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Effects of Perinatal Nutrition on Metabolic and Hormonal Profiles of Goat Kids (Capra hircus) during Their First Day of Life*

Pietro Celi, Adriana Di Trana[1], Salvatore Claps[2] and Paola Di Gregorio[1]**
Faculty of Veterinary Science, University of Sydney, PMB 3, 425 Werombi Rd, Camden, NSW 2570, Australia

ABSTRACT : The aim of the present work was to monitor metabolic and hormonal profiles in newborn kids, born from dams fed diets with low or high levels of energy requirements. Starting from the last month of pregnancy, 14 goats were randomly allocated to two groups: Group LD (low diet) and Group HD (high diet) that received a diet that covered 80% and 140% of their energy requirement, respectively. At delivery, the kids were weighed and a blood sample was taken before they suckled colostrum (Time 0) and 1, 2, 3, 12 and 24 h after they started suckling. Plasma insulin, IGF-I, glucose, fT3 and fT4 concentrations were not influenced by the dietary treatments, but a significant effect of time was observed as they progressively increased during the first 12 h of life. Plasma cholesterol, triglyceride, albumin, globulin and total protein plasma concentrations were significantly higher in Group HD than those of Group LD. In Group HD, cortisol concentrations were significantly lower than those of Group LD. Positive correlations were observed between LW and IGF-I (r = 0.71; p<0.05), plasma insulin and glucose (r = 0.79; p<0.05) and total protein and globulin concentrations (r = 0.97; p<0.001). Our results show that perinatal nutrition affects newborn goat kids' metabolic and hormonal profile. (**Key Words :** Newborn Goat, Perinatal Nutrition, Metabolic Profile, Hormonal Profile)

INTRODUCTION

At birth the controlled uterine environment ends, and the subsequent 24 h represent a critical transition phase between the foetal functions and those of the newborn. The survival of the newborn depends on rapid adaptation to new environmental conditions which requires the establishment of cardiovascular, respiratory, metabolic and thermoregulatory homeostasis mechanisms that are essential for survival and growth (Mellor, 1988).

Under appropriate environmental and nutritional conditions, vital life support systems can mature sufficiently to allow extremely low birth weight lambs to survive and achieve rapid growth (Greenwood et al., 1998).

Underfeeding pregnant sheep can have deleterious effects on foetal and/or newborn lambs by adversely affecting placental size, foetal growth, deposition of foetal fat reserves for use after birth, maternal udder development and colostrum/milk production (Mellor, 1983; Mellor, 1988; Gao et al., 2008). This may be even more important in grazing goats because they cannot meet their energy requirements for late pregnancy especially when parturition is scheduled out-of-season, or in the instance of marginal and hill land goat production. Therefore goats fed pasture or roughage should benefit from being supplemented with a diet of high nutritional level in late pregnancy. The objective of this study, therefore, was to investigate the hypotheses that perinatal nutrition of goats affects the metabolic and hormonal profile in the neonatal kid.

MATERIALS AND METHODS

Animals, location and experimental protocol

The study was conducted in southern Italy (40° 38' N; 15° 49' E) at the "Unita di Ricerca per la Zootecnia Estensiva (CRA)" (Bella, Italy) experimental farm located at 360 m above sea level, during the month of October. We used 14 kids born from Red Syrian goats homogeneous for age (4 to 5 years), live weight (46±1.6 kg) and body

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** Corresponding Author: Pietro Celi (DVM, PhD). Tel: +61-2-9351-1782, Fax: +61-2-9351-1693, E-mail: pietroc@camden.usyd.edu.au
[1] Dipartimento di Scienze delle Produzioni Animali, Universita' degli Studi della Basilicata; Via dell'Ateneo Lucano, 10-85100 Potenza, Italy.
[2] Consiglio per la Ricerca e la Sperimentazione in Agricoltura (C.R.A.), Unita di Ricerca per la Zootecnia Estensiva, Via Appia, Bella Scalo- 85054 Muro Lucano (PZ), Italy.
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Table 1. Ingredients and chemical composition of diets administered

	Diets	
	LD	HD
Ingredient composition (g/kg)		
Alfalfa hay 2nd cut	624	403
Maize	56	197
Barley	75	66
Chickpea	150	0
Dried beet pulps	75	137
Field beans	19	197
Chemical composition (g/ kg diet DM)		
Organic matter	926.7	939.4
Crude protein	155.1	155.9
Ether extract	22.5	16.5
Ashes	73.3	60.6
Neutral detergent fibre	367.4	353.1
Acid detergent fibre	262.7	236.8
Non fibrous carbohydrate	381.6	414.0
Nutritive value (n/kg diet DM)		
Milk forage unit[1]	0.82	0.89

[1] INRA, 1988.

condition score (2.9±0.1; arbitrary units). Briefly, body condition was scored by the same person adopting a six-point scale method (Santucci et al., 1991). In May, the goats were oestrous synchronised and mated so that kidding occurred within the first week of October.

All animals were housed in an experimental building where they had free access to water and salt blocks. All goats were acclimatized to individual pens (5 m^2) for at least 4 weeks before the start of the experiment. Starting at day 120 of pregnancy, goats were divided into two groups and they were fed daily a diet designed to cover 80% (low diet Group; LD; 846 g of DM; n = 8) or 140% (high diet Group, HD; 1,325 g of DM; n = 6) of their energy requirements (INRA, 1988).

Sampling

Feed samples were collected, and their chemical composition and nutritive value (INRA, 1988) is reported in Table 1. Dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE) and ashes were measured according to the Association of Official Analytical Chemists methods (AOAC, 1984). The neutral-detergent fibre (NDF) and acid detergent fibre (ADF) were measured according to the method described by Goering and Van Soest (1970).

Beginning at day 140 of pregnancy, goats were observed daily for signs of parturition every 2 hours and then were observed continuously once parturition started. All goats gave birth over a 7 days period. Within 20 min after parturition and before suckling, kids were weighed and a blood sample was taken from all kids (Time 0). The time of the day when kids first started suckling was noted and then blood was sampled at 1, 2, 3, 12 and 24 h after the beginning of suckling. All kids started suckling within 1 h from birth. Blood samples (6 ml) were taken from the jugular vein using a Vacutainer (Becton, Dickinson and Company, Franklin Lakes, NJ, USA) tube containing lithium heparin. Blood was centrifuged immediately at 1,400 g for 10 min and plasma was poured into a plastic tube and stored at -20°C until assayed.

Analysis

Glucose was assayed in fresh blood using a Blood Glucose Testing System (Medisense, Bedford, MA, USA). Commercially available ELISA kits were used to determine IGF-I (Immunodiagnostic Systems Ltd., Boldon, UK), cortisol (IBL-HAMBURG, Hamburg, Germany), insulin (IBL-HAMBURG, Hamburg, Germany), free triiodothyronine (fT_3; DiaMetra S.r.l., Milano, Italy) and free thyroxine (fT_4; DiaMetra Srl, Milano, Italy). Inter- and intra-assay coefficients of variations for the assays were less than 10%.

The following measurements were also carried out on plasma with commercial kits and using a Polimak PM M10/2 (Polimak, Roma, Italy): urea, triglycerides, cholesterol, total protein and albumin, calcium and inorganic phosphorus (Futura System s.r.l., Roma, Italy). Globulin concentration was calculated as the difference between total protein and albumin.

Statistical analysis

Changes in plasma concentration of hormones and metabolites were analysed by means of ANOVA repeated measures procedure. Analysis included: between-subjects main effect of feeding regimen (HD, LD), within-subjects main effect of time of sampling and interaction time of sampling x feeding regimen. The effects were considered to be significant at $p<0.05$; differences between means were tested using least significant difference. Pearson's correlation coefficients were calculated between the parameters measured in this study.

RESULTS

Gestational length was similar between the two groups (Group LD 150±0.2 days and Group HD 150±0.8). Sex of kids, which was balanced between treatment groups, did not affect any hormones or metabolites measured. At birth kids liveweight was similar between the two groups (Group LD 3.27±0.17 kg and Group HD 3.45±0.34 kg). The kid's metabolic and hormonal profiles are reported in Table 2 and Table 3, respectively. Plasma glucose and insulin concentrations increased soon after kids began suckling ($p<0.001$ and $p<0.01$, respectively) but their values were not influenced by the dietary treatments. Total protein, globulin and albumin concentrations were higher in the HD

Table 2. The effect of perinatal nutrition and time from suckling (T) on the metabolic profile of neonatal goat kids born from dams fed a high diet (HD) or a low diet (LD)

Parameters	Diet (D)	Time from suckling (T)						SEM	p-value		
		0	1	2	3	12	24		D	T	D×T
Glucose	HD	3.34	3.58	3.52	4.56	5.52	5.26	0.83			
(mmo/L)	LD	1.79	1.92	2.47	3.15	4.63	5.60	0.88	NS	***	NS
	All	2.61^{b}	2.80^{b}	3.02^{b}	3.89^{ab}	5.10^{a}	5.42^{a}	0.61			
Total protein	HD	59.4	58.3	64.6	66.8	104.7	96.4	2.96			
(g/L)	LD	40.5	42.7	41.0	45.8	75.4	72.6	2.79	***	***	NS
	All	49.4^{b}	50.0^{b}	52.1^{b}	55.7^{b}	89.2^{a}	83.8^{a}	2.23			
Albumin	HD	31.0	32.0	33.4	32.9	35.0	36.0	1.06			
(g/L)	LD	28.0	29.0	31.0	30.0	34.0	33.0	1.00	*	***	NS
	All	29.4^{b}	30.4^{b}	32.1^{b}	31.3^{b}	34.5^{a}	34.4^{a}	0.75			
Globulin	HD	28.4	26.3	31.2	33.9	69.7	60.4	2.89			
(g/L)	LD	12.5	13.7	10.0	15.8	41.3	39.5	2.72	**	***	NS
	All	20.0^{b}	19.6^{b}	20.0^{b}	24.3^{b}	54.7^{a}	49.4^{a}	2.15			
Urea	HD	7.21	7.44	6.79	7.12	7.50	7.89	0.30			
(mmo/L)	LD	6.75	7.25	7.20	6.67	7.36	7.47	0.32	NS	*	NS
	All	6.99^{b}	7.35^{ab}	6.98^{b}	6.91^{b}	7.43^{bc}	7.69^{ac}	0.22			
Cholesterol	HD	0.953	0.935	0.988	1.089	1.124	1.383	0.12			
(mmo/L)	LD	0.724	0.737	0.784	0.868	0.939	1.087	0.11	*	**	NS
	All	0.831^{b}	0.829^{b}	0.879^{b}	0.971^{b}	1.025^{bc}	1.225^{ac}	0.08			
Triglycerides	HD	0.541	0.551	0.668	0.829	0.903	0.927	0.12			
(mmo/L)	LD	0.336	0.342	0.381	0.591	0.638	0.768	0.11	*	**	NS
	All	0.432^{b}	0.440^{b}	0.515^{bc}	0.702^{ac}	0.762^{a}	0.842^{a}	0.09			
Ca	HD	1.80	2.06	2.12	2.58	2.96	3.25	0.29			
(mmo/L)	LD	1.88	1.80	2.10	2.35	2.51	2.86	0.24	NS	***	NS
	All	1.85^{c}	1.90^{c}	2.11^{cd}	2.44^{bd}	2.69^{ab}	3.02^{a}	0.20			
Pi	HD	1.68	1.74	1.85	2.13	2.41	2.64	0.36			
(mmo/L)	LD	1.77	1.61	1.74	2.14	2.34	2.45	0.30	NS	*	NS
	All	1.73^{bc}	1.66^{c}	1.78^{bc}	2.14^{abc}	2.37^{ab}	2.53^{a}	0.26			

*** p<0.001; ** p<0.01; * p<0.05; NS = Not significant; means with different superscript letters within a row are significantly different (p<0.05).

kids than in the LD kids (p<0.001, p<0.01 and p<0.05, respectively; Table 2). Their values were also significantly affected by time as they progressively increased after kids started suckling colostrum, reaching their highest values 12 h after the beginning of suckling. A similar trend was observed for cholesterol and triglycerides concentrations (Table 2): their values increased after kids of both groups started suckling (p<0.01) and higher concentrations were observed in the HD kids compared to the LD kids (p<0.05). Plasma concentrations of urea, calcium and phosphorus increased over time (p<0.05, p<0.001 and p<0.05, respectively; Table 2). Plasma concentrations of fT3, fT4 and IGF-I (Table 3) increased during the first 12 hours of life (p<0.001, p<0.001 and p<0.05, respectively). Plasma cortisol concentration was higher in the LD kids than in the HD kids (207.23±17.09 vs. 139.60±19.74 ng/ml; p<0.05). The interaction between feeding regimen×time from suckling was not significant for any of the parameters measured in this study.

DISCUSSION

Metabolic and endocrine profiles have been utilized to evaluate the metabolic status in animals and to identify pathological conditions such as certain infectious diseases and nutritional deficiencies. This study determined the concentrations and changes in concentrations of selected plasma constituents in neonatal goat kid in response to maternal dietary level during the last 4 weeks of gestation. This work demonstrates that perinatal nutrition affects the metabolic and hormonal profile of the newborn goat kid.

Differences in mean birth weights of kids between the two nutritional treatments were not significant. Similarly, when ewes were fed with a diet designed to provide either 100 or 160% of their energy requirements, no differences in lamb birth weight were noted (Muhlhausler et al., 2006). One possible explanation is that in well fed ewes foetal growth is reduced during the last 30 days of pregnancy because of a placental limit on the supply of nutrients

Table 3. The effect of perinatal nutrition and time from suckling (T) on the hormonal profile of neonatal goat kids born from dams fed a high diet (HD) or a low diet (LD)

Parameter	Diet (D)	Time from suckling (T)						SEM	p-value		
		0	1	2	3	12	24		D	T	D×T
IGF-I	HD	22.11	19.93	20.31	25.04	32.56	20.39	3.85			
(ng/ml)	LD	28.73	23.92	20.90	27.67	27.78	29.19	3.34	NS	*	NS
	All	25.89^{ab}	22.21^{b}	20.65^{b}	26.54^{ab}	29.83^{a}	25.42^{ab}	2.68			
Cortisol	HD	199.36	136.80	124.78	125.14	123.27	128.28	46.61			
(ng/ml)	LD	261.68	200.95	198.72	152.66	184.76	244.61	40.37	*	NS	NS
	All	234.97	173.46	167.03	140.87	158.41	194.75	31.98			
Insulin	HD	14.32	13.76	3.83	3.61	3.25	16.34	5.46			
(μIU/ml)	LD	7.42	12.38	9.94	10.70	5.51	36.41	4.73	NS	**	NS
	All	10.38^{b}	12.97^{b}	7.33^{b}	7.66^{b}	4.54^{b}	27.81^{a}	4.27			
fT3	HD	2.12	2.41	2.33	2.63	4.16	3.25	0.51			
(pg/ml)	LD	2.72	2.30	2.52	2.96	5.35	3.71	0.51	NS	***	NS
	All	2.42^{c}	2.36^{c}	2.43^{c}	2.80^{cd}	4.76^{a}	3.48^{bd}	0.37			
fT4	HD	1.79	2.08	2.06	2.25	2.73	1.36	0.34			
(ng/dl)	LD	1.97	2.39	2.50	3.09	3.04	2.14	0.29	NS	***	NS
	All	1.89^{b}	2.25^{bc}	2.31^{bc}	2.73^{ac}	2.91^{ac}	1.80^{b}	0.23			

*** $p<0.001$; ** $p<0.01$; * $p<0.05$; NS = Not significant; means with different superscript letters within a row are significantly different ($p<0.05$).

(Mellor, 1983). In other studies, maternal nutrient restriction resulted in a 9% and 18% decrease in mean kid (Bajhau et al., 1990) and lamb (Thompson, 1959) birth weight, respectively. Finally, kids birth weight was significantly lower in male kids but not in female kid when goats were fed on a low plane of feeding (Chowdhury et al., 2002). Goats used in this study may have had relatively more adequate energy reserves before introduction of nutritional treatment, or the treatments were not too severe, or both. It could also be likely that the efficiency of feed utilization in the underfed goats was increased (Lu et al., 2005).

In the current study, plasma concentrations of plasma fT_3 and fT_4 were in the physiological range and were not influenced by maternal perinatal nutrition. The findings that thyroid hormone concentrations were not affected by different feeding intensities in neonatal calves (Hadorn et al., 1997; Kühne et al., 2000; Nussbaum et al., 2002) are in agreement with our observations. In response to extrauterine cooling at parturition, there is a substantial rise in plasma fT_3 and fT_4 concentrations in newborn ruminants (Davicco et al., 1982; Polk, 1995). Our results are in agreement with previous observations in suckling neonatal lambs (Cabello, 1986), where the increase in plasma fT_3 and fT_4 was concomitant. This observation seems to be ascribable to an increase in thyreotrophin secretion that induced by the spontaneous cooling of the newborn (Fisher et al., 1977).

Transition from foetal to postnatal life is characterized by a decline in somatotropin and an increase in IGF-I concentrations in plasma (Gluckman et al., 1999). In precocial mammals, birth is associated with maturation of the somatotropic/IGF axis, which has an important role in regulating anabolism and catabolism (Gluckman et al., 1999). The positive correlation between liveweight and IGF-I concentrations observed in this study ($r = 0.71$; $p<0.05$) suggests that the somatotropic/IGF axis was mature at birth in these animals. This axis is influenced by nutrition in later life (McGuire et al., 1992; Bauman et al., 1995; Katoh et al., 2007).

High plasma cortisol values at birth are indicating cortisol hypersecretion by the foetal adrenal glands. Plasma cortisol concentrations decreased soon after birth in agreement with previous studies in lambs (Mellor et al., 1977; Wrutniak et al., 1987) but remained high in the LD kids, in agreement with the observations of Hough et al. (1990). Different plasma cortisol concentrations immediately before and after the first feeding were probably due to individual differences and possibly to different reactions to birth stress. Elevations in cortisol concentrations have been observed in acutely cold-stressed lambs and calves (Cabello, 1983; Lammoglia et al., 1999b). Perhaps the increased cortisol concentration observed in LD kids in the present study was an adaptive mechanism to nutritional stress due to differences in energy intake. In support of this hypothesis are the observations that a more marked postprandial decrease of cortisol concentrations has been noted in calves fed large amounts of first colostrum (Rauprich et al., 2000).

Blood glucose concentrations play an important role in thermogenesis in the newborn (Godfrey et al., 1991; Lammoglia et al., 1999a) supplying substrate for shivering thermogenesis. Glucose concentrations at birth were low and increased after suckling, as shown in other studies in newborn calves (Hadorn et al., 1997; Rauprich et al., 2000) and lambs (Wrutniak et al., 1987). Increased serum glucose concentrations in kids during the first 24 h of life are consistent with consumption of high concentrations of lactose and other gluconeogenic energy substrates via colostrum (Rauprich et al., 2000). Plasma insulin concentrations mirrored those of glucose, as expected, and indeed the two parameters were positively correlated ($r = 0.79$; $p<0.05$).

Total protein, albumin and globulin concentrations similarly increased after first feed intake in both groups. Total protein and globulin concentrations were highly correlated ($r = 0.97$; $p<0.001$) and increased rapidly in HD and LD kids as a consequence of immunoglobulin absorption. A strong correlation between plasma total protein and immunoglobulin G (IgG) concentrations has been demonstrated in goats and calves (O'Brien et al., 1993; Campbell et al., 2007). Once suckling is achieved, the serum immunoglobulin rise rapidly during the first hour and peak about at 24 h after birth (Eales et al., 1981). Total protein and globulin concentrations were significantly higher in the HD kids than in the LD ones even before kids began to suckle. Normally, in the foetus, the concentration of total protein and albumin progressively increases with little change in globulins and an absence of gamma-globulin. In agreement with our observation, Öztabak and Özpinar (2006) measured a similar range of precolostral globulin concentrations in lambs at birth. The presence of high plasma globulin concentrations in kids before ingestion of colostrum may have been due to transplacental transfer or de novo globulin production by the foetus. Gamma- and beta-globulins have been detected in lambs and birth (Larson et al., 1974) and gamma-globulins have also been noted in bovine foetal serum samples (Kniazeff et al., 1967). These observations have been attributed to transplacental transfer. The sheep foetus is capable of producing measurable amounts of immunoglobulin (Silverstein et al., 1963) which have also been found in lambs before colostrum intake (Smith et al., 1976). This latter observation could be attributed to transplacental infection by some other specific undetermined pathogen, or alternatively, should be considered a common event associated with in utero exposure and response to a broad range of antigens. Finally, it seems that micronutrients supplementation in dams prior to parturition, play an important role in the newborn immunity development (Sikka and Lal, 2006). In this study, kids from well fed goats had precolostral globulins concentrations 2 times higher than kids from feed restricted goats. Finally, it is interesting to note that total protein concentrations below 54 g/L have been suggested for failure of passive transfer of immunity in goat kids (O'Brien et al., 1993). Plasma concentrations of total protein were well above this threshold in kids born from dams fed 40% above their energy requirements, while in kids born from dams fed 20% below their energy requirements, they rose above this threshold only 24 h after birth. These findings suggest that in our study the kids born from dams fed a HD might have had higher IgG concentrations compared to the kids born from dams fed a LD. This hypothesis, however, needs to be tested in further studies where the different classes and subclasses of immunoglobulins need to be measured.

In this study, plasma concentrations of cholesterol increased by almost 50% within the first 24 h of life. This is consistent with the observations in lambs where a marked increase in the concentration of plasma cholesterol soon after birth has been described (Noble et al., 1971; Noble et al., 1975). A rise of plasma triglyceride and cholesterol concentration in goat kids of both groups may be attributable to the high fat intake by ingestion of colostrum (Leat, 1967). Differences in plasma triglyceride concentrations observed in this study could be due to a better fat absorption in the HD kids, as the intake of great amounts of colostrum improves fat absorption and fatty acid status in neonatal calves (Blum et al., 1997; Kühne et al., 2000).

In physiological conditions without hepatic and kidney dysfunctions, plasma urea concentrations are dependent on protein intake, synthesis, and degradation. Plasma urea concentrations observed in this study were slightly higher than those measured in a previous study (Celi et al., 1995). However, they fell in the physiological range and were not influenced by maternal perinatal nutrition. The relatively high urea concentrations on the first day of life possibly reflected the relatively high protein intake. The increase in urea concentration suggests that protein degradation and amino acid deamination was enhanced in kids of both groups. Amino acids were likely also used for gluconeogenesis (Kalhan et al., 2000) that occurs soon after birth in lambs (Townsend et al., 1989) to support the rapid postnatal rise in plasma glucose concentration.

Our results show that perinatal nutrition affects newborn goat kids' metabolic and hormonal profile. Overall, goat kids born from dams that received a HD had higher plasma concentrations of cholesterol, triglycerides, total protein, albumin and globulin that the kids born from dams that were fed with a LD. These findings are quite relevant as the higher plasma concentrations of the above mentioned parameters suggest a better intestinal absorption competency in the HD kids. Furthermore, the higher concentration of total protein and globulin observed in the HD kids is also quite relevant as it proposes the existence of a nutrition-induced increase in transplacental transfer or de novo globulin production by the foetus. These hypotheses need to be tested in further studies where the different classes and subclasses of immunoglobulin need to be measured in colostrum, milk and blood serum of newborn kids and their dams. In conclusion, feeding goats 40% above their energy requirements during the peripartum period ameliorates kids' metabolic profile.

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