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**Original article**

# Iodine nutrition in ewes. 2. Effects of low to high iodine intake by ewes on the I content of biological fluids and plasma immunoglobulins G in newborn lambs *

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**Summary** — 1. In two experiments samples of blood and organs were taken from newborn and young lambs born to five groups of ewes that received different dietary iodine (I) levels. Dietary I contents (mg/kg dry matter [DM]) in pregnancy and lactation, respectively, were : Experiment 1 — 0.36 and 0.26 for group C, 2.01 and 1.94 for group D; Experiment 2 — 0.13 and 0.12 for group A, 0.22 and 0.20 for group B, 10.77 and 8.88 for group E.
2. I intake of ewes had no effect on birthweight, body weight gain, or mortality between birth and wk 2 of life. No difference between the groups was recorded in the weights of brain, heart, lungs, and liver of lambs killed at birth. However, the weight of both the thyroid lobes in lambs from group E was lower than that of the other groups. The I content of the thyroid lobes of lambs from group A was 30—40% lower than that of the other groups.
3. The plasma inorganic iodine (PII) of lambs from birth to d42 of life was affected by ewe I intake, except for groups A and B, during the first 16 h of life. The PII of lambs increased with the I intake *via* milk in each group. The ratio of PII of lambs at birth/PII of ewes at d7 prepartum was 3.77, 2.96, 1.68, 1.39 and 8.62, respectively, for groups A, B, C, D and E.
4. The high I intake by group E ewes induced a higher plasma T4 concentration in lambs at birth. The decrease in plasma immunoglobulins G (IgG) recorded for the lambs in this group might be explained by this increase in plasma concentration.

**dietary iodine — newborn lambs — iodide in plasma — thyroxine — triiodothyronine — immunoglobulins G**

**Résumé — Nutrition en iode des brebis. 2. Effet de différents niveaux d'ingestion d'iode par des brebis, sur les teneurs en iodure du plasma et sur des paramètres du métabolisme thyroïdien des agneaux nouveau-nés.** *1. Des prélèvements de sang et d'organes ont été effectués sur des agneaux nouveau-nés et des jeunes agneaux de brebis recevant 5 régimes dont les teneurs en iode étaient égales, respectivement en gestation et en lactation, à 0,13 et 0,12 mg/kg MS (lot A), 0,22 et 0,20 mg/kg MS (lot B), 0,36 et 0,26 mg/kg MS (lot C), 2,01 et 1,94 mg/kg MS (lot D), 10,77 et 8,88 mg/kg MS (lot E).*
*2. La concentration en iode du régime n'a pas eu d'effet sur le poids à la naissance, la croissance et la mortalité des agneaux entre la naissance et la deuxième semaine de vie. La quantité d'iode*

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*ingérée par la brebis n'a pas modifié les poids du cerveau, du cœur, des poumons et du foie des agneaux à la naissance. Le poids des lobes thyroïdiens des agneaux à la naissance du lot E était inférieur à ceux des autres lots. La teneur en iode des lobes thyroïdiens des agneaux du lot A était 30-40% inférieure à celle des autres lots.*

*3. La teneur en iodure du plasma des agneaux de la naissance au 42e jour de vie est sous la dépendance de la teneur en iode du régime des brebis excepté pour les lots A et B. Le rapport iodures plasmatiques des agneaux à la naissance sur iodures plasmatiques des brebis était égal à 3,77, 2,96, 1,68, 1,39 et 8,62 respectivement pour les groupes A, B, C, D et E.*

*4. L'ingestion d'iode en excès (lot E) a induit une augmentation de la thyroxinémie des agneaux à la naissance. Ceci a diminué le taux plasmatique d'immunoglobulines G des agneaux de ce lot.*

***iode — agneaux nouveau-nés — iodure plasmatique — thyroxine — triiodothyronine — immunoglobulines G***

## Introduction

Iodine (I) nutrition studies in the ruminant are relevant to both pathophysiology and nutrition. However, dietary I allowances for ruminants and other domestic animals are based entirely on clinical investigations. During fetal life, the thyroxine secretion rate of the fetus is 5 times higher than that of the ewe (Dussault *et al.*, 1972). Furthermore, in the first hours of life, the peripheral conversion of thyroxine to triiodothyronine is improved (Cabello and Wrutniak, 1984). Therefore, in these periods the requirements for thyroid hormone and for I *per se* are probably high. Unfortunately, they have not been investigated.

Potter *et al.* (1984) reported retarded fetal brain development resulting from a severe dietary deficiency in sheep. However, the change of plasma inorganic iodine (PII), which has to be trapped by the thyroid gland, was not described. Such severe I deficiencies are rare in stock farms. In a previous paper (Aumont *et al.*, 1989), experimental designs that allowed the I intake from a subdeficient to a subtoxic level to be strictly monitored were described with particular attention to the change of the PII of ewes and the I in milk. These I spaces are the single I sources for the fetus and the newborns, respectively. In fact, there is no significant thyroid hormone transfer across the placental barrier in sheep (Hopkins and Thorburn, 1971; Dussault *et al.*, 1971; Nathanielsz *et al.*, 1973; Erenberg *et al.*, 1974).

The purpose of the present study was to investigate the effect of five I intake levels, by pregnant and lactating ewes, on lamb development, the PII and plasma thyroid hormone of newborns and lambs. The absorption of immunoglobulins G (IgG) from colostrum by the lamb is strongly affected by the thyroid status (Cabello *et al.*, 1980; Cabello and Levieux, 1981a). Because an inadequate I intake might have disturbed the thyroid metabolism, plasma IgG were also assessed in lambs during the first hours of life.

## Materials and Methods

### *Animal design, diet, management and sampling*

#### *Experiment 1*

Ninety-three multiparous Ile-de-France (IdF) ewes with a dated pregnancy of 30—40 d were randomly assigned to two groups, C and D, composed of 46 and 47 animals, respectively. The ewes were less than 7 yr of age. Body weight, changes in plasma thyroxine (T4), and length of pregnancy were the same in both

groups. They received the experimental diet from wk 7 of pregnancy until the wk 2 of lactation. At lambing, each ewe was placed in an individual cage where observations and sampling of the newborn were easiest. 16 h after parturition the supernumerary lambs, i.e. the 3rd or 4th lightest lambs, were put into a milk-substitute feeding park and excluded from the experiment. The others were returned to their dams in their respective group paddocks.

Except for the I contents, the diets were the same for both groups. They were based on forage and concentrates, plus mineral supplements. In pregnancy and lactation, respectively, this provided an I content of 0.36 and 0.26 mg/kg of dry matter (DM) (group C), and 2.01 and 1.94 mg/kg of DM (group D).

The sampling design in ewes and all details have been reported (Aumont *et al.*, 1989). Blood samples were collected from lambs in a tube with sodium heparin by puncture of the left jugular vein at birth, 6 h, 16 h, 1 wk and 2 wk postpartum. The thyroid glands of dead lambs were removed and weighed. All samples were stored at –18°C until analysis.

### *Experiment 2*

Thirty nulliparous Romanov x IdF ewes with a dated pregnancy of 30—40 d were assigned to three equal groups (A, B, E). Changes in body weight, plasma T4 concentration, and length of pregnancy were the same for all groups. They received the experimental diet from wk 7 of pregnancy until wk 6 of lactation. Ewe management during the lambing periods was similar to that of Experiment 1. However, one lamb chosen randomly from each litter at birth was killed after the first blood sampling. All the other lambs were returned 16 h after parturition to their dams in their respective paddocks.

The diets were composed of a crude forage and a pregnancy or lactation concentrate. The composition and manufacturing methods were the same for all three groups (Aumont *et al.*, 1989). The I content of the whole diets, respectively, was 0.13 and 0.12 mg/kg DM (group A), 0.22 and 0.20 mg/kg DM (group B), and 10.77 and 8.88 mg/kg DM (group E) in pregnancy and lactation.

Lamb blood samples were collected and stored as for Experiment 1. Both lobes of the thyroid gland were removed from dead lambs and weighed immediately to avoid drying. The left lobes were then fixed in Bouin's fluid for 48 h. Then they were washed and stored in ethanol solution (15.2 mol/l) until histological examination. The right lobes were stored at –18°C until analysis. The brain, heart, lungs, and kidneys were removed and weighed.

### *Analyses*

PII was determined according to the method of Aumont and Tressol (1987). The plasma IgG of lambs collected 6 h and 16 h postpartum was assessed by radial immunodiffusion (Mancini *et al.*, 1965) with antibodies directed against ovine IgG (Levieux, 1974). Thyroxine (T4) and triiodothyronine (T3) were determined in plasma by radioimmunological methods as described by Cabello and Levieux (1980b). The right thyroid lobes were homogenized in 5 ml of sodium chloride solution (0.154 mol/l) with a Potter Elvehjem homogenizer. The total I content of the thyroid lobes was determined in 0.5 ml of homogenized tissue (Aumont and Tressol, 1986). Classical histological examinations were performed in the Laboratory of Anatomo-Pathology at l'Ecole Nationale Vétérinaire d'Alfort, Paris.

### *Statistical analysis*

Statistical methods have been described previously (Aumont *et al.*, 1989). Analysis of variance—covariance (Seebeck, 1973), with birthweight as a covariable, was usually used because of the decisive role of this variable in lamb physiology. In Experiment 1, the analysis of variance—covariance of plasma IgG 6 h and 16 h postpartum involved sex, litter size, and I intake as factors, and birthweight, plasma T4 concentration at birth, and length of pregnancy as covariables. In Experiment 2, nonparametric methods (Siegel, 1956) were used to describe plasma IgG because these variables could not be normalized.

## Results

### *Birth weight, organ weight, growth and mortality*

### *Experiment 1*

No significant difference in birth weight was noted between groups with regard to

litter size or sex. However, length of pregnancy, as a covariable, was significant ($F = 15.65$; $P < 0.01$; coefficient of regression (CR) : 122.88; SD : 31.06; Table I). Ewe I intake had no effect on the body weight gain from birth to d10 of life, but birth weight, as a covariable, was significant ($F = 5.99$; $P < 0.01$; CR = 31.40; SD = 12.83; Table I). Lamb mortality until d14 of life was 14.9% in group C and 15.6% in group D. No significant difference was noted. The weights of the right thyroid lobes, expressed in milligrams per kilogram of body weight, of lambs that died between birth and d14 of life were higher than those of the left thyroid lobes for each group ($P < 0.01$; Table I). Neither lamb sex nor ewe I intake had any effect on the weights of the left thyroid lobes. In contrast, the weights of the right lobes of group D lambs were 2.4% lower than those of group C ($P < 0.05$; Table I).

*Experiment 2*

There was no significant difference in birth weight between groups for each litter size, but length of pregnancy, as a covariable, was significant ($F = 4.51$; $P < 0.01$; CR = 0.1189; SD = 0.039; Table II). Ewe I intake had no effect on body weight gain from birth to d10 of life, but birth weight, as a covariable, was significant ($F = 9.49$; $P < 0.001$; CR = 31.42; SD = 10.20; Table II). The same significance was recorded for the analysis of body weight gain from birth to d40 of life (birth weight as a covariable; $F = 14.68$; $P < 0.01$; CR = 43.78; SD = 11.42; Table II). One lamb, three lambs, and one lamb, respectively, from groups A, B, and E, died between birth and d42 of life. Left thyroid weight, expressed as milligrams per kilogram of body weight, of lambs killed at birth was 34.1% and 7.9% lower, respectively, ($P < 0.01$) for groups A and B than right thyroid weight (Table II). However, these differences were not seen in group E. The weights of the right and left thyroid lobes from group E lambs were lower than those in the other groups (Table II; $P < 0.01$). The histological structures of the thyroid lobes were not different between groups. When body weight was referred to, no significant different between groups was noted as regards weights of brain, lung, heart, and liver. Nevertheless, the brain weight of group A lambs was lower than that of the other groups, although this difference was not significant ($P < 0.072$; Table II).

*Plasma inorganic iodine (PII)*

*Experiment 1*

Logarithmic transformation was required to normalize the distribution of the PII in lambs. The mean values are reported in Figure 1 after exponential reconversion. The PII of lambs from group D inversely correlated with the birth weight ($r = -0.4247$; $N = 109$; $P < 0.01$). The birth weight, involved as a covariable in the analysis of the variance—covariance of PII of lambs, was significant at birth, at 6 h, and on d7 of life. The PII of group D lambs was up to 3 times higher ($P < 0.001$) than that of group C from birth to 16 h postpartum and up to 5 or 6 times higher between the d7 and d14 of life (Table III). The PII of lambs remained constant from birth to 16 h postpartum ($P < 0.01$) and then increased ($P < 0.01$) up to four-fold in group C and up to six- to eight-fold in group D (Fig. 1). Lamb PII at birth was not correlated within the groups with ewe PII at 7d prepartum or with ewe PII at 16 h postpartum. The lambs were ranked from the heaviest to the lightest in each litter; number 1 was the heaviest lamb. Within groups, the coefficients of correlation between the PII at birth of

**Table I.** Effects of ewe iodine intake during pregnancy and lactation (Group C : 0.36 and 0.26 mg/kg; Group D : 2.01 and 1.94 mg/kg) on the birthweight, daily body weight gain, and weight of the thyroid lobes.

| *Experimental groups* | *Group C* | | | | | | *Group D* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sex* | *Male* | | | *Female* | | | *Male* | | | *Female* | | |
| Litter size | *Mean ** and Se of birthweight (kg)* | | | | | | | | | | | |
| 1 | 4.98 | 1.15 | (5) | 4.88 | 0.06 | (3) | 5.00 | 0.00 | (2) | 4.75 | 0.92 | (2) |
| 2 | 4.28 | 0.56 | (13) | 4.04 | 0.65 | (27) | 4.44 | 0.60 | (21) | 4.20 | 0.71 | (18) |
| 3 | 3.73 | 0.59 | (23) | 3.56 | 0.69 | (24) | 3.54 | 0.87 | (24) | 3.47 | 0.64 | (34) |
| 4 | 4.10 | 0.43 | (4) | 2.68 | 0.45 | (2) | 3.01 | 1.19 | (7) | 3.70 | – | (1) |
| | *Mean ** and SE of the body weight gain of lamb (g/d)* | | | | | | | | | | | |
| 1 | 368 | 83 | (4) | 255 | 30 | (3) | 255 | 0 | (2) | 288 | 25 | (2) |
| 2 | 242 | 96 | (12) | 255 | 99 | (21) | 212 | 54 | (19) | 208 | 79 | (16) |
| 3 | 262 | 117 | (19) | 241 | 91 | (19) | 261 | 136 | (19) | 242 | 109 | (28) |
| 4 | 333 | 45 | (3) | 188 | 88 | (4) | 238 | 93 | (7) | 135 | – | (1) |
| | *Mean ** and SE of thyroid lobes of lambs dead between birth and 10 d (mg/kg body wt)* | | | | | | | | | | | |
| Right lobe | 183 | 59 | (15) | | | | 147 | 31 | (15) | | | |
| Left lobe | 144 | 35 | (15) | | | | 130 | 32 | (15) | | | |

* Means within groups and between groups with unlike superscript letters were significantly different (*t*-test, 1% risk).
** Numbers in parentheses refer to numbers of lambs.

**Table II.** Effects of ewe iodine intake during pregnancy and lactation (group A : 0.13 and 0.12 mg/kg DM; group B : 0.22 and 0.21 mg/kg DM; group E : 10.77 and 8.87 mg/kg DM) on birth weight, body weight gain, and weight of organs.

| *Experimental groups* | *A* | | | *B* | | | *E* | | |
|---|---|---|---|---|---|---|---|---|---|
| Litter size | *Mean ** and SE of birthweight (kg)* | | | | | | | | |
| 1 | 4.65 | 0.78 | (2) | 4.80 | 0.31 | (2) | 3.70 | – | (1) |
| 2 | 2.65 | 0.55 | (10) | 2.31 | 0.27 | (8) | 2.55 | 0.28 | (10) |
| 3 | 2.19 | 0.49 | (9) | 1.96 | 0.50 | (12) | 1.75 | 0.25 | (6) |
| 4 | | – | | | – | | 1.63 | 0.40 | (4) |
| | *Mean ** and SE of body wt gain of lamb (g/d)* | | | | | | | | |
| Between birth & 10 d | 183 | 53 | | 145 | 33 | | 201 | 49 | |
| Between birth & 40 d | 204 | 69 | | 177 | 99 | | 184 | 54 | |
| | *Mean ** and SE of wg of organs removed from lambs sacrified at birth (g/kg of body wt)* | | | | | | | | |
| Right thyroid lobe | 0.179 | 0.054 | | 0.163 | 0.038 | | 0.092 | 0.023 | |
| Left thyroid lobe | 0.123 | 0.038 | | 0.151 | 0.048 | | 0.089 | 0.017 | |
| Brain | 17.42 | 2.56 | | 20.91 | 4.56 | | 20.54 | 4.53 | |
| Heart | 8.60 | 0.68 | | 8.79 | 2.08 | | 8.90 | 1.05 | |
| Lungs | 24.31 | 5.04 | | 23.44 | 4.89 | | 22.31 | 4.65 | |
| Liver | 24.21 | 2.38 | | 22.79 | 3.66 | | 25.24 | 3.80 | |

* Means within groups and between groups with unlike superscript letters were significantly different (*t*-test, 1% risk).
** Numbers in parentheses represent numbers of lambs.

lambs of different numbers from the same litter were significant (Table III). The mean ratio of PII of lambs of birth/PII of ewes d7 prepartum (95% interval) was 1.68 (1.55—1.81) for group C and 1.39 (1.24—1.54) for group D.

*Experiment 2*

The PII of lambs of group E was 9 or 10 times higher than the PII of the other groups. Ewe I intake in groups A and B had no effect on the PII of lambs until d7 of life. Thus, the PII of group B lambs was 55—57% higher ($P < 0.01$) than that of group A from d7 to d14 of life (Fig. 1). The PII of lambs at birth was either not correlated or poorly correlated to ewe PII 7d prepartum and to ewe PII 16 h postpartum (Table III). Despite the high value of the coefficients of within-group correlation between the PII of lambs of the same litter, no statistical significance was recorded except for group E (Table IV). The mean ratio of PII of lambs at birth/PII of ewes 7d prepartum (95% interval) was 3.77 (2.87—4.28) for group A, 2.96 (2.44—3.32) for group B, and 8.62 (6.54—11.28) for group E ($P < 0.001$).

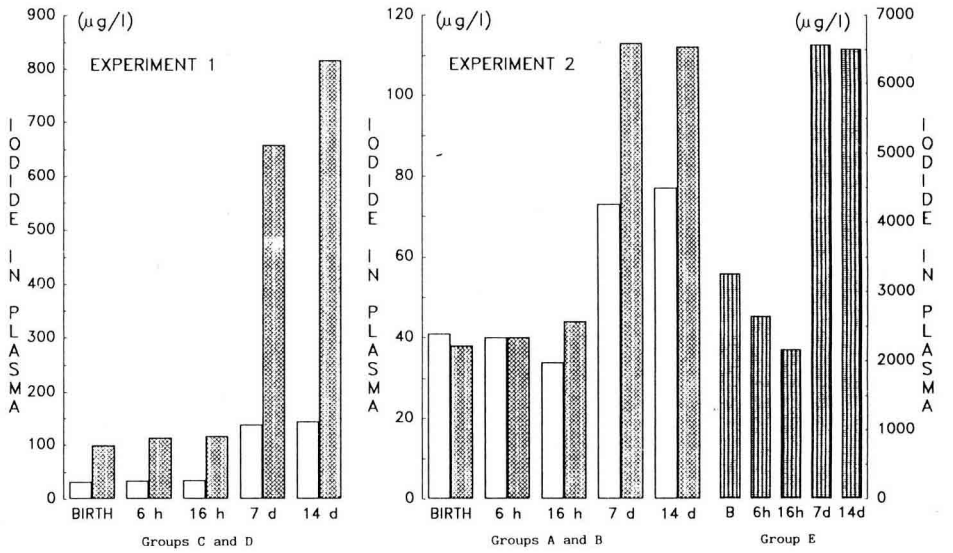


**Fig. 1.** Effects of ewe iodine intake on the plasma inorganic iodine of lambs (iodine intake of ewes, in pregnancy and lactation, respectively; **C,** 0.36 and 0.26 mg/kg DM; **D,** 2.01 and 1.94 mg/kg DM; **A,** 0.13 and 0.12 mg/kg DM; **B,** 0.22 and 0.21 mg/kg DM; **E,** 10.77 and 8.87 mg/kg DM). Comparison between groups and within experiment (*t*-test) * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. Group E is not involved in between-groups comparison because of the high values of PII recorded in this group. Logarithm transformation and exponential reconversion.

*Plasma T4 and T3 concentrations*

*Experiment 1*

The plasma T4 concentration of lambs was significantly correlated with weight at birth ($r = 0.534$; $N = 203$; $P < 0.01$), at 6 h ($r = 0.428$; $N = 201$; $P < 0.001$), at 16 h ($r = 0.346$; $N = 201$; $P < 0.01$), on d7 of life ($r = 0.263$; $N = 148$; $P < 0.01$), and on d14 of life ($r = 0.162$; $N = 144$; $P < 0.05$). Ewe I intake had no effect on plasma T4 concentration from birth to d14 of life. Plasma T4 concentration increased from birth to 6 h, decreased from 6 h to 16 h ($P < 0.01$), slightly increased within the first 2 wk of life ($P < 0.01$; Table V). Plasma T3 concentration was correlated to weight at birth ($r = 0.281$; $N = 203$; $P < 0.01$) and at 16 h ($r = 0.316$; $N = 201$; $P < 0.001$). Ewe I intake had a slight effect (F ranged between 3.93 and 4.38; $P < 0.05$) on plasma T3 concentration at birth and at 6 h. Within the first 6 h of life, plasma T3 concentration of group D lambs was lower than that of group C (birth 13%; 6 h 14%). However, the intake by ewes explained less than 2% of the whole variance. Plasma T3 concentration increased from birth to 6 h ($P < 0.001$) then decreased from 6 h to d14 of life ($P < 0.001$).

*Experiment 2*

Plasma T4 concentration of lambs correlated with weight at birth (groups A and B : $r = 0.431$; $N = 40$; $P < 0.02$; group E : $r = 0.3577$; $N = 20$; NS), and at 6 h postpartum (groups A, B, and E : $r = 0.324$; $N = 32$; $P < 0.05$). Ewe I intake had a significant effect ($P < 0.01$) on plasma T4 concentration at birth and at 6 h. Plasma T4 concentration of group E

**Table III.** Coefficient of correlation between plasma inorganic iodine (PII) of lambs at birth and PII of ewes in periparturient period.

| *Experiment* | *1* | | *2* | | |
|---|---|---|---|---|---|
| *Experimental group* | *C* | *D* | *A* | *B* | *E* |
| | *Coefficient of correlation between PII of lambs at birth and PII of ewes* | | | | |
| 7 d prepartum | 0.278 ** (99) | 0.040 (104) | − 0.097 (21) | 0.073 (19) | − 0.024 (20) |
| 16 h postpartum | − 0.078 (99) | − 0.035 (104) | − 0.173 (21) | 0.040 (19) | − 0.011 (20) |
| | *Coefficient of correlation between PII of lambs at birth within litter +* | | | | |
| Lamb 1 *vs* lamb 2+ | 0.447 ** (36) | 0.641 *** (40) | 0.705 (5) | 0.634 (6) | 0.940 *** (8) |
| Lamb 2 *vs* lamb 3+ | 0.458 * (17) | 0.705 *** (17) | 0.989 (3) | 0.958 (3) | – |
| Lamb 1 *vs* lamb 3+ | 0.500 * (16) | 0.765 *** (17) | 0.778 (3) | 0.817 (3) | – |

I intake by ewes in pregnancy and in lactation, respectively, group C : 0.36 and 0.26 mg/kg dry matter (DM); group D : 2.01 and 1.94 mg/kg DM; group A : 0.13 and 0.12 mg/kg DM; group B : 0.22 and 0.21 mg/kg DM; group E : 10.77 and 8.87 mg/kg DM.
+ within litter: lamb 1 was the heaviest lamb of the litter, lamb 3 was the lightest lamb of the litter.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
Numbers in parentheses represent numbers of lambs.

**Table IV.** Effects of ewe iodine intake on thyroxinemia and triiodothyroninemia of lambs.

| *Experiment* | *1* | | *2* | | |
|---|---|---|---|---|---|
| *Experimental group* | *C* | *D* | *A* | *B* | *E* |
| | | *Plasma T4 concentration of lambs (mmol/l)* | | | |
| Birth | 82 [a] (28) | 81 [a] (29) | 132 [a] (41) | 121 [a] (29) | 172 [c] (38) |
| 6 h | 92 [b] (26) | 89 [b] (24) | 149 [b] (41) | 134 [b] (43) | 174 [c] (45) |
| 16 h | 70 [a] (22) | 70 [a] (22) | 124 [a] (55) | 131 [ab] (50) | 144 [a] (14) |
| 7 d | 84 [ab] (14) | 84 [ab] (19) | 80 [d] (17) | 77 [d] (13) | 88 [d] (17) |
| 14 d | 87 [ab] (12) | 90 [d] (44) | 79 [d] (25) | 83 [d] (18) | 85 [d] (26) |
| | | *Plasma T3 concentration of lambs (nmol/l)* | | | |
| Birth | 1.86 [a] ± 0.72 | 1.65 [a] ± 0.66 | 2.04 [a] ± 0.92 | 1.56 [a] ± 0.56 | 1.89 [a] ± 0.57 |
| 6 h | 2.92 [b] ± 1.01 | 2.55 [d] ± 0.74 | 2.87 [b] ± 0.67 | 2.69 [b] ± 0.75 | 2.49 [b] ± 1.05 |
| 16 h | 1.62 [a] ± 0.78 | 1.51 [ac] ± 0.72 | 1.84 [a] ± 0.57 | 2.54 [b] ± 0.76 | 2.78 [b] ± 0.92 |
| 14 d | – | – | 1.00 [c] ± 0.39 | 1.66 [a] ± 0.87 | 1.25 [c] ± 0.69 |

Iodine intake of ewes in pregnancy and lactation, respectively, Group C : 0.36 and 0.26 mg/kg dry matter (DM); Group D : 2.01 and 1.94 mg/kg DM; Group A : 0.13 and 0.12 mg/kg DM; Group B : 0.22 and 0.21 mg/kg DM; Group E : 10.77 and 8.87 mg/kg DM.
Means with unlike superscript letters were significantly different within groups (Newman—Keul test, 5% risk) and between groups (t-test, 1% risk).
Numbers in parentheses represent numbers of lambs.

lambs was higher ($P < 0.01$) than that of the other groups at birth and at 6 h (Table IV). Plasma T4 concentration increased from birth to 6 h ($P < 0.01$) and decreased from d6 to d7 of life ($P < 0.01$). It then remained at the same level (Table IV). Plasma T3 concentration of lambs was not affected by ewe I intake from birth to d14 of life (Table IV). This concentration increased from birth to 6 h ($P < 0.001$), then decreased from 6 h to d14 of life ($P < 0.001$).

*Plasma immunoglobulin G (IgG)*

*Experiment 1*

The plasma IgG of lambs was correlated after a logarithmic transformation with the birth weight (at 6 h : $r = 0.279$; $N = 202$; $P < 0.001$; at 16 h : $r = 0.253$; $N = 201$; $P < 0.05$) and with the length of pregnancy (at 6 h : $r = 0.239$; $N = 202$; $P < 0.01$; at 16 h : $r = 0.233$; $N = 202$; $P < 0.01$). The factor I intake by ewes had no effect on plasma IgG at 6 h and 16 h postpartum. The mean values for plasma IgG varied from 6 h to 16 h between 4.8 and 14.1 g/l in group C ($P < 0.05$) and between 5.2 and 14.6 g/l in group D ($P < 0.05$; Table V).

*Experiment 2*

The plasma IgG of group E lambs at 6 h and 16 h was lower ($P < 0.01$) than that of the other groups. In group E more lambs had no IgG in plasma at 6 h and 16 h than in groups A and B ($P < 0.01$; Table V).

## Discussion

Birth weight is one of the major factors controlling the viability and postnatal performance of lambs (Alexander, 1974; Villette and Thériez, 1981; Villette *et al.*, 1984). In our experiments, the analysis of variance—covariance involving litter size, sex, and length of pregnancy showed that ewe I intake from 0.13 to 10.77 mg/kg DM had no effect on birth weight. Thus, only slight disturbances in body weight gain, weight of nonthyroid organs, and lamb variability could be expected. The status of preterm newborn lambs is largely affected by length of pregnancy and birth weight (Cabello and Levieux, 1980a, b). However, birth weight may also account for the variables affecting fullterm lambs (plasma T4 concentration, plasma T3 concentration, PII). This is why birth weight was considered in all our analyses of variance—covariance.

The lower I content in the thyroid lobes of lambs with lower I intake was a sign of a depletion of the lamb stocks. Such a depletion has also been reported in ewes receiving 0.12 mg of I/kg DM (Aumont *et al.*, 1989). No symptom of hypothyroidism was noted, and the thyroid status of this group was normal. Also, the slight drop in brain weight was not comparable to that recorded by Potter *et al.* (1984) in lambs from ewes that received a severely I-deficient diet. As in young rats before weaning (Vigouroux and Rostaqui, 1980; Zeghal *et al.*, 1985), our results suggest that the young lambs were more resistant to I deficiency than their dams. Gondran *et al.* (1985) have shown that I has a higher turnover rate in the thyroid gland of deficient young rats than in their mothers. This could explain why, despite a lower I content in the thyroid gland, the thyroxine secretion rate of the lambs was not impaired, whereas it was impaired in the dams during lactation (Aumont *et al.*, 1989). In any case, 0.12 mg of I/kg DM can be assumed to be the lowest limit for I intake before a deficiency occurs in lactating ewes and in their fetuses and lambs at birth.

**Table V.** Effects of ewe iodine intake of plasma immunoglobulins G of lambs.

| *Experiment* | | *1* | | *2* | | |
|---|---|---|---|---|---|---|
| *Experimental group* | | *C* | *D* | *A* | *B* | *E* |
| | | *Mean + and ranges of limmunoglobulin G (g/l)* | | | | |
| 6 h postpartum | Mean | 4.8 [a] | 5.2 [a] | 3.2 [a] | 3.9 [a] | 1.8 [c] |
| | Range | 0.0—25.8 | 0.0—20.1 | 0.0—5.5 | 0.7—7.0 | 0.0—8.8 |
| 16 h postpartum | Mean | 14.1 [b] | 14.6 [b] | 6.2 [b] | 8.5 [b] | 3.1 [d] |
| | Range | 0.0—28.0 | 0.0—27.7 | 0.4—15.5 | 2.7—13.5 | 0.0—14.6 |
| | | *Number * of lambs with any immunoglobulin G in plasma* | | | | |
| 6 h postpartum | | 30 [e] (97) | 26 [e] (104) | 1 [e] (12) | 0 [e] (10) | 4 [f] (12) |
| 16 h postpartum | | 17 [g] (97) | 22 [g] (104) | 0 [g] (12) | 0 [g] (10) | 4 [h] (12) |

Iodine intake of ewes in pregnancy and in lactation, respectively, C : 0.36 and 0.26 mg/kg dry matter (DM); D : 2.01 and 1.94 mg/kg DM; A : 0.13 and 0.12 mg/kg DM; B : 0.22 and 0.21 mg/kg DM; E : 10.77 and 8.87 mg/kg DM.

+ Samples within or between groups with unlike superscript letters were significantly different (within-group Wilcoxon test, $P < 0.01$; between-groups *t*-test at $P < 0.01$ for Exp. 1 and Mann—Whitney test at $P < 0.01$ for Exp. 2).

* Samples within-experiment and between-groups with unlike superscript letters were significantly different (chi-square test was carried out on each variable, *i.e.* 6 h and 16 h; $P < 0.01$).

The lower weight of the lamb right thyroid, which was recorded in group D, compared to that of group C, could not be explained since no variation in plasma T4 was significant. This difference, and the slight decrease in plasma T3 concentration at birth and at 16 h postpartum for lambs in this group, were probably due to methodological artefacts. Despite the lack of histological evidence, the marked decrease in the weight of lamb thyroid glands from the highest I intake group was probably due to hypostimulation induced by the hyperthyroxinemia recorded at birth and at 6 h postpartum.

The PII of lambs was two or three times higher than that recorded by Malvaux *et al.* (1965) in childhood. However, it was one-fifth of that reported in newborn lambs (Davicco *et al.*, 1980) and in newborn calves (Davicco *et al.*, 1982), which are the only reports on PII in ruminants. In these studies, I intake by the mothers was not recorded. Furthermore, the methods of PII determination used were largely different from ours. In fact, in those studies the method of Vigouroux (1976) was used, where I is separated from organic-bound I by perchloric acid protein precipitation. In our method, unbound thyroxine was removed from the plasma by ion—exchange chromatography (Aumont and Tressol, 1987). Thus, the discrepancies between the analytical methods, particularly iodine contamination with free thyroxine, could explain why Davicco *et al.* (1980) recorded a rise in PII at 6 h postpartum, whereas no such rise was noted in our experiments. The increased PII of lambs in the first 2 wk of life was probably due to the high I intake *via* milk since large amounts of I are lost in this way in ovines (Aumont *et al.*, 1989).

At 16 h postpartum, lactation had occurred, and thus milk I was already excreted. As this would lead to large disturbances in the volume of I distribution to the different compartments of the organism, we chose the PII of ewes at 7 days prepartum as the reference variable for the iodine level in plasma during the last part of pregnancy. Despite the lack of a strongly significant within-group correlation, between the PII of lambs at birth and that of ewes 7d prepartum, there was a marked maternal effect (litter effect) on lamb PII; the within-litter correlations between the PII of the different lambs was significant. Unfortunately, the maternal factors involved in this were not determined, *e.g.*, placenta size or number of cotyledons, efficiency of a possible I-trapping mechanism across the placental barrier. However, the significant inverse correlation between the PII of lambs at birth and the birth weight suggest that the rate of I passage across the placenta was independant of fetal weight. The PII values of lambs at birth/ewe PII in pregnancy were lower than those reported with radioactive I tracers (Miller *et al.*, 1967) in bovines (range : 4—6) and in ovines (range : 8—9) (Book *et al.*, 1974). Nevertheless, I intake had a great effect on this ratio which correlated inversely with the I content of food (from 0.13 to 2.01 mg/kg DM). The transplacental passage of I appeared to be regulated like the iodine of the thyroid gland. This transfer is the only physiologically essential I source for the fetus since there is no significant passage of thyroid hormones or organic I across the ovine placenta (Dussault *et al.*, 1971, 1972; Erenberg *et al.*, 1974) or the bovine placenta (Miller *et al.*, 1967; Hernandez *et al.*, 1972). The regulation of this transfer was disturbed by the large dietary I content (> 10 mg/kg DM). For such a high I intake, the ratio of lamb PII at birth/ewe PII 7d prepartum was improved to levels above 8 which induced the high PII recorded at birth in lambs (> 2 500 µg of I/l).

During pregnancy these high PII values induced hypersecretion of thyroxine in lambs without any increase in plasma T3 concentration. Since > 70% of triiodothyronine results from the peripheral deiodination of thyroxine (Walfish, 1981; Faber, 1984; Laurberg, 1984), the high level of PII could also be assumed to inhibit the conversion of T4 to T3. Results recorded on ewes (Aumont *et al.,* 1989) have also suggested this hypothesis. The changes of plasma T3 and T4 concentrations in our experiments are similar to other reported results (Klein *et al.,* 1978; Davicco *et al.,* 1980; Cabello and Wrutniak, 1984).

The plasma IgG of lambs 6 h and 16 h after birth reflects the amount of IgG absorbed by lambs from the colostrum. Three elements are involved in this absorption: (1) the amount of IgG available in the colostrum; (2) the sucking activity of the lambs; and (3) the intestinal absorption of the ingested IgG. These elements depend on several factors: maternal age (Villette and Levieux, 1981); length of pregnancy (Cabello and Levieux, 1980b); litter size, sex, and birth weight (Villette *et al.,* 1984; Halliday, 1978); genetic factors (Villette *et al.,* 1984); thyroid status (Cabello and Levieux, 1978, 1980a, 1981). In Experiment 1, the ewes were multiparous but were not more than 7 yr old. Because no difference between the groups was recorded as regards length of pregnancy, birth weight, litter size, or plasma thyroid hormone at birth, the I intake from 0.3 to 2.0 mg/kg DM could be expected to have no effect on IgG absorption. In contrast, in Experiment 2, the higher level of plasma T4 concentration at birth in lambs of the higher I intake group might induce impaired digestive absorption of the IgG from ingested colostrum. In fact, Cabello and Levieux (1978, 1980a, b, 1981) showed that excess thyroxine improved the maturation of intestinal epithelium, decreasing the passage of macromolecules across the intestinal mucosa. The decreased plasma IgG that we recorded enabled us to set the upper limit of I intake for ewes at 9 mg/kg DM. This limit is largely below that suggested by other studies (McCauley *et al.,* 1973; Wagner *et al.,* 1984) on growing lambs.

In conclusion, our studies have shown the high ability of ruminants to regulate I metabolism and thyroid metabolism between the 0.12 and 9.0 mg/kg DM limits of the I content in food. Beyond these limits, inadequate I intake may disturb the thyroid function without clinical symptoms. Such disorders may impair flock productivity. Despite the usual allowances, the most critical period for I supplementation is pregnancy, not lactation. No experimental evidence supports raising the I intake to two or three times the current practical levels (Aumont *et al.,* 1987). When there is no goitrogen in food, the dietary I allowances for yielding ewes should range between 0.2 and 0.5 mg of I/kg DM. Further studies are needed to investigate I metabolism in ruminants, particularly I transplacental passage and the regulation of I secretion in milk.

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