**INVITED REVIEW: Improving neonatal survival in small ruminants: science into practice: Supplementary Material**

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***Thermogenic mechanisms of the newborn ruminant***

Thermogenic mechanisms mature over the final days of gestation, but it is the combination of the birth process and exposure to cold in the extra-uterine environment that are responsible for the onset of thermogenesis. Fetal cortisol and thyroid hormones play an important role in the maturation of the lamb, with significant individual variation in the timing and magnitude of the prepartum cortisol surge, which may explain the diversity in vigour at birth (Symonds *et al*. 1995). Changes in metabolism by BAT and the liver stimulate heat production and lipid and glycogen reserves are mobilised to meet the increased oxygen consumption (Mellor and Cockburn, 1986). The thermogenic activity of BAT increases in the first two hours following birth in full term neonates. However, the availability of carbohydrates in the liver limits this period with depletion of liver glycogen, the main source of circulating glucose until the lamb ingests lactose contained in colostrum, and the resulting hypoglycaemia leads to depressed heat production, hypothermia, compromised brain function and death. Skeletal muscle glycogen is used directly by the muscle itself, releasing large amounts of unmetabolised lactate that is used during locomotion and shivering (Alexander, 1979). The high mortality rate observed during or shortly after periods of bad weather are largely the results of hypoglycaemia which in turn produces hypothermia and death, before total depletion of the fat body reserves. Normoglycaemia is therefore an important indication of neonatal well-being. Hypoglycaemia and hypogammaglobulinaemia are associated with hypothermia and are often fatal (Eales *et al*. 1986; Vihan, 1988). Once colostrum is ingested, protein, glucose and cholesterol concentrations in the plasma increase within hours (Eales *et al*. 1982; Chniter *et al*. 2013).

**Details of recent genetic analyses of lamb survival**

Recent analyses of 174K lamb survival records rate between the years 1976-2011 for Scottish Blackface sheep in the UK (Conington et al., 2013) used subsequent records of lamb weights to retrospectively assign a lamb survival record to lambs born within the national Sheepbreeder sheep improvement programme. The average survival was 87.8%. Lamb survival (SURV01) was coded 0=dead if any lamb recorded at birth had no live weight recorded at either 8 weeks or subsequent weighing occasions, and 1=alive, if it survived at least until 8 weeks with a record of live weight. The main influencing factors were flock, year/season, age of dam, sex of lamb, birth type and birth weight. Figure 4 (main paper) shows the relationship between lamb birth weight and lamb mortality. Lamb birth weight is the most important predictor of lamb survival, Figures 1 and 2 (Supplementary Material) show the effect of dam age and lamb gender on lamb survival odds. Compared to male lambs, female lambs have a 1.3 times better survival odds. Lambs from 3 year old ewes are 1.6 times more likely to survive compared to lambs from 1 year old ewes and have the highest survival odds compared to all other ewe ages. The heritability estimate was between 0.05 and 0.09, depending on the model used in the analyses. New lamb survival heritability estimates for Texel, Lleyn and Dorset breeds are currently being analysed and it is expected that lamb survival as a breeding goal trait will be included into UK sheep breeding programmes from 2016.

Figure 1: Effect of dam age on lamb survival

Figure 2: Effect of lamb gender on lamb survival

lcl= 0.70, ucl=0.79, s.e.d.= 0.03

***Details of French Participative Research Project: Massif Central case study***

During 2011-2013, a prevalence study was conducted with 60 farmers in the Massif Central of France and in three farming systems: system with two lambing periods, pastoral system and accelerated system (3 lambing in two years). The purpose of this study was to evaluate directly on farms, during two production cycles, the rate of lamb mortality, the age at death, the main causes of death and the frequency of exposure to different recognised risk factors for lamb mortality.

For each farm participating in the study, farmers were encouraged to keep exhaustive records on lambing (dates, number of ewes, litter size, sex) and lamb mortality (date, number of lambs or ewes, causes of mortality from a standardised list). Moreover, in each farm, one or two lambing batches participated in enhanced monitoring to provide an assessment of the level of exposure to the different risk factors. In total 46 of the 60 farms provided usable data for analysis.

The median pre-weaning lamb mortality rate for 2011-2013 was 13.4% (including aborted and stillborn lambs). This result can be considered relatively low in comparison to published figures (Fig 1, main paper), and raises the question of the representativeness of the farms included in this study. Between the two productions cycles, the mortality rate remained quite stable with respectively 13.7% and 13.3% in 2011-12 and 2012-13. However, this study confirmed the published findings in other countries that the rate of lamb mortality is highly variable between farms within and between farming system, with mortality rates at 60 days ranging from 3.6% to 31.2% between farms. This also reinforces the feeling that progress is possible. Overall, farms practicing the accelerated system (where ewes lambed 3 times in 2 years) had a higher lamb mortality rate (median 18.4%) in contrast to the pastoral system (median 14.6%) and the system with two lambing periods (median 12.7%).

In common with published studies, lamb mortality was highest in the first 48 hours of life, with 54% of deaths related to abortions or stillborn lambs and to lambs dying within their first 2 days of life. It is, therefore, in the very early mortality that progress to improve survival can be significant. However, the farmers in the study generally felt that they had little or no ability to influence lamb mortality during this period. They considered it to be inherent to the system, and outside their control. On the other hand, they felt they had more opportunity to improve the mortality that occurred after the first 2 days of life of the lamb.

The distribution of causes of death by lamb age is consistent with the published literature. From birth to 48 hours of age, the causes of death were mostly classified as “unknown" (including aborted foetuses and stillborn) and non-infectious (very small lamb, unable to begin independent breathing, misplaced, sucking problem). In contrast, after 10 days of age, infectious causes (enterotoxemia, respiratory infections, diarrhoea) were predominant. However, the three leading causes of death were, in descending order, "unknown" (24.9%), “very small lamb" (11.6%) and "sucking problems" (7.5%).

**Additional References used for this section and the main paper** (other references are given in the main paper)

Alexander G 1962. Temperature regulation in the newborn lamb. IV. The effect of wind and evaporation of water from the coat on metabolic rate and body temperature. Australian Journal of Agricultural Research 13, 82-99.

Alexander G. 1979. Cold thermogenesis. International Review of Physiology 20, 43-155.

Alexander G 1984. Constraints to lamb survival. In Reproduction in sheep (eds DR Lindsay and DT Pearce). pp 199-208. Canberra: Australian Academy of Science, Australian Wool Corporation.

Alexander G and McGance I 1958. Temperature regulation in the new-born lamb. I. Changes in rectal temperature within the first six hours of life. Australian Journal of Agricultural Research 9, 339-347.

Alexander G and Williams D 1968. Shivering and non-shivering thermogenesis during summit metabolism in young lambs. Journal of Physiology (London)198, 251-276

Allain D, Foulquie D, Autran P, Francois D and Bouix J 2014. Importance of birthcoat for lamb survival and growth in the Romane sheep breed extensively managed on rangelands. Journal of Animal Science 92, 54-63.

Ameh JA, Egwu GO and Tijjani AN 2000. Mortality in sahelian goats in Nigeria. Preventive Veterinary Medicine 44, 107-111.

Annett RW, Dawson, LER, Edgar, H, and Carson, AF 2009. Effects of source and level of fish oil supplementation in late pregnancy on feed intake, colostrum production and lamb output of ewes. Animal Feed Science and Technology 154, 169-182.

Awemu EM, Nwakalor LN and Abubakar BY 1999. Environmental influences on preweaning mortality and reproductive performance of Red Sokoto does. Small Ruminant Research 34, 161-165.

Baumrucker CR and Bruckmaier RM 2014. Colostrogenesis: IgG1 transcytosis mechanisms. Journal of Mammary Gland Biology and Neoplasia 19, 103-117.

Bekele T, Otesile EB and Kasali OB 1992. Influence of passively acquired colostral immunity on neonatal lamb mortality in Ethiopian Highland sheep. Small Ruminant Research 9, 209-215.

Blumm JW and Hammon H 2000. Colostrum effects on the gastrointestinal tract, and on nutritional, endocrine and metabolic parameters in neonatal calves. Livestock Production Science 66, 151-159.

Briefer E and McElligott AG 2011. Mutual mother-offspring vocal recognition in an ungulate hider species (Capra hircus). Animal Cognition 14, 585-598.

Broster JC, Dehaan RL, Swain DL and Friend, MA 2010. Ewe and lamb contact at lambing is influenced by both shelter type and birth number. Animal 4, 796-803.

Campbell SG, Siegel MJ and Knowlton BJ 1977. Sheep immunoglobulins and their transmission to the neonatal lamb. New Zealand Veterinary Journal 25, 361–365.

Capper JL, Wilkinson RG, MacKenzie AM and Sinclair LA 2006. Polyunsaturated fatty acid supplementation during pregnancy alters neonatal behavior in sheep. Journal of Nutrition 136, 397-403.

Chowdhury SA, Bhuiyan MSA and Faruk S 2002. Rearing black bengal goat under semi-intensive management 1. Physiological and reproductive performances. Asian-Australasian Journal of Animal Sciences 15, 477-484.

Conington J, Moore K, Glasgow A and Dwyer C. 2013. Including lamb survival as a breeding goal in sheep breeding programmes. Proceedings of the British Society for Animal Science, Nottingham, UK. Paper 0067.

de Medeiros JM, Tabosa LM, Simoes SVD, da Nobrega JE, de Vasconcelos JS and Riet-Correa, F 2005. Perinatal mortality in kids in the semiarid region of Paraiba, Brazil. Pesquisa Veterinaria Brasileira 25, 201-206.

Deribe G, Abebe G and Tegegne A 2014. Non-genetic factors influencing reproductive traits and pre-weaning mortality of lambs and kids under smallholder management, Southern Ethiopia. Journal of Animal and Plant Sciences 24, 413-417.

Dwyer CM 2008a. The welfare of the neonatal lamb. Small Ruminant Research 76: 31-41

Dwyer CM 2008b. Genetic and physiological determinants of maternal behavior and lamb survival: implications for low-input sheep management. Journal of Animal Science 86, 46-58.

Dwyer CM 2014. Maternal behaviour and lamb survival: From neuroendocrinology to practical application. Animal8, 102-112

Dwyer CM, Lawrence AB and Bishop SC 2001. Effects of selection for lean tissue content on maternal and neonatal lamb behaviours in Scottish Blackface sheep. Animal Science 72, 555-571.

Dwyer CM, Lawrence AB, Brown HE and Simm G 1996. Effect of ewe and lamb genotype on gestation length, lambing ease and neonatal behaviour in lambs. Reproduction, Fertility and Development 8, 1123-1129.

Eales FA, Gilmour JS, Barlow RM and Small J 1986. Causes of hypothermia in 89 lambs. The Veterinary Record 6, 118-120.

Fisher GEJ and MacPherson A 1991. Effect of cobalt deficiency in the pregnant ewe on reproductive-performance and lamb viability. Research in Veterinary Science 50, 319-327.

Forrest RH, Hickford JGH, and Frampton CM 2007. Polymorphism at the ovine β3-adrenergic receptor locus (ADRB3) and its association with lamb mortality. Journal of Animal Science 85, 2801-2806.

Kott RW, Thomas, VM, Hatfield, PG, Evans, T and Davis, KC 1998. Effects of dietary vitamin E supplementation during late pregnancy on lamb mortality and ewe productivity. Journal of the American Veterinary Medical Association 212, 997-1000.

Lopez-Villalobos N. and Garrick, DJ. 1999. Genetic parameter estimates for lamb survival in Romney sheep. Proceedings of the New Zealand Society for Animal Production 59, 121-124.

MacFarlane JM, Matheson SM and Dwyer CM 2010. Genetic parameters for birth difficulty, lamb vigour and lamb sucking ability in Suffolk sheep. Animal Welfare19, 99-105.

Madani T, Allouche L, Saffidine N, Kaouane N, Belkasmi F and Semara L 2013. Maternal and neonatal behaviors of Ouled Djellal sheep breed and their effects on production parameters. Small Ruminant Research 114, 46-50.

McCutcheon SN, Holmes CW, McDonald MF and Rae AL 1983. Resistance to cold stress in the newborn lamb. 1. Responses of Romney, Drysdale x Romney, and Merino lambs to components of the thermal environment. New Zealand Journal of Agricultural Research 26, 169-174.

Mellor DJ 1988. Integration of perinatal events, pathophysiological changes and consequences for the newborn lamb. British Veterinary Journal 144, 552-569.

Mellor DJ and Stafford KJ 2004. Animal welfare implications of neonatal mortality and morbidity in farm animals. The Veterinary Journal 168, 118-133.

Morel PCH, Morris ST and Kenyon PR 2008. Effect of birthweight on survival in triplet-born lambs. Australian Journal of Experimental Agriculture 48, 984-987.

Munoz C, Carson AF, McCoy MA, Dawson LER, O'Connell NE and Gordon AW 2008. Nutritional status of adult ewes during early and mid-pregnancy. 2. Effects of supplementation with selenised yeast on ewe reproduction and offspring performance to weaning. Animal 2, 64-72.

Nash ML, Hungerford LL, Nash TG and Zinn GM 1996. Risk factors for perinatal and postnatal mortality in lambs. Veterinary Record 139, 64-67.

Nowak, R., Murphy, T. M., Lindsay, D. R., Alster, P., Andersson, R., Uvnäs-Moberg, K. 1997. Development of a preferential relationship with the mother by the newborn lamb: Importance of the sucking activity. Physiology and Behavior 62, 681-688.

Obst JM and Ellis JV 1977. Weather, ewe behaviour and lamb mortality. Agricultural Record 4, 44-49.

Pattinson SE, Davies DAR and Winter AC 1995. Changes in the secretion rate and production of colostrum by ewes over the first 24 h post-partum. Animal Science 61, 63-68.

Putu IG, Poindron P and Lindsay DR 1988. Early disturbance of ewes from the birth site increases lamb separations and mortality. Proceedings of Australian Society for Animal Production 17, 298-301.

Riggio V., Finocchiaro R. and Bishop S. C. 2008. Genetic parameters for early lamb survival and growth in Scottish Blackface sheep. *Journal of Animal Science*, **86**:1758-1764.

Robertson SM, King BJ, Broster JC and Friend MA 2012 The survival of lambs in shelter declines at high stocking intensities. Animal Production Science 52, 497-501.

Rooke JA, Houdijk JGM, McIlvaney K, Ashworth CJ and Dwyer CM 2010 Differential effects of maternal undernutrition between days 1 and 90 of pregnancy on ewe and lamb performance and lamb parasitism in hill or lowland breeds*.* Journal of Animal Science 88, 3833-3842.

Shubber AH, Doxey DL, Black WJM and FitzSimons 1979. Colostrum production by ewes and the amounts ingested by lambs. Research in Veterinary Science 27, 280-282.

Slayi M, Maphosa V, Fayemi OP and Mapfumo L 2014. Farmers' perceptions of goat kid mortality under communal farming in Eastern Cape, South Africa. Tropical Animal Health and Production 46, 1209-1215.

Slee J. 1981. A review of genetic aspects of survival and resistance to cold in newborn lambs. Livestock Production Science 8, 419-429.

Slee J 1978. The effects of breed, birthcoat and body weight on the cold resistance of newborn lambs. Animal Production 27, 43-49.

Slee J, Alexander G, Bradley LR, Jackson N, and Stevens D 1991. Genetic aspects of cold resistance and related characters in newborn Merino lambs. Australian Journal of Experimental Agriculture 31, 175-182.

Slee J and Simpson SP 1991. Description of the effects of a single gene which inhibits the normal metabolic response of newborn lambs to exogenous noradrenaline. Research in Veterinary Science 51, 34-39

Slee J and Springbett A 1986. Early postnatal behaviour in lambs of ten breeds. Applied Animal Behaviour Science 15, 229-240.

Snyman MA 2010. Factors affecting pre-weaning kid mortality in South African Angora goats. South African Journal of Animal Science 40, 54-64.

Swanson TJ, Hammer CJ, Luther JS, Carlson DB, Taylor JB, Redmer DA, Neville TL, Reed JJ, Reynolds LP, Caton JS and Vonnahme KA 2008. Effects of gestational plane of nutrition and selenium supplementation on mammary development and colostrum quality in pregnant ewe lambs. Journal of Animal Science 86, 2415-2423.

Taylor DB, Schneider DA, Brown WY, Price IR, Trotter MG, Lamb DW and Hinch GN 2011. GPS observation of shelter utilisation by Merino ewes. Animal Production Science 51, 724-737.

Terrazas A, Robledo V, Serafin N, Soto R, Hernandez H and Poindron P 2009. Differential effects of undernutrition during pregnancy on the behaviour of does and their kids at parturition and on the establishment of mutual recognition. Animal 3, 294-306.

Turkson PK, Antiri YK and Baffuor-Awuah O 2005. Risk factors for kid mortality in West African Dwarf goats under an intensive management system in Ghana. Tropical Animal Health and Production 36, 353-364.

Van der Linden DS, Kenyon PR, Lopez-Villalobos N, Jenkinson CMC, Peterson SW and Blair HT 2010. Effects of ewe size and nutrition during pregnancy on performance of 2-year-old female offspring. Journal of Agricultural Science 148, 465-475.

Vincent IC, Williams HL and Hill R 1985. The influence of a low-nutrient intake after mating on gestation and perinatal survival of lambs. British Veterinary Journal 141, 611-617.

Vihan VS 1988. Immunoglobulin levels and their effect on neonatal survival in sheep and goats. Small Ruminant Research 1, 135–144.

Wu G, Bazer FW, Wallace JM and Spencer TE 2006. BOARD-INVITED REVIEW: Intrauterine growth retardation: Implications for the animal sciences. Journal of Animal Science 84, 2316-2337.