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Effect of Maternal Undernutrition during Late Pregnancy on Growth and Development of Ovine Fetal Visceral Organs*

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ABSTRACT : This study investigated the effect of maternal undernutrition during late pregnancy on the growth and development of ovine fetal visceral organs. One hundred Mongolian ewes were mated at a synchronized oestrus and divided into three groups and offered 0.175 MJ ME $kgw^{-0.75}$ d^{-1} (Restricted Group1; RG1), 0.33 MJ ME $kgw^{-0.75}$ d^{-1} (Restricted Group2; RG2) and *ad libitum* access to feed (Control Group; CG) during late pregnancy (90 days). Selected animals in each group were slaughtered immediately at d 90 of pregnancy and after parturition (neonatal lambs), and major visceral organs were removed and weighed separately. The results indicated that the weights of lung ($p<0.01$), spleen ($p<0.01$), heart ($p<0.05$), liver ($p<0.05$) and abomasum ($p<0.01$) in RG1 were significantly lighter than those of CG. For RG2, only the weights of the lung ($p<0.05$) and spleen ($p<0.01$) were significantly lighter than those of CG; when expressed as a percentage of body weight, significance was retained in the spleen ($p<0.01$) for both restricted groups, but the percentage of brain in RG1 was significantly higher than that in CG ($p<0.01$). For lung and spleen, the amount of DNA was significantly lower ($p<0.01$) in both groups of restricted neonatal lambs compared to CG; however, there was a significant difference only between RG1 and CG for protein: DNA ratio ($p<0.01$). The DNA content of kidney, abomasum and jejunum were decreased ($p<0.05$) in RG1 neonatal lambs, but protein: DNA ratio in the liver was decreased compared with that of CG ($p<0.05$). The plane of maternal undernutrition during late pregnancy had a significant effect on the growth and development of fetal visceral organs, which altered ontogeny of fetal organ growth and development. These perturbations in fetal visceral development may have significant implications on postnatal growth and adult health. (**Key Words :** Ewe, Undernutrition, Fetal Visceral Organs, Growth and Development)

INTRODUCTION

The period of growth and development of the fetus is a specific physiological process (Gao et al., 2008). It is well established that inadequate maternal nutrition during pregnancy influences the growth trajectory of the fetus (Robinson et al., 1999), which is called intrauterine growth restriction (IUGR). IUGR, resulting in low birth weight, has been associated with altered development of the major organ systems (Robinson et al., 1999; Osgerby et al., 2002). Recent experimental studies have documented the effects of maternal undernutrition on fetal cardiovascular systems (McMillen et al., 2001; Vonnahme et al., 2003), which can alter gene expression in the ovine fetal heart (Han et al., 2004), and may result in permanently structural alterations in the lungs (Maritz et al., 2004) and delay fetal gastrointestinal tract (Trahair et al., 1997; Gao et al., 2008a) and ovarian development in sheep (Rae et al., 2001). These "programmed" changes may be the origin of a number of diseases in later life, including coronary heart disease and the related disorders of stroke, diabetes, hypertension (Baker, 1999) and respiratory illness (Maritz et al., 2004). They may also have an adverse effect on postnatal growth, could result in lack of compensatory growth and have been associated with an increased risk of perinatal morbidity and mortality. However, despite these significant effects on clinical and agricultural domains, the mechanism by which maternal undernutrition affects the growth and development of fetal visceral organs remains unclear. The splanchnic organs play important roles during fetal and postnatal life. Although they only represent 6% to 10% of body weight,

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Table 1. Chemical composition and nutritive value of grass fed and left during restriction period (late pregnancy)

	ME (MJ/kg)*	DM (%)	CP (%)	EE (%)	NDF (%)	ADF (%)	ASH (%)	Ca (%)	P (%)
Fed grass	8.79	85.89	8.49	2.59	76.20	49.43	5.23	0.56	0.24
Left grass	-	82.60	6.45	1.83	81.75	56.03	5.79	0.56	0.24

* ME = Metabolisable energy; DM = Dry matter; CP = Crude protein; EE = Ether extract; NDF = Neutral detergent fiber; ADF = Acid detergent fiber; Ca = Calcium; P = Phosphorus.

the energy cost required to maintain function of these tissues can account for up to 50% of total energy expenditure (Burrin et al., 1990). Future feeding systems will require a better understanding of the underlying biological mechanisms. This information is one of the vital basic factors in our understanding of the capacity of the fetal visceral organs to undergo postnatal growth and health, and will allow more effective prediction of fetal response to harsh conditions. Thus, the objective of this study was to determine the effect of intrauterine growth restriction on the growth and development of ovine fetal visceral organs.

MATERIAL AND METHODS

Animals

The experimental design and detailed procedures were outlined previously (Gao et al., 2007; 2008a; 2008b). Briefly, 100 Mongolian ewes in their second or third parity, which had similar live weight (mean 42.43±0.47 kg), were mated at a synchronized oestrus after treatment for twelve days with intravaginal progestagen pessaries (each contained 0.3 g progesterone in inert silicone elastomer) and an injection of PMSG. Pregnancies were confirmed by ultrasound scanning at approximately 40 d of gestation. Based on the fact that the fetus is considered to achieve 80%-85% of its final birth weight during the last two months of pregnancy (Robinson et al., 1999; Symonds et al., 2001), maternal undernutrition was carried out from 90 days of gestation to parturition. Three maternal treatments were designed during late pregnancy: Restricted Group1 (RG1, 0.175 MJ ME $kgw^{-0.75}$ d^{-1}), Restricted Group2 (RG2, 0.33 MJ ME $kgw^{-0.75}$ d^{-1}) and Control Group (CG, *ad libitum*). Out of 100 Mongolian ewes at d 90 of pregnancy, 4 animals were slaughtered at the beginning of the experiment to determine initial fetal body and organ weight, and the remaining 96 animals were allocated to three different groups. All animals were housed in individual pens and fed chopped natural hay (Table 1). Following a one-week acclimatization, the amount of feed offered (Table 2) was constant throughout the restricted period. Restricted ewes were fed at 08:30 and 16:00 h each day. *Ad libitum* fed ewes were offered feed at 08:30, 11:00 and 16:00 h daily (the feed refusals were approximately 10% of the total amount offered). The animals had free access to water and mineral mixture block. The feed refusals were collected daily and recorded before feeding at 08:30 and sub-sampled for chemical analysis.

Maternal net body weight

During restriction, maternal initial net body weight (INBW) and the final net body weight (FNBW) were determined. After parturition, the neonatal lambs were dried and birth weights were recorded immediately.

Slaughtering procedures

At the onset of the restriction (on day 90 of gestation), 4 ewes, whose live weights were near to the average body weight of all sheep, were selected and weighed prior to slaughter to serve as an initial comparison group. Blood was collected and weighed. After dressing, gravid uterine tissue and fetuses were removed, followed by weighing of each placentome and amniotic fluid. Data was collected for each fetus including total body weight, crown-rump length (CRL), thoracic girth, umbilical girth and carcass weight, and all visceral organs were removed and weighed separately. Then samples of all organs were packed separately into plastic bags and rapidly frozen in liquid nitrogen and stored at -70°C for subsequent mincing pending analyses for protein and DNA. Immediately after birth, 4 neonatal lambs in each restricted group, born on the same day and whose maternal live weights were near to the average body weight of each respective group, were selected and slaughtered immediately. For the Control Group (CG), only three neonatal lambs were congruous and selected for slaughter.

Table 2. Levels of nutrition during restriction period (late pregnancy) in different groups

Levels of nutrition	CG (*ad libitum*)*	RG2	RG1
Mean daily grass intake (g/d)	1,332.52	719.33	383.99
Mean daily crude protein intake (g/d)	113.13	61.07	32.60
Daily metabolizable energy intake (MJ ME $kgw^{-0.75}d^{-1}$)	0.61	0.33	0.175

* CG = Control group; RG2 = Restricted group2; RG1 = Restricted group1.

Table 3. Effects of maternal undernutrition during late pregnancy on maternal net body weight loss

	CG*	RG2	RG1
Initial net body weight (INBW) (kg)	42.19±4.70 [a]	40.40±4.08 [a]	40.41±4.17 [a]
Final net body weight (FNBW) (kg)	38.69±5.32 [a]	33.79±3.78 [c]	30.85±4.52 [d]
Net body weight loss (NBWL) (kg)	3.50±1.55 [a]	6.61±1.98 [c]	9.56±1.98 [e]
NBWL/INBW×100 (%)	8.52±0.04 [a]	16.35±0.05 [c]	24.82±0.05 [e]

Means with same superscripts within a row and dimension differ at $p>0.05$, with adjacent superscripts and dimension differ at $p<0.05$, and with interval superscripts and dimension differ at $p<0.01$.

* CG = Control group; RG2 = Restricted group2; RG1 = Restricted group1.

Contents of tissue DNA and protein

The procedure used to analyze DNA concentrations with Hoescht33258 was as described by Sambrook and Russell (2001). Briefly, about 0.5 g of each organ was homogenized in 20 ml of buffer (0.05 M Na_3PO_4, 2.0 M NaCl, 0.002 M EDTA, pH 7.4). The standard was DNA Type I from calf thymus. Concentrations of protein in tissue homogenates were determined by the method of Bradford with BSA as the standard (Swanson et al., 1999). Total DNA and protein contents were calculated by multiplying tissue concentrations by fresh tissue weights (Reynolds and Redmer 1992; Jin et al., 1994). Content of DNA was used as an index of tissue hyperplasia (change in cell number), and protein: DNA ratios were used as an index of tissue hypertrophy (change in cell size).

Statistical analysis

All the data were assessed according to the general linear model (GLM) procedure of the SAS Institute, Inc. (2001). Duncan's test was used to identify significant differences between mean values. Data were presented as means±standard error. Significance was declared at $p<0.05$ and $p<0.01$.

RESULTS

Maternal net body weight loss

Effects of maternal undernutrition during late pregnancy on maternal net body weight loss are presented in Table 3. With the supply of exogenous energy decreasing, maternal net body weight loss in RG1 and RG2 were significantly increased compared to CG during the restricted phases ($p<0.01$), so that the maternal body in RG1 and RG2 mobilized 16.35% and 24.04% of initial net body weight, respectively, and there were significant differences between RG1, RG2 and CG ($p<0.01$).

Fetal weight and measurements

Effects of maternal undernutrition during late pregnancy on fetal weight and other measurements are showed in Table 4 and Table 5. Fetal daily growth rate and lamb birth weight in RG1 ($p<0.01$) and RG2 ($p<0.05$) during late gestation were significantly reduced when compared to CG. From d 90 of gestation to birth, the fetal CRL, thoracic girth

Table 4. Effects of maternal undernutrition on fetal daily growth rate and lamb birth weight during late pregnancy

Treatments	Fetal body weight on d 90 of gestation (kg)	Lamb birth weight (kg)	Daily growth rate of fetus (g/d)
CG*	0.48±0.02	3.61±0.51[a]	52.10±8.44[a]
RG2	0.48±0.02	3.36±0.39[b]	47.72±6.42[b]
RG1	0.48±0.02	2.80±0.30[d]	38.71±5.08[d]

* CG = Control group; RG2 = Restricted group2; RG1 = Restricted group1.

Means with adjacent superscripts within a column and dimension differ at $p<0.05$, and with interval superscripts and dimension differ at $p<0.01$.

Table 5. Effects of maternal undernutrition on the change of measurements in all groups during late pregnancy

Item (cm)	Fetal measurements at 90 d gestation	Neonatal measurements (at birth)		
		CG [a]	RG2	RG1
Crown–rump length (CRL)	26.25±1.26 [E]	51.33±2.31 [A]	48.25±2.22 [BC]	45.75±1.71 [C, **]
Thoracic girth	16.95±1.10 [E]	38.00±0.00 [A]	35.00±1.15 [C, **]	34.25±1.50 [C, **]
Umbilical girth	18.75±0.50 [C]	35.00±1.73 [A]	32.25±2.87 [A]	32.00±2.94 [A]

[a] CG = Control group; RG2 = Restricted group2; RG1 = Restricted group1.

[A-E] Means within a row for each group between at d 90 of gestation and term (at birth) followed by adjacent letters are different at $p<0.05$, and by interval superscripts are different at $p<0.01$.

Significant differences are described for the neonatal lambs (at birth) between restricted groups (RG1 and RG2) and control groups in the text and indicated by * $p<0.05$ and ** $p<0.01$.

and umbilical girth for each group were increased significantly ($p<0.01$). There were significant differences ($p<0.01$) in neonatal thoracic girth between RG1, RG2 and CG. CRL in RG1 was significantly reduced compared to CG ($p<0.01$), but there was no significant difference in umbilical girth of the neonatal lambs between CG or nutrient-restricted groups ($p>0.05$).

Weights of visceral organs

From d 90 of gestation to birth, the fetal organ weights for each group were increased significantly ($p<0.01$). Organ weights in neonatal lambs from underfed ewes, except those of rumen and reticulum-omasum, tended to be lighter (Table 6). The weights of lung, spleen, abomasum ($p<0.01$), liver and heart ($p<0.05$) of neonatal lambs in RG1 were lighter than those of CG. There was a difference in the weight of the lung ($p<0.05$) and the spleen ($p<0.01$) of neonatal lambs between RG2 and CG, but the other organs measured were not affected. However, when expressed as a percentage of body weight, the organ weights evaluated were similar ($p>0.05$) among RG1, RG2 and CG, with the exception of spleen weights (%) in RG2 and RG1 which were lower than in CG ($p<0.01$) and brain weight (%) in RG1 which was higher than in CG lambs ($p<0.01$).

Tissue DNA contents and protein: DNA ratios

The amount of DNA in the neonatal lung was significantly lower ($p<0.01$) in both restricted groups than

Table 6. Effects of maternal undernutrition on organ weights in all groups during late pregnancy

Item	At 90d gestation	Neonatal lambs (at birth)		
		CG [a]	RG2	RG1
Carcass weight (g)	360.16±15.82 ^{E}	1709.77±174.28 ^{A}	1356.80±43.73 ^{BC}	1176.08±119.41 $^{C, *}$
Heart (g)	3.94±0.40 ^{D}	29.07±1.26 ^{A}	26.30±2.01 ^{AB}	22.15±1.85 $^{B, *}$
Lung (g)	21.48±2.03 ^{E}	65.32±3.03 ^{A}	49.12±4.73 $^{C, *}$	39.76±1.48 $^{C, **}$
Kidney (g)	5.50±0.28 ^{D}	20.46±1.12 ^{A}	21.99±2.93 ^{A}	15.96±1.46 ^{B}
Liver (g)	27.75±0.60 ^{E}	65.63±6.69 ^{A}	56.11±5.89 ^{AB}	43.88±3.68 $^{D, *}$
Spleen (g)	0.71±0.025 ^{E}	6.21±0.52 ^{A}	3.70±0.37 $^{C, **}$	2.27±0.20 $^{D, **}$
Rumen (g)	2.32±0.24 ^{C}	8.23±2.06 ^{A}	8.69±1.08 ^{A}	8.37±0.91 ^{A}
Abomasum (g)	1.15±0.16 ^{E}	21.92±2.55 ^{A}	20.19±1.90 ^{A}	12.45±1.34 $^{C, **}$
Reticulum-omasum (g)	1.37±0.095 ^{D}	6.47±0.41 ^{A}	6.17±0.76 ^{A}	4.60±0.31 ^{A}
Small intestine (g)	10.75±0.57 ^{D}	122.54±19.49 ^{A}	113.07±12.60 ^{AB}	77.91±7.68 $^{B, **}$
Pancreas (g)	0.42±0.00 ^{C}	3.01±0.42 ^{A}	3.50±0.42 ^{A}	2.40±0.35 ^{A}
Brain (g)	13.34±0.64 ^{C}	58.00±1.91 ^{A}	55.23±3.15 ^{A}	53.05±2.75 ^{A}
Total weight (g)	79.71±5.25 ^{E}	404.48±49.49 ^{A}	362.47±79.54 ^{AB}	269.36±32.72 $^{C, *}$
% Body weight				
Carcass weight	74.96±2.52 ^{A}	44.70±1.27 ^{C}	43.77±1.14 ^{C}	45.84±3.44 ^{C}
Heart	0.82±0.075	0.77±0.038	0.84±0.036	0.87±0.075
Lung	4.47±0.39 ^{A}	1.74±0.15 ^{C}	1.58±0.12 ^{C}	1.56±0.085 ^{C}
Kidney	1.14±0.070 ^{A}	0.55±0.055 ^{C}	0.70±0.055 ^{C}	0.62±0.038 ^{C}
Liver	5.78±0.080 ^{A}	1.72±0.087 ^{C}	1.79±0.12 ^{C}	1.71±0.090 ^{C}
Spleen	0.15±0.0050 ^{AB}	0.16±0.0029 ^{A}	0.12±0.0090 $^{C, **}$	0.089±0.0065 $^{D, **}$
Rumen	0.49±0.060 ^{A}	0.21±0.035 ^{C}	0.28±0.047 ^{BC}	0.33±0.028 ^{BC}
Abomasum	0.24±0.035 ^{D}	0.58±0.075 ^{AB}	0.65±0.050 ^{A}	0.48±0.037 ^{B}
Reticulum-omasum	0.28±0.015 ^{A}	0.17±0.0092 ^{C}	0.20±0.015 ^{C}	0.18±0.015 ^{C}
Small intestine	2.27±0.23 ^{B}	3.23±0.52 ^{AB}	3.61±0.22 ^{A}	3.03±0.21 ^{AB}
Pancreas	0.086±0.015	0.079±0.0098	0.11±0.010	0.095±0.016
Brain	2.77±0.090 ^{A}	1.53±0.081 $^{E, **}$	1.79±0.12 ^{CE}	2.08±0.11 ^{C}
Total weight	16.61±0.55 ^{A}	9.29±0.675 ^{C}	10.04±0.675 ^{C}	9.07±0.24 ^{C}

[a] CG = Control group; RG2 = Restricted group2; RG1 = Restricted group1.

$^{A-E}$ Means within a row for each group between at d90 of gestation and term (at birth) followed by adjacent letters are different at $p<0.05$, and by interval superscripts are different at $p<0.01$.

Significant differences are described for the neonatal lambs (at birth) between restricted groups (RG1 and RG2) and control groups in the text and indicated by * $p<0.05$ and * * $p<0.01$.

Table 7. Effects of maternal undernutrition on DNA content and protein: DNA of fetal organs during late pregnancy

	At 90 d gestation	Neonatal lambs (at birth)		
		CG[a]	RG2	RG1
DNA content (μg)				
Heart	7.64±1.16[C]	71.94±8.58[A]	63.38±12.54[A]	53.83±15.52[A]
Lung	60.49±7.63[E]	294.77±29.60[A]	212.39±32.44[C, **]	202.76±46.27[C, **]
Kidney	14.62±1.99[C]	32.11±6.25[A]	35.40±7.70[A]	22.90±2.29[B, *]
Liver	143.71±7.62[A]	142.56±22.84[A]	130.37±24.01[AB]	108.93±9.03[B]
Spleen	-	29.02±4.42[a]	18.10±2.86 **	11.31±0.93 **
Rumen	5.04±1.38[C]	19.71±10.18[A]	22.57±4.98[A]	21.11±2.17[A]
Abomasum	2.10±0.44[E]	49.51±5.99[A]	44.95±4.06[A]	28.80±8.52[C]
Jejunum	-	321.22±33.64	340.26±92.26	203.72±49.40 *
Brain	19.63±4.88[C]	89.45±20.55[A]	75.13±19.00[A]	76.71±14.76[A]
Protein:DNA ratio				
Heart	17.48±3.87[A]	13.04±1.13[AB]	9.60±0.76[B]	11.86±3.46[B]
Lung	13.33±1.66[A]	12.33±1.27[A]	12.78±1.42[A]	9.80±1.38[B, *]
Kidney	18.02±3.51[C]	36.37±3.39[A]	37.61±2.43[A]	37.31±6.57[A]
Liver	13.47±0.61[E]	47.42±6.08[A]	39.25±3.97[BC]	36.94±4.48[C, *]
Spleen	-	15.30±2.22	13.30±2.31	11.90±1.12
Rumen	13.37±1.46	12.09±0.48	11.31±1.89	11.74±1.20
Abomasum	17.73±0.41	20.67±0.57	19.71±2.96	20.86±1.81
Jejunum	-	19.69±3.88	18.21±5.31	17.89±5.85
Brain	21.24±5.28	29.78±6.72	28.79±17.32	27.95±1.69

[a] CG = Control group; RG2 = Restricted group2; RG1 = Restricted group1.

[A-E] Means within a row for each group between at d 90 of gestation and term (at birth) followed by adjacent letters are different at $p<0.05$, and by interval superscripts are different at $p<0.01$.

Significant differences are described for the neonatal lambs (at birth) between restricted groups (RG1 and RG2) and control groups in the text and indicated by * $p<0.05$ and ** $p<0.01$.

that in CG (Table 7); however, there was a significant difference only between RG1 and CG for protein: DNA ratio ($p<0.01$). In the neonatal liver and reticulum, the protein: DNA ratios were decreased ($p<0.05$) in RG1 compared with CG. The DNA contents of the neonatal kidney, spleen, abomasum and jejunum in RG1 were lower than in CG ($p<0.05$).

DISCUSSION

It has been suggested that nutrition plays an important role in metabolism of the fetus and is associated with growth and development of the organs. In the present study, the development of the organs was retarded for the neonatal lambs which experienced intrauterine growth restriction, which is in agreement with the results of Coulter et al (2002). As pregnancy progressed, the effects of maternal undernutrition on the various categories of retarded organs became widespread in general. There is a close relationship between level of nutrition and weights of organs (Drouillard et al., 1991). Undernutrition reduces carcass weight (Aziz et al., 1992), and a significant reduction in some noncarcass parts can be observed also (Aziz et al., 1993). This reduction can alter the proportion of some organs in relation to body weight during restriction, and the extent of this decrease can be influenced by the severity of undernutrition (Aziz et al., 1994).

The hypothesis known as the 'fetal origins of adult disease' suggests that intrauterine growth restriction in humans is associated with an increased predisposition to cardiovascular disease in later life (Barker, 1999). In this study, the effects of maternal undernutrition on the heart, an organ central to the hypothesis, became widespread as pregnancy progressed and the growth of the neonatal heart in RG1 was retarded severely. Fetuses identified as being growth retarded have been found to be hypoxemic and hypoglycemic, which has been shown to retard lung maturation (Joyce et al., 2001). In this study, the lung weights of RG1 and RG2 were lighter than those of CG, again demonstrating that fetal lung development could be significantly affected by nutritional treatment. Furthermore, retardation of fetal lung development in RG2 caused by maternal undernutrition was largely accounted for by cell proliferation as determined by the amount of DNA. However, the retardation in RG1 was mainly due to reduction of DNA contents and protein: DNA ratios, which

indicated that cells decreased both in number and size per unit of tissue. The changes of lung development induced by hypoxemia or nutrient restriction during fetal stages may result in changes in the structure of the lungs of the offspring and affect respiratory health and impair lung function permanently during postnatal life (Maritz et al., 2004). The weights of the spleen in RG2 and RG1, both absolute or expressed as a percentage of body weight, were markedly lower than in CG. Cell proliferation of the spleen in RG2 and RG1 was affected and determined the amounts of DNA in RG2 and RG1, which were significantly lower than those in CG. Modifications caused by the detrimental effects of maternal malnutrition during late pregnancy on fetal spleen development could possibly influence the immunocompetence of the offspring. This may partly explain the high neonatal morbidity and mortality. For the neonatal liver, maternal undernutrition during late pregnancy had a significant effect on the weight and protein: DNA ratio in RG1. Nutritional restriction results in a decreased number of receptors for growth hormone (GH) because of restriction of the liver (Dauncey et al., 1994). It may influence the active role of the fetal somatotropic axis, including regulation of the distribution of limited substrates during adaptation of the fetus to nutritional limitation, which could lead to growth retardation of the fetus.

Although the weight of neonatal brain in RG1 was affected to some extent by maternal undernutrition, the difference was not significant when compared to CG. However, when brain weight was expressed as a percentage of body weight, the value for RG1 was higher than for CG. It has been suggested that during late pregnancy the development of brain compared to other organs was less affected. The weight of the carcass was lighter and the growth of lung, liver, spleen and abomasum was retarded, which contributed to the higher value of brain expressed as a percentage of body weight in RG1. This may be attributed to a brain protective reflex whereby more nutrients are diverted to brain metabolism at the expense of the trunk, limbs and abdominal viscera (Godfey and Robinsion, 1998). As an adaptation, the redistribution of fetal cardiac output to chronic maternal undernutrition plays an important role in maintaining the relative growth and optimal function of key fetal organs. However, redistribution of cardiac output away from particular regional circulation in late gestation may have some negative consequences (McMillen et al., 2001), which could have an influence on cell size (hypertrophy) or cell number (hyperplasia) and result in growth restriction of gastrointestinal tract (GIT) tissues. In this experiment, the growth of the GIT was affected to different extents by maternal undernutrition. The weights of abomasum and jejunum in neonatal lambs of RG1 were considerably lighter than those of CG, which contributed to the growth retardation of stomach and intestine, respectively. For RG1 neonatal lambs, the DNA contents of abomasum and jejunum were significantly lower than for CG. The restriction of fetal GIT tissues in RG1 may influence the growth and viability of neonatal lambs.

The data indicated that, during maternal undernutrition, not only were the growth and development of IUGR fetal organs restricted but also the effects were disproportionate. Brain, as an early maturing component, has high priority for use of the available nutrients in the blood stream and is less affected by maternal malnutrition than late-maturing organs like the lung, liver and spleen. Additionally, effects of undernutrition on fetal organ growth and development were weakened because of the maternal protective adaption to restriction. The lower the plane of nutrition was, the more reserves were mobilized to maintain pregnancy and fetal growth. However, when the plane of nutrition was below a threshold, the growth of the fetus was impaired and this may lead to a permanent reprogramming of the developmental pattern of key tissues and organ systems that results in pathological consequences in adult life (Barker, 1999), and the ability of complete compensatory growth during postnatal life could be lost. The mechanisms of switching from reversible to nonreversible processes are not known, but the more severe intrauterine insults may be more likely to persist in the postnatal period.

In conclusion, the plane of maternal undernutrition during late pregnancy had a significant effect on hyperplasia and hypertrophy of fetal visceral organs. The weight and content of DNA in lung and spleen of both restricted groups were significantly lower compared with CG in the present study. However, with decreasing nutrient supply, the negative reactions of fetal organs in RG1 to maternal undernutrition became more severe than those of RG2. There were significant differences only between RG1 and CG for the DNA content in kidney, abomasum, jejunum and for protein:DNA ratio in liver and lung. The appearance of altered pathways of cell hyperplasia and hypertrophy suggests that defective organ function in the growth-retarded fetus arises as a consequence of altered ontogeny of organ developments. Further study during realimentation is required to evaluate whether irreversible alterations resulting in postnatal growth retardation occur in RG1 and RG2.

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