Perinatal complications and early growth in a sheep model characterised by premature delivery and low birthweight.

A thesis presented for the degree of Human Embryology and Developmental Biology, Bachelor of Science with Honours at the University of Aberdeen

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Contents

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Declaration

I hereby declare that all the work described in this thesis was carried out by me (Paul Oliver Shepherd), and that I have written this thesis independently with all work and contributions duly acknowledge and cited: Paul Shepherd (03/04/2020).

Acknowledgements

I would like to express my deepest gratitude to my supervisor, Dr Jacqueline Wallace for mentoring me through and beyond this project at times when it was really needed. Dr Derryck Shewan, Dr John Barrow, Rowett Institute team past and present I would like to recognize the invaluable assistance that you all provided to this project, it is much appreciated. I would like to pay special regards to Dr Richard Anderson for his guidance and friendship. Finally, I wish to thank my friends, family and partner for their support.

Abstract

Background: Sheep production is worth £1.26billion annually and is economically important for the UK but lamb mortality rate is stubbornly high. Breeding ewe lambs during adolescent life has the potential to improve lamb production over a female's lifetime but average birthweights are low and hence neonatal morbidity and mortality can be high. Optimal dam nutrition during pregnancy and neonatal care regimes have the potential to improve this situation.

Aim: To develop scoring systems to quantify and analyse the incidence of perinatal complications and associated interventions in an adolescent sheep model where fetal growth has been manipulated by varying pregnancy nutrition.

Methods: Data was extracted from hand-written neonatal records from optimal control n=61, overnourished n=186 and undernourished n=24 dams, which delivered singleton lambs all of which received proactive neonatal care. Birthweight and early delivery categories determined using the control group, with the developed rational scoring systems allowed for statistical analysis of the perinatal complications and interventions.

Results: Overnourished adolescent dams delivered premature and low birthweight lambs, which lambed easier but needed more intervention to keep alive pre than post 24hours. These dams had increased compromised lactation and mismothering which got worse after 24hours.

Conclusions: With optimum nutrition and proactive care ewe lamb breeding limitations can be overcome and lamb mortality can decrease to 4.4% even within a population characterised by a high percentage of extremely premature and low birthweight lambs. The developed scoring systems allow for accurate on farm flock data gathering to reduce lamb mortality.

1.0 Introduction

1.1 Current economic context of sheep production in Scotland

The economic value of UK mutton and lamb production in 2018 was estimated to be £1.26 billion with approximately a third of the meat produced being exported, primarily to other countries within the European Union (EU) (UK Government, 2019a). Within the UK, reliance on imports from the southern hemisphere to balance the seasonality of lamb supply continues to decline. Accordingly, Scotland is increasingly self-sufficient for sheep meat but still needs to maintain market share of premium lamb exports to preserve vulnerable farm incomes in a challenging marketplace (QMS Scotland 2019a).

Sheep production is currently the most common farming activity in Scotland (29.3%, Scottish Government 2019a). In 2018 there were 2,555,029 breeding ewes in Scotland across 12,738 farms (Scottish Government 2019b) and 3,141,320 lambs which are primarily produced for meat (Scottish Government 2018). The popularity of sheep farming in Scotland reflects that much of its land is classified as a "Less Favoured Area" (LFA). This means that the land topography and soil composition is mainly suitable for low intensity farming involving grazing ruminants. Sheep farming in these disadvantaged hill and upland areas is much less productive than in lowland farms with fewer lambs produced per ewe in her lifetime and higher lamb mortality rates from birth to slaughter (Scottish Government 2016, QMS Scotland 2019b).

1.2 Lamb mortality and morbidity rates

1.2.1 Lamb mortality rates

Lamb mortality varies depending on management and environment, but publications across multiple countries have shown there has been no improvement since 1970, averaging at 15% (Dennis 1970, 1971; Huffman *et al.*, 1985; Green and Morgan 1993; Nash *et al.*, 1996; Forrest *et al.*, 2006; Riggio *et al.*, 2008; Hatcher *et al.*, 2009; Figure 1.2A, Dwyer *et al.*, 2015). This wastage greatly reduces productivity which reduces profits, as 80-85% of the costs are incurred before birth, and negatively affects animal welfare, therefore it is important to find solutions to reduce this issue (Haughey 1991; Mellor and Stafford 2004; Mohajer *et al.*, 2013).

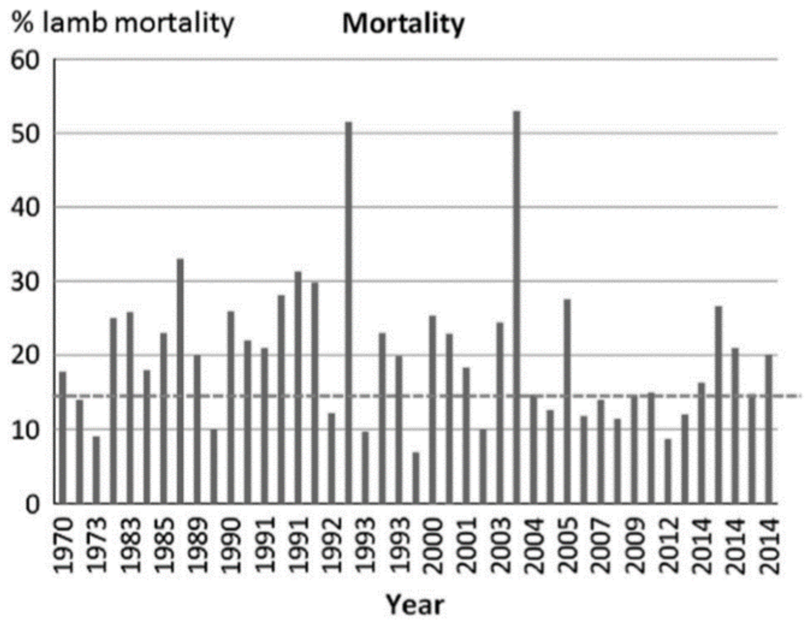


Figure 1.2A (from Dwyer *et al.*, 2015): Published mean lamb mortality percentages between 1970 and 2014 from multiple countries.

From 2016-2018 average lamb mortality in Scotland was 12%, using QMS 2019b data (Figure 1.2B). The increased lamb mortality of hill flocks at 14% compare to lowland and upland flocks at 11%, shows the positive impact of human intervention (Binns *et al.*, 2002; Fisher 2003 Tongue *et al.*, 2016).

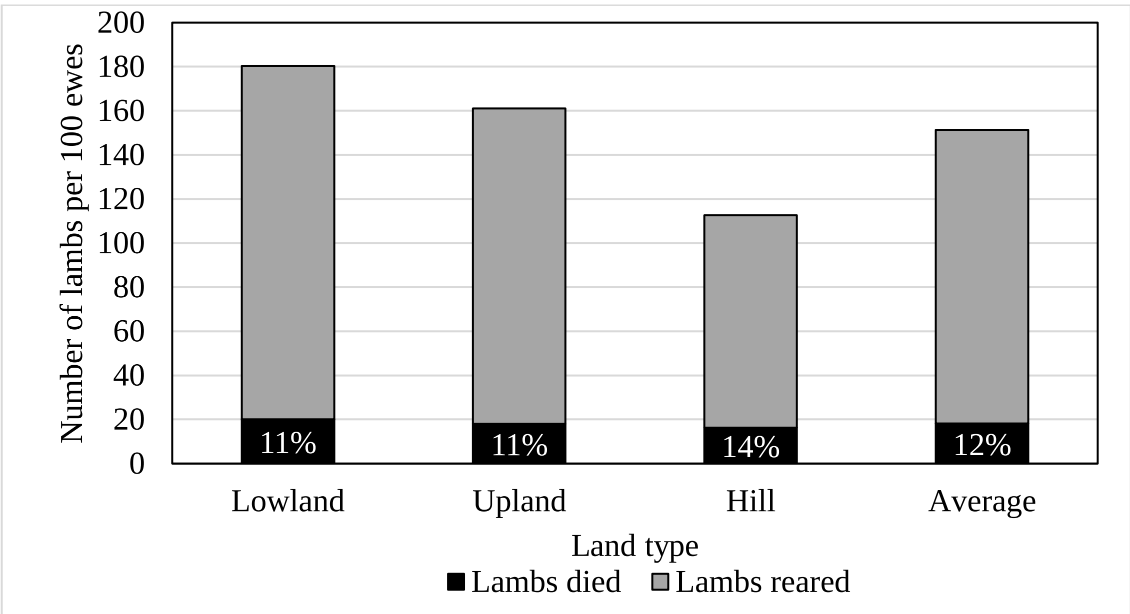


Figure 1.2B: Mean rates of lamb mortality in Scotland in accordance to land type 2016-2018. This data from QMS Cattle & Sheep Enterprise Profitability in Scotland 2019b, recorded lamb mortality of 13-15 lowland flocks, 31-34 LFA upland flocks, and 22-25 LFA hill flocks.

1.2.2 Timing of lamb losses

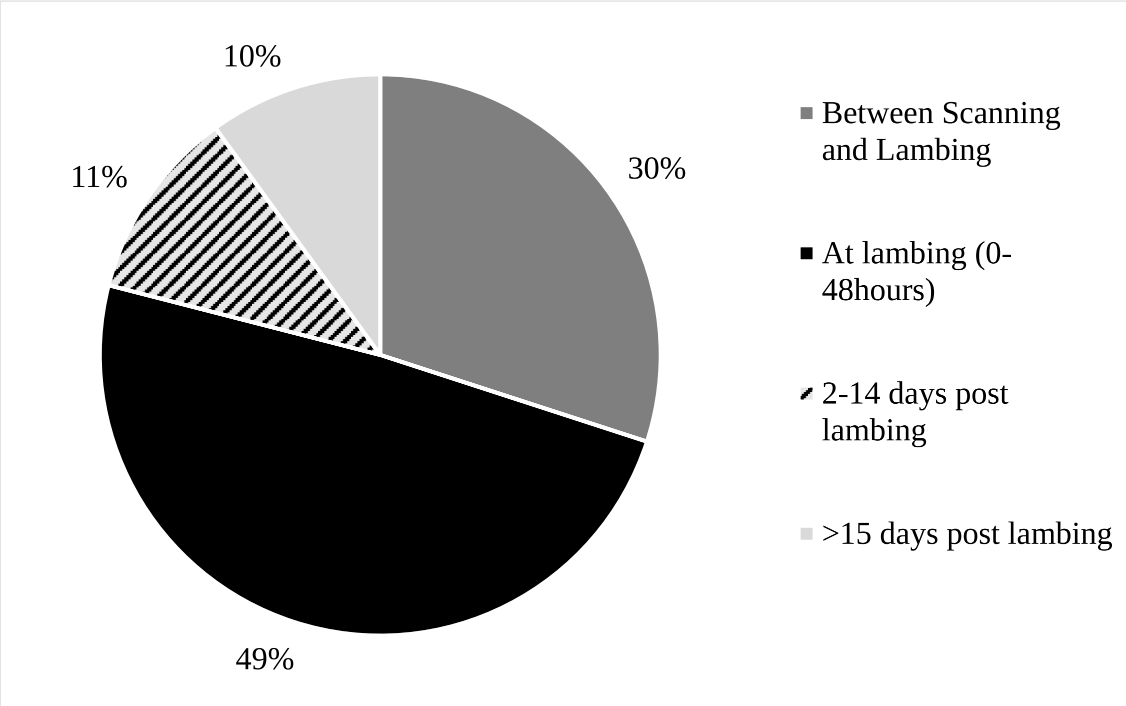
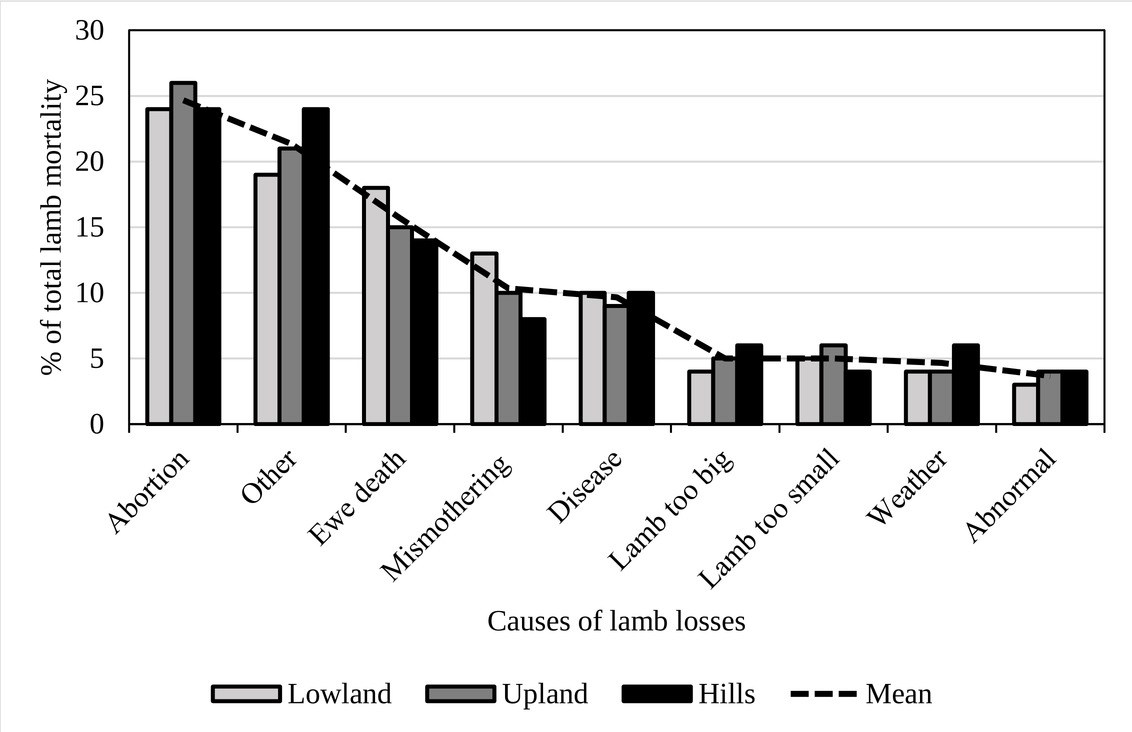


Figure 1.2C: When neonatal lamb losses occurs, as a percentage of total lamb deaths. This data from the HCC lambing Project 2010/2011, recorded lamb losses from 70 Welsh farms, scanning 40,050 ewes (21,709 hill, 13,808 upland, and 4,533 lowland).

Figure 1.2C shows approximately one third of lamb deaths occurred antenatally, and 50% occurred within the first 48 hours after birth, with a further 10% dying within 2 weeks and the final 10% dying over 15 days post lambing. This matches the documented pattern that most lamb deaths occur within the first 14days (Dennis 1970; Wiener *et al.*, 1983; Huffman *et al.*, 1985; Green and Morgan 1993; Boujenane *et al.*, 2013), but there will always be variation in these figures as there are numerous factors, such as disease, which can greatly affect when age specific mortality occurs.

1.2.3 Causes of lamb losses



Abortion includes stillbirth, weather includes predation, abnormal means congenital abnormalities, and ewe death is before/during lambing.

Figure 1.2D: Causes of lamb losses in relation to land type, using the same HCC lambing Project 2010/2011 data as figure 1.2C.

Figure 1.2D shows little variation in causes between land types. Abortion/stillbirth were the most common at ~25%, these most likely had no specific abortive agent but instead were freshly dead/mummified (Green and Morgan 1993). Disease varies considerably but ~10% fits the literature, some are zoonotic, and infectious respiratory disease is prevalent with pneumonia being common (Wiener *et al.*, 1983; Chakraborty *et al.*, 2014; Contreras-Luna *et al.*, 2017; Lindström *et al.*, 2018). Disease in dams contribute to ewe and lamb death, mastitis affects 2.1-3.0% of ewes and is linked to lamb starvation, which can account for over half of lamb deaths (Johnston *et al.*, 1980; Wiener *et al.*, 1983; Huffman *et al*., 1985; Green and Morgan 1993; Holmøy *et al*., 2014; Grant *et al*., 2016). Dystocia (difficulty lambing) also contributes to ewe and lamb death, as malpresentation or the lamb being too big have been associated with fatal crushing (Dennis 1970; Wiener et al., 1983; Green and Morgan 1993). Cold weather kills lambs with rates seen to follow temperature fluctuations for outdoor/indoor lambing (Holmøy and Waage 2015).

1.3 Risk Factors affecting lamb mortality

In farming, dam age is entirely linked to gravidity, so it is very difficult to separate the two effects, but dam age is associated with lamb mortality with survival again showing a curvilinear effect. It is highest for young females, which can be double mature ewes, but at old age lamb mortality increases again with no evidence of improved maternal behaviour between mature and old ewes (Karn and Penrose 1951; Alexander *et al.*, 1993; Holmøy *et al.*, 2014). Litter size is associated with lamb neonatal mortality with the chances of at least one lamb dying substantially increasing when litter size exceeds 2. For those experiencing dystocia, increasing litter size decreases the chances of losing one or more lambs while singletons experiencing dystocia are 5 times more likely to die than singletons that did not (Huffman *et al*., 1985; Holmøy *et al*., 2014). Lamb gender has been associated with lamb neonatal mortality with incidences of dystocia being greater in males than females with a ratio of 5:3 (Dennis 1970; Huffman *et al.*, 1985).

Optimum lamb birthweight varies between breeds, like lamb mortality, but optimum birthweight is generally 4.2-5.5kg which is slightly greater than mean birthweight. Deviation from the mean increases the likelihood of lamb mortality, therefore survival against birthweight follows a curvilinear pattern (Karn and Penrose 1951; Hinch *et al.,* 1985; Huffman *et al*., 1985; Scales *et al*., 1986). This means heavier lambs have decreased survival as they are more likely to have difficult births / increased dystocia and disease susceptibility, suggesting that growth could come at the expense of immune function (Holst *et al.*, 2002; Gardner *et al.,* 2007; Hatcher *et al.,* 2009; Hinch and Brien, 2013; Lima *et al*., 2020). This also means lightweight lambs have decreased survival and is because of reduced vigour, poor thermoregulation, various organ issues, abnormal metabolism as well as body composition in later life (Barker 2006; Ibáñez *et al.,* 2006; Gardner *et al.,* 2007; Crane *et al.,* 2016; Wallace *et al.,* 2018; Swarnkar *et al.,* 2019; Wallace 2019). After rapid compensatory growth the long-term negative consequences for these low birthweight lambs are numerous, including; increased likelihood of stunted adult size, lower bone density, raised body fat percentage and type II diabetes (Whincup *et al.,* 2008; Araújo de Franca *et al.,* 2014; Belbasis *et al.,* 2016; Wallace 2018).

1.4 Interventions to prevent mortality

Increased neonatal survival is independently associated with the following; lambing season, monitoring of ewes, active colostrum support where needed, supplementary feeding e.g. with grass silage as opposed to grass alone and providing roughage two times a day as opposed to once a day (Holmøy *et al.,* 2012). In short to reduce lamb mortality it is important to have good feeding practices during the indoor feeding period, as well as good monitoring and management during the lambing period. With colostrum and milk support it is important to note that there can be a high incidence of E. coli enteritis with bottle feeding and nursing in an indoor environment (Dennis 1970), so precautionary steps should be taken. This is often in the form of antibiotics to treat and prevent disease, this prevention also includes preventing the spread of zoonotic bacterial pathogens (Santman-Berends *et al.,* 2014; Davies *et al.,* 2017). Breeding and culling dams to produce desired flock attributes has long been practiced with some farmers focusing on cross breeding flocks to produce lambs with increased survivability, cold tolerance and ease of care (Wiener *et al.,* 1983; Fisher 2003; Forrest *et al.,* 2014).

1.5 Breeding and feeding ewe lambs

Although most ewe lambs selected as breeding replacements reach puberty at approximately 8 months of age, they are rarely mated for the first time until they are approximately 18-20 months old. Achieving a successful pregnancy in the first year of life has the potential to increase reproductive efficiency and farm profitability, while reducing the environmental impact per kg of meat produced over the animal’s lifetime. This does not come without its challenge’s as farms in the UK, New Zealand and Australia have low uptake of breeding ewe lambs in their first year of life, <30% (Kenyon *et al.,* 2014a). This is because farmers currently believe the disadvantages outweigh the advantages (Figure 1.2E) as ewe lambs have poor reproductive performance due to; high embryo loss and fertilisation failure rate on top of a low ovulation rate with a short inconstant window as puberty varies and the first breeding season is reduced (Beck *et al.,*1996; Kenyon *et al.,* 2014a; 2014b; Edwards and Juengel 2017). They also often produce low birthweight lambs and the mother’s lactation is impaired (Umberger *et al.,* 1985; Wallace 2019). One of the main difficulties is nutritionally managing the ewe lambs to ensure appropriate fetal growth and mammary gland function, while they themselves are still growing and have not reached their mature body size.

Advantages	Disadvantages
Increased feed demand during lactation, therefore taking advantage of the increased natural herb growth in spring.	Reduced and varied reproductive performance.
Increase in the amount of lambs born, therefore increased income through sales.	Increased feed demand to support pregnancy, lactation as well as dam body growth.
Earlier selection factor of ewe replacements.	Increased early live weight targets .
More offspring born to each farm, therefore decreasing replacement selection pressures.	Reduced future productivity and live weight (if not well managed).
Reduced generation interval because of the selection of offspring born from the ewe lambs.	Lambs from ewe lambs show decreased survival, plus reduced weight at birth and weaning.
Reduced greenhouse gas emissions per lamb produced.	Can increase on farm expenses.
	Can increase the amount of work for the farmer and give them less management flexibility
	Increased mortality rates for the ewe lambs while pregnant or lactating compared to non-pregnant counterparts.
	Decreased wool production of pregnant/lactating ewe lambs compared to non-pregnant counterparts.

Figure 1.2E: Advantages and disadvantages of breeding ewe lambs (Kenyon 2014a)

Similarly, in humans becoming pregnant at a young age is associated with premature delivery of low birthweight babies (De Azevedo *et al.,* 2015; Wallace 2019) and the Scottish Government's sustained support of the Rowett's Adolescent Pregnancy Project was primarily to model this clinical issue and understand the underlying mechanisms. The model which used peripubertal ewe lambs or 'adolescents' is extremely robust and showed how best to nutritionally manage ewe lambs to optimise pregnancy outcome, neonatal survival and offspring growth to weaning with control optimally fed dams. The overnourished dams were an extreme model of how not to approach feeding these pregnant dams and was set up to model the clinical problem of continued maternal growth during human adolescent pregnancy. These overnourished pregnancies are characterised by rapid maternal growth and increased adiposity at the expense of the gravid uterus. This results in poor placental growth, a decrease in uteroplacental blood flows and thereby nutrient delivery to the growing fetus resulting in premature delivery of low birthweight lambs that have negatively affected endocrine and metabolic systems throughout their lives. Rapid maternal growth in these overnourished adolescent dams also impacts the development of the mammary gland and initial colostrum availability is impaired (Wallace *et al.*, 1997; 2014; 2018; 2020; Wallace 2019).

2.0 Aims

Primary aim: To develop scoring systems to quantify the incidence of perinatal complications and associated interventions in an adolescent sheep model where fetal growth has been manipulated by varying pregnancy nutrition.

Secondary aim: To quantify the incidence of perinatal complications as well as lamb growth to weaning in terms of birthweight extremes and degree of prematurity.

3.0 Materials and Methods

Every procedure was approved by the Rowett Institute's Review Committee and licensed under the UK's 1986 Animal (Scientific Procedures) Act.

Hand-written neonatal records were available from five individual adolescent pregnancy studies carried out in consecutive years by the same research team. Research facility environment, animals, pregnancy method, parturition management and neonatal care were equivalent between studies as follows;

3.1 Research facility environment, animals and pregnancy method

Ewes were housed at 57°N, 2°W under natural light in individual pens that allowed nose to nose contact with neighbouring sheep. As per Wallace et al., 1997, adult superovulated ewes (Scottish blackface x Border Leicester) were the source of oocytes fertilised by laparoscopic intrauterine insemination using a single sire (Dorset Horn). On day 4 after oestrus the high-quality embryos were transferred in singleton into approximately 8.5 months old ewe lambs (Dorset Horn x Mule) of similar initial adiposity and weight. Adolescent recipients at transfer had a mean liveweight and adiposity score of 44.1±0.42kg and 2.3±0.02 units, respectively, equalling 23% body fat using the Russel *et al.*, 1969 5-point scale, where extremely obese=5 and emaciated=1.

3.2 Management

3.2.1 Nutritional management

Directly after embryo transfer and throughout pregnancy recipients were split into control, high-level, and low-level diet groups offered the same complete diet, which per kg supplied 12MJ of metabolizable energy (ME) and 140g of crude protein (composition and analysis found in Wallace *et al.*, 2006). Control group dietary requirements were calculated and adjusted to maintain maternal adiposity throughout gestation, while supplying 100% of the ME and protein requirements of each adolescent carrying a singleton fetus (AFRC 1993: normal fetoplacental growth). The high-level group were overnourished receiving ~2.25 times the control group, which promoted continued maternal growth and increased adiposity at the expense of the conceptus (fetoplacental growth-restricted). Rations increased over 2 weeks, until daily food refusal reached ~15% total offered (*ad libitum*). The low-level group were undernourished receiving ~0.7 times the control group, resulting in progressive adiposity depletion through pregnancy. Sixty-one control, 186 overnourished, and 24 undernourished dams had viable pregnancies as initially verified by ultrasound.

3.2.2 Parturition management and neonatal care

As overnourished adolescent ewes consistently deliver early, all ewes were supervised during the expected delivery period from day 135 of gestation to the last control birth on day 149. To prevent the high neonatal mortality linked to prematurity, low birthweight, reduced passive immunity and/or reduced nutrition from insufficient colostrum supply, a standard proactive system was used across studies (summarised in Figure 3.2A and Appendix 3.1 contains pictures for context). Lambing assistance matched requirement was recorded in the notes, and ranged from unassisted to caesarean section, also if the lamb was not breathing after birth immediate intervention was taken. All lambs were then dried, weighed, measured and received vitamin E – selenium plus the first dose of their 5-day course of prophylactic antibiotics (Baytril). Oxytocin was administered to the ewe and all available colostrum harvested from the udder and weighed. The lamb would then receive this colostrum in an initial feed by bottle or stomach tube, the amount related to birthweight, and insufficient maternal colostrum would result in supplementation. Weight gain monitoring helped ensure survival. Inadequate weight gain for any 8-hour period in the first 5 days of life would result in colostrum (<24hours) or ewe milk supplementation. The placenta was weighed and assessed after it was delivered, 2-12 hours after lamb delivery. Dams and/or lambs with additional health issues were treated on an individual basis as detailed in their specific record sheets. Weight at the end of lactation (11 weeks) was also recorded (Wallace *et al*., 2014; Carr *et al*., 2016).

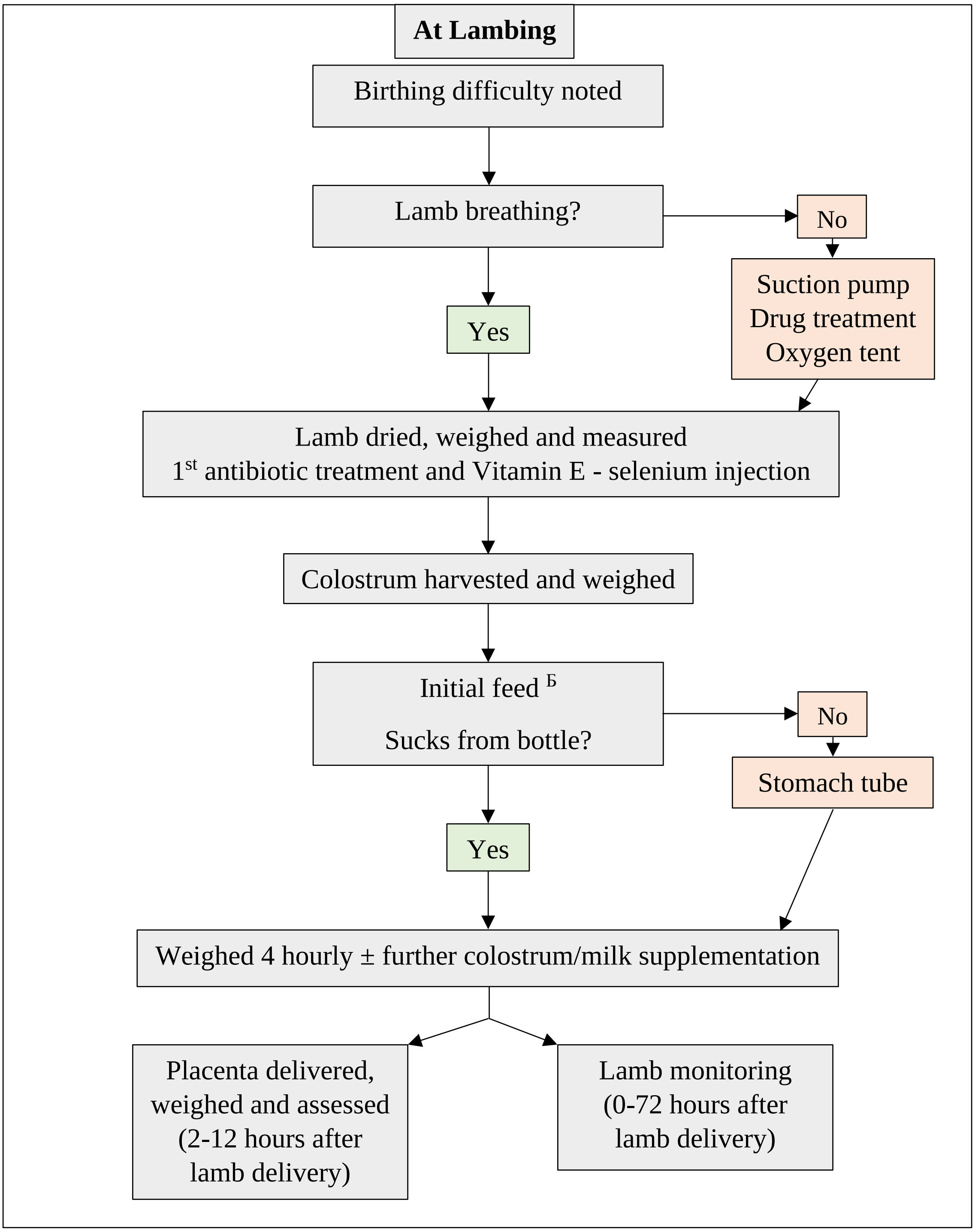


Figure 3.2A, Neonatal care flowchart starting with lambing dystocia and ending with lamb monitoring.

Ƃ Birthweight determined initial feed amount, <2.5kg lambs received 50cc and 50cc 2hours later, due to their small stomach size, >2.55kg lambs received 50cc per kg of bodyweight.

3.3 Records

Hand-written neonatal records were kept for each lamb in the five studies, which also included dam issues and treatment; Figures 3.3A-F are two examples. The five studies were designed for other purposes, but the extensive records contained unexamined material. Guidance on the shorthand used was provided by the original research team and appropriate information for the topic was summarised in scoring systems specifically developed for this report. For objectivity I was blinded to nutritional treatment.

LA05-04

Ewe Number : 5045 Pen No : 73 Date : 8/6/6

Time of Parturition : 17:00 Lamb No : 6664 Male

Lamb Birthweight (Kg): 5.07

Lamb Girth (cm): 39 Day 1 Girth: 41.5

Lamb Length (cm): 51 Day 1 Length: 51

Lamb Height (cm): 39.5 Day 1 Height: 39

Colostrum Yield (ml): 108ml.

Total Placental Weight (g): 442g

Cotyledon Number: 105

Cotyledon Weight: 133g

Membrane Weight: 284g

Baytril	Day 0	Day 1	Day 2	Day 3	Day 4
Date Time	8/6 17:00	9/6 11:00	10/6	11/6	12/6

Dystosel (tick): ✓ +Finadyne repeated 24h a

Duph-strep	Day 0	Day 1	Day 2
Date Time	✓ 8/6	✓ 9/6	10/6

Comments: + Finadyne 2½ - external tear + haem
+ 4cc Duph-Strep
+ 1cc Oxy.

Figure 3.3A: Front sheet for lamb 6664, a normal birthweight lamb from study LA05-04, with lambing comments showing an external tear with haemorrhage on the ewe, which received pain killers (Finadyne, twice), a course of antibiotics (Duphstrep) and oxytocin to constrict the uterus and limit further bleeding.

05/04: viability checks and supplementary feeding

Lamb No: 6664 Pen No: 73 Date of birth: 8/6/6

Date/Time	Date/Time	Date/Time	Date/Time	Date/Time	
8/6 17:40	8/6 21:00	9/6 01:10	9/6 06:10	9/6 11:00	
60ml mum, 40ml P.68 Colostrum + 90ml frozen colostrum by bottle.	5.11	5.21 Has been suckling	5.25	5.16 −150cc by tube milk from P64 w. 30cc cols	
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time	
9/6 15:30	9/6 20:00	9/6 24:00	10/6 06:20	10/6 11:30	
5.22	5.24 Stretch	5.20	5.24 + 180ml. lamlac	5.38	
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time	
16:30 10/6	10/6 20:00	11/6 02:05	11/6 06:20	11/6 12:30	
5.48	5.53	5.63	5.70	5.74	
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time	
11/6 18:45	12/6 02:00	12/6 14:20	13/6 09:25	09:30 14/6	15/6 09:20
5.84	5.95	6.18	6.44	6.99	7.37

Figure 3.3B: Lamb notes for lamb 6664 showing; routine initial colostrum feed from multiple sources by bottle, weight monitoring, a 150cc supplementary milk feed administered by stomach tube and a 180ml supplementary feed given by bottle (lamlac=powdered milk replacement for sheep).

28·2 % Fat

LA06-05 and 07-02

Ewe Number : 7515 **Pen No :** 68 **Date :** 26/4/8

Time of Parturition : 14:05 **Lamb No :** 9046 **Sex :** FEMALE

Lamb Birthweight (Kg): 1.88

Lamb Girth (cm): 29

Colostrum Yield (ml): 0

Total Placental Weight (g): 190g (191g)

Cotyledon Number: 76

Cotyledon Weight: 36g

Membrane Weight: 119g

Baytril	Day 0	Day 1	Day 2	Day 3	Day 4	D5	D6
Date Time	26/4 14:05	27/4 10:30	28/4	29/4 ✓ 09·10	30/4	1/5	2/5

Dystosel (tick): ✓

	Date	**Time**
Duphapen-strep		
Duphapen-fort		

Comments: Dopram
Myophyll.

Figure 3.3C: Front sheet for lamb 9046, a very low birthweight lamb from study LA06-05, which had respiratory issues at birth (hence treated with respiratory stimulants, Dopram and Myophylline) and extended prophylactic antibiotics (Baytril) due to its small size.

BWt = 1.88

①

LA06/05 and 07-02 : viability checks and supplementary feeding

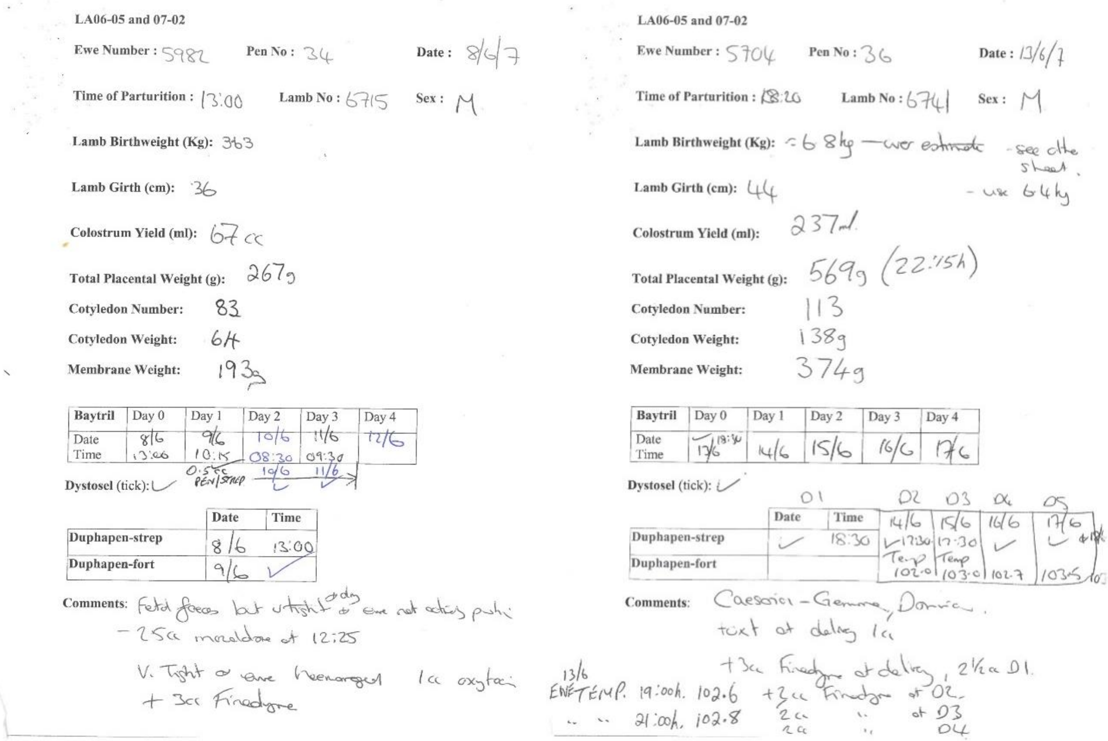
Lamb No: 9046 Pen No: 68 Date of birth: 26/4/8

Date/Time	Date/Time	Date/Time	Date/Time	Date/Time
26/4 14:30	26/4 17:30	26/4 21:00	27/4 00:15	03:30 27/4
75cc Col by bottle. ≠ Normal prec	50cc Col by bottle	Wet towel. 50ml ewe milk by bottle. 1	Wet towel 50ml ewe milk by bottle. 2	50ml Mothers (very wild) milk by bottle 3
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time
27/4 7:00	27/4 10:40	14:30 27/4	27/4 18:15	27/4 23:45
50MLS MILK BY BOTTLE LOTS OF P + P 4	75cc milk by bottle - wet & change 5	75cc milk by bottle - wet & change 6	75 ml milk by bottle. Wet - changed. Ewe milked. + a wee suck from Mum 7	80ml ewe milk by bottle 8
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time
28/4 04:30	28/4 08:40	10:30	28/4 11:55	28/4 16:08
1.84→1.96 Sucked from mother. She is wild	187. 193 Out suckling by itself	Mum trampled it when it escaped from box. + Diph & Metacam + Bg E.	75cc ewe milk by bottle 9	+ OXT 1.91 ↓ 1.96
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time
28/4 20:30	28/4 24:20	29/4 0500	29/4 09.10	29/4 13:35
1.915 75ml ewe milk by bottle. Wet towel. 10	1.98 ↓ 2.07 + OXT.	1.98 ↓. 2.10	2.02 ↓ 2.09 wet	2.03 ↓ 2.08 + + metacam + B

wet.

- ½ enema as I have not seen poo & tummy seems v. full ⟹ got a result

Figure 3.3D: Lamb notes for lamb 9046, showing; initial colostrum supplementation spread over two separate feeds as the lamb and hence it's stomach was very small, 10 supplementary bottle feeds with fresh ewe milk, bad maternal behaviour ("very wild"/ "she is wild"/ "mum trampled it"), holding dam to allow lamb to suckle with or without oxytocin to induce milk let-down (weigh-re-weigh technique), urine and faecal monitoring. The latter was to check that the kidneys were working and to facilitate the lamb was restricted to a corner of the pen with a towel on top of straw. Absence of faeces for 2 days and a full stomach resulted in an enema being administered. The lamb survived and went on to be studied into adult life.



LA06-05 and 07-02

Ewe Number : 5982 Pen No : 34 Date : 8/6/7

Time of Parturition : 13:00 Lamb No : 6715 Sex : M

Lamb Birthweight (Kg): 363

Lamb Girth (cm): 36

Colostrum Yield (ml): 67 cc

Total Placental Weight (g): 267g

Cotyledon Number: 83

Cotyledon Weight: 64

Membrane Weight: 193g

Baytril	Day 0	Day 1	Day 2	Day 3	Day 4
Date	8/6	9/6	10/6	11/6	12/6
Time	13:00	10:15	08:30	09:30	

0.5cc PEN/STREP 10/6 11/6

Dystosel (tick): ✓

	Date	Time
Duphapen-strep	8/6	13:00
Duphapen-fort	9/6	✓

Comments: Fetal faeces but v tight & ewe not actively pushing
- 2.5cc monzaldon at 12:25
V. Tight & ewe haemorraged 1cc oxytocin
+ 3cc Finadyne

LA06-05 and 07-02

Ewe Number : 5704 Pen No : 36 Date : 13/6/7

Time of Parturition : 18:20 Lamb No : 6741 Sex : M

Lamb Birthweight (Kg): ≈ 6.8kg — over estimate - see other sheet. - use 6.4kg

Lamb Girth (cm): 44

Colostrum Yield (ml): 237ml

Total Placental Weight (g): 569g (22:15h)

Cotyledon Number: 113

Cotyledon Weight: 138g

Membrane Weight: 374g

Baytril	Day 0	Day 1	Day 2	Day 3	Day 4
Date / Time	13/6 18:50	14/6	15/6	16/6	17/6

Dystosel (tick): ✓

	Date	Time	14/6	15/6	16/6	17/6
	01		02	03	04	05
Duphapen-strep	✓	18:30	✓ 17:30	17:30	✓	✓
Duphapen-fort			Temp 102.0	Temp 103.0	102.7	103.5

Comments: Caesarian - Gemma, Dominic.
1cc oxyt at delivery
+3cc Finadyne at delivery, 2½cc D1.
13/6 EWE TEMP. 19:00h. 102.6 +3cc Finadyne at 02.
.. .. 21:00h. 102.8 2cc .. at 03
2cc .. 04

Figure 3.3E: Front sheets for low birthweight lamb 6715 and oversized lamb 6741 both were delivered by caesarean (C) section. 6715 was given 2.5cc Monzaldon to help ripen the cervix as delivery was failing to progress, and the ewe was not actively pushing. The ewe haemorrhaged and was given 1cc of oxytocin to constrict the uterus and reduce bleeding and 3cc of painkiller (Finadyne), and a course of antibiotics (Duphapen-strep and Duphapen-fort). Although C-section is not specifically mention on this front sheet it was stated on other documents and confirmed by a member of the original research team. Also 6715 defecated during lambing, later in the notes it had gastrointestinal issues and was given an additional 3-day course of antibiotics (Pen/Strep) seen under the Baytril boxes. 6741 had its size overestimated at first and was corrected after the 2nd weighing. Ewe 5704 was given very similar treatment as ewe 5982 but did not receive Monzaldon as the issue was not failure to progress but size of the lamb. 5704 received more doses of painkiller and antibiotics, as well as further temperature monitoring as she developed an infection after her C-Section.

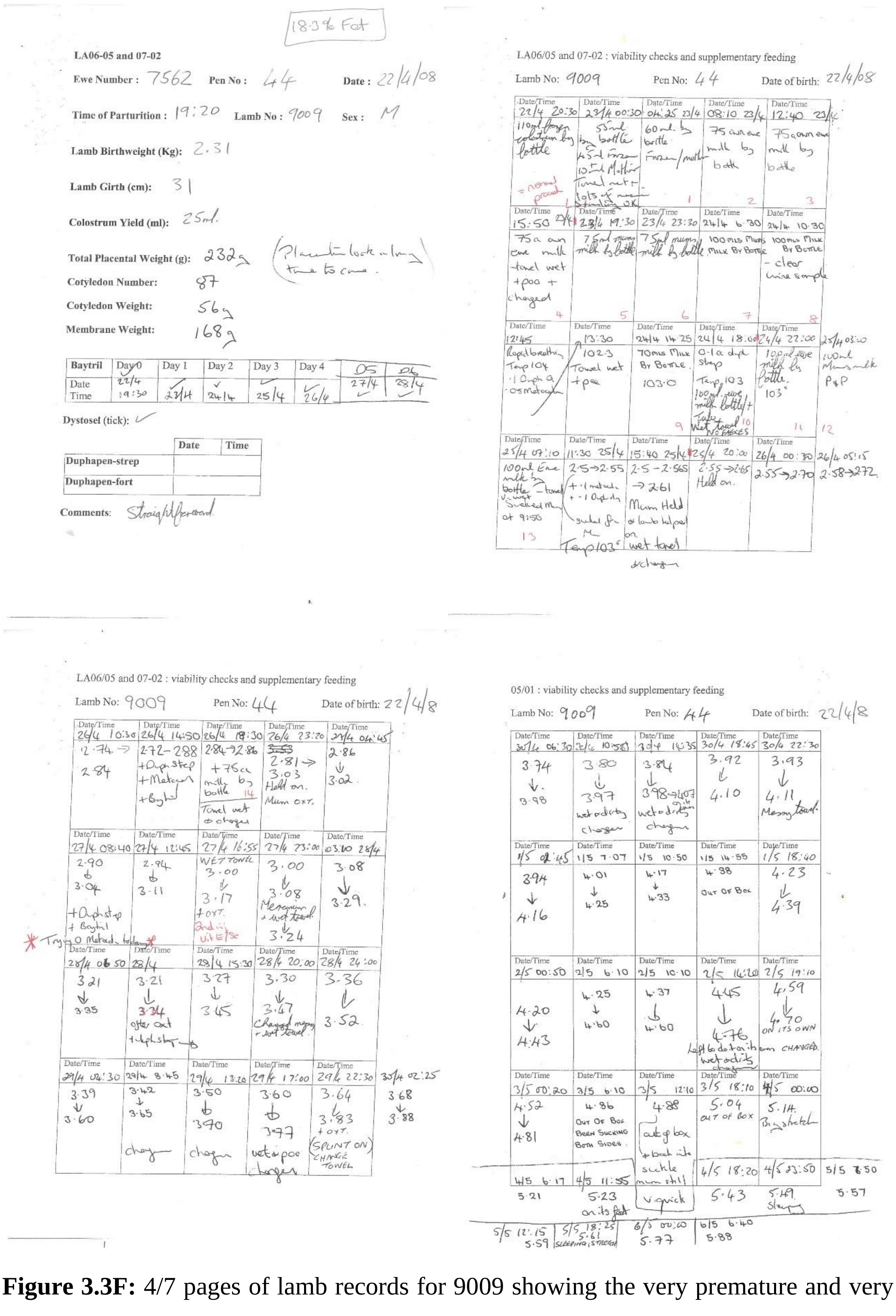


Figure 3.3F: 4/7 pages of lamb records for 9009 showing the very premature and very low birthweight lamb received; many supplementary feeds, additional antibiotic treatment, leg splinting as muscles poorly developed, urine and faecal monitoring, but eventually progressed to not needing additional support.

3.4 Developing scoring systems

The information from the 271 handwritten lamb records was transferred into an excel spreadsheet (see Appendix 3.1 and 3.2). To categorise the type and degree of perinatal compromise plus neonatal intervention six scoring systems were researched, developed and refined.

Dystocia is the difficulty of birth. Previous scoring systems have been binary (unassisted/minor assistance vs manual delivery) or ranging from 1-4 (1 = unassisted, 2 = minor assistance, 3 = major assistance, and 4 = requiring a vet) (George 1976; Speijers *et al.*, 2009; Annett *et al.*, 2013; McHugh *et al.*, 2016). Adapting these on-farm scoring systems using the greater amount of information recorded in the research facility lambing notes enabled a 0 to 5-point scoring system to be developed (Table 3.4.1).

Compromised lactation is the reduced ability or inability of a dam to produce milk. Milk volume and lamb growth are used to monitor lactation in dairy and meat sheep (Ramsey *et al.*, 1998; Banos *et al.*, 2019; Yuan *et al.*, 2019). As milk volume was not recorded and milk intervention occurred, the failed lactation score used a 0 to 2-point system summarising the amount of supplementary milk feeding required, whether oxytocin treatment was required to induce milk let-down and whether lactation ultimately failed (Table 3.4.2).

Dam mismothering was summarised in the maternal behaviour score, which was split into before and after 24hours. Both followed a 3-point system using the notes mentioning bad dam behaviour and safeguarding treatment (Table 3.4.3).

Maternal health scoring (Table 3.4.4) and the four intervention scores (Table 3.4.5) again followed a 0 to 2-point system, using the medical and feeding notes recorded. Maternal health had half scores for greater accuracy, while proportionally following the same grading scale.

Lamb vigour has previously been assessed by behaviours such as time to standing, which was recorded but would be inaccurate due to the initial colostrum intervention meaning the need to stand and seek the teat/suckle was removed. Previous scoring systems that used feeding assistance or a combination of both behaviours and feeding assistance (Matherson *et al.*, 2010; Peel *et al.*, 2012) were adapted to the detailed feeding records resulting in the 0 to 3-point scoring system pre and post 24 hours (Table 3.4.6).

Table 3.4.1: Dystocia score

Dystocia score	
Score	**Description**
0	no assistance, lamb often born unsupervised.
1	minimal assistance, uncomplicated delivery, ewe could most likely have lambed herself if unsupervised. No maternal antibiotic or painkiller required or administered.
2	moderate assistance due to malpresentation (e.g. leg(s) back, head back or down or twisted) or oversize, or tight at some stage of birth canal (cervix or coming through pelvis). No maternal antibiotic or painkiller required or administered.
3	major assistance due to malpresentation (as above but also including breach delivery, with or without drugs) or oversize or tight at some stage of birth canal. Considerable effort required to deliver lamb, tight at cervix/pelvis/vagina and 'arm' often well into uterus. Maternal antibiotic ± painkiller administered.
4	major assistance and effort required for reasons stated above, also failure to progress requiring drug treatment to ripen cervix (Monzaldon), ewe haemorrhaged or prolapsed at delivery. Should probably have performed a caesarean section. Maternal antibiotic ± painkiller administered.
5	caesarean section due to failure to progress (cervix remains closed) or oversized lamb. Maternal antibiotic and painkiller administered.

Table 3.4.2: Maternal health score

Maternal health score	
Score	**Description**
0	No problems.
0.5	Pain killers (Finadyne) and / or Antibiotics without a stated reason and/or dystocia category 3+4 with no other statement.
1	Swollen vagina after a difficult delivery and/or vaginal tear and/or attempting to prolapse and/or retained placenta and/or mastitis.
1.5	Two of category 1 together.
2	Associated recovery after a caesarean section and/or prolapse before or after delivery and/or severe postpartum haemorrhage and/or pneumonia.

Table 3.4.3: Compromised lactation score

Compromised lactation score	
Score	**Description**
0	No problems / normal lactation, - lamb requires virtually no supplementary feeding
1	Partial deficit in early lactation, - lamb requires supplementary feeding (by bottle or tube) >3x after 24 hours and/or ewe requires oxytocin to induce milk let-down and to be held at frequent intervals and/or ewe develops mastitis but recovers after treatment.
2	Complete loss of lactation, - lamb moved to lamb bar (with indication in notes that it is not just for bad mothering ability) - lamb requires extensive supplementary feeding (by bottle or stomach tube) extending well beyond 72 hours.

Table 3.4.4: Maternal behaviour scores

Maternal behaviour score	
Less than 24-hour Maternal Behaviour Score	
Score	**Description**
0	No problems / good mother.
1	Ewe had to be held to allow lamb to suckle.
2	Ewe harms e.g. pushes lamb away with its head, kicks lamb when it tries to go into suckle, stamps feet when lamb approaches her. Lamb placed in a protective ‘wired’ corner so mother can see, smell and hear it, but not cause any further damage.
Over 24-hour Maternal Behaviour Score	
Score	**Description**
0	No problems / good mother.
1	Ewe had to be held to allow lamb to suckle.
2	Ewe harms e.g. pushes lamb away with its head, kicks lamb when it tries to go into suckle, stamps feet when lamb approaches her. Lamb placed in a protective ‘wired’ corner so mother can see, smell and hear it but not cause any further damage. In extreme cases and if behaviour persists ewe tethered, but never within first 24h of giving birth.

Table 3.4.5: Supplementary feeding and other intervention scores

Intervention scores	
Lamb Safeguarding Score	
Score	**Description**
0	No intervention.
1	Minor intervention, lamb put into safeguarding box (c.f. incubator) and/or ewe held when lamb suckled to prevent injury.
2	Major intervention, lamb put into safeguarding cage and/or ewe tethered to prevent lamb injury.
Medical intervention score	
Score	**Description**
0	No intervention.
1	Minor intervention, extended course of prophylactic antibiotics (baytril) and/or energaid and/or kaogel.
2	Major intervention, pain killers (Finadyne) and/or antibiotics and/or illness specific treatment e.g. leg splints.
Less than 24-hour feeding intervention score (colostrum)	
Score	**Description**
0	No intervention
1	Minor intervention, additional colostrum supplemented by bottle.
2	Major intervention, additional colostrum supplemented by stomach tube.
Over 24-hour feeding intervention score (milk)	
Score	**Description**
0	No intervention
1	Minor intervention, 3 or more supplementary feeds by bottle.
2	Major intervention, 3 or more supplementary feeds by stomach tube.

Energaid = high energy but low protein hydration therapy used when small lambs have low urine output
Kaogel = first stage treatment for diarrhoea of unknown cause

Table 3.4.6: Lamb vigour scores

Lamb vigour score	
Less than 24-hour lamb vigour score	
Score	**Description**
0	No assistance.
1	Minimal assistance due to lamb being unable to independently suckle, lamb required and was able to suck one or more supplementary feeds by bottle during this period.
2	Moderate assistance due to lamb not only being unable to independently suckle dam but also unable to suck bottle meaning that the lamb required one supplementary feed by stomach tube.
3	Major assistance due to lamb requiring more than one supplementary feed by stomach tube, but only fell into this category if more than two thirds of supplementary feed volume was administered by tube.
Over 24-hour lamb vigour score	
Score	**Description**
0	No assistance.
1	Minimal assistance due to lamb being unable to independently suckle, lamb required and was able to suck one or more supplementary feeds by bottle within a 24-hour period.
2	Moderate assistance due to lamb not only being unable to independently suckle dam but also unable to suck bottle meaning that the lamb required one supplementary feed by stomach tube within a 24-hour period.
3	Major assistance due to lamb requiring more than one supplementary feed by stomach tube within a 24-hour period, but only fell into this category if more than two thirds of supplementary feed volume was administered by tube.
*Note feeds had a 100ml threshold, it did not count as an assisted feed unless it was 100ml or more, because if would generally mean that feeding assistance was not essential. This threshold did not apply if the lamb weight was in the first quartile for birthweight **(<3.555kg)** as very small and would require proportionally less volume.	

3.5 Data analysis

Data were analysed using Minitab (version 19.2.0.0; Minitab Inc., State College, PA). Key outcomes, such as birthweight, were checked for normality using Anderson-Darling testing and outlier testing using Grubbs' testing. Low birthweight and early delivery categories were defined using the mean and standard deviation (SD) for optimal control deliveries (Table 3.5.1). As males were heavier than females (mean ±SD: 5,472±1,281kg vs 4,899±769kg, respectively) the birthweight categories were defined on a sex-specific basis. In addition, lambs were considered oversized if weight was in the top quartile of control birthweights (sex-specific). Gestation length was not influenced by sex and was 144.5±1.65 days for controls. All the aforementioned perinatal scores were summarized in relation to maternal nutrition, and by extremes of birthweight and degree of prematurity categories independent of maternal nutrition.

Table 3.5.1: Birthweight and delivery category definitions.

Birthweight Category Definitions			
Classification	**Weight (grams)**		**Description (Sex-specific)**
	Male	**Female**	
Normal birthweight	>4,191 - 5,979	>3,745 - 5,305	Between low birthweight and oversized limits
Low birthweight	2,910 - 4,191	2,592 - 3,745	Control mean minus 1.5×SD
Extremely low birthweight	<2,910	<2,592	Control mean minus 3×SD
Oversized	≥5,980	≥5,306	Top quartile of control

Delivery Category Definitions		
Classification	**Gestation Length (days)**	**Description**
Term	143-149	Above premature cut-off
Premature	140-142	Control mean minus 2×SD
Very Premature	134-139	Control mean minus 3×SD

Table 3.5.2: Liveweight gain and fractional growth rate to weaning equations.

Equations	
Classification	**Equation**
Liveweight gain	$\frac{(weight\ at\ weaning\ in\ grams - birthweight\ in\ grams)}{age\ in\ days}$
Fractional growth rate	$\frac{(((weight\ at\ weaning\ in\ grams - birthweight\ in\ grams) \times 100) - 100)}{age\ in\ days}$

Results for continuous data presented as mean ± standard error of the mean (SEM) and compared using one-way-ANOVA and where significant followed by Tukey's pairwise comparisons. Discrete variables and categorical data were compared using Chi-Squared testing (Pearson at 95% confidence). Grouping for discrete variables were determined by comparing significant differences between each category.

4.0 Results

4.1: Summary of pregnancy outcome by gestational intake.

Relative to optimally nourished controls the key features of overnourished adolescents are observed in this data set, namely; a reduction in gestation length, birthweight, placental weight and initial colostrum yield (Table 4.1). Although a small number of control lambs were prematurely delivered and had a low birthweight, it was overwhelmingly the overnourished pregnancies that were similarly compromised. Also, only the overnourished group had very premature delivery and extremely low birthweight (23.1% and 17.2%, respectively). None of the undernourished lambs were delivered prematurely and for this group, both average birthweight and the incidence of low birthweight were equivalent to controls. There were fewer oversized lambs born to the overnourished and undernourished dams relative to controls.

4.2: Influence of gestational intake on perinatal scores and lamb data at weaning.

Overall mean dystocia score was lowest in the overnourished category followed by control, and highest in the undernourished dams (Table 4.2). Overnourished dams were the only ones to lamb unassisted (score 0), and showed lower rates of major assistance, (score 3,4,5 combined) compared to controls. It is unsurprising therefor that the overnourished dams also had fewer health problems after delivery (80% had no problems, maternal health score 0). The degree of birth difficulty was similar in undernourished versus control dams. In contrast the overnourished group had the highest compromised lactation score reflecting either a partial early deficit or complete loss of lactation. Only overnourished dams were in the highest category, completely losing lactation.

Although maternal behaviour scoring within the first 24hours was not influenced by pregnancy nutrition overall, several overnourished dams (n=9) physically harmed their lambs within the first 24h of life and in two cases this bad behaviour persisted throughout the monitoring period. After 24hours a small number of both overnourished and undernourished dams required to be held when the lamb required to suckle. These mismothering rates are reflected in the lamb safeguarding score with the 12 lambs receiving the most protection, in the form of cages and/or tethering the ewe all being born to overnourished dams. This group also had double the rate of safeguarding boxes and/or having to hold the ewe when suckling (minor safeguarding) compared to lambs born to control dams. Lambs born to undernourished dams also had high rates of minor safeguarding. Relative to controls lambs born to overnourished dams also required more minor and major medical intervention.

In keeping with the low initial yield, lambs born to overnourished dams required more colostrum intervention than lambs from control dams, having the highest mean score and more lambs requiring bottle supplementation. Lambs from undernourished dams also required more colostrum supplementation by bottle, requiring approximately the same rate of colostrum intervention as lambs from overnourished dams. After 24hours these differences evened out with milk intervention showing no variation between the three gestational intake groups. Lamb vigour scoring also showed no variation between 24-72 hours, and in line with colostrum intervention within the first 24hours lamb vigour scoring showed that least vigorous lambs were from overnourished dams. This group in <24hour lamb vigour scoring had the highest mean and the least rate of lambs being able to independently suckle (score 0).

Like birthweight (Table 4.1), 11-week weaning weight and liveweight gain (Table 4.2) are reduced in lambs from overnourished dams when comparing them to the lambs from control dams, while lambs born to undernourished dams showed no difference from either category. Finally, fractional growth rate and fat percentage at weaning were significantly greater in lambs born to overnourished dams compared to control dams.

Table 4.1: Summary of pregnancy outcome by gestational intake.

Gestational intake	Control	Overnourished (ON)	Undernourished (UN)	P-value			
				3 groups	Control vs ON	Control vs UN	ON vs UN
Number of pregnancies	61	186	24	-	-	-	-
Gestation Length (days)	144.5±0.21^{a}	140.9±0.16^{b}	146.2±0.31^{c}	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Ч Premature delivery (incl. v. premature), n (%)	6 (9.8%) ^{a}	151 (81.2%) ^{b}	0 (0.0%) ^{a}	**<0.001**	**<0.001**	~0.111	**<0.001**
Ч Very premature delivery, n (%)	0 (0.0%) ^{a}	43 (23.1%) ^{b}	0 (0.0%) ^{a}	~**<0.001**	**<0.001**	n/a	~**0.008**
Placental weight (g)	410.4±14.5^{a}	299.3±7.75^{b}	365.1±16.2^{a}	**<0.001**	**<0.001**	0.076	**0.003**
Fetal cotyledon weight (g)	136.6±5.47^{a}	80.9±2.51^{c}	112.0±6.75^{b}	**<0.001**	**<0.001**	**0.013**	**<0.001**
Fetal cotyledon number	89.4±1.82^{a}	84.8±1.15^{a}	100.9±3.01^{b}	**<0.001**	**0.041**	**0.001**	**<0.001**
Lamb birth weight (kg)	5.190±0.110^{a}	3.914±0.081^{b}	4.782±0.128^{a}	**<0.001**	**<0.001**	**0.037**	**<0.001**
Ч Incidence low birthweight, n (%)	4 (6.6%) ^{a}	88 (47.3%) ^{b}	4 (16.7%) ^{a}	**<0.001**	**<0.001**	~0.151	**0.004**
Ч Incidence extremely low birthweight, n (%)	0 (0.0%) ^{a}	32 (17.2%) ^{b}	0 (0.0%) ^{a}	~**<0.001**	**0.001**	n/a	~**0.027**
Ч Incidence of oversized birthweight, n (%)	15 (24.6%) ^{a}	10 (5.4%) ^{b}	2 (8.3%) ^{b}	~**<0.001**	**<0.001**	~0.092	~0.557
Colostrum yield (g)	354.5±30.3^{a}	175.8±10.6^{b}	309.2±34.2^{a}	**<0.001**	**<0.001**	0.393	**<0.001**
Lamb girth at umbilicus at birth (cm)	39.3±0.35^{a}	36.1±0.31^{b}	37.9±0.47^{ab}	**<0.001**	**<0.001**	**0.023**	**0.047**

Gestation Length = from day of laparoscopic intrauterine insemination to day of birth,
Premature/Very premature and Low birthweight/Very Low Birthweight /Oversized see table 3.5.1
Placental weight = placental membrane weight + cotyledon weight,
Values are mean ± SEM, these were compared by one-way-ANOVA, and posthoc comparisons were determined by Tukey at. Within a row groups with a differing superscript are different at $P<0.05$, Ч Chi-Squared Test used on discrete variables (Pearson at 95% confidence). ~ before results are Chi-Squared Test did not have all cells >5, making the results less reliable.
Significant P-Values are bold, non-significant are grey and trends (0.1-0.05) are standard black text.

Table 4.2: Influence of gestational intake on perinatal scores and lamb growth to weaning.

Gestational Intake	**Control (C)**	**Overnourished (ON)**	**Undernourished (UN)**	**P – value**			
				3 groups	Control vs ON	Control vs UN	ON vs UN
Number of pregnancies	61	186	24	-	-	-	-
Dystocia Score							
0, n (%)	0 (0.0%)	18 (9.7%)	0 (0.0%)	~**0.012**	~**0.012**	n/a	~0.111
1, n (%)	28 (45.9%)[a]	91 (48.9%)[a]	10 (41.7%)[a]	0.763	0.682	0.724	0.503
2, n (%)	13 (21.3%)[a]	46 (24.7%)[a]	4 (16.7%)[a]	0.625	0.587	~0.630	0.383
3, n (%)	18 (29.5%)[a]	20 (10.8%)[b]	8 (33.3%)[a]	~**<0.001**	**<0.001**	0.730	~**0.002**
4, n (%)	1 (1.6%)	6 (3.2%)	1 (4.2%)	n/a	0.517	n/a	n/a
5, n (%)	1 (1.6%)	5 (2.7%)	1 (4.2%)	n/a	0.644	n/a	n/a
0+1 Grouped, n (%)	28 (45.9%)[a]	109 (58.6%)[a]	10 (41.7%)[a]	0.097	0.083	0.724	0.115
3, 4, 5 Grouped, n (%)	20 (32.8%)[a]	31 (16.7%)[b]	10 (41.7%)[a]	**0.002**	**0.007**	0.441	~**0.004**
Mean ± SE Mean	1.92±0.127[ab]	1.57±0.079[a]	2.13±1.154[b]	**0.012**	**0.027**	0.410	**0.020**
Range	1 – 5	0 - 5	1 – 5	-	-	-	-
Maternal Health Score							
0, n (%)	40 (65.6%)[a]	148 (80.0%)[b]	14 (58.3%)[a]	**0.012**	**0.021**	0.532	**0.017**
0.5, n (%)	16 (26.2%)[a]	21 (11.4%)[b]	6 (25.0%)[ab]	~**0.010**	**0.005**	0.907	~0.061
1, n (%)	2 (3.3%)	7 (3.8%)	1 (4.2%)	n/a	0.855	n/a	n/a
1.5, n (%)	0	0	1 (4.2%)	n/a	n/a	n/a	n/a
2, n (%)	3 (4.9%)[a]	9 (4.9%)[a]	2 (8.3%)[a]	~0.767	~0.987	~0.547	~0.474
1, 1.5+2 Grouped, n (%)	5 (8.2%)[a]	16 (8.6%)[a]	4 (16.7%)[a]	~0.421	0.913	~0.253	~0.209
Mean ± SE Mean	0.26±0.061[a]	0.19±0.035[a]	0.40±0.128[a]	0.130	0.317	0.293	0.058
Range	0-2	0-2	0-2	-	-	-	-

Gestational Intake	Control	ON	UN	3 groups	C vs ON	C vs UN	ON vs UN
Compromised Lactation Score							
0, n (%)	57 (95.0%)[a]	150 (83.8%)[b]	22 (91.7%)[ab]	~0.064	**0.027**	~0.560	~0.314
1, n (%)	3 (5.0%)[a]	24 (13.4%)[a]	2 (8.3%)[a]	~0.180	0.075	~0.560	~0.485
2, n (%)	0 (0.0%)	5 (2.8%)	0 (0.0%)	n/a	~0.191	n/a	n/a
1+2 Grouped, n (%)	3 (5.0%)[a]	29 (16.2%)[b]	2 (8.3%)[ab]	~0.064	**0.027**	~0.560	~0.314
Mean ± SE Mean	0.05±0.028[a]	0.19±0.034[a]	0.08±0.057[a]	**0.049**	**0.024**	0.565	0.269
Range	0-1	0-2	0-1	-	-	-	-
Maternal Behaviour Score 0-24h							
0, n (%)	57 (93.4%)[a]	161 (88.5%)[a]	19 (79.2%)[a]	~0.168	0.268	~0.054	~0.197
1, n (%)	4 (6.6%)[ab]	12 (6.6%)[a]	5 (20.8%)[b]	~**0.047**	~0.992	~0.054	~**0.017**
2, n (%)	0	9 (4.9%)	0	n/a	~0.077	n/a	~0.265
1+2 Grouped, n (%)	4 (6.6%)[a]	21 (11.5%)[a]	5 (20.8%)[a]	~0.168	0.268	~0.054	~0.197
Mean ± SE Mean	0.07±0.032 [a]	0.17±0.036[a]	0.21±0.085[a]	0.240	0.129	0.055	0.677
Range	0-1	0-2	0-1	-	-	-	-
Maternal Behaviour Score >24h							
0, n (%)	60 (100%)[a]	163 (91.6%)[b]	20 (83.3%)[b]	~**0.016**	~**0.020**	~**0.001**	~0.194
1, n (%)	0[a]	13 (7.3%)[b]	4 (16.7%)[b]	~**0.015**	~**0.031**	~**0.001**	~0.121
2, n (%)	0	2 (1.1%)	0	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	0[a]	15 (8.4%)[b]	4 (16.7%)[b]	~**0.016**	~**0.020**	~**0.001**	~0.194
Mean ± SE Mean	0±0[a]	0.10±0.025[a]	0.17±0.078[a]	**0.033**	**0.027**	**0.001**	0.333
Range	0-0	0-2	0-1	-	-	-	-

Gestational Intake	Control	ON	UN	3 groups	C vs ON	C vs UN	ON vs UN
Lamb Safeguarding Score							
0, n (%)	57 (93.4%)^{a}	145 (80.6%)^{b}	19 (79.2%)^{ab}	~0.055	**0.018**	~0.054	~0.872
1, n (%)	4 (6.6%)^{a}	23 (12.8%)^{a}	5 (20.8%)^{a}	~0.168	0.183	~0.054	~0.281
2, n (%)	0	12 (6.7)	0	~0.051	0.039	n/a	~0.192
1+2 Grouped, n (%)	4 (6.6%)^{a}	35 (19.4%)^{b}	5 (20.8%)^{ab}	~0.055	**0.018**	~0.054	~0.872
Mean ± SE Mean	0.07±0.032^{a}	0.26±0.043^{b}	0.21±0.085^{ab}	**0.034**	**0.010**	0.055	0.663
Range	0-1	0-2	0-1	-	-	-	-
Medical Intervention Score							
0, n (%)	57 (95.0%)^{a}	127 (70.6%)^{b}	23 (95.8%)^{a}	**<0.001**	**<0.001**	~0.871	**0.008**
1, n (%)	0	13 (7.2%)	0	~0.041	~0.032	n/a	0.174
2, n (%)	4 (6.7%)^{a}	44 (24.4%)^{b}	1 (4.2%)^{a}	**~0.001**	**0.003**	~0.662	**0.024**
1+2 Grouped, n (%)	4 (6.7%)^{a}	57 (31.7%)^{b}	1 (4.2%)^{a}	**<0.001**	**<0.001**	~0.871	**0.008**
Mean ± SE Mean	0.13±0.064^{a}	0.55±0.063^{b}	0.08±0.083^{a}	**<0.001**	**<0.001**	0.678	**0.009**
Range	0-2	0-2	0-2	-	-	-	-
<24h Colostrum Intervention Score							
0, n (%)	41 (67.2%)^{a}	75 (41.7%)^{b}	11 (45.8%)^{ab}	**0.003**	**0.001**	0.069	0.698
1, n (%)	11 (18.0%)^{a}	73 (40.6%)^{b}	10 (41.7%)^{b}	**0.005**	**0.001**	**0.023**	0.917
2, n (%)	9 (14.8%)^{a}	32 (17.8%)^{a}	3 (12.5%)^{a}	~0.724	0.587	~0.788	~0.519
1+2 Grouped, n (%)	20 (32.8%)^{a}	105 (58.3%)^{b}	13 (54.2%)^{ab}	**0.003**	**0.001**	0.069	0.698
Mean ± SE Mean	0.48±0.095^{a}	0.76±0.055^{b}	0.67±0.143^{ab}	**0.033**	**0.009**	0.282	0.553
Range	0-2	0-2	0-2	-	-	-	-

Gestational Intake	Control	ON	UN	3 groups	C vs ON	C vs UN	ON vs UN
24h-72h Milk Intervention Score							
0, n (%)	54 (88.5%)[a]	151 (84.8%)[a]	23 (95.8%)[a]	0.294	0.476	~0.229	0.143
1, n (%)	5 (8.2%)[a]	24 (13.5%)[a]	1 (4.2%)[a]	~0.269	0.275	~0.514	~0.193
2, n (%)	1 (1.6%)	3 (1.7%)	0	n/a	~0.981	n/a	n/a
1+2 Grouped, n (%)	6 (9.8%)[a]	27 (15.2%)[a]	1 (4.2%)[a]	0.294	0.476	~0.229	0.143
Mean ± SE Mean	0.12±0.048[a]	0.17±0.031[a]	0.04±0.042[a]	0.274	0.394	0.355	0.146
Range	0-2	0-2	0-1	-	-	-	-
Lamb Vigour Score <24h							
0, n (%)	45 (73.8%)[a]	80 (44.9%)[b]	14 (58.3%)[ab]	**<0.001**	**<0.001**	0.164	0.217
1, n (%)	9 (14.8%)[a]	70 (39.3%)[b]	7 (29.2%)[ab]	**0.002**	**<0.001**	~0.126	0.336
2, n (%)	5 (8.2%)[a]	19 (10.7%)[a]	2 (8.3%)[a]	~0.825	0.578	~0.984	~0.724
3, n (%)	2 (3.3%)	9 (5.1%)	1 (4.2%)	~0.844	~0.567	n/a	~0.850
2+3 Grouped, n (%)	7 (11.5%)[a]	28 (15.7%)[a]	3 (12.5%)[a]	~0.688	0.417	~0.895	~0.680
Mean ± SE Mean	0.41±0.100[a]	0.76±0.063[b]	0.58±0.169[ab]	**0.017**	**0.005**	0.368	0.338
Range	0-3	0-3	0-3	-	-	-	-
Lamb Vigour Score 24-72h							
0, n (%)	39 (65.0%)[a]	120 (67.8%)[a]	14 (58.3%)[a]	0.636	0.690	0.567	0.356
1, n (%)	12 (20.0%)[a]	40 (22.6%)[a]	7 (29.2%)[a]	0.663	0.674	0.364	0.476
2, n (%)	7 (11.7%)[a]	13 (7.3%)[a]	2 (8.3%)[a]	~0.581	0.298	~0.655	~0.863
3, n (%)	2 (3.3%)	4 (2.3%)	1 (4.2%)	n/a	~0.647	n/a	n/a
2+3 Grouped, n (%)	9 (15.0%)[a]	17 (9.6%)[a]	3 (12.5%)[a]	~0.503	0.248	~0.767	~0.657
Mean ± SE Mean	0.53±0.108[a]	0.44±0.055[a]	0.58±0.169[a]	0.552	0.413	0.804	0.378
Range	0-3	0-3	0-3	-	-	-	-

Gestational Intake	Control	ON	UN	3 groups	C vs ON	C vs UN	ON vs UN
Lamb data at weaning							
Number of lambs	60	172	22	-	-	-	-
11-week weaning weight (kg)	35.8±0.41[a]	33.0 ± 0.31[b]	33.9±0.58[ab]	**<0.001**	**<0.001**	**0.013**	0.362
Liveweight gain from birth to weaning (g/day)	397±5.1[a]	376±3.7[b]	378±7.4[ab]	**0.009**	**0.003**	**0.044**	0.884
Fractional growth rate (birth to weaning)(%/day)	7.8±0.20[a]	9.9±0.19[b]	8.0±0.28[a]	**<0.001**	**<0.001**	0.604	**0.001**
Dexa fat % at weaning (only 06-05S + 08-06 number below)	15.2±0.95[a] n = 35	18.2±0.95[b] n = 64	n/a n = 0	n/a	**0.046**	n/a	n/a

Values are mean ± SEM, these were compared by one-way-ANOVA, and posthoc comparisons were determined by Tukey at. Within a row groups with a differing superscript are different at P<0.05, Chi-Squared Test used on discrete variables (Pearson at 95% confidence). ~ before results are Chi-Squared Test did not have all cells >5, making the results less reliable.
Significant P-Values are bold, non-significant are grey and trends (0.1-0.05) are standard black text
Number of missing lambs shown in Appendix 3.3.

4.3: Influence of birthweight category on perinatal scores and lamb data at weaning.

In Table 4.3 the perinatal scores are presented and analysed in relation to birthweight category, irrespective of maternal nutrition. Dystocia score tracked birthweight. Accordingly, the lowest mean score and the least incidence of major lambing assistance (score 3,4, and 5 combined) was extremely low birthweight (ELBW) lambs while oversized lambs (O) had the highest dystocia score. In spite of this maternal health score was largely independent of lamb birthweight category. Ewes that gave birth to ELBW lambs had the highest rates of both a partial and full deficit in lactation; both were approximately 10x the rate of the normal birthweight (NBW) group. The low birthweight (LBW) group were less compromised but still had approximately double the rate of partial lactation loss compared to the normal group.

Maternal behavior was worse in dams that gave birth to ELBW and LBW compared to NBW lambs. Seven out of the 9 lambs that were harmed by their dams in the first 24hours after birth were ELBW or LBW: during this period there were also raised rates of these categories of dams having to be held to allow the lamb to suckle safely and this continued beyond 24h after birth. The only two lambs that were harmed after 24hours were both ELBW. Lamb safeguarding again reflects this with ELBW lambs receiving the most protection, followed by LBW lambs, then oversized lambs, and NBW lambs received the least. Medical intervention seems proportional to birthweight category as oversized lambs required the least medical treatment, and ELBW lambs required the most. For the latter group this was to treat; 8 renal issues (plus 8 lambs that had suspected issues requiring monitoring), 7 initial respiratory issues, 6 later respiratory issues, 2 neurological issues, 2 locomotory issues, and 2 gastrointestinal issues. Seven of these lambs that received treatment died also of the 12 lambs that died 7 were ELBW, 1 was LBW and 4 were NBW. 4 were put down (3 for broken ribs, 1 for kidney issues), 4 were respiratory (1 being pneumonia), 2 were crushed, 1 had brain damage and 1 was suspected to have died from recurrent in utero hypoxic-ischemic injury also there was not clear relationships between birthweight category and cause of death.

Colostrum intervention also tracked birthweight with ELBW lambs receiving the most proactive supplementation and >LBW>NBW=O. After 24hours these differences decreased in magnitude but ELBW and LBW lambs still had the highest incidence of requiring milk supplementation. During the first 24h after birth the mean lamb vigour score was ELBW>LBW>NBW>O ($P<0.001$) with the latter category being most vigorous, but after 24h of age the mean was similar between birthweight categories. Reflecting this was an increase in the rate of small lambs being able to independently suckle - from 7.7% to 38.5% for ELBW lambs, and 42.2% to 63.5% for LBW lambs.

Lamb weight at weaning and liveweight gain showed a positive relationship with birthweight as ELBW lambs were still the lightest after 11 weeks gaining the least weight per day, and the oversized lambs were still the heaviest gaining the most weight per day. Conversely fractional growth rate showed a negative relationship with birthweight with ELBW lambs gaining the most weight proportional to their birthweight and oversized lambs gained the least. Finally, body fat percentage at weaning was independent of birthweight category.

Table 4.3: Influence of birthweight category on perinatal scores and lamb growth to weaning.

Birthweight Category	Normal Birthweight (NormBW)	Extremely Low Birthweight (ELBW)	Low Birthweight (LBW)	Oversized (O)	P-value						
					4 groups	N-O	N-L	N-E	L-E	L-O	E-O
Number of pregnancies	148	32	64	27							
Dystocia Score											
0, n (%)	7 (4.7%)[a]	6 (18.8%)[b]	5 (7.8%)[ab]	0[b]	~**0.015**	~ns	~ns	~**	~ns	~ns	~*
1, n (%)	76 (51.4%)[a]	17 (53.1%)[a]	36 (56.3%)[a]	0[b]	**<0.001**	***	ns	ns	ns	***	***
2, n (%)	29 (19.6%)[a]	5 (15.6%)[a]	13 (20.3%)[a]	16 (59.3%)[b]	**<0.001**	***	ns	ns	ns	***	***
3, n (%)	31 (20.9%)[a]	0[b]	6 (9.4%)[b]	9 (33.3%)[a]	~**0.001**	ns	*	**	~T	~**	~***
4, n (%)	3 (2.0%)	2 (6.3%)	3 (4.7%)	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5, n (%)	2 (1.4%)	2 (6.3%)	1 (1.6%)	2 (7.4%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
0+1 Grouped, n (%)	83 (56.1%)[a]	23 (71.9%)[a]	41 (64.1%)[a]	0[b]	**<0.001**	***	ns	ns	ns	***	***
3, 4, 5 Grouped, n (%)	36 (24.3%)[ab]	4 (12.5%)[b]	10 (15.6%)[b]	11 (40.7%)[a]	**0.029**	T	ns	ns	~ns	**	*
Mean ± SE Mean	1.68±0.083[a]	1.41±0.237[a]	1.52±0.130[a]	2.57±0.163[b]	**<0.001**	***	ns	ns	ns	***	***
Range	0-5	0-5	0-5	2-5	-	-	-	-	-	-	-
Maternal Health Score											
0, n (%)	109 (73.6%)[ab]	25 (80.6%)[ab]	52 (81.3%)[b]	16 (59.3%)[a]	0.136	ns	ns	ns	ns	*	T
0.5, n (%)	26 (17.6 %)[ab]	2 (6.5%)[b]	7 (10.9%)[b]	8 (29.6%)[a]	~0.061	ns	ns	~ns	~ns	*	*
1, n (%)	5 (3.4%)	2 (6.5%)	2 (3.1%)	1 (3.7%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1.5, n (%)	1 (0.7%)	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2, n (%)	7 (4.7%)[a]	2 (6.5%)[a]	3 (4.7%)[a]	2 (7.4%)[a]	~0.926	~ns	~ns	~ns	~ns	~ns	~ns
1,1.5+2 Grouped, n (%)	13 (8.8%)[a]	4 (12.9%)[a]	5 (7.8%)[a]	3 (11.1%)[a]	~0.850	~ns	ns	~ns	~ns	~ns	~ns
Mean ± SE Mean	0.23±0.040[a]	0.23±0.098[a]	0.18±0.058[a]	0.33±0.107[a]	0.607	ns	ns	ns	ns	ns	ns
Range	0-2	0-2	0-2	0-2	-	-	-	-	-	-	-

Birthweight Category	NormBW	ELBW	LBW	O	4 groups	N-O	N-L	N-E	L-E	L-O	E-O
Compromised Lactation Score											
0, n (%)	139 (94.6%)^{a}	12 (46.2%)^{c}	53 (84.1%)^{b}	25 (92.6%)^{ab}	~**<0.001**	~ns	*	~***	***	~ns	***
1, n (%)	7 (4.8%)^{a}	11 (42.3%)^{c}	9 (14.3%)^{b}	2 (7.4%)^{ab}	~**<0.001**	~ns	*	~***	**	~ns	**
2, n (%)	1 (0.7%)	3 (11.5%)	1 (1.6%)	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	8 (5.4%)^{a}	14 (53.8%)^{c}	10 (15.9%)^{b}	2 (7.4%)^{ab}	~**<0.001**	~ns	*	~***	***	~ns	***
Mean ± SE Mean	0.06±0.022^{a}	0.65±0.135^{b}	0.18±0.053^{a}	0.07±0.051^{a}	**<0.001**	ns	*	***	***	ns	***
Range	0-2	0-2	0-2	0-1	-	-	-	-	-	-	-
Maternal Behaviour Score 0-24h											
0, n (%)	140 (94.6%)^{a}	22 (78.6%)^{b}	52 (81.3%)^{b}	23 (85.2%)^{ab}	~**0.008**	~T	**	~**	ns	~ns	~ns
1, n (%)	6 (4.1%)^{a}	4 (14.3%)^{b}	7 (10.9%)^{ab}	4 (14.8%)^{b}	~0.066	~*	~T	~*	~ns	~ns	~ns
2, n (%)	2 (1.4%)	2 (7.1%)	5 (7.8%)	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	8 (5.4%)^{a}	6 (21.4%)^{b}	12 (18.8%)^{b}	4 (14.8%)^{ab}	~**0.008**	~T	**	~**	ns	~ns	~ns
Mean ± SE Mean	0.07±0.025^{a}	0.29±0.113^{ab}	0.27±0.075^{b}	0.15±0.070^{ab}	**0.006**	ns	**	**	ns	ns	ns
Range	0-2	0-2	0-2	0-1	-	-	-	-	-	-	-
Maternal Behaviour Score >24h											
0, n (%)	142 (97.3%)	18 (69.2%)	57 (90.5%)	26 (96.3%)	~**<0.001**	n/a	~*	~***	~*	~ns	~*
1, n (%)	4 (2.7%)	6 (23.1%)	6 (9.5%)	1 (3.7%)	~0.186	n/a	*	n/a	~ns	~ns	~ns
2, n (%)	0	2 (7.7%)	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	4 (2.7%)	8 (30.8%)	6 (9.5%)	1 (3.7%)	~**<0.001**	n/a	~*	~***	~*	~ns	~*
Mean ± SE Mean	0.03±0.014^{a}	0.39±0.125^{b}	0.10±0.037^{a}	0.04±0.037^{a}	**<0.001**	ns	*	***	**	ns	**
Range	0-1	0-2	0-1	0-1	-	-	-	-	-	-	-

Birthweight Category	NormBW	ELBW	LBW	O	4 groups	N-O	N-L	N-E	L-E	L-O	E-O
Lamb Safeguarding Score											
0, n (%)	139 (93.9%)^{a}	9 (34.6%)^{c}	50 (78.1%)^{b}	23 (85.2%)^{ab}	**~<0.001**	~ns	**	~***	***	ns	***
1, n (%)	7 (4.7%)^{a}	13 (50.0%)^{c}	8 (12.5%)^{b}	4 (14.8%)^{b}	**~<0.001**	~*	~*	~***	***	~ns	**
2, n (%)	2 (1.4%)	4 (15.4%)	6 (9.6%)	0	**~0.002**	n/a	~**	n/a	~ns	~ns	~*
1+2 Grouped, n (%)	9 (6.1%)^{a}	17 (65.4%)^{c}	14 (21.9%)^{b}	4 (14.8%)^{ab}	**~<0.001**	~ns	**	~***	***	ns	***
Mean ± SE Mean	0.07±0.026^{a}	0.81±0.136^{c}	0.31±0.080^{b}	0.15±0.070^{ab}	**<0.001**	ns	***	***	**	ns	***
Range	0-2	0-2	0-2	0-1	-	-	-	-	-	-	-
Medical Intervention Score											
0, n (%)	130 (87.8%)^{a}	7 (23.3%)^{c}	45 (70.3%)^{b}	25 (92.6%)^{a}	**<0.001**	~ns	**	***	***	*	***
1, n (%)	2 (1.4%)	9 (30.0%)	2 (3.1%)	0	**<0.001**	n/a	~ns	***	***	n/a	**
2, n (%)	16 (10.8%)^{a}	14 (46.7%)^{b}	17 (17%)^{b}	2 (7.4%)^{a}	**<0.001**	~ns	**	***	T	*	**
1+2 Grouped, n (%)	18 (12.2%)^{a}	23 (76.7%)^{c}	19 (29.7%)^{b}	2 (7.4%)^{a}	**<0.001**	~ns	**	***	***	*	***
Mean ± SE Mean	0.23±0.052^{a}	1.23±0.149^{c}	0.56±0.111^{b}	0.15±0.103^{ab}	**<0.001**	ns	**	***	**	*	***
Range	0-2	0-2	0-2	0-2	-	-	-	-	-	-	-
<24h Colostrum Intervention Score											
0, n (%)	82 (55.8%)^{a}	2 (7.2%)^{c}	25 (39.1%)^{b}	18 (66.7%)^{a}	**<0.001**	ns	*	***	**	*	***
1, n (%)	43 (29.3%)^{a}	16 (59.3%)^{b}	27 (42.2%)^{a}	8 (29.6%)^{ab}	**0.013**	ns	T	**	ns	ns	*
2, n (%)	22 (15.0%)^{a}	9 (33.3%)^{b}	12 (18.8%)^{a}	1 (3.7%)^{ab}	**~0.027**	~ns	ns	~*	ns	~T	**
1+2 Grouped, n (%)	65 (44.2%)^{a}	25 (92.6%)^{c}	39 (60.9%)^{b}	9 (33.3%)^{a}	**<0.001**	ns	*	***	**	*	***
Mean ± SE Mean	0.59±0.061^{a}	1.26±0.114^{b}	0.80±0.092^{a}	0.37±0.109^{a}	**<0.001**	ns	T	***	**	**	***
Range	0-2	0-2	0-2	0-2	-	-	-	-	-	-	-

Birthweight Category	NormBW	ELBW	LBW	O	4 groups	N-O	N-L	N-E	L-E	L-O	E-O
24h-72h Milk Intervention Score											
0, n (%)	134 (92.4%)^{a}	16 (61.5%)^{b}	55 (85.9%)^{b}	23 (85.2%)^{ab}	~**<0.001**	~ns	ns	~***	*	~ns	T
1, n (%)	10 (6.9%)^{a}	9 (34.6%)^{b}	7 (10.9%)^{b}	4 (14.8%)^{ab}	~**0.001**	~ns	ns	~***	~**	~ns	ns
2, n (%)	1 (0.7%)	1 (3.8%)	2 (3.1%)	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	11 (7.6%)^{a}	10 (38.5%)^{b}	9 (14.1%)^{b}	4 (14.8%)^{ab}	~**<0.001**	~ns	ns	~***	*	~ns	T
Mean ± SE Mean	0.08±0.025^{a}	0.42±0.113^{b}	0.17±0.057^{a}	0.15±0.070^{ab}	**0.001**	ns	T	***	*	ns	*
Range	0-2	0-2	0-2	0-1	-	-	-	-	-	-	-
Lamb Vigour Score <24h											
0, n (%)	91 (62.3%)^{a}	2 (7.7%)^{c}	27 (42.2%)^{b}	19 (70.4%)^{a}	**<0.001**	ns	**	***	**	*	***
1, n (%)	35 (24.0%)^{a}	18 (69.2%)^{c}	25 (39.1%)^{b}	8 (29.6%)^{ab}	**<0.001**	ns	*	***	**	ns	**
2, n (%)	13 (8.9%)^{ab}	3 (11.5%)^{ab}	10 (15.6%)^{b}	0^{a}	~0.135	~ns	ns	~ns	~ns	~*	~T
3, n (%)	7 (4.8%)	3 (11.5%)	2 (3.1%)	0	~0.211	~ns	~ns	~ns	~ns	n/a	~T
2+3 Grouped, n (%)	20 (13.7%)^{a}	6 (23.1%)^{a}	12 (18.8%)^{a}	0^{b}	~0.067	~*	ns	~ns	ns	~*	~**
Mean ± SE Mean	0.56±0.070^{ab}	1.27±0.152^{c}	0.80±0.102^{bc}	0.30±0.090^{a}	**<0.001**	ns	T	***	*	**	***
Range	0-3	0-3	0-3	0-1	-	-	-	-	-	-	-
Lamb Vigour Score 24-72h											
0, n (%)	104 (71.7%)^{a}	10 (38.5%)^{b}	40 (63.5%)^{a}	19 (70.4%)^{a}	**0.010**	ns	ns	**	*	ns	*
1, n (%)	24 (16.6%)^{a}	13 (50.0%)^{b}	14 (22.2%)^{a}	8 (29.6%)^{ab}	**0.002**	ns	ns	***	*	ns	ns
2, n (%)	14 (9.7%)^{a}	2 (7.7%)^{a}	6 (9.5%)^{a}	0^{a}	~0.410	~T	ns	~ns	~ns	~T	n/a
3, n (%)	3 (2.1%)	1 (3.8%)	3 (4.8%)	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2+3 Grouped, n (%)	17 (11.7%)^{ab}	3 (11.5%)^{ab}	9 (14.3%)^{b}	0^{a}	~0.253	~T	ns	~ns	~ns	~*	~T
Mean ± SE Mean	0.42±0.062^{a}	0.77±0.150^{a}	0.56±0.108^{a}	0.30±0.090^{a}	0.078	ns	ns	*	ns	ns	**
Range	0-3	0-3	0-3	0-1	-	-	-	-	-	-	-

Birthweight Category	NormBW	ELBW	LBW	O	4 groups	N-O	N-L	N-E	L-E	L-O	E-O
Lamb data at weaning											
Number of lambs	142	25	60	27	-	-	-	-	-	-	-
11-week weaning weight (kg)	34.8±0.28[a]	27.8±0.57[d]	31.9±0.50[c]	37.5±0.60[b]	**<0.001**	***	***	***	***	***	***
Liveweight gain from birth to weaning (g/day)	390±3.5[a]	330±6.9[c]	369±6.2[b]	407±7.58[a]	**<0.001**	T	**	***	***	**	***
Fractional growth rate (birth to weaning)(%/day)	8.3±0.10[a]	14.4±0.41[d]	10.6±0.17[c]	6.7±0.15[b]	**<0.001**	***	***	***	***	***	***
Dexa fat % at weaning (only 06-05S + 08-06 number below)	17.2±0.98[a] n = 52	16.6±1.95[a] n = 15	17.7±1.66[a] n = 44	16.7±1.69[a] n = 10	0.966	ns	ns	ns	ns	ns	ns

Values are mean ± SEM, these were compared by one-way-ANOVA, and posthoc comparisons were determined by Tukey at. Within a row groups with a differing superscript are different at P<0.05,
Chi-Squared Test used on discrete variables (Pearson at 95% confidence), ~ before results are Chi-Squared Test did not have all cells >5, making the results less reliable.
Significant P-Values are bold (with; *** = P ≤ 0.001, ** = P ≤ 0.01, * = P ≤ 0.05), non-significant are grey “ns” and trends (0.1-0.05) are standard black “T”.
Number of missing lambs shown in Appendix 3.3.

4.4: Influence of degree of prematurity on perinatal scores and lamb growth to weaning.

Irrespective of gestational intake, ewes that gave birth prematurely, either <139 days or between 140-142 days gestation had a lower mean dystocia score than ewes delivering at term reflecting a lower incidence of malpresentation (Table 4.4). The mothers who gave birth early had fewer delivery- associated health issues but their ability to lactate was more often compromised relative to those delivering at term. Nevertheless, maternal behaviour towards the lamb was unrelated to gestation length category either during the first 24 h of life or thereafter. There was no difference in the proportion of lambs requiring minor safeguarding, but a slightly higher proportion of very premature lambs required major protection from their mothers than both the premature and term categories. Lamb medical intervention also tracked prematurity categorisation with the rates requiring medical treatment being 59.5% for very premature, 24.8% for premature and 7.9% for term.

The requirement for colostrum supplementation was consistent with compromised lactation and with lamb vigour score pre 24hours: more premature lambs required suckling assistance and colostrum intervention. Bottled milk supplementation, due to being unable to suckle the ewe directly and /or poor milk supply was required at double the rate for very premature lambs compared to premature and term lambs. Milk supplementation by stomach tube due to being unable to suckle teat or bottle occurred twice in both the very premature and premature categories, while the term category had none.

Weaning weight and liveweight gain from birth to weaning both decreased with severity of prematurity, with term being the heaviest and gaining the most weight over 11 weeks, and very premature being the lightest gaining the least weight. Both fractional growth rate and body fat percentage tracked delivery category, with the very premature lambs proportionally gaining the most weight and body fat, and term proportionally gaining the least weight and bodyfat.

Table 4.4: Influence of degree of prematurity on perinatal scores and lamb growth to weaning.

Delivery Category	Term	Premature (Prem)	Very Premature (VPrem)	P - value			
				3 groups	Term vs Prem	Term vs VPrem	Prem vs VPrem
Number of pregnancies	114	114	43	-	-	-	-
Dystocia Score							
0, n (%)	1 (0.9%)^{a}	8 (7.0%)^{b}	9 (20.9%)^{c}	~**<0.001**	~**0.017**	~**<0.001**	~**0.012**
1, n (%)	47 (41.2%)^{a}	58 (50.9%)^{a}	24 (55.8%)^{a}	0.173	0.144	0.102	0.581
2, n (%)	30 (26.3%)^{a}	30 (26.3)^{a}	3 (7.0%)^{b}	**0.023**	1.000	**0.008**	**0.008**
3, n (%)	30 (26.3%)^{a}	14 (12.3%)^{b}	2 (4.7%)^{b}	**0.001**	**0.007**	**0.003**	~0.159
4, n (%)	3 (2.6%)^{a}	3 (2.6%)^{a}	2 (4.7%)^{a}	~0.773	~1.000	~0.520	~0.520
5, n (%)	3 (2.6%)	1 (0.9%)	3 (7.0%)	~0.099	~0.313	~0.205	~**0.031**
0+1 Grouped, n (%)	48 (42.1%)^{a}	66 (57.9%)^{b}	33 (76.7%)^{c}	**<0.001**	**0.017**	**<0.001**	**0.029**
3, 4, 5 Grouped, n (%)	36 (31.6%)^{a}	18 (15.8%)^{b}	7 (16.3%)^{ab}	**0.010**	**0.005**	0.055	0.940
Mean ± SE Mean	1.97±0.097^{a}	1.55±0.089^{b}	1.37±0.211^{b}	**0.001**	**0.002**	**0.004**	0.354
Range	0-5	0-5	0-5	-	-	-	-
Maternal Health Score							
0, n (%)	75 (65.8%)^{a}	94 (82.5%)^{b}	33 (78.6%)^{ab}	**0.012**	**0.004**	0.125	0.580
0.5, n (%)	27 (23.7%)^{a}	12 (10.5%)^{b}	4 (9.5%)^{b}	**0.012**	**0.008**	**0.049**	~0.855
1, n (%)	5 (4.4%)^{a}	4 (3.5%)^{a}	1 (2.4%)^{a}	~0.832	~0.734	~0.564	~0.723
1.5, n (%)	1 (0.9%)	0	0	n/a	n/a	n/a	n/a
2, n (%)	6 (5.3%)^{a}	4 (3.5%)^{a}	4 (9.5%)^{a}	~0.323	0.518	~0.335	~0.131
1,1.5+2 Grouped, n (%)	12 (10.5%)^{a}	8 (7.0%)^{a}	5 (11.9%)^{a}	~0.535	0.349	~0.806	~0.327
Mean ± SE Mean	0.28±0.048^{a}	0.16±0.040^{a}	0.26±0.094^{a}	0.149	**0.048**	0.846	0.230
Range	0-2	0-2	0-2	-	-	-	-

Delivery Category	Term	Prem	VPrem	3 groups	Term vs Prem	Term vs VPrem	Prem vs VPrem
Compromised Lactation Score							
0, n (%)	105 (93.8%)[a]	96 (85.7%)[b]	28 (71.8%)[b]	**0.002**	**0.048**	~**<0.001**	0.051
1, n (%)	7 (6.3%)[a]	15 (13.4%)[ab]	7 (17.9%)[b]	~0.076	0.072	~**0.030**	0.487
2, n (%)	0	1 (0.9%)	4 (10.3%)	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	7 (6.3%)[a]	16 (14.3%)[b]	11 (28.2%)[b]	**0.002**	**0.048**	~**<0.001**	0.051
Mean ± SE Mean	0.06±0.063[a]	0.15±0.036[b]	0.38±0.108[b]	**<0.001**	**0.039**	**<0.001**	**0.009**
Range	0-1	0-2	0-2	-	-	-	-
Maternal Behaviour Score 0-24h							
0, n (%)	100 (87.7%)[a]	101 (89.4%)[a]	36 (90.0%)[a]	~0.892	0.694	~0.699	~0.912
1, n (%)	12 (10.5%)[a]	8 (7.1%)[a]	1 (2.5%)[a]	~0.247	0.360	~0.116	~0.290
2, n (%)	2 (1.8%)[a]	4 (3.5%)[a]	3 (7.5%)[a]	~0.221	~0.402	~0.078	~0.303
1+2 Grouped, n (%)	14 (12.3%)[a]	12 (10.6%)[a]	4 (10.0%)[a]	~0.892	0.694	~0.699	~0.912
Mean ± SE Mean	0.14±0.037[a]	0.14±0.041[a]	0.18±0.087[a]	0.903	0.982	0.669	0.700
Range	0-2	0-2	0-2	-	-	-	-
Maternal Behaviour Score >24h							
0, n (%)	106 (94.6%)[a]	103 (92.0%)[a]	34 (89.5%)[a]	~0.521	0.423	~0.270	~0.637
1, n (%)	6 (5.4%)[a]	8 (7.1%)[a]	3 (7.9%)[a]	~0.803	0.581	~0.569	~0.878
2, n (%)	0	1 (0.9%)	1 (2.6%)	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	6 (5.4%)[a]	9 (8.0%)[a]	4 (10.5%)[a]	~0.521	0.423	~0.270	~0.637
Mean ± SE Mean	0.05±0.021[a]	0.09±0.030[a]	0.13±0.067[a]	0.349	0.332	0.147	0.513
Range	0-1	0-2	0-2	-	-	-	-

Delivery Category	**Term**	**Prem**	**VPrem**	3 groups	Term vs Prem	Term vs VPrem	Prem vs VPrem
Lamb Safeguarding Score							
0, n (%)	100 (87.7%)^{a}	93 (83.0%)^{ab}	28 (71.8%)^{b}	0.069	0.319	**0.020**	0.130
1, n (%)	12 (10.5%)^{a}	14 (12.5%)^{a}	6 (15.4%)^{a}	~0.712	0.642	~0.416	0.647
2, n (%)	2 (1.8%)^{a}	5 (4.5%)^{ab}	5 (12.8%)^{b}	~**0.016**	~0.240	~**0.004**	~0.071
1+2 Grouped, n (%)	14 (12.3%)^{a}	19 (17.0%)^{ab}	11 (28.2%)^{b}	0.069	0.319	**0.020**	0.130
Mean ± SE Mean	0.14±0.037^{a}	0.21±0.048^{ab}	0.41±0.115^{b}	**0.016**	0.224	**0.004**	0.066
Range	0-2	0-2	0-2	-	-	-	-
Medical Intervention Score							
0, n (%)	105 (92.1%)^{a}	85 (75.2%)^{b}	17 (40.5%)^{c}	**<0.001**	**0.001**	**<0.001**	**<0.001**
1, n (%)	1 (0.9%)^{a}	5 (4.4%)^{a}	7 (16.7%)^{b}	~**<0.001**	~0.096	~**<0.001**	~**0.011**
2, n (%)	8 (7.0%)^{a}	23 (20.4%)^{b}	18 (42.9%)^{c}	**<0.001**	**0.003**	**<0.001**	**0.005**
1+2 Grouped, n (%)	9 (7.9%)^{a}	28 (24.8%)^{b}	25 (59.5%)^{c}	**<0.001**	**0.001**	**<0.001**	**<0.001**
Mean ± SE Mean	0.15±0.049^{a}	0.45±0.077^{b}	1.02±0.143^{c}	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Range	0-2	0-2	0-2	-	-	-	-
<24h Colostrum Intervention Score							
0, n (%)	64 (56.1%)^{a}	49 (43.4%)^{b}	14 (36.8%)^{b}	0.052	0.054	**0.039**	0.481
1, n (%)	34 (29.8%)^{a}	44 (38.9%)^{a}	16 (16%)^{a}	0.233	0.148	0.163	0.730
2, n (%)	16 (14.0%)^{a}	20 (17.7%)^{a}	8 (21.1%)^{a}	0.553	0.450	0.304	0.645
1+2 Grouped, n (%)	50 (43.9%)^{a}	64 (56.6%)^{b}	24 (63.2%)^{b}	0.052	0.054	**0.039**	0.481
Mean ± SE Mean	0.58±0.068^{a}	0.74±0.070^{a}	0.84±0.122^{a}	0.093	0.093	0.058	0.481
Range	0-2	0-2	0-2	-	-	-	-

Delivery Category	**Term**	**Prem**	**VPrem**	3 groups	Term vs Prem	Term vs VPrem	Prem vs VPrem
24h-72h Milk Intervention Score							
0, n (%)	103 (91.2%)^{a}	99 (88.4%)^{a}	26 (70.3%)^{b}	~**0.004**	0.495	**0.001**	**0.009**
1, n (%)	10 (8.8%)^{a}	11 (9.8%)^{a}	9 (24.3%)^{b}	~**0.029**	0.802	~**0.014**	~**0.025**
2, n (%)	0	2 (1.8%)	2 (5.4%)	n/a	n/a	n/a	n/a
1+2 Grouped, n (%)	10 (8.8%)^{a}	13 (11.6%)^{a}	11 (29.7%)^{b}	~**0.004**	0.495	**0.001**	**0.009**
Mean ± SE Mean	0.09±0.027^{a}	0.13±0.037^{a}	0.35±0.097^{b}	**0.002**	0.320	**<0.001**	**0.011**
Range	0-1	0-2	0-2	-	-	-	-
Lamb Vigour Score <24h							
0, n (%)	72 (63.2%)^{a}	52 (46.4%)^{b}	15 (40.5%)^{b}	**0.011**	**0.012**	**0.016**	0.532
1, n (%)	27 (23.7%)^{a}	44 (39.3%)^{b}	15 (40.5%)^{b}	**0.024**	**0.012**	**0.047**	0.892
2, n (%)	10 (8.8%)^{a}	11 (9.8%)^{a}	5 (13.5%)^{a}	~0.703	0.786	~0.402	~0.529
3, n (%)	5 (4.4%)^{a}	5 (4.5%)^{a}	2 (5.4%)^{a}	~0.965	~0.977	~0.798	~0.815
2+3 Grouped, n (%)	15 (13.2%)^{a}	16 (14.3%)^{a}	7 (18.9%)^{a}	0.686	0.805	0.388	0.499
Mean ± SE Mean	0.54±0.078^{a}	0.72±0.077^{a}	0.84±0.866^{a}	0.104	0.104	0.067	0.468
Range	0-3	0-3	0-3	-	-	-	-
Lamb Vigour Score 24-72h							
0, n (%)	79 (70.5%)^{a}	73 (65.2%)^{a}	21 (56.8%)^{a}	0.291	0.391	0.122	0.357
1, n (%)	22 (19.6%)^{a}	24 (21.4%)^{a}	13 (35.1%)^{a}	0.137	0.741	0.054	0.094
2, n (%)	9 (8.0%)^{a}	10 (8.9%)^{a}	3 (8.1%)^{a}	~0.969	0.810	~0.989	~0.878
3, n (%)	2 (1.8%)	5 (4.5%)	0	n/a	~0.249	n/a	~0.191
2+3 Grouped, n (%)	11 (9.6%)^{a}	15 (13.4%)^{a}	3 (8.1%)^{a}	~0.572	0.404	~0.757	~0.392
Mean ± SE Mean	0.41±0.068^{a}	0.53±0.079^{a}	0.51±0.107^{a}	0.496	0.267	0.441	0.930
Range	0-3	0-3	0-2	-	-	-	-

Delivery Category	Term	Prem	VPrem	3 groups	Term vs Prem	Term vs VPrem	Prem vs VPrem
Lamb data at weaning							
Number of lambs	110	110	34	**-**	**-**	-	**-**
11-week weaning weight (kg)	35.1±0.36[a]	33.5±0.36[b]	29.8±0.80[c]	**<0.001**	**0.002**	**<0.001**	**<0.001**
Liveweight gain from birth to weaning (g/day)	392±4.2[a]	382±4.0[a]	344±8.7[b]	**<0.001**	0.101	**<0.001**	**<0.001**
Fractional growth rate (birth to weaning)(%/day)	8.2±0.16[a]	9.7±0.21[b]	11.4±0.54[c]	**<0.001**	**<0.001**	**<0.001**	**0.001**
Dexa fat % at weaning (only 06-05S + 08-06 number below)	15.5±1.02[a] n = 39	16.9±0.98[a] n = 49	23.9±2.22[b] n = 11	**0.002**	0.310	**0.001**	**0.004**

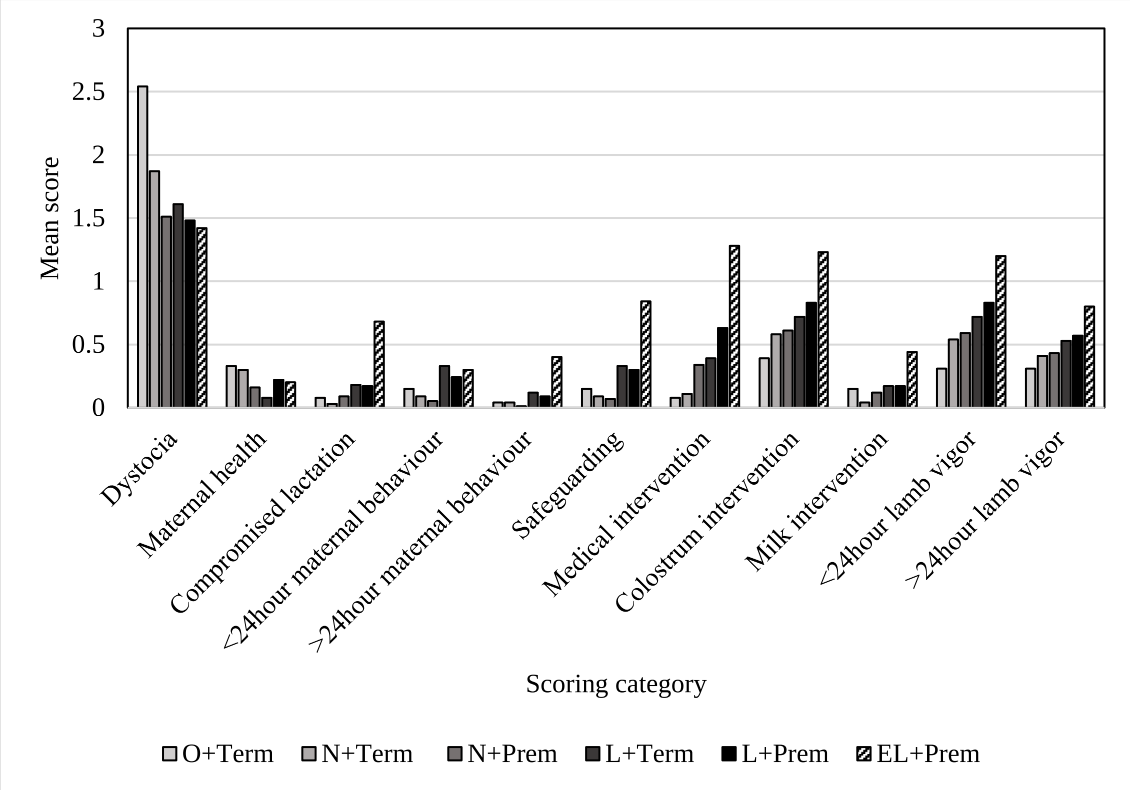
Values are mean ± SEM, these were compared by one-way-ANOVA, and posthoc comparisons were determined by Tukey at. Within a row groups with a differing superscript are different at P<0.05, Chi-Squared Test used on discrete variables (Pearson at 95% confidence). ~ before results are Chi-Squared Test did not have all cells >5, making the results less reliable.
Significant P-Values are bold, non-significant are grey and trends (0.1-0.05) are standard black text
Number of missing lambs shown in Appendix 3.3.

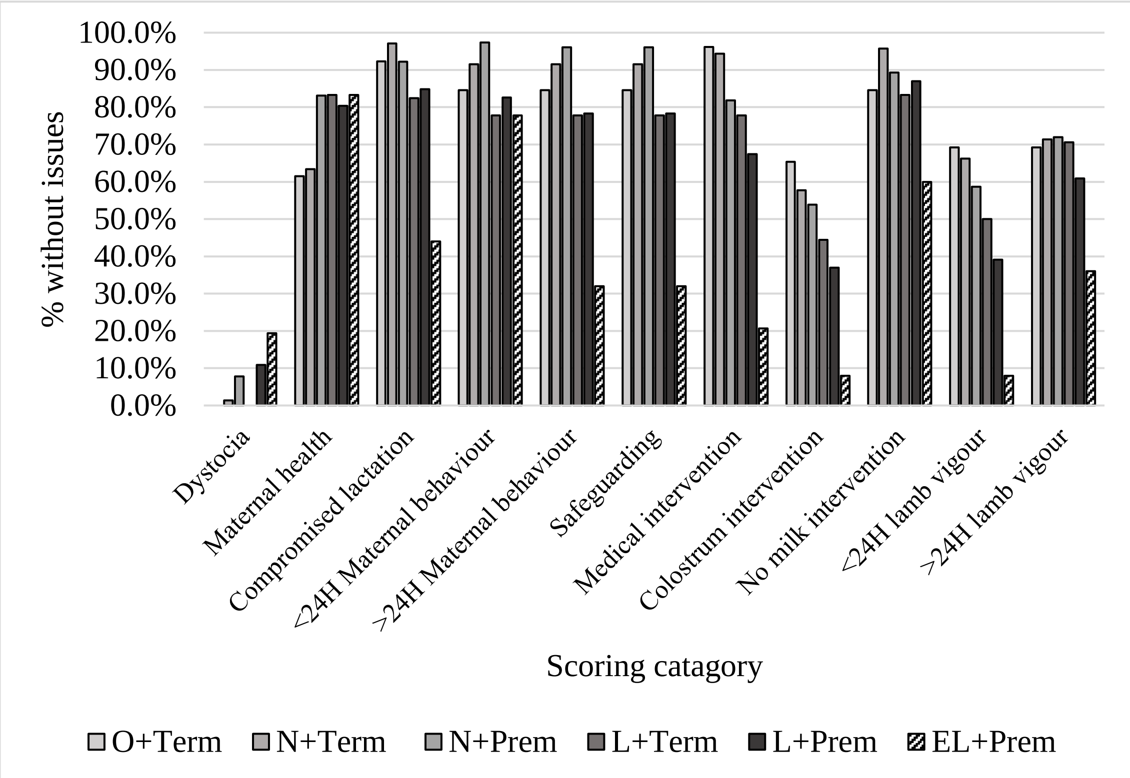
4.5: Influence of birthweight and degree of prematurity on perinatal scores and lamb growth to weaning.

As birthweight and degree of prematurity are linked, lambs were grouped by both to show the extremes and to try to separate two factors to determine which is the main issue for a certain area i.e. being too small or being premature. The groups and numbers per group can be seen on Figure 5.4A and in the full table in Appendix 4.1. Mean dystocia was highest in dams that gave birth to oversized lambs at term, and lowest in extremely low birthweight premature lambs (Figure 4.5A). Of the 18 lambs born without any assistance, only 1 was born at term and 17 were premature/very premature, predominantly reflecting their small size (Figure 4.5B). Only dams that lambed prematurely had complete loss of lactation and rates were again linked to decreased birthweight. Partial milk deficit occurred in all groups but was markedly increased in dams with ELBW premature lambs (Figure 4.5C).

Birthweight category appears to be the more important category for maternal behavior pre and post 24hours. This is shown by increased mean maternal behavior scores and decreased rates of dams showing no behavioural issues for reduced birthweight lambs irrespective of delivery category and no increase in the NBW premature group (Figure 4.5A/D). This is reinforced by mean lamb safeguarding being increased in the same pattern as well as ~20% of LBW lambs and <10% NBW lambs needing protection measures regardless of prematurity (Figure 4.5A/E). Rates of lambs needing no medical intervention were highest in the oversized+term category and lowest in ELBW+premature/very premature category. ~80% of lambs that were ELBW+premature/very premature lambs, needed medical intervention which is over double the ~30% LBW+premature/very premature lambs and almost quadruple the ~20% of NBW+premature/very premature or LBW+term lambs (Figure 4.5A/E).

This compounding is seen again in required colostrum intervention (Figure 4.5A/F). The need for milk intervention was highest in ELBW+premature/very premature lambs, as well as raised in LBW compared to NBW lambs, with delivery category appearing to have less of an impact (Figure 4.5A/F). Lamb vigour pre and post 24 hours appears to track birthweight instead of prematurity with the oversized+term lambs requiring the least mean scores and no assistance rates, while ELBW+premature/very premature category requiring the most (Figure 4.5A/G).





O = oversized, N = normal birthweight, L = low birthweight, E = extremely low birthweight, Prem = premature including very premature, example L+Prem = low birthweight and premature/very premature

Figure 4.5A: Mean perinatal scores (a) and % of animals with no issues, 0 score (b) for aspects of maternal and lamb health, wellbeing and feeding interventions in relation to birthweight and gestation length category.

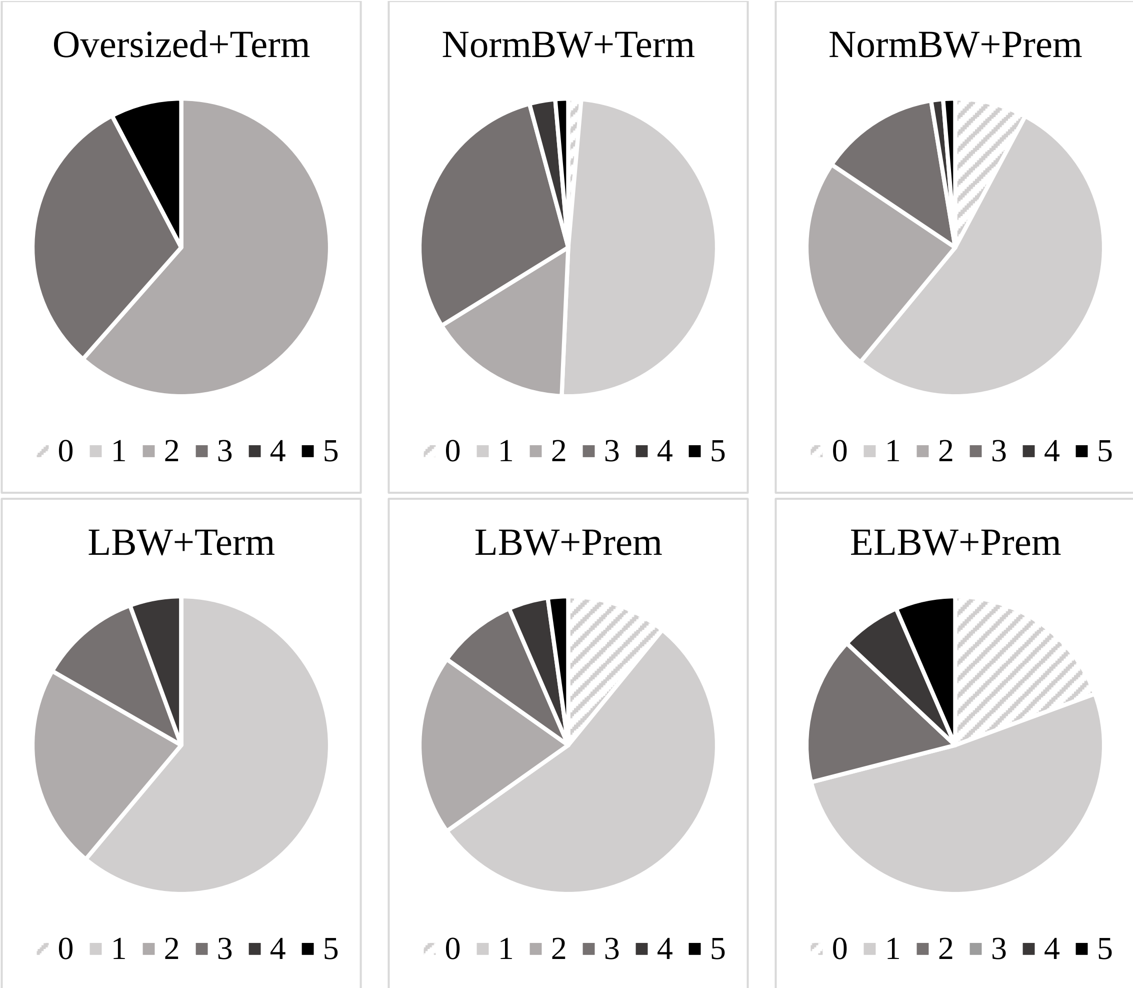
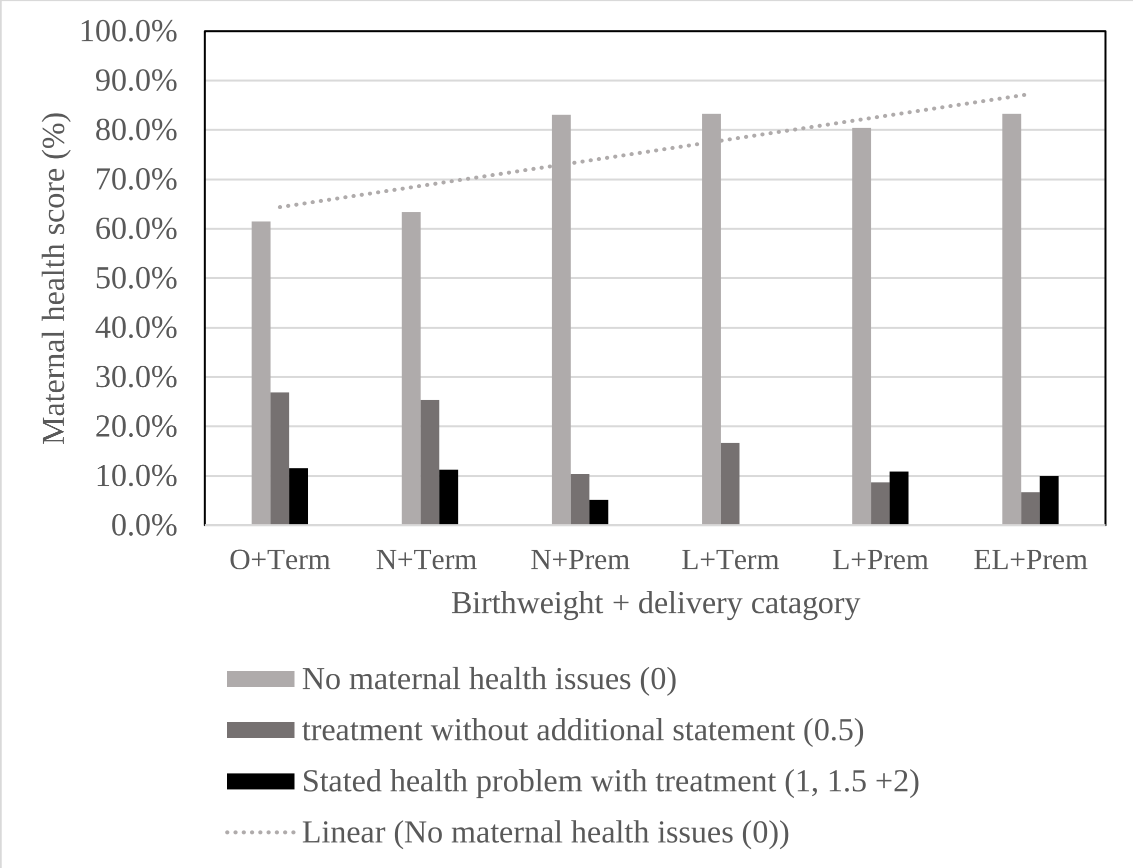


Figure 4.5B: Dystocia scores for birthweight plus delivery catagories. Where; 0 = no assistance, lamb often born unsupervised, 1 = minimal assistance, 2 = moderate assistance, 3 = major assistance, 4 = major assistance (should have probably performed a caesarean section), and 5 = caesarean section.



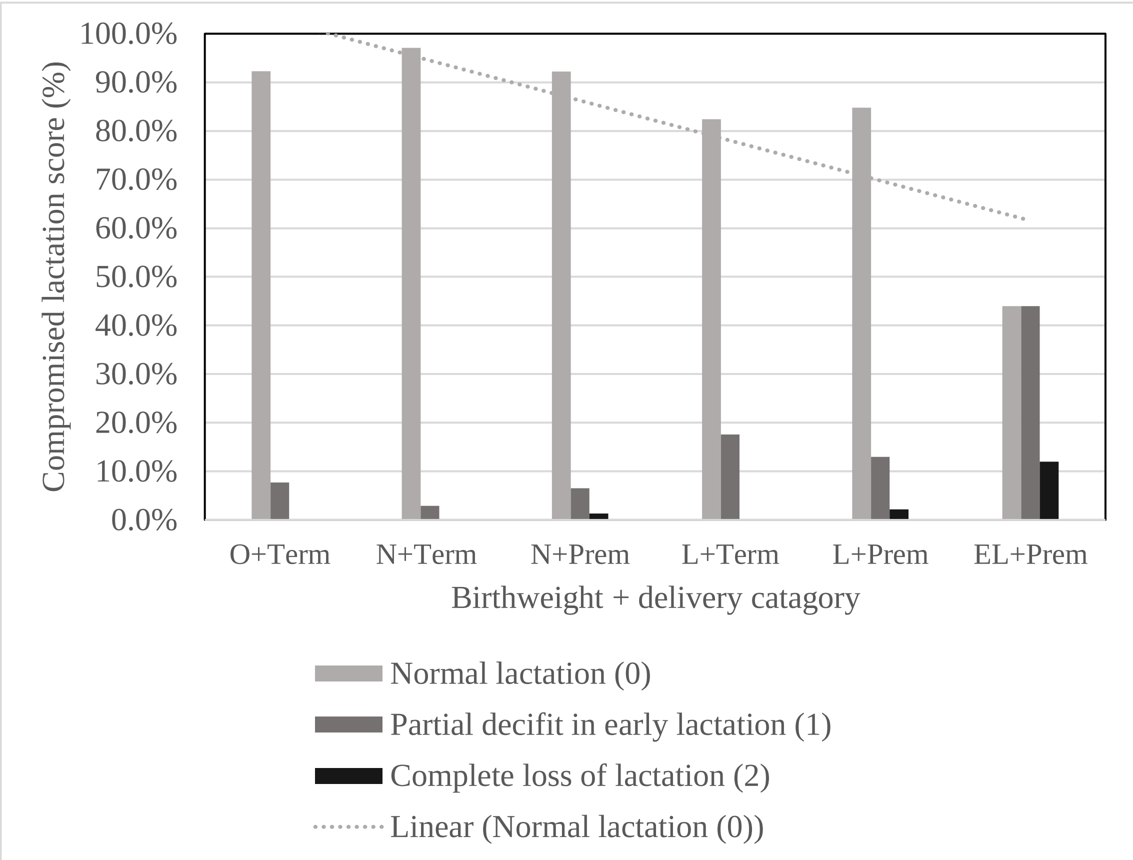
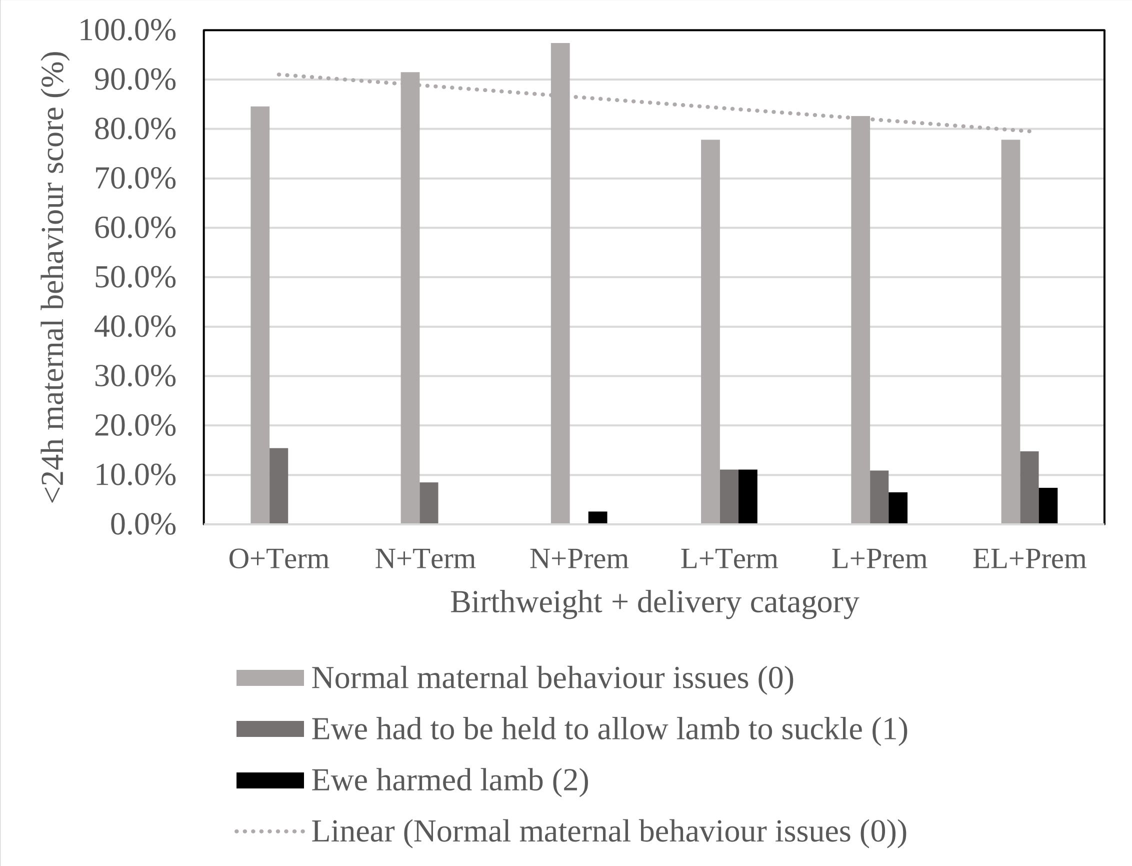


Figure 4.5C: Maternal health scores for birthweight plus delivery catagories (above). Compromised lactation scores for birthweight plus delivery catagories (below).



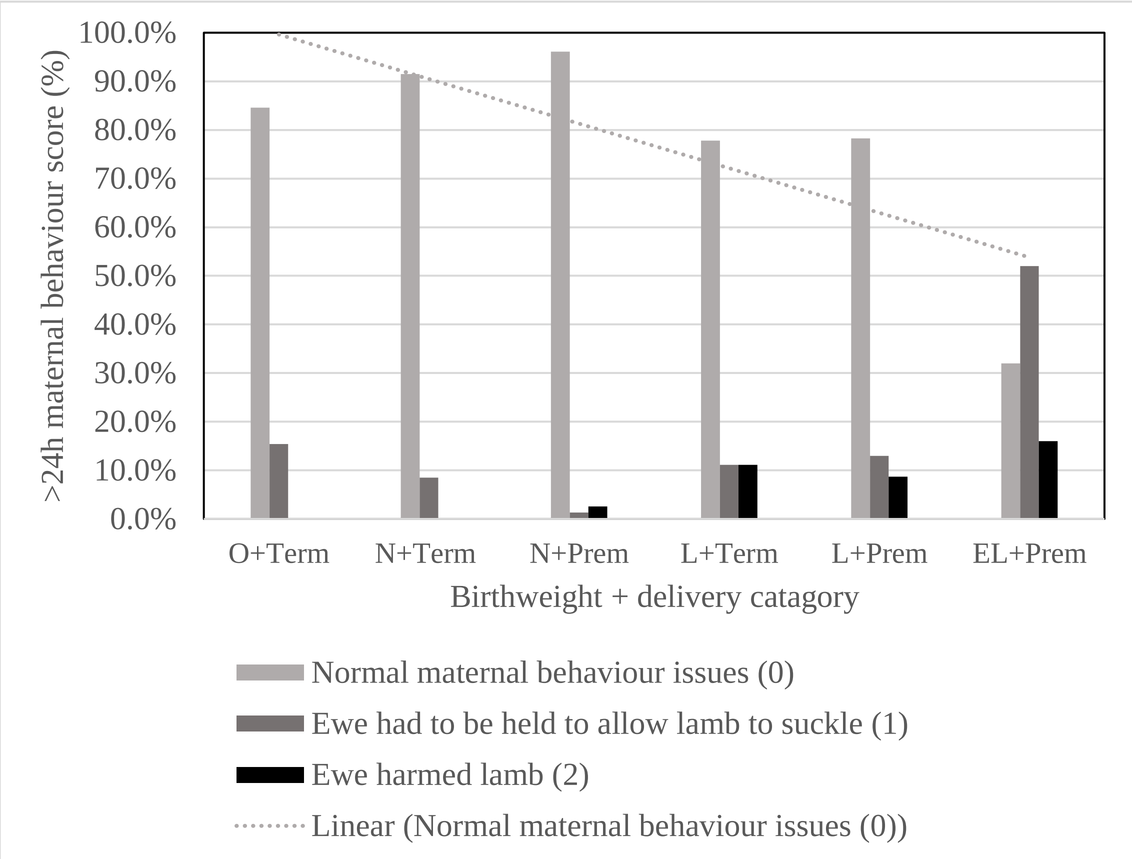


Figure 4.5D: 0-24hours (above) and 24-72hours (below) maternal behaviour scores for birthweight plus delivery catagories.

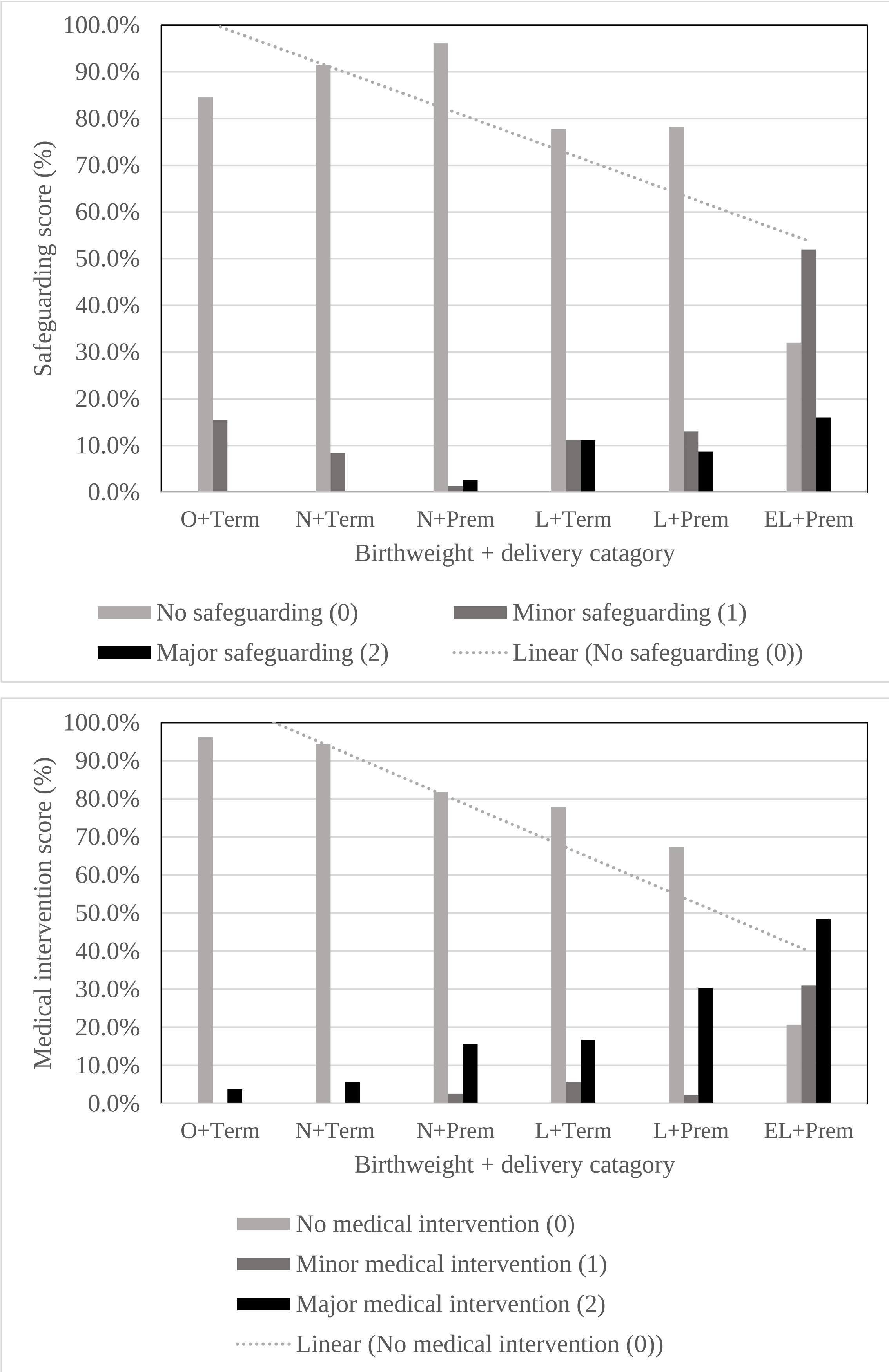
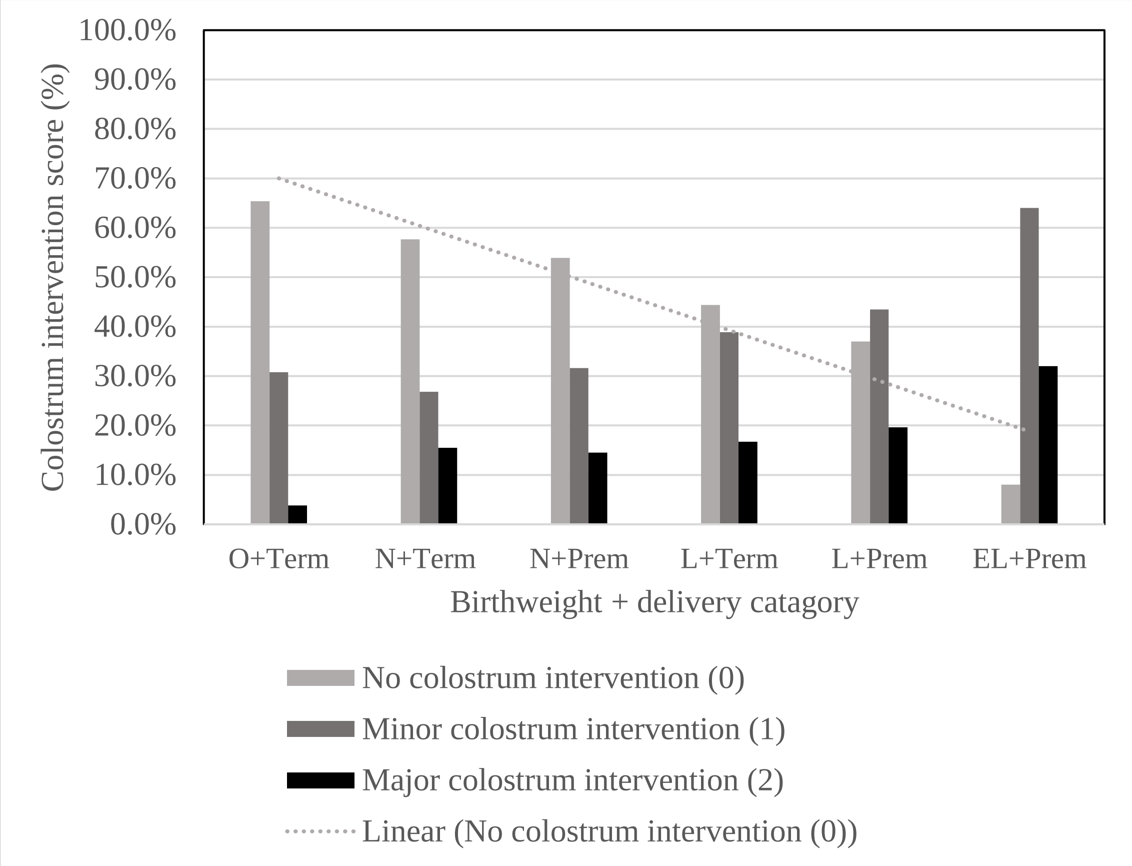


Figure 4.5E: Safeguarding scores (above) and medical intervention scores (below) for birthweight plus delivery categories.



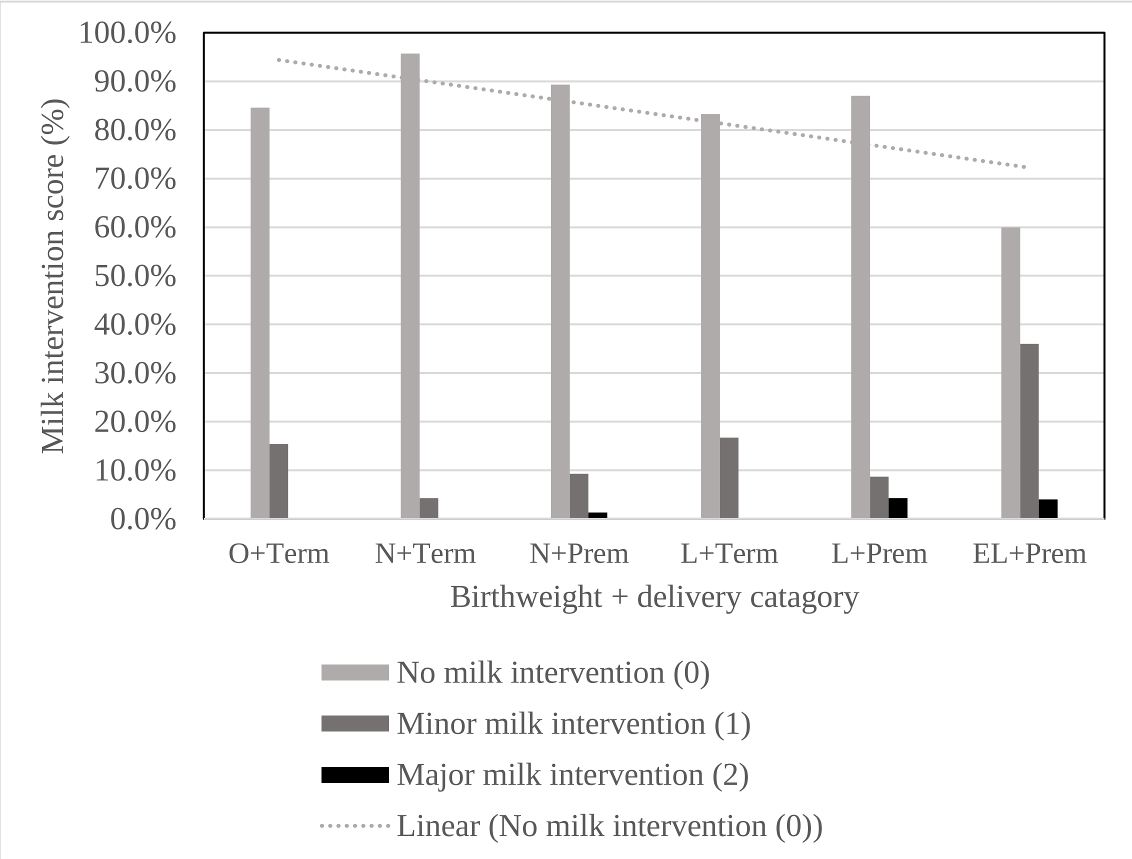
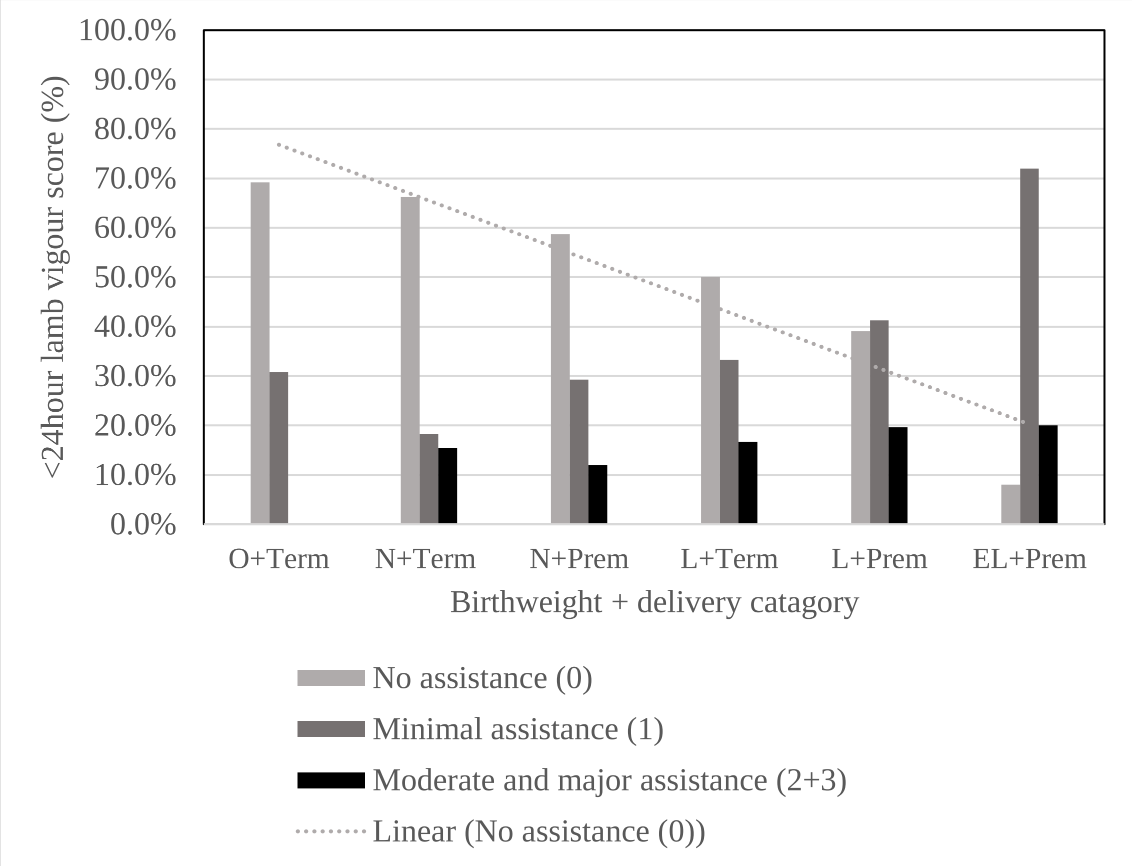


Figure 4.5F: Colostrum (above) and milk (below) intervention scores for birthweight plus delivery categories.



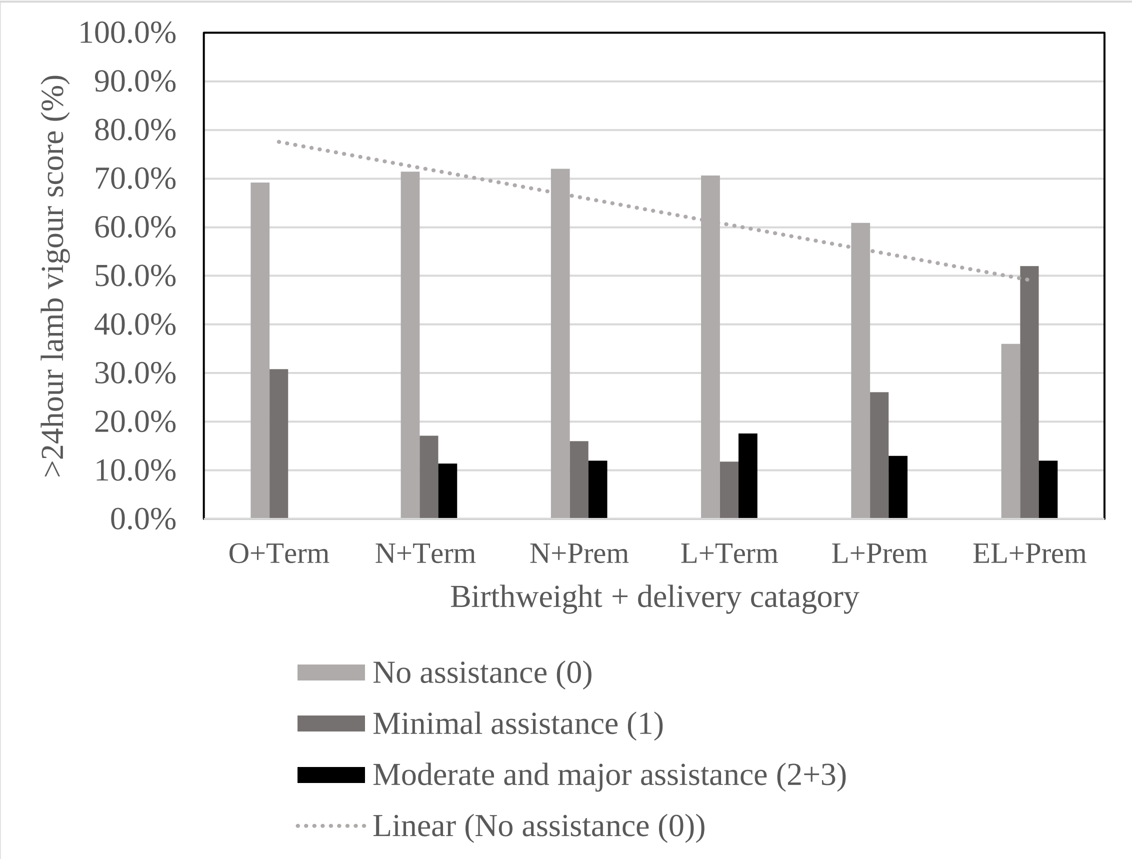


Figure 4.5G: <24hour (above) and >24hour (below) lamb vigour scores for birthweight plus delivery categories.

5.0 Discussion

5.1 Summary of pregnancy outcome by gestational intake.

The 271 pregnancy outcomes in this data set were representative of the previously published material on this adolescent sheep model, with overnourished obese dams prematurely delivering growth-restricted lambs, as in humans (Aly *et al.,* 2010 Wallace *et al.,* 2019). The effect on placental growth, lamb birthweight and colostrum yield for these overnourished and undernourished models relative to optimally nourished control adolescent dams has been well characterised. The results in table 4.1 fit with these observations which are a result of the maternal-fetal competition for nutrients where adolescent dams, as in humans, prioritise their own growth at the expense of the fetus' (Scholl *et al.,* 1994; Wallace *et al.,* 2010; 2019). In combining five studies this thesis represents the most comprehensive assessment of basic pregnancy outcomes for these overnourished and undernourished models. As such it may be a valuable resource for farmers considering breeding their replacement females in the first year of life.

5.2: Maternal scores

Dystocia being reduced in overnourished dams is probably because of the lambs being proportionally smaller relative to the mother's body size allowing for easier delivery. Conversely undernourished dams having a raised dystocia is probably due to the lambs being proportionally larger as a result of the reduced dam growth/size. An observation from a member of the original research team was that overnourished dams with very low birthweight lambs usually had much shorter labour than normal birthweight lambs, although this was not measured it fits with the idea that these smaller lambs were delivered easier. This could mean that larger lambs took longer to lamb and therefore dystocia could also be linked to duration of labour, which has been seen to be the case in humans (Gemer *et al.,* 1999; Haram *et al.,* 2002; Teal *et al.,* 2018). With dystocia score being ELBW>LBW>NBW>O and maternal health doing the opposite these could be linked, but not at the most complex end as caesarean sections occurred relatively evenly in all weight categories as well as very premature to term births. All other specific maternal health problems did not occur in enough numbers to determine relationships, possibly trends could be seen with greater numbers and could be an area for further investigation.

This was not the case for compromised lactation scoring with only dams that lambed prematurely having complete loss of lactation and rates were again linked to decreased birthweight. This is partly because the placenta is a source of lactogenic hormones and so when the placenta is small, as in low birthweight animals the endocrine drive to the mammary gland is low. One such hormonal example would be prolactin, which is; required for milk production, it is reduced in pre-term births, and linked to maternal behaviour, but other factors such as neurobiological status could also be affected (Barrett and Fleming, 2010; Powe *et al.*, 2010; Bridges 2015).

In a farming environment most dams that harm their lambs will be culled, so as all the dams were inexperienced first-time mothers the increased maternal behaviour issues compared to adult ewes was to be expected. The fact that it was raised in reduced birthweight groups but not pre-term groups suggests that it is more to do with the fact that these lambs are small instead of premature. This is unusual because oxytocin the hormone involved in mothers love is linked to progesterone being high pre-term dropping off at term causing estrogen dominance and increased oxytocin (Kota *et al.*, 2013; Yuan and Hou, 2015). While an impaired ewe-lamb bond linked to a mismatch or reduction in bonding hormones is one possibility it could also be that the large clumsy overnourished dams do not notice where these little lambs are, and squash them while they are tired and sore, accounting for some of the injuries. It is also important to note that three out of the seven dams that had caesarean sections had maternal behavioural issues within the first 24 hours, two of which persisted after 24 hours, which seems to point to it affecting ewe lamb bonding as these are in much higher proportions. This fits with the human studies which have found that mothers who underwent caesarean delivery have significantly worse bonding than those that delivery vaginally and more frequently had abnormal bonds 10-12 weeks after delivery (Zanardo *et al.*, 2016; Forti-Buratti *et al.*, 2017). In these sheep poor maternal behaviour generally reduced after 24hours for every group apart from ELBW showing that the extra safeguarding care should be provided during this critical period. These studies did not monitor the previously studied specific mothering ability behaviours, which arguably are too hard to realistically monitor on a farm. By making the scoring system limited to three clear options (no sign of harmful behaviours, possibly harmful behaviours and actually harming) it provides a simple system to track dam behavior, especially in this important period just after lambing (Kendrick and Keverne 1991; Dwyer 2008; 2013; Dwyer *et al.*, 2015; Mora-Medina *et al.*, 2016).

5.3: Lamb scores

A lot of safeguarding would have been precautionary for the extremely low birthweight and very premature lambs produced by the overnourished dams, thus skewing the results, but this precaution was proportional to the risk for these lambs. This risk was seen in the greatly increased amount of medical intervention required for these lambs. As in addition to being small and born too early, many of these neonatal lambs displayed issues with; thermoregulation, locomotion, their gastrointestinal tract, as well as lung and kidney function. It could be argued that this not only shows the negative impact of being small and premature but also shows the positive effect of the neonatal care protocol by the original research team. Mismothering accounted for 5 out of the 12 lamb deaths, while this proportion is higher than the ~10% seen in Figure 1.2D total lamb mortality was reduced to ~4%, which is significantly less than the 12/15% average. This shows the success of these safeguarding methods in this group of adolescent first-time mothers that are notoriously bad for maternal behaviour. These safeguarding and feeding intervention methods also prevented all deaths caused by lambs being too small or large which each accounted for ~5% of lamb mortality, again seen in Figure 1.2D. As it would only take two lamb deaths in any of these categories one could argue the total numbers were not enough to show these guidelines prevent deaths for lambs that are considered too big. I would argue due to the greater proportion of lambs that are "too small" these numbers are sufficient to show that these guidelines prevent these deaths.

The definitions for feeding intervention and lamb vigour scoring are difficult to separate as both are just variation in feeding assistance, but they are inherently linked. This scoring system showed that if these premature and low birthweight lambs were assisted in the first 24hours they would recover and be as vigorous as their normal counterparts. With there being no behaviours recorded as with previous papers designed to studying lamb vigour, and not enough numbers to do a more in-depth/separating lamb vigour scoring system (including various additional aid and supplementary feeding beyond 72hours) the system used here is a practical alternative that could be done on farm (Dwyer *et al.*, 2005; Abdul-Rahman and Bernard 2017; Gronqvist *et al.*, 2019).

5.4: Lamb growth to weaning.

This previously mentioned feeding intervention, which prevented lamb deaths understandably positively affects lamb growth rate by not allowing the lambs that may struggle to suckle to fail to thrive. The previously reported gestational intake grouping fits with previous publications (Wallace *et al.,* 2010; 2020), and the new ways of categorising the lambs by degree of prematurity and birth weight extremes showed clear relationships that are understandable. The fact that lower birthweight lambs and very premature lambs have less liveweight gain from birth to weaning is probably simply because they are smaller and there is a limit on how much these tiny lambs can "catch up" in 11-weeks. Despite the largest lambs being 3x the size of the smallest lambs the fractional growth rate showed the lower birthweight and more premature lambs proportionally gained more weight. When looking at bodyfat percentage at weaning the only categories that displayed variation were the early delivery categories, with very premature lambs proportionally gaining the most weight and considerably more body fat in comparison to premature and term. This can be seen in humans with childhood obesity and shorter stature being more common in preterm deliveries and small for gestational age when compared to their term and appropriate gestational age birthweight counterparts (Albertsson-Wikland *et al.,* 1998; Hong and Chung 2018; Nam and Lee 2018). This demonstrates the importance of getting maternal nutrition correct for ewe lambs and could be linked to the "catch-up growth" hypothesis. This hypothesis speculates that intrauterine growth retardation causes changes in the endocrine system with reductions in insulin and insulin-like growth factors as well as increased growth hormone and insulin-like growth factor-binding proteins causing a predisposition for obesity (Cianfarani *et al*., 1999; Ibáñez *et al.,* 2006; Vasylyeva *et al.,* 2013; Cho and Suh 2016; Wallace *et al.,* 2020). This could be exploited by the farming industry to create the lamb equivalent of wagyu beef which have increased fat percentages. These cattle have been selectively bred to produce these results so should there be a demand for this in lambs it is likely easier to breed and cull for the desired properties (Gotoh and Joo 2016). With farmers being financially penalised for fat carcasses this shows that there is not a demand for fatty lambs so should be actively avoided.

5.5: Scoring system and stats evaluation

Testing between studies could be evaluated for every parameter using unsupervised cluster analysis, this could also give starting points for causes of certain results. Similarly testing the effect between scores, such as what is the effect of dystocia on maternal health score and/or maternal behaviour scoring, but there was not enough time in this project to explore this but could be a useful area of future research. Number of lambs could be a limiting factor for these statistical tests, just as they were limited for doing Chi-Squared testing. This was because results in the tables marked with "~" demonstrate not all cells were greater than 5 making the test not an exact fit, Fisher exact tests for example would sometimes be more appropriate, but given the time constraints the Chi-Squared test was a good enough fit to demonstrate variance.

The scoring systems themselves were done in a rational approach, but this data can be verified using a frequency approach, such as adding up the number of problems and/or drugs prescribed for health scoring. This rational approach however could be easily implemented on farms by farmers to gather specific data about flocks that would allow farmers to decrease lamb mortality. This would be similar to what the AHDB and vets have been promoting, which is farmers monitoring lamb mortality through methods such as post mortems to know how best to reduce issues causing lamb mortality in their flocks (AHDB 2015; Gascoigne *et al.*, 2017; Gascoigne and Davies 2019). If monitoring using these scoring systems were conducted on farms, like the HCC lambing project, this would not only give the research team sufficient numbers to do the proposed future statistics above but would also give farmers clear objectives for preventing lamb losses in their own flocks increasing their profits.

5.6: Precautions / preventative methods and future farming

As the proactive neonatal care was effective in reducing lamb mortality down to 4.4% in this population that would have a greater lamb mortality on a normal farm where the incidence of low birthweight is much lower, and the incidence of prematurity is practically absent. This project gives clear evidence that this care system works and elements of which can be implemented on farms with the developed scoring systems. This project also emphasises the importance of optimum gestational intake for ewe lambs as previously reported, as well as the care required for if it should go wrong. The classic approach of selective breeding and culling can be done with these scoring systems to breed more resilient breeding ewes that ultimately would produce greater profits over their lifetimes (Byrne, 1967; Fisher 2003; Kenyon 2014a). Profits are as important as ever with Britain leaving the EU despite none of the rural Scottish constituency voting in favour of it. All sectors of the rural Scottish economy are expected to be negatively affected, with farming, and food sectors being very vulnerable and Scotland's premium lamb exports having punitive tariffs (Scottish Government 2019c). Hence British and Scottish farmers should use the lessons learnt in breeding ewe lambs and decreasing lamb mortality for financial gain. Whether these methods of neonatal care are practically or financially feasible on a farm can only be determined by farmers. Arguably it is morally correct both in terms of animal welfare and the rule of rescue that farmers prevent unnecessary suffering as well as death through increasing neonatal care for the first 24hours allowing them to minimise lamb mortality (Mckie and Richardson, 2003; Mellor and Stafford, 2004).

5.7: Conclusion

In conclusion, overnourished adolescent dams delivered increased rates of premature and low birthweight lambs. Dams that delivered early to low birthweight lambs had increased compromised lactation and mismothering which got worse after 24hours. These low birthweight and premature lambs lambed with less dystocia but needed more intervention to keep alive pre than post 24hours. Despite proportionally growing faster the low birthweight and premature lambs had less liveweight gain and increased body fat percentage. These experiments proved that with carefully calculated nutrition as well as proactive care lamb mortality decreased, and adolescent sheep can be a viable model to produce more lambs over its lifetime. Whether ewe lambs are a financially viable option will have to be determined by the farmers, but the optimum gestational nutrition guidelines overcame some of their limitations. While the developed rational scoring systems, and neonatal care practices could be used to reduce lamb mortality whatever the birthweight while breeding ewe lambs or adults.

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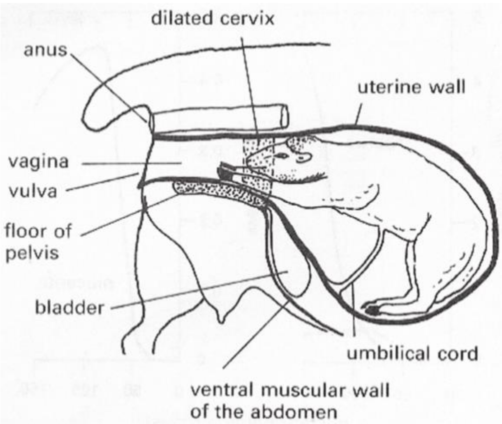
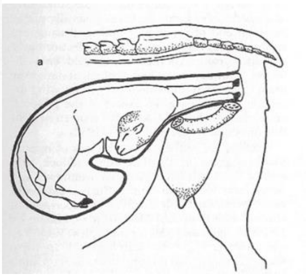
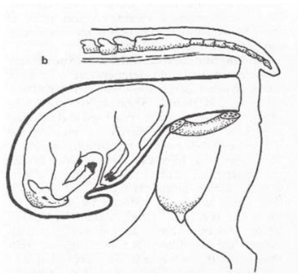
Appendix 3.1: Photos for context


Ewe and lamb pens in the research facility.


Research facility medical and record station. Low birthweight lamb next to normal lamb.



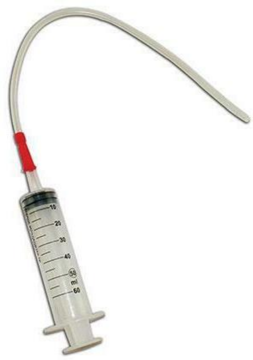




Lambing presentation from Arthur *et al*., 1982; usual (left), abnormal presentation with head remaining in the uterus and forefeet anteriorly presented (a / middle), abnormal posterior presentation with both hindlegs retained also known as breech (b / right).

Appendix 3.1 (Continued)

Lamb Suction, and lamb being weighed

Images of hand lactation assistance, bottle feeding and a stomach tube.

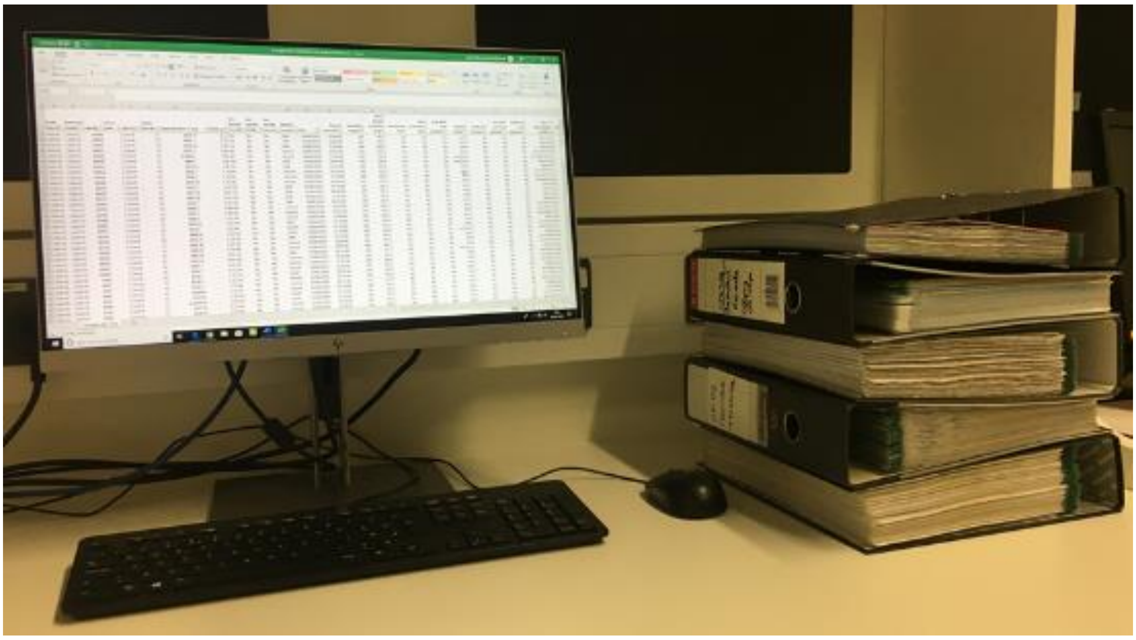
 

Locomotor support in the form of leg splinting.

Preventing crush injuries with container (left), and monitoring urine and meconium using a towel (right).

Appendix 3.1 (Continued)



271 lamb records from five studies, one folder per study, data put into excel document.

Appendix 3.2: Neonatal care guidelines for small or weak lambs (Blue font = further explanations) – From original research team

Feeding

If lamb weighs 2-2.5kg, only administer 50cc colostrum at birth, 50cc at 2h and then onto 4 hourly feeds, weight and temperature checks. Check glucose only if lamb not suckling dam, temperature low or no positive weight change. Do not exceed 200cc colostrum /kg bodyweight on Day 0. Use sterilised bottle in preference to tube where possible. If using tube- use the short, small diameter one. (glucose checked using a bench-side glucose monitor but doubt we had to do this for the studies you are looking at)

If lamb weighs 2.55kg or > at birth, administer 50cc colostrum per kg as normal and then onto 4-6hrly weight / temperature checks ± feeds as needed.

In some cases, a lamb will be 3.0kg or more but just as much at risk particularly if it is premature or had a difficult delivery or mum rejects it. If in doubt treat as if very small - the above are meant as guidelines only. Contact Raymond or Jacqueline if unsure about a case.

NB. First feed must be ewe colostrum. Feed 2 must be colostrum for small lambs and feed 2 and 3 can be 'second milk' for bigger lambs (= mix of colostrum and ewe milk produced naturally by the ewe). Thereafter if lamb not suckling - milk ewe and administer milk by bottle but try to teach lamb to suckle on dam (involved holding ewe and encouraging lamb to latch on-replicating ewe behaviour by tickling top of tail, placing teat in mouth and depressing teat so that milk on lamb's mouth). If ewe has no milk after oxytocin injection, obtain milk from another ewe or use from frozen bank. Do not use lamlac for small lambs. Can be used for larger lambs with care.

TROUBLE SHOOTING

1.LOW TEMP (<101ºF): alter environment, introduce heating lamp (± warming box in pen). Can briefly remove to warming box in heated surgery if required but remember to humidify by boiling kettle. Best to limit time in surgery if possible because ewe may reject lamb on its return.

2.HIGH TEMP (>104ºF): Call vet after checking environment/ glucose. Place on bag of ice to try and take temperature down if vet not immediately available

3.BREATHING DIFFICULTIES (rare): Remove to surgery and administer low level oxygen via hood or small mask system. Wrap lamb in towel or bubble wrap to keep warm as oxygen will cool it down rapidly. Administer myophylline (respiratory stimulant) and monitor temperature/ colour. Some lambs will also have received dopram at birth= another respiratory stimulant dropped onto tongue.

4.LOW GLUCOSE: If after appropriate feeding, check ZST levels if Mon-Fri, administer 20% dextrose i.v. or i.p. (Ewe plasma i.p. can also be administered if colostrum mal-absorption indicated 50cc/kg). Rarely used

Appendix 3.2 (Continued)

5.RETAINED MERCONIUM (common in very small lambs and those who have not suckled mum or bottle): sometimes presents like human baby colic! or clear discomfort when thermometer introduced. Administer enema using syringe and fine tubing, check effectiveness at 30 min (black meconium voided). For very small lambs use only 2.5mls of enema solution. If meconium does not clear from gut and lamb is over 24h old withdraw colostrum /milk and switch to energaid as below for a couple of feeds.

6.SCOUR (rare in first 72h): Call vet and ask her to check antibody sensitivity, administer alternative antibiotics. Sample scour and take to vet labs
Withdraw colostrum / milk and maintain with oral energaid for 24h and then introduce 1:1 milk/energaid if scour dried up. Lamb will drink energaid with stat (Kaogel) added to it so saves oral dosing. If scours within 24h, boost antibody transfer with IP ewe plasma injection is an option (rarely if ever used).

6. NO or very little URINE (usually an indication that kidneys struggling in very small lambs and around day 2), Withdraw milk and transfer to energaid (little and often, and by bottle). Sample for urea (blood sample if no urine and send sample to Veterinary Investigation lab, but more normally dip stick a urine sample) and if very high urea (protein) and or blood may need to insert an i.v. drip (Hartmann's solution) with assistance from vet or Raymond.

Notes

Low glucose = < 2.5mmol/l. Needs help now! If after feeding, 2 consecutive samples in range 2.5-3 then lamb needs to be checked every 2hours until glucose levels start to rise (Rare)

Ideal temp 102ºF

Energaid = 1 pack (42g) per 500 ml warm sterile water.

Try to avoid using stomach tube at all costs. If colostrum exceptionally thick add a few mls only of sterile saline or water so that the lamb can suck it from bottle.

If ewe not bonding with lamb either place in incubator under lamp (towel with a little straw on top - take care not too hot when lamb stands, and change towel twice daily so that you can monitor urination) or tether ewe and supervise suckling episodes in both cases.

Appendix 3.3

Alt. Cat. 7	Term	Prem	VPrem
Dystocia Score			
Failed Lactation Score	2	2	4
Maternal Behaviour Score 0-24h		1	3
Maternal Behaviour Score >24h	2	2	3
Maternal Health Score			1
<24h Colostrum Intervention Score		1	5
24h-72h Milk Intervention Score	1	2	6
Medical Intervention Score		1	1
Lamb Protection Intervention Score		2	4
Lamb Vigour Score <24h		2	6
Lamb Vigour Score 24-72h	2	2	6

Gestational Intake	Control	ON	UN
Dystocia Score			
Failed Lactation Score	1	7	
Maternal Behaviour Score 0-24h		4	
Maternal Behaviour Score >24h	1	8	
Maternal Health Score		1	
<24h Colostrum Intervention Score		6	
24h-72h Milk Intervention Score		8	
Medical Intervention Score	1	6	
Lamb Protection Intervention Score		6	
Lamb Vigour Score <24h		8	
Lamb Vigour Score 24-72h	3	6	1

Alt Cat. 6.5	NormBW	VLBW	LBW	O
Dystocia Score				
Failed Lactation Score	1	6	1	
Maternal Behaviour Score 0-24h		4		
Maternal Behaviour Score >24h	2	6	1	
Maternal Health Score		1		
<24h Colostrum Intervention Score	1	5		
24h-72h Milk Intervention Score	3	6		
Medical Intervention Score		2		
Lamb Protection Intervention Score		6		
Lamb Vigour Score <24h	2	6		
Lamb Vigour Score 24-72h	3	6	1	

Appendix 3.3 (continued)

Alt. Cat. 7	NormBW + Term	NormBW + VPrem + Prem	VLBW + VPrem + Prem	LBW + VPrem + Prem	LBW + Term	O + Term
Dystocia Score						
Failed Lactation Score	1		6		1	
Maternal Behaviour Score 0-24h			4			
Maternal Behaviour Score >24h	1	1	6		1	
Maternal Health Score			1			
<24h Colostrum Intervention Score		1	6			
24h-72h Milk Intervention Score	1	2	6			
Medical Intervention Score			2			
Lamb Protection Intervention Score			6			
Lamb Vigour Score <24h		2	6			
Lamb Vigour Score 24-72h	1	2	6		1	

Appendix 4.1: Influence of birthweight plus delivery category on perinatal scores and lamb data at weaning.

Birthweight Category + Delivery Category (Alt. Cat. 4.5)	NormBW + Term	NormBW + Premature incl. VPrem	ELBW + Premature incl. VPrem	LBW + Premature incl. VPrem	LBW + Term	Oversized + Term	P-values [n] 6 groups
Lamb number	71	77	31	46	18	26	-
Dystocia Score							
0, n (%)	1 (1.4%)	6 (7.8%)	6 (19.4%)	5 (10.9%)	0	0	**~0.008**
1, n (%)	35 (49.3%)	41 (53.2%)	16 (51.6%)	25 (54.3%)	11 (61.1%)	0	**<0.001**
2, n (%)	11 (15.5%)	18 (23.4%)	5 (16.1%)	9 (19.6%)	4 (22.2%)	16 (61.5%)	**~<0.001**
3, n (%)	21 (29.6%)	10 (13.0%)	0	4 (8.7%)	2 (11.1%)	8 (30.8%)	**~0.001**
4, n (%)	2 (2.8%)	1 (1.3%)	2 (6.5%)	2 (4.3%)	1 (5.6%)	0	n/a
5, n (%)	1 (1.4%)	1 (1.3%)	2 (6.5%)	1 (2.2%)	0	2 (7.7%)	n/a
0+1 Grouped, n (%)	36 (50.7%)	47 (61.0%)	22 (71.0%)	30 (65.2%)	11 (61.1%)	0	**<0.001**
3, 4, 5 Grouped, n (%)	24 (33.8%)	12 (15.6%)	4 (12.9%)	7 (15.2%)	3 (16.7%)	10 (38.5%)	**0.012**
Mean ± SE Mean	1.87±0.124[ab]	1.51±0.109[b]	1.42±0.244[b]	1.48±0.161[b]	1.61±0.216[ab]	2.54±0.169[a]	**<0.001**
Range	0-5	0-5	0-5	0-5	0-4	2-5	-
Maternal Health Score							
0, n (%)	45 (63.4%)	64 (83.1%)	25 (83.3%)	37 (80.4%)	15 (83.3%)	16 (61.5%)	**~0.024**
0.5, n (%)	18 (25.4%)	8 (10.4%)	2 (6.7%)	4 (8.7%)	3 (16.7%)	7 (26.9%)	**~0.026**
1, n (%)	3 (4.2%)	2 (1.3%)	1 (3.3%)	2 (4.3%)	0	1 (3.8%)	n/a
1.5, n (%)	1 (1.4%)	0	0	0	0	0	n/a
2, n (%)	4 (5.6%)	2 (2.6%)	2 (6.7%)	3 (6.5%)	0	2 (7.7%)	n/a
1,1.5+2 Grouped, n (%)	8 (11.3%)	4 (5.2%)	3 (10.0%)	5 (10.9%)	0	3 (11.5%)	~0.529
Mean ± SE Mean	0.30±0.062[a]	0.16±0.049[a]	0.20±0.098[a]	0.22±0.079[a]	0.08±0.045[a]	0.33±0.111[a]	0.220
Range	0-2	0-2	0-2	0-2	0-0.5	0-2	-

Birthweight + Delivery Category	NormBW + Term	NormBW + Prem+VPrem	ELBW + Prem+VPrem	LBW + Prem+VPrem	LBW + Term	Oversized + Term	P-values[¤] 6 groups
Compromised Lactation Score							
0, n (%)	68 (97.1%)	71 (92.2%)	11 (44.0%)	39 (84.8%)	14 (82.4%)	24 (92.3%)	~**<0.001**
1, n (%)	2 (2.9%)	5 (6.5%)	11 (44.0%)	6 (13.0%)	3 (17.6%)	2 (7.7%)	~**<0.001**
2, n (%)	0	1 (1.3%)	3 (12.0%)	1 (2.2%)	0	0	n/a
1+2 Grouped, n (%)	2 (2.9%)	6 (7.8%)	14 (56.0%)	7 (15.2%)	3 (17.6%)	2 (7.7%)	**~<0.001**
Mean ± SE Mean	0.03±0.020[a]	0.09±0.038[a]	0.68±0.138[b]	0.17±0.065[a]	0.18±0.095[a]	0.08±0.053[a]	**<0.001**
Range	0-1	0-2	0-2	0-2	0-1	0-1	-
Maternal Behaviour Score 0-24h							
0, n (%)	65 (91.5%)	75 (97.4%)	21 (77.8%)	38 (82.6%)	14 (77.8%)	22 (84.6%)	**~0.017**
1, n (%)	6 (8.5%)	0	4 (14.8%)	5 (10.9%)	2 (11.1%)	4 (15.4%)	**~0.048**
2, n (%)	0	2 (2.6%)	2 (7.4%)	3 (6.5%)	2 (11.1%)	0	n/a
1+2 Grouped, n (%)	6 (8.5%)	2 (2.6%)	6 (22.2%)	8 (17.4%)	4 (22.2%)	4 (15.4%)	**~0.017**
Mean ± SE Mean	0.09±0.033[a]	0.05±0.037[a]	0.30±0.117[a]	0.24±0.083[a]	0.33±0.162[a]	0.15±0.072[a]	**0.032**
Range	0-1	0-2	0-2	0-2	0-2	0-1	-
Maternal Behaviour Score >24h							
0, n (%)	67 (95.7%)	75 (98.7%)	17 (68.0%)	42 (91.3%)	15 (88.2%)	25 (96.2%)	~**<0.001**
1, n (%)	3 (4.3%)	1 (1.3%)	6 (24.0%)	4 (8.7%)	2 (11.8%)	1 (3.8%)	**~0.003**
2, n (%)	0	0	2 (8.0%)	0	0	0	n/a
1+2 Grouped, n (%)	3 (4.3%)	1 (1.3%)	8 (32.0%)	4 (8.7%)	2 (11.8%)	1 (3.8%)	~**<0.001**
Mean ± SE Mean	0.04±0.024[a]	0.01±0.013[a]	0.40±0.129[b]	0.09±0.042[a]	0.12±0.081[a]	0.04±0.039[a]	**<0.001**
Range	0-1	0-1	0-2	0-1	0-1	0-1	-

Birthweight + Delivery Category	**NormBW + Term**	**NormBW + Prem+VPrem**	**ELBW + Prem+VPrem**	**LBW + Prem+VPrem**	**LBW + Term**	**Oversized + Term**	**P-values**[n] 6 groups
Lamb Safeguarding Score							
0, n (%)	65 (91.5%)	74 (96.1%)	8 (32.0%)	36 (78.3%)	14 (77.8%)	22 (84.6%)	**~0.001**
1, n (%)	6 (8.5%)	1 (1.3%)	13 (52.0%)	6 (13.0%)	2 (11.1%)	4 (15.4%)	**~0.001**
2, n (%)	0	2 (2.6%)	4 (16.0%)	4 (8.7%)	2 (11.1%)	0	n/a
1+2 Grouped, n (%)	6 (8.5%)	3 (3.9%)	17 (68.0%)	10 (21.7%)	4 (22.2%)	4 (15.4%)	**~0.001**
Mean ± SE Mean	0.09±0.033^{a}	0.07±0.039^{a}	0.84±0.138^{b}	0.30±0.093^{a}	0.33±0.162^{a}	0.15±0.072^{a}	**<0.001**
Range	0-1	0-2	0-2	0-2	0-2	0-1	-
Medical Intervention Score							
0, n (%)	67 (94.4%)	63 (81.8%)	6 (20.7%)	31 (67.4%)	14 (77.8%)	25 (96.2%)	**~0.001**
1, n (%)	0	2 (2.6%)	9 (31.0%)	1 (2.2%)	1 (5.6%)	0	n/a
2, n (%)	4 (5.6%)	12 (15.6%)	14 (48.3%)	14 (30.4%)	3 (16.7%)	1 (3.8%)	**~0.001**
1+2 Grouped, n (%)	4 (5.6%)	14 (18.2%)	23 (79.3%)	15 (32.6%)	4 (22.2%)	1 (3.8%)	**~0.001**
Mean ± SE Mean	0.11±0.055^{a}	0.34±0.084^{abc}	1.28±0.148^{d}	0.63±0.137^{c}	0.39±0.183^{abc}	0.08±0.077^{ab}	**<0.001**
Range	0-2	0-2	0-2	0-2	0-2	0-2	-
<24h Colostrum Intervention Score							
0, n (%)	41 (57.7%)	41 (53.9%)	2 (8.0%)	17 (37.0%)	8 (44.4%)	17 (65.4%)	**<0.001**
1, n (%)	19 (26.8%)	24 (31.6%)	16 (64.0%)	20 (43.5%)	7 (38.9%)	8 (30.8%)	**0.021**
2, n (%)	11 (15.5%)	11 (14.5%)	8 (32.0%)	9 (19.6%)	3 (16.7%)	1 (3.8%)	~0.156
1+2 Grouped, n (%)	30 (42.3%)	35 (46.1%)	24 (96.0%)	29 (63.0%)	10 (55.6%)	9 (34.6%)	**<0.001**
Mean ± SE Mean	0.58±0.890^{a}	0.61±0.084^{a}	1.23±0.115^{b}	0.83±0.109^{ab}	0.72±0.177^{ab}	0.39±0.112^{a}	**0.001**
Range	0-2	0-2	0-2	0-2	0-2	0-2	-

Birthweight + Delivery Category	NormBW + Term	NormBW + Prem+VPrem	ELBW + Prem+VPrem	LBW + Prem+VPrem	LBW + Term	Oversized + Term	P-values[n] 6 groups
24h-72h Milk Intervention Score							
0, n (%)	67 (95.7%)	67 (89.3%)	15 (60.0%)	40 (87.0%)	15 (83.3%)	22 (84.6%)	**~0.001**
1, n (%)	3 (4.3%)	7 (9.3%)	9 (36.0%)	4 (8.7%)	3 (16.7%)	4 (15.4%)	**~0.001**
2, n (%)	0	1 (1.3%)	1 (4.0%)	2 (4.3%)	0	0	n/a
1+2 Grouped, n (%)	3 (4.3%)	8 (10.7%)	10 (40.0%)	6 (13.0%)	3 (16.7%)	4 (15.4%)	**~0.001**
Mean ± SE Mean	0.04±0.024^{a}	0.12±0.042^{a}	0.44±0.117^{b}	0.17±0.072^{ab}	0.17±0.090^{ab}	0.15±0.072^{ab}	**0.003**
Range	0-1	0-2	0-2	0-2	0-1	0-1	-
Lamb Vigour Score <24h							
0, n (%)	47 (66.2%)	44 (58.7%)	2 (8.0%)	18 (39.1%)	9 (50.0%)	18 (69.2%)	**<0.001**
1, n (%)	13 (18.3%)	22 (29.3%)	18 (72.0%)	19 (41.3%)	6 (33.3%)	8 (30.8%)	**<0.001**
2, n (%)	8 (11.3%)	5 (6.7%)	3 (12.0%)	8 (17.4%)	2 (11.1%)	0	~0.229
3, n (%)	3 (4.2%)	4 (5.3%)	2 (8.0%)	1 (2.2%)	1 (5.6%)	0	n/a
2+3 Grouped, n (%)	11 (15.5%)	9 (12.0%)	5 (20.0%)	9 (19.6%)	3 (16.7%)	0	~0.254
Mean ± SE Mean	0.54±0.102^{ab}	0.59±0.097^{a}	1.20±0.141^{d}	0.83±0.118^{abcd}	0.72±0.211^{abcd}	0.31±0.092^{abc}	**0.001**
Range	0-3	0-3	0-3	0-3	0-3	0-1	-
Lamb Vigour Score 24-72h							
0, n (%)	50 (71.4%)	54 (72.0%)	9 (36.0%)	28 (60.9%)	12 (70.6%)	18 (69.2%)	**0.024**
1, n (%)	12 (17.1%)	12 (16.0%)	13 (52.0%)	12 (26.1%)	2 (11.8%)	8 (30.8%)	**~0.003**
2, n (%)	7 (10.0%)	7 (9.3%)	2 (8.0%)	4 (8.7%)	2 (11.8%)	0	~0.711
3, n (%)	1 (1.4%)	2 (2.7%)	1 (4.0%)	2 (4.3%)	1 (5.9%)	0	n/a
2+3 Grouped, n (%)	8 (11.4%)	9 (12.0%)	3 (12.0%)	6 (13.0%)	3 (17.6%)	0	~0.519
Mean ± SE Mean	0.41±0.088^{a}	0.43±0.089^{a}	0.80±0.153^{a}	0.57±0.123^{a}	0.53±0.229^{a}	0.31±0.092^{a}	0.234
Range	0-3	0-3	0-3	0-3	0-3	0-1	-

Birthweight + Delivery Category	NormBW + Term	NormBW + Prem+VPrem	ELBW + Prem+VPrem	LBW + Prem+VPrem	LBW + Term	Oversized + Term	P-values[¤] 6 groups
Lamb data at weaning							
Number of lambs	68	74	24	43	17	26	-
11-week weaning weight (kg)	35.0±0.39^{b}	34.7±0.40^{b}	27.9±0.59^{d}	31.6±0.58^{c}	32.7±1.01^{bc}	37.4±0.63^{a}	**<0.001**
Liveweight gain from birth to weaning (g/day)	391±5.0^{ab}	391±4.9^{ab}	332±7.1^{d}	366±7.1^{c}	377±12.4^{bc}	406±7.9^{a}	**<0.001**
Fractional growth rate (birth to weaning)(%/day)	8.1±0.15^{b}	8.6±0.13^{b}	14.5±0.42^{d}	10.6±0.20^{c}	10.4±0.35^{c}	6.7±0.15^{a}	**<0.001**
Dexa fat % at weaning (only 06-05S + 08-06 number below)	15.6±1.40^{a} n = 25	18.6±1.34^{a} n = 27	17.0±2.03^{a} n = 16	18.9±2.00^{a} n = 15	14.2±2.42^{a} n = 5	17.33±1.76^{a} n = 9	0.437

Values are mean ± SEM, these were compared by one-way-ANOVA, and posthoc comparisons were determined by Tukey at. Within a row groups with a differing superscript are different at P<0.05, Chi-Squared Test used on discrete variables (Pearson at 95% confidence). ~ before results are Chi-Squared Test did not have all cells >5, making the results less reliable.

Significant P-Values are bold, non-significant are grey and trends (0.1-0.05) are standard black text

Number of missing lambs shown in Appendix 3.3.