uterus, maintaining fetal growth during periods of moderate under-nutrition in late pregnancy compared to lean ewes.[17] Lean or moderately fat ewes fed *ad libitum* in late pregnancy had similar placental and fetal birth weights despite different intake amounts (29% higher for lean ewes), suggesting placental mitigation of available nutrients in controlling fetal growth.[16]

In primigravid, singleton-bearing ewes, placental growth and ultimately, lamb birth weight was restricted when fed for rapid growth after the first trimester.[31] Rapid maternal growth during the first trimester, followed by moderate growth, stimulated compensatory placental growth and moderate birth-weight lambs.[31] Placental weight is the primary determinant of fetal weight.[11] Fetal cotyledon number was influenced by first-trimester nutritional status, whereas cotyledon weight was mediated by second-trimester nutrition.[31] Fetal number and placement within uterine horns further mitigate the relationship between gestational nutrition and fetal growth.[11]

Beyond birth weight, maternal milk production will affect growth and survival of the neonate. Inadequate nutrition during late pregnancy influences milk production and composition,[28] possibly as a result of compromised mammary gland development.[7] Dietary protein content of 11% CP (9.8 g/kg $BW^{.75}$), slightly higher than National Research Council (NRC) recommendations,[20] is recommended for adequate late-gestation nutrition of the doe to meet fetal and subsequent lactational needs.[27] A new NRC publication for small ruminant nutrient requirements is under development and should be released within the year.

Preventing Periparturient Disease

These described changes in nutrient requirements over the transition period require appropriate modifications in the feeding program, as well as metabolic alterations by the dam to adequately support late gestation and lactation. If these metabolic changes are not effectively enacted, metabolic disease and reduced neonate viability may result. Four critical control points during the transition period that need to be addressed to prevent periparturient problems are: 1) maximizing dry matter intake; 2) minimizing negative energy and protein balance; 3) maintaining calcium homeostasis, and 4) minimizing immune system dysfunction.[10]

Maximizing Dry Matter Intake

Dietary recommendations for energy, crude protein, calcium and phosphorus for the late- gestation ewe or doe are 1.5 to 2.0 times greater compared to early gestation, with an even larger increase to support lactation.[20,21] Of concern in reviewing dietary nutrient intakes recommended by NRC publications, one notices an expectation for dry matter intake to increase throughout these transitions (Figure 2). This is a point of concern in late pregnancy where physical fill limitation and other metabolic or endocrine factors may decrease intake capacity, thus resulting in greater potential for pregnancy toxemia and hypocalcemia metabolic problems.[9]

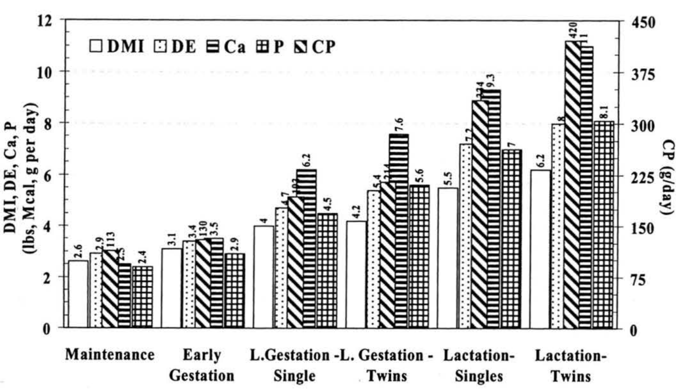

Figure 2. Comparison of recommended daily amounts of dry matter intake (DMI), digestible energy (DE), crude protein (CP), calcium (Ca) and phosphorus (P) for a mature 154 lb (70 kg) ewe at various physiologic states (Maintenance; Early and Late Gestation and Lactation with single or twins; based on data from NRC, 1985).

Neutral detergent fiber (NDF) content of forages or total diet has been shown to be a primary mediator of intake in dairy cattle. Work by Mertens has shown an optimal limit of NDF intake as 1.2% of body weight.[19] Other work has shown a lesser ability of pregnant cows to consume NDF. Expected NDF intakes for pregnant cows ranges from 0.8% of body weight at the end of pregnancy up to approximately 1.0% of body weight during the early dry period. Younger animals (first parity) have lower NDF capacity (0.1 to 0.2 units lower) compared to mature animals. Other issues, such as forage quality and environmental factors, will also influence intake capacity.[9] Role of forage quality on potential intake as determined by NDF intake capacity is demonstrated in Table 1. As forage (or total dietary) NDF increases, maximal intake capacity is reduced. For example, if forage (or total diet) NDF is 50% and NDF intake capacity is 1% of body weight, then the animal could consume 2% of body weight as forage or total diet. If NDF intake capacity is reduced to 0.8% of body weight, then intake would be only 1.6% of body weight for this same NDF level. The NRC recommendations assume an intake level between 1.8 and 2% of body weight for late pregnancy, suggesting a maximal dietary NDF content less than 44%.

Limitation of intake by NDF physical fill can be applied to other ruminant species, including small ruminants.[9] However, selective feeding behaviors typical of goats may overcome dietary limitations from NDF content. This is assuming the animal is capable of separating digestible feed components from fibrous components. Legume forages facilitate this process as the stems are separate from the leaves; however, grass forages do not have this distinction. Data from the literature suggest sheep have similar NDF capacities during pregnancy as cattle.[15,24]

In the McNeil study, twin pregnant ewes were fed isocaloric diets with differing protein content (8, 11 and

Table 1. Predicted dry matter intake (DMI) as a percent of body weight related to neutral detergent fiber (NDF) intake capacity.

Forage NDF %	DMI	NDF Capacity (% of Body Wt)			
		1.2	1.0	0.8	0.6
38	Intake as a % of Body Weight	3.16	2.63	2.11	1.58
42		2.86	2.38	1.90	1.43
44		2.61	2.27	1.74	1.36
46		2.73	2.17	1.82	1.30
50		2.40	2.00	1.60	1.20
54		2.22	1.85	1.48	1.11
58		2.07	1.72	1.38	1.03
62		1.94	1.61	1.29	0.97
66		1.82	1.52	1.21	0.91

15% crude protein).[15] Diets contained similar NDF content ranging from 39.3 to 42.9%. Calculated NDF intake as a percent of body weight was 0.71, 0.78 and 0.89 for 8, 11 and 15% crude protein diets, respectively. These diets were fed between 110 and 140 days of gestation and are consistent with observed lower NDF intake capacity of late-pregnant cows. Of interest is the dietary protein effect, which may be the result of improved fiber digestibility with increasing dietary protein. In another study monitoring intake with silage-based diets, calculated NDF intake as a percent of body weight decreased with increasing week of gestation and fetal numbers (Table 2).[24] Again, NDF intake was below 0.8% of body weight in late pregnancy, similar to what is observed in dairy cattle. In this same study, forage quality effects on NDF intake at different weeks of gestation and pregnancy status were evaluated. Again, higher fetal numbers and later gestational status resulted in lower NDF intake capacity.

Based on NRC recommendations, a late pregnant ewe (154 lb [70 kg] body weight) with twins should consume 4.2 lb (1.9 kg) dry matter (2.7% of body weight).[21] Using a NDF intake capacity of 0.7% of body weight, maximal dietary NDF content would be 26% (0.7/2.7*100). Extending this example further, if one assumes the 65% forage ration suggested by NRC, this would mean forage NDF could not exceed 40%. Forage quality may be the most limiting factor in maintaining transition intake for small ruminants. To maintain high intake potential, late pregnant animals should receive higher quality forages (<40% NDF), have feed available at least 21 hours per day, and should be managed to minimize excess body condition.

Table 2. Calculated neutral detergent intake (NDF) as a percent of body weight in ewes fed differing quality silages over weeks of gestation and pregnancy status.[1]

Pregnancy week[2]	NDF intake as % of Body weight		
	Singles	Twins	Triplets
15	0.83	0.81	0.74
16	0.81	0.73	0.71
17	0.81	0.65	0.68
18	0.74	0.65	0.64
19	0.69	0.62	0.59
20	0.70	0.60	0.55
Mean	0.76	0.68	0.65

Forage NDF%	Week	NDF intake as %BW		
		Singles	Twins	Triplets
48.5	15-17	0.82	0.74	0.71
63.8	15-17	0.78	0.70	0.70
44.9	18-20	0.83	0.70	0.70
48.5	18-20	0.71	0.62	0.59

[1]Adapted from Orr *et al*, *Animal Production* 36:21-27, 1983.
[2]Silage (48.5% NDF) fed at 25% of dietary dry matter

Minimizing Negative Energy and Protein Balance

Nutrient balance is a function of dry matter intake and nutrient composition. If dry matter intake declines in late gestation, appropriate modifications to nutrient density will be necessary to ensure adequate nutrient intake. Otherwise the pregnant dam will experience negative energy balance, which could lead to rapid mobilization of fat reserves and subsequent hepatic lipidosis and pregnancy toxemia. Increasing grain amount in the diet (0.75–1.5 lb/day; 0.3–0.68 kg) can help compensate for low dietary energy availability, as well as acclimate rumen microbes in an effort to prevent potential acidosis and off-feed problems.

Gestation-diet protein content needs to be considered when one increases grain to accommodate intake. Maternal protein deficiency in late gestation seemingly has a greater impact on birth weight than does energy deficiency. Severe or prolonged maternal protein undernutrition can result in intrauterine growth retardation of the fetus, as well as negatively impact viability through decreased thermogenic capacity and reduced production of quality colostrum. Although the NRC recommends 11.3% CP diet for late-gestation ewes, this assumes an intake level of 2.7% of body weight. Based on NRC nutrient amount recommendations and varying late-gestation intake capacity between 2.0 and 2.6% of body weight, necessary dietary nutrient densities were calculated for twin pregnant ewes (Table 3). Ewes need to consume a 15% CP diet in order to equal daily protein needs as a result of reduced intake, consistent with the observations of the McNeil study.[15] If the diet cannot meet protein needs, then the dam will mobilize body protein to meet fetal amino acid needs. Mobilization of maternal skeletal protein ("labile" protein) can explain why birth weight is not dramatically affected within reasonable variation in maternal nutritional status, at the expense of maternal protein mass. Prepartum loss in maternal nutrient reserves or body protein may have a severe detrimental impact on health, lactation and reproductive performance following parturition, since these nutrient pools are critical to support early lactational nutrient losses.

Maintaining Calcium Homeostasis

Ewes and does can experience prepartum hypocalcemia as a result of insufficient calcium intake to meet fetal calcium demands. In addition, dairy breed does may

Table 3. Impact of dry matter intake capacity on dietary nutrient content. Requirements based on 154 lb (70 kg) mature ewe in late pregnancy with an expected lambing rate of 180-225% (based on NRC, 1985 recommendations).[1]

NRC Req.	DMI		ME	CP	Ca	P
Total	4.2 lb		4.7 Mcal	214 g	7.6 g	4.5 g
Density	2.7% BW		1.12 Mcal/lb	11.3%	0.4%	0.24%
Adjusted Intake	lb	% BW	Mcal/lb	% DM	% DM	% DM
Level	3.1	2.0	1.52	15.2	0.54	0.32
	3.4	2.2	1.38	13.9	0.49	0.29
	3.7	2.4	1.27	12.7	0.45	0.27
	4.0	2.6	1.18	11.7	0.42	0.25

[1]Abbreviations: Req. = requirements; DMI = dry matter intake; ME = metabolizable energy; CP = crude protein; Ca = calcium; P = phosphorus; BW = body weight; DM = dry matter.

experience postparturient hypocalcemia similar to the syndrome seen in dairy cattle. Pathogenesis of prepartum milk fever is uncertain, whereas cationic diets are primarily responsible for the postparturient syndrome. Milk fever can be prevented by ensuring sufficient calcium and phosphorus are available from the diet, accounting for observed level of intake.

Minimizing Immune System Dysfunction

Trace minerals are lost during gestation from the dam to the fetus, where they are concentrated in the fetal liver to be used as a postnatal mineral reserve.[13] Fetal hepatic micromineral reserves are also augmented by consumption of colostrum, a highly concentrated source of most essential nutrients. Therefore, available neonatal nutrient reserves are the sum of placental transport and colostrum consumption, both of which are highly influenced by maternal nutrient status. In contrast to the microminerals, fat-soluble vitamins like vitamins A and E do not appreciably cross the placenta, resulting in no gestational liver reserve.[12,22,29] The neonate's primary source of vitamins A, D and E comes via colostrum ingestion supplied from an adequately supplemented dam. These trace nutrients not only are required for normal growth and development of the lamb, but also are essential to normal function of the immune system. The loss of trace minerals and fat-soluble vitamins in late gestation may compromise the dam's immune status if she was in a marginal nutritional state. One should ensure that adequate supplementation of minerals and vitamins is available throughout the late-pregnancy period. Free choice mineral feeding is often the most economic and practical, but also opens the door for the greatest variability in potential intake, leading in many instances to marginal deficiencies.

Conclusions

Similar to transition cow feeding and management practices currently being employed on most dairy farms, transition programs for small ruminants can also be of use. Whether servicing camelid, sheep or goat enterprises, transition nutrition can have tremendous impact on performance and viability of the neonatal animal. Late-gestation diets should be formulated to at least meet the minimum NRC requirements, but adjusted to an appropriate intake level and forage quality. Based on current NRC nutrient recommendations, late-gestation diets for sheep and goats should contain between 13 and 15% crude protein and be fortified with minerals and vitamins. Good quality forage (<42% NDF) with 1.0 to 1.5 lb (0.45 to 0.68 kg) of a concentrate should be an adequate blend to meet energy needs of the animal. Veterinarians can play an important role in their client's transition program through nutritional monitoring of body condition score, forage quality and metabolic parameters of energy balance and protein status.

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