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Maternal environment as a regulator of birth weight and body dimensions of newborn lambs

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ABSTRACT

The present research study was undertaken to investigate the effect of maternal uterine environment on birth weight of lambs. Embryos were transferred within, and reciprocally between, Suffolk and Cheviot sheep to establish four groups of pregnancies: Suffolk in Suffolk (SinS; Large control), Suffolk in Cheviot (SinC; Restricted uterine environment) Cheviot in Suffolk (CinS; Luxurious uterine environment) and Cheviot in Cheviot (CinC; Small control). Birth weight and other morphological characteristics of lambs such as head width, head length, crown-rump length, heart girth, fore leg length, hind leg length and femur length were recorded within 24 h of birth. Various placental parameters were also recorded at lambing. Birth weight of SinC lambs (5.04 ± 0.20 kg) was significantly (P <0.05) lower than SinS lambs (5.93 ± 0.19 kg). All of the body dimensions were also significantly (P <0.05) reduced in SinC compared with SinS lambs. However, neither birth weight nor other morphological parameters were significantly different (P >0.05) between CinC and CinS lambs. Among placental parameters, cotyledon number was significantly (P <0.05) lower in CinS (57.48 ± 6.27) than SinS group (74.17 ± 5.88). These results indicate that a restricted maternal uterine environment affects birth weight probably via alteration to placental characteristics.

Keywords: sheep; maternal environment; newborn lambs; birth weight.

INTRODUCTION

Various production traits of animals such as milk, wool and carcass characteristics are directly related to birth weight and postnatal growth (Greenwood *et al.*, 1998; Bell, 2006). To maximise productivity in the livestock sector, it is imperative to achieve high perinatal survival and subsequent growth rates. Optimising birth weight is essential to achieve both of these. A low birth weight has been shown to be associated with increased neonatal mortality (Morel *et al.*, 2008) and poor subsequent productivity (Greenwood *et al.*, 1998). Birth weight is regulated through the genotype of the individual and the maternal environment that it experiences *in utero.* Of these factors, maternal environment is perhaps the more critical. Based on the early epidemiological findings in a human population, Barker (1995) proposed a ‘foetal origin hypothesis’ in which he postulated that ‘foetal undernutrition in middle to late gestation leads to disproportionate foetal growth and programmes later coronary heart disease’. Recent epidemiological studies in humans have indicated that low birth weight is linked with adult-onset diseases such as non-insulin-dependent diabetes, coronary heart disease and hypertension (Godfrey and Barker, 2000; Gluckman and Hanson, 2004)

Earlier work by Walton and Hammond (1938) demonstrated that maternal size has a marked influence on the pre- and post-natal growth in foals. Subsequently, similar findings were reported by Cowley *et al.* (1989) in mice, Allen *et al.* (2004) in horses and Gardner *et al.* (2007) in sheep. A recent study by Jenkinson *et al.* (2007) has shown that crossbred foetuses from breeds of sheep of different size were significantly heavier at birth when born to a larger compared with a smaller breed. These findings further suggest that the uterine environment of the smaller dam restricted foetal growth. Beside restricted uterine capacity, the supply of nutrients from mother to foetus is also a critical factor regulating foetal growth. This indicates that the placenta, which is the site for exchange of nutrients from mother to foetus and waste products from foetus to mother, is likely to be a mediator in this process. A recent study in horses (Allen *et al.*, 2002) has reported that placental morphology is modified to adequately support foetal growth if the foetus is developing in an impaired uterine capacity. Similar findings by Vonnahme *et al.* (2006) in sheep have suggested that a change in placental morphology is evident to maintain adequate nutrient supply to the foetus during conditions of maternal nutrient restriction.

The present study was undertaken to further understand the effect of maternal environment on birth weight and body dimensions of newborn lambs by transferring pure-bred embryos within and reciprocally between two breeds of sheep of markedly different body weight and size.

MATERIALS AND METHODS

Experimental design and animals

Pure-breed embryos were collected from donors of Suffolk and Cheviot sheep and transferred into the same and opposite breeds to examine the effects of maternal uterine environment upon birth weight and size of newborn lambs. These breeds of sheep differ markedly from each other in respect of mature live weight with a mean ± standard deviation of 74.3 ± 9.2 kg for the Suffolk and 57.9 ± 7.3 kg for the Cheviot.

All donor ewes were four years old, whereas the recipients were mixed-aged. All ewes were of good body condition score with an overall mean of 2.5 and a range of between 1.5 and 4.0. The recipients of each breed were randomly divided into two groups; so that one group received embryos of its own breed and the other group received embryos of the opposite breed. A total of four groups of pregnancies were therefore established as Suffolk in Suffolk (SinS; Large control), Suffolk in Cheviot (SinC; Restricted uterine environment), Cheviot in Suffolk (CinS; Luxurious uterine environment) and Cheviot in Cheviot (CinC; Small control). These recipient ewes were allowed to carry lambs until full term.

Oestrus in both donors and recipients was synchronised by placement of CIDR (Eazi-breed; Pharmacia; Auckland) for 13 days. Superovulation of donor ewes was achieved by injecting a total of 216 mg FSH–p (Folltropin–V; Bioniche Animal Health; Canada) administered in seven tapering divided doses (48, 48, 28, 28, 24, 20, 20 mg/dose) at 12 h intervals beginning at 60 hours prior to CIDR removal. Semen was collected by electroejaculation from 1 or 2 rams per breed and donor ewes were inseminated laparoscopically with 0.5 ml of semen of the ram of the same breed, 32 h post CIDR removal. Six days post-insemination, pure-bred embryos were recovered from donors by midline laparotomy performed under general anaesthesia. The embryos were immediately transferred by laparoscopy into recipients at the rate of one embryo per recipient. The proportion of transferable embryos in the late morulae and early blastocyst stage was similar in each group. Embryos were implanted near the tip of the uterine horn ipsilateral to a corpus luteum. The required number of pregnancies in each group was achieved by undertaking two successive synchronisation, superovulation, and embryo transfer sessions. All the animals were managed under standard farm conditions on rye grass/white clover pastures at the Massey University, Keeble Farm. Ewes were allowed to lamb spontaneously with regular observation. All the experimental work was conducted with approval of theMassey University Animal Ethics Committee.

Placental parameters

Placentas were collected in clean plastic bags within 12 h of lambing and dissected for various placental characteristics including foetal membrane weight with cotyledons (FMWC), foetal membrane weight without cotyledons (FMWOC), number of cotyledons (CN) and weight of cotyledons (CW). Mean cotyledon weight per ewe (MCWPE) was calculated by dividing the weight of cotyledons of a placenta by its total cotyledon number.

Assessment of lamb birth weight and body dimensions

All lambs were weighed within 24 h of birth. Head width, head length, crown-rump length, heart girth, fore leg length, hind leg length and femur length of lambs were measured at the same time.

Statistical analysis

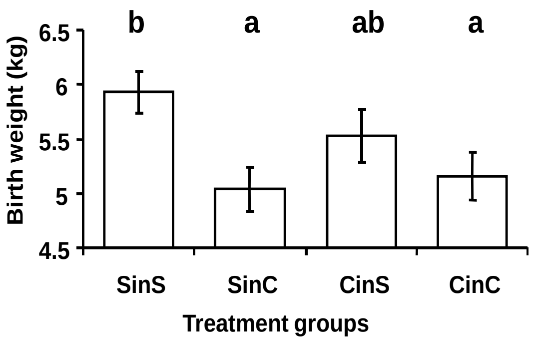
Data were subjected to two way analysis of variance using least significant differences (SAS, 2005) with the model including breed of ewe, breed of lamb and embryo transfer session as fixed effects. All main effects and interactions were included in the initial model, with the interaction terms progressively removed if found to be not significant (P >0.05).

TABLE 1: Mean ± standard error of the mean for body dimensions of lambs at birth. SinS = Suffolk in Suffolk (Large control), SinC = Suffolk in Cheviot (Restricted uterine environment), CinS = Cheviot in Suffolk (Luxurious uterine environment), CinC = Cheviot in Cheviot (Small control).

Treatment group	Number of lambs born	Head width (cm)	Head length (cm)	Crown rump length (cm)	Heart girth (cm)	Fore leg length (cm)	Hind leg length (cm)	Femur length (cm)
SinS	31	$12.9^{b} \pm 0.2$	$17.6^{b} \pm 0.2$	$58.9^{b} \pm 0.8$	$42.1^{b} \pm 0.7$	$41.8^{c} \pm 0.5$	$40.5^{c} \pm 0.4$	$12.7^{b} \pm 0.2$
SinC	29	$12.0^{a} \pm 0.2$	$16.9^{a} \pm 0.2$	$56.4^{a} \pm 0.8$	$39.9^{a} \pm 0.7$	$39.3^{b} \pm 0.5$	$38.9^{b} \pm 0.5$	$11.6^{a} \pm 0.2$
CinS	21	$12.6^{b} \pm 0.28$	$17.7^{b} \pm 0.3$	$55.9^{ab} \pm 0.2$	$41.6^{ab} \pm 0.8$	$39.2^{ab} \pm 0.6$	$36.2^{a} \pm 0.5$	$11.4^{a} \pm 0.3$
CinC	23	$12.0^{b} \pm 0.27$	$17.6^{b} \pm 0.3$	$56.2^{a} \pm 0.9$	$39.7^{a} \pm 0.8$	$38.4^{a} \pm 0.6$	$36.8^{a} \pm 0.5$	$11.2^{a} \pm 0.3$

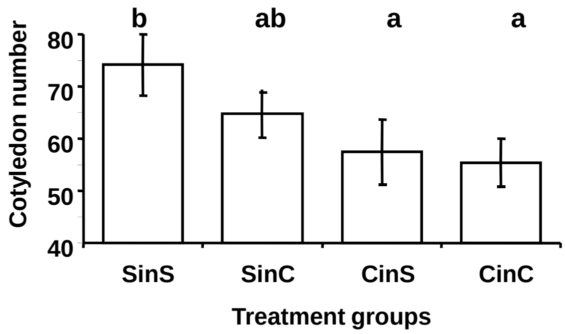
Means within a column that are labelled with different superscripts are significantly (P <0.05) different from each other.

FIGURE 1: Mean ± standard error of the mean of lamb birth weight in the four treatment groups. SinS = Large control (Suffolk in Suffolk), SinC = Restricted environment (Suffolk in Cheviot), CinS = Luxurious environment (Cheviot in Suffolk), CinC = Small control (Cheviot in Cheviot).



Columns that are labelled with different superscripts are significantly (P <0.05) different from each other.

FIGURE 2: Mean ± standard error of the mean of cotyledon number at lambing in the four treatment groups. SinS = Large control (Suffolk in Suffolk), SinC = Restricted environment (Suffolk in Cheviot), CinS = Luxurious environment (Cheviot in Suffolk), CinC = Small control (Cheviot in Cheviot).



Columns that are labelled with different superscripts are significantly (P <0.05) different from each other.

RESULTS

The overall pregnancy rate was 74.4 %. There was no significant (P >0.05) difference due to breed of donor, breed of recipient, first or second embryo transfer period, on pregnancy rate or sex ratio. There was also no significant (P >0.1) difference of embryo transfer period on lamb birth weight, morphological dimensions or placental parameters. All ewes lambed at full term after more than144 days of gestation. Male lambs were heavier (P <0.05) than female lambs regardless of the treatment group.

SinC lambs were smaller (P <0.05) than SinS lambs (Table 1). All the parameters of body morphology such as lamb head width, head length, crown-rump length, heart girth, foreleg length, hind leg length and femur length were significantly less (P <0.05) in SinC lambs than in SinS lambs.

SinC lambs were also significantly (P <0.05) lighter than SinS lambs (birth weight: 5.04 ± 0.20 kg vs 5.93 ± 0.19 kg, respectively) (Figure 1). On the other hand, CinS and CinC lambs did not differ (P>0.05) either in birth weight or in body dimensions.

Among placental characteristics, cotyledon number was significantly lower (P <0.05) in the CinS group than in the SinS group (57.48 ± 6.27 vs 74.17 ± 5.88, respectively). A similar difference (P <0.05) was also observed between CinC and SinS groups (55.45 ± 4.6 vs 74.17 ± 5.88, respectively) (Figure 2).

However, none of the other placental parameters were significantly (P >0.05) different between either of the groups (Table 2).

DISCUSSION

The present research clearly illustrates the effect of maternal uterine environment on birth weight and morphological characteristics of lambs. The key finding was that the birth weight and body dimensions of lambs were impaired when they developed in a restricted uterine environment (SinC), but were not enhanced when they developed in a luxurious environment (CinS). Similar findings were reported by Jenkinson *et al.* (2007) by crossbreeding animals from the same flock of ewes. These authors found that crossbred foetuses were significantly heavier at birth when born to a larger compared with a smaller breed. The present results are also akin to the earlier study by McCoard *et al.* (1997), who suggested limited maternal uterine space as a factor for reduced muscular development in twin lambs compared to single born lambs.

The present results are also partially in accord with Allen *et al.* (2004), who, by cross-transferring embryos between Thoroughbred and Pony horses, showed that the growth of Thoroughbred-in-Pony foals with a restricted uterine environment, was significantly less than Thoroughbred-in-Thoroughbred. However, these authors also found that the overall growth of Pony-in-Thoroughbred foals with a luxurious uterine environment, was greater than of Pony-in-Pony foals. The latter finding is contrary to the results of the present study inasmuch as the growth of lambs was not enhanced in a luxurious uterine environment. Whether such a discrepancy in findings may be explicable in terms of the different types of placentation in the equine and ovine species (Noakes, 2001) has not been investigated.

TABLE 2: Mean ± standard error of the mean for placental parameters at lambing. FMWC = Foetal membrane weight with cotyledons, FMWOC = Foetal membrane weight without cotyledons, CN = Cotyledon number, CW = Cotyledon weight, MCWPE = Mean cotyledon weight per ewe, SinS = Suffolk in Suffolk (Large control), SinC = Suffolk in Cheviot (Restricted uterine environment), CinS = Cheviot in Suffolk (Luxurious uterine environment), CinC = Cheviot in Cheviot (Small control).

Treatment group	Number of lambs born	FMWC (g)	FMWOC (g)	CN	CW (g)	MCWPE (g)
SinS	15	$373^{a} \pm 30$	$222^{a} \pm 19$	$74^{b} \pm 6$	$116^{a} \pm 12$	$1.7^{a} \pm 0.2$
SinC	21	$336^{a} \pm 25$	$216^{a} \pm 15$	$65^{ab} \pm 5$	$106^{a} \pm 10$	$1.8^{a} \pm 0.2$
CinS	15	$385^{a} \pm 24$	$218^{a} \pm 20$	$57^{a} \pm 6$	$129^{a} \pm 12$	$2.1^{a} \pm 0.2$
CinC	21	$363^{a} \pm 25$	$230^{a} \pm 15$	$55^{a} \pm 5$	$113^{a} \pm 10$	$2.0^{a} \pm 0.2$

Means within a column that are labelled with different superscripts are significantly ($P <0.05$) different from each other

The role of placenta as a mediator in this process was also apparent in the present study, since there were fewer cotyledons in CinS than in SinS placentas. This indicates that cotyledons originating from Cheviot genotype lambs could not interact with all of the available caruncles of Suffolk dams. This might explain why the Cheviot lambs appeared unable to grow more in spite of developing in a luxurious uterine environment. This notion is supported by the fact that the placenta, besides being an organ responsible for foetal nutrition, is also an active autocrine, paracrine and endocrine organ, which secrets many hormones, growth factors and cytokines, that have been shown to both regulate development of feto-placental unit and to alter maternal physiology (Gootwine, 2004). In other words it appears that the inability of Cheviot lambs to colonise all of the caruncles of the Suffolk uterus becomes the limiter to the growth of such lambs *in utero*. On the other hand, although Suffolk lambs had a tendency, albeit not significant, to colonise with more caruncles in the Cheviot uterus compared with Cheviot lambs in the Cheviot uterus, the impaired birth weight and body dimensions of SinC lambs suggest that this colonisation was insufficient to compensate for their restricted maternal environment, which further supports the role of placenta.

Nevertheless, from the present study it is clear that maternal uterine environment has the potential to affect the birth weight and body size of lambs to the extent that it can even override their genetic potential. This is evident because Suffolk lambs despite having a greater genetic potential for growth, could not achieve the expected growth when developed in a restrictive uterine environment. Since there was no difference in the placental characteristics between these two groups, SinC versus SinS, it appears that the growth retardation in SinC lambs may be either due to a limited capacity of the Cheviot uterus or an alteration in the feto-maternal dialogue during an early critical stage of gestation.

It was concluded that lamb growth up to the point of birth is significantly reduced in a restricted uterine environment, but is not significantly enhanced in a luxurious uterine environment. It seems probable that the placenta is a mediator of this process.

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