

Scotland's Rural College

## Improving neonatal survival in small ruminants: science into practice

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1 **INVITED REVIEW: Improving neonatal survival in small ruminants: science into**  
2 **practice**

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22 Running head: improving neonatal survival in small ruminants

**23 Abstract**

24 Neonatal mortality in small ruminant livestock has remained stubbornly unchanging over the  
25 past 40 years, and represents a significant loss of farm income, contributes to wastage and  
26 affects animal welfare. Scientific knowledge about the biology of neonatal adaptation after  
27 birth has been accumulating but does not appear to have had an impact in improving  
28 survival. In this paper we ask what might be the reasons for the lack of impact of the  
29 scientific studies of lamb and kid mortality, and suggest strategies to move forward.  
30 Biologically, it is clear that achieving a good intake of colostrum, as soon as possible after  
31 birth, is crucial for neonatal survival. This provides fuel for thermoregulation, passive  
32 immunological protection and is involved in the development of attachment between the ewe  
33 and lamb. The behaviour of the lamb in finding the udder and sucking rapidly after birth is a  
34 key component in ensuring sufficient colostrum is ingested. In experimental studies, the  
35 main risk factors for lamb mortality are low birth-weight, particularly due to poor maternal  
36 nutrition during gestation, birth difficulty, litter size, and genetics, which can all be partly  
37 attributed to their effect on the speed with which the lamb reaches the udder and sucks.  
38 Similarly, on commercial farms, low birth-weight and issues with sucking were identified as  
39 important contributors to mortality. In epidemiological studies, management factors, such as  
40 providing assistance with difficult births, were found to be more important than risk factors  
41 associated with housing. Social science studies suggest that farmers generally have a  
42 positive attitude to improving neonatal mortality but may differ in beliefs about how this can  
43 be achieved, with some farmers believing they had no control over early lamb mortality.  
44 Facilitative approaches, where farmers and advisors work together to develop neonatal  
45 survival strategies, have been shown to be effective in achieving management goals, such  
46 as optimising ewe nutrition, that lead to reductions in lamb mortality. We conclude that  
47 scientific research is providing useful information on the biology underpinning neonatal  
48 survival, such as optimal birth-weights, lamb vigour and understanding the importance of  
49 sufficient colostrum intake, but the transfer of that knowledge would benefit from an

50 improved understanding of the psychology of management change on farm. Developing  
51 tailored solutions, on the basis of adequate farm records, that make use of the now  
52 substantial body of scientific literature on neonatal mortality will help to achieve lower  
53 neonatal mortality.

54

55 **Keywords:**

56 Neonatal mortality, sheep, goat, knowledge transfer

57

58 **Implications**

59 Research into neonatal mortality of small ruminants has addressed relevant biological  
60 issues, and provided practical solutions to some of the issues (such as improving ewe  
61 nutrition, and ensuring adequate colostrum intakes). There is, however, more that could be  
62 done in transferring this information into practice, and application of social science methods  
63 to address barriers to uptake would be beneficial, as would improved record keeping on  
64 farm. Due to the multifactorial nature of lamb survival, and differing risk factors on different  
65 farms, it is likely that individual farm-specific solutions would be required to achieve  
66 improved survival.

67

68 **Introduction**

69 The mortality of neonatal farmed livestock is a source of wastage, affects farm profitability,  
70 impacts on animal welfare and, frequently, farmer morale. Animals are most vulnerable on  
71 the day that they are born, with up to 50% of all preweaning mortality occurring on this day in  
72 sheep (Nowak *et al.* 2000) and goats (Singh *et al.* 2008). Newborns move from the warm  
73 and protected uterus into a more challenging extra-uterine environment, which can occur in

74 a cold or wet environment, where predators or other animals may behave aggressively  
75 towards the young animal. Thus, it is perhaps not surprising that mortality rates have proved  
76 remarkably stubborn and resistant to attempts to reduce them – published average mortality  
77 figures for sheep for the last 40 years across many countries and systems remain almost  
78 unchanging at 15% (Fig. 1). Although fewer studies have been conducted in goats,  
79 published estimates of kid mortality range from 11.5 to 37% (e.g. Thiruvankadan and  
80 Karunanithi 2007; and Supplementary Material), suggesting that the scale of the problem is  
81 similar in both small ruminant species. However, there is significant between-farm variation  
82 with some farms able to reduce mortality to low levels. For example, on New Zealand sheep  
83 farms, mortality was reported to vary from 1.4% to 43.5% of all lambs in a survey of 22 farms  
84 (Forrest *et al.* 2006). Similarly, in goat farms in Tamil Nadu, India, annual mortality was  
85 reported to range from 2.2% to 30.5% (Thiruvankadan and Karunanithi, 2007). Analysis of  
86 lamb mortality associated with disease led Fragkou *et al.* (2010) to suggest that lamb  
87 mortality should be as low as 3%, with an upper acceptable limit of 5%: a figure that is  
88 currently not achieved on many farms.

89 Considerable scientific knowledge about neonatal mortality has accumulated but does not  
90 appear to have led to substantive reductions in lamb or kid losses. Lack of uptake or impact  
91 of this research may have occurred for several reasons: 1) many studies have characterised  
92 the causes of lamb mortality, but have not provided practical, on farm solutions to address  
93 these; 2) experimental studies may not adequately replicate the 'real' on farm environment  
94 and therefore may not provide relevant solutions; 3) scientific investigations have often  
95 concentrated on single issues or causal factors, when mortality is a complex interaction of  
96 many factors; 4) the scientific solutions may not have been properly communicated to  
97 farmers or other barriers, such as availability of affordable skilled labour, exist to prevent  
98 implementation on farm; or 5) improvements have been achieved but these have not been  
99 reported in the scientific literature. In this paper we will address the reasons for the lack of  
100 impact of the scientific studies of lamb and kid mortality, and discuss how progress can be

101 made. Firstly, we will address the current scientific knowledge which may provide solutions  
102 that could be implemented on farm. Secondly, we will consider more practical applications of  
103 this knowledge on commercial farms and how readily these practices can be adopted to  
104 improve lamb survival.

105

#### 106 **Biological factors involved in lamb and kid mortality/survival**

107 The causes of lamb mortality have been extensively researched. The overall consensus is  
108 that lamb mortality occurs due to: 1) birth trauma following a difficult or prolonged delivery  
109 that results in hypoxia and usually stillbirth; 2) development of a poor bond between the ewe  
110 and lamb which causes starvation and hypothermia in the lamb usually resulting in death on  
111 the day of birth; 3) infectious disease and 4) a number of other relatively minor causes of  
112 mortality including congenital malformation, predation and accident (See references in  
113 Supplementary Materials). The relative prevalence of these causes of mortality will vary in  
114 different systems, for example infectious disease may be higher in housed systems but  
115 deaths from traumatic injury may be reduced as obstetric assistance can be provided more  
116 readily. In outdoor lambing systems, mortality from starvation, hypothermia or predation may  
117 be more important than infectious disease. Goats have been less well studied compared to  
118 sheep, and the available literature has tended to concentrate on traditional small-scale or  
119 village production environments (e.g. in West and South Africa, India, Middle East, Central  
120 and Southern America) rather than larger scale commercial production environments, which  
121 have been the focus of sheep studies. Nonetheless the causes of kid mortality are very  
122 similar to those of lambs, although mortality due to disease (neonatal infections, tick-borne  
123 or parasitic) appears to be more prevalent (e.g. Singh *et al.* 2008; and see Supplementary  
124 Material). Whether this is related to a greater susceptibility of goat kids to disease, or  
125 because, in the published studies, they are more likely to be exposed, and less likely to have

126 been vaccinated against common infectious diseases affecting small ruminants (such as  
127 clostridial disease via dam vaccination), is not clear.

128 Risk factors for lamb mortality are also well-described. Lamb mortality is higher in low  
129 birthweight lambs, lambs born in larger litters, lambs born to inexperienced or young mothers  
130 and in male lambs (e.g. Sawalha *et al.* 2007 and see Supplementary Material). Management  
131 factors relating to nutrition, breeding objectives, hygiene practices around lambing and  
132 management interventions can all contribute to the rate of lamb survival. Similar risks  
133 associated with birth-weight, sex, parity, and litter size have also been reported in goats,  
134 although season of birth is also a significant risk factor (e.g. Singh *et al.* 2008; and see  
135 Supplementary Material). As most studies are concentrated in tropical regions, seasonal  
136 effects (largely whether it is the rainy or dry season) are probably related primarily to  
137 nutritional influences, although level of parasites and pathogens may also be relevant.

138 The success with which the kid or lamb achieves the critical adjustments required to  
139 establish independent life after birth are influenced by interacting biological processes,  
140 outlined in Figure 2. Expulsion from the uterus at birth requires profound physiological  
141 adjustments: establishing pulmonary respiration, cardiovascular adjustment, loss of thermal  
142 insulation and placental nutrient supply, vigorous locomotor activity and coordination  
143 necessary to express teat-seeking behaviour, ingestion of colostrum and, consequently,  
144 gastrointestinal and metabolic adaptation, and the development of neonatal immunity.

145 The key physiological, behavioural and immunological challenges experienced by the  
146 neonate are discussed below, and the impact of nutritional and genetic factors on these  
147 interactions considered.

148

149 *Behaviour and neonatal survival*

150 Imminent parturition triggers a decreased social affiliation in the ewe who seeks a suitable  
151 place to give birth (see reviews: Dwyer and Lawrence, 2005 and Supplementary Material).  
152 Birth site selection will determine the micro-environment in which the lamb will be born, and  
153 can potentially influence the success of lamb thermoregulatory responses (see below) if  
154 ewes select sheltered and protected birth sites. Wet, windy and cold weather are important  
155 factors in deaths of lambs from hypothermia (Alexander *et al.* 1980). In addition, time spent  
156 at the birth site is an important factor in preventing separation between ewes and lambs,  
157 thus selection of a birth site with features that will encourage the ewe to remain at the site for  
158 a prolonged period can also influence survival.

159 Maternal behaviour of parturient ewes and goats is very similar (Poindron *et al.* 2007).  
160 During and immediately after birth ewes and goats are very attracted to the smell and taste  
161 of amniotic fluids, and will lick fluids that have been spilt during the birth process, transferring  
162 this attraction to the newborn. Maternal behaviour in the first few hours after delivery  
163 consists of focussed licking and grooming of the young, accompanied by frequent low-  
164 pitched bleats, and acceptance of the neonate at the udder. Licking or grooming serves to  
165 dry the offspring, and is important in the formation of an exclusive olfactory memory in the  
166 mother for her own neonates. This is established within an hour or so of giving birth, and the  
167 dam will then restrict her maternal care only to those offspring with which she has formed an  
168 exclusive attachment. Failure to develop this attachment will result in the mother not  
169 recognising the lamb or kid as her own and rejecting attempts by the neonate to access the  
170 udder and suck. Since other lactating females will also reject the lamb or kid, these  
171 newborns will not survive without human intervention. Following olfactory recognition,  
172 mothers then learn to identify their lamb or kid via their visual appearance at a distance, and  
173 then by their vocalisations (Poindron *et al.*, 2007).

174 Maternal behaviour by the ewe can facilitate lamb sucking responses, by standing and  
175 making the udder more available to the teat-seeking lamb. Inexperienced ewes are less  
176 likely to cooperate with lamb sucking attempts, initially, which may contribute to the reduced



177 survival of the lambs of primiparous ewes. However, ewe behaviour alone cannot induce the  
178 lamb to suck, and separation of ewe and lamb behavioural effects by embryo transfer  
179 (Dwyer and Lawrence, 1999), suggests that maternal behaviour does not encourage greater  
180 vigour and vitality in her newborn lamb. Maternal attachment scores have a negligible  
181 correlation with lamb survival (Hatcher *et al.* 2010) and measures of maternal behaviour are  
182 also poorly genetically correlated with lamb survival (Brien *et al.* 2014), suggesting that  
183 variation in the quantity or quality of maternal behaviour expressed may not have a great  
184 influence on lamb survival.

185 In contrast, lamb behaviour is crucial in determining survival. At birth lambs move through a  
186 series of behavioural events directed towards standing, udder seeking and sucking.  
187 Standing reduces heat loss to the ground, so helping the lamb to maintain body temperature,  
188 and the lamb then employs a series of reflex and coordinated responses to move along the  
189 body of the ewe and locate the udder. The speed with which the lamb accomplishes these  
190 behaviours is known to be related to its probability of survival (Dwyer *et al.* 2003). Moreover,  
191 lambs that derive from sires or lines of sheep with good survival are quicker to stand and  
192 suck than lambs from high loss lines or sires (Cloete and Scholtz, 1998; Hergenhan *et al.*  
193 2014). Suckling quickly provides the lamb with nutrients, particularly to sustain  
194 thermoregulation, and immunoglobulins to provide passive immunity. In addition, suckling  
195 and ingestion of colostrum play a role in the development of attachment of the lamb for its  
196 mother (Goursaud and Nowak, 1999).

197 Lamb and kid behaviour is affected by many of the same risk factors that are associated with  
198 increased mortality. Behavioural development is impaired in lambs that have been delivered  
199 after a prolonged labour, in larger litters and in male lambs compared to female (Dwyer,  
200 2003). Furthermore, lamb birth-weight exhibits a U-shaped distribution with lamb vigour at  
201 birth in a similar way to lamb survival (Dwyer *et al.* 2003). Breed, line and sire within breed  
202 variation in lamb behaviour has been demonstrated in many studies (Cloete and Scholtz,  
203 1998; Hergenhan *et al.* 2014, and see Supplementary Materials). The early vigour or sucking

204 ability of lambs has been shown to have a moderate heritability (Matheson *et al.* 2012),  
205 suggesting that improving lamb vigour may be possible by genetic selection, which would  
206 lead to improved survival. Whether similar genetic relationships, and phenotypic  
207 associations with survival exist for goat kid behaviour is not known.

208

### 209 *Physiology and neonatal survival*

210 At birth ambient temperatures can drop from 39°C *in utero* to 10°C or lower. Maintenance of  
211 body temperature depends on the balance between heat loss and heat production. Heat loss  
212 is mainly affected by body surface area (small lambs have a higher surface area / body  
213 weight ratio than large lambs thus they lose heat faster and are more at risk of hypothermia)  
214 and the insulation value of the coat (short, fine birth coats have lower insulation value than  
215 long, coarse coats). A wet coat, by amniotic fluid, reduces insulation value but removal of  
216 the fluid by maternal licking or grooming contributes to the lamb's ability to maintain normal  
217 body temperature. Within 10 min of birth the lamb increases heat production but important  
218 inter-individual variations are observed (Dwyer and Morgan, 2006), and in the most extreme  
219 cases, where lambs are unable generate sufficient heat, hypothermia is irreversible. Heat  
220 production comes from two main mechanisms in the neonate: non-shivering thermogenesis,  
221 mostly if not all attributable to brown adipose tissue (BAT), and shivering thermogenesis,  
222 which usually takes place under cold conditions, mainly in older, dry lambs, and metabolizes  
223 muscle glycogen. Details of the thermogenic mechanisms employed by neonatal small  
224 ruminants are given in the Supplementary Material.

225 Colostrum contains nutrients, immunoglobulins, and other elements such as enzymes,  
226 hormones, growth factors, and neuroendocrine peptides. Colostrum contains fat (7-13%),  
227 non-immunoglobulin protein (4-10%) and lactose (2-5%), and provides 6-7 kJ of energy per  
228 ml (Nowak and Poindron, 2006; Banchemo *et al.* 2015). At 18-26°C, lambs require 50 ml  
229 colostrum/kg within the first 18 hours of life to make up for lipid energy deficit and prevent

230 hypothermia, at 0-10°C requirements increase to 280 ml colostrum/kg. Early ingestion of  
231 colostrum has an additional benefit in that it increases heat production by 17% even if body  
232 energy reserves are still replete, enhancing resistance to hypothermia. Under optimal  
233 conditions, neonates would consume sufficient colostrum to meet their carbohydrate  
234 requirement for 14h of the first 24 h of life (Mellor and Cockburn, 1986). Utilization of  
235 glycogen is therefore essential to make up the difference and lambs face the first few days  
236 with liver and muscle glycogen largely depleted. Colostrum yield is dependant on adequate  
237 supplies of both energy and protein in the last 3 weeks of gestation. Although twin-bearing  
238 ewes generally yield more colostrum than single-bearing ewes, their onset of lactation is  
239 slower and they do not produce as much colostrum per lamb (Banchero *et al.* 2015). Thus  
240 multiple-born lambs, compared to singles, are disadvantaged, in addition to lower birth-  
241 weights and energy reserves, and higher surface area/body weight ratios. Inadequate  
242 nutrition during gestation can delay the onset of lactogenesis, reduce colostrum and milk  
243 production, and affect colostrum viscosity (Banchero *et al.* 2015). As a consequence,  
244 delayed suckling may lead to energy reserves being exhausted within six hours of birth and  
245 result in depressed heat production. Insufficient intake of colostrum is the second major  
246 factor affecting neonatal survival after body reserve depletion.

247 Late pregnancy is associated with a considerable rise in cortisol concentration in the lamb in  
248 the last 24-48 h, since activation of the hypothalamic-pituitary-adrenal function triggers the  
249 birth process (Challis and Brooks, 1989). This results in high circulating cortisol, which may  
250 be responsible for vigorous locomotor activity and teat-seeking behaviour, since vaginal birth  
251 and concomitant stress hormones are associated with increased neonatal arousal  
252 (Lagercrantz and Slotkin, 1986). High plasma cortisol in lambs in the first postnatal hours  
253 prevents premature gut closure and therefore may enhance macromolecule absorption  
254 (Hough *et al.* 1990). The decline in cortisol concentration observed in the following days  
255 coincides with periods during which thyroid hormones increase as thermal efficiency  
256 improves and rectal temperature stabilizes. The perinatal rise of cortisol is accompanied by

257 an increase in triiodothyronine and thyroxine which is maintained throughout early postnatal  
258 life. Thyroid hormones are known to play an important role in regulating oxygen  
259 consumption; failure to maintain high plasma triiodothyronine concentration results in a  
260 decrease in oxygen consumption, hypothermia and death (Symonds *et al.* 1995). However,  
261 the relationship of cortisol with survival is complex: alongside the beneficial effects of  
262 elevated neonatal cortisol, excessively high levels at birth may be related to difficult  
263 parturition and fatal dystocia, while an increase in circulating cortisol in the following days  
264 reflect a state of chronic stress due to inadequate milk supply and is associated with  
265 elevated blood glucose to compensate for lack of nutrient intake (Chniter *et al.* unpublished).

266 Improved lamb viability beyond 72h is associated with decreased vulnerability to chilling,  
267 singleton status, higher pre-suckling body temperature, , decreased pre-suckling glucose  
268 concentrations, high plasma concentration of proteins, lipids, and immunoglobulins, and a  
269 moderate rise in neonatal cortisol concentration (Eales *et al.* 1982; Miller *et al.* 2010). Being  
270 bigger is an advantage in terms of vigour and thermoregulation, as lambs are more efficient  
271 in their suckling activity and in resisting cold exposure. However, birth weight can be  
272 affected by breed (Slee, 1981; Dwyer and Morgan, 2006), season of birth (Chniter *et al.*  
273 2013), variation within a litter or prenatal nutrition.

274

#### 275 *Immune function and neonatal survival*

276 The ruminant placenta is epitheliochorial and does not allow the transfer of immune  
277 components from the mother to the young. Newborn lambs and kids are thus born markedly  
278 hypogammaglobulinaemic, and depend entirely on passive transfer of colostral  
279 immunoglobulins, acquired by suckling, for immunological protection after birth. Passive  
280 immunity must be acquired within a very narrow time window since, in newborn lambs, gut  
281 closure to immunoglobulin absorption occurs between 24 and 36 h after birth (Hough *et al.*,  
282 1990). However, colostral immunoglobulins also decline rapidly in the hours after birth, to

283 virtually zero within 24 h of birth (Al Sabbagh *et al.* 1995), so early suckling is a prerequisite  
284 for effective transfer. Lamb mortality is associated with low immunoglobulin status 24 h after  
285 birth (Kenyon *et al.* 2005), demonstrating the importance of ensuring good colostrum intake  
286 in newborn small ruminants.

287 Adequate colostrum intake relies on two complementary factors: the ability of the lamb to  
288 ingest sufficient amounts (through vigorous sucking behaviour) and the concentration and  
289 quantities of colostral immunoglobulins available from the ewe. Partitioning the sources of  
290 variation in lamb serum immunoglobulin on farm suggests that 56% of the variation can be  
291 attributed to the lamb (e.g. volume ingested), 36% to the ewe and only 7% to the farm  
292 (Christley *et al.*, 2003). Correlation between ewe colostral immunoglobulin concentrations  
293 and lamb serum immunoglobulin concentrations is generally low (McGuire *et al.* 1983),  
294 suggesting that other factors are important in ensuring good immunological protection for the  
295 offspring. Ensuring adequate sucking behaviour from the newborn, and cooperation from the  
296 dam, are therefore crucial to achieve adequate immunological protection. However,  
297 improving maternal immunoglobulin supply would also be beneficial. On farm data suggests  
298 that 22% of ewes produced less than 50 g/l immunoglobulin G at lambing, which is  
299 considered inadequate to meet the needs of a lamb due to its ingestion capacity. The  
300 considerable between-animal variation in the amount of IgG available in colostrum is  
301 affected by dam age (younger ewes produced more immunoglobulin), litter size, udder  
302 health, season of lambing in tropical regions and late gestational nutrition (Gilbert *et al.*,  
303 1988; and see Supplementary Material). There is some evidence for genetic factors  
304 influencing maternal colostrum immunoglobulin content with sire and breed effects reported,  
305 and a heritability of 0.19 for ewe immunoglobulin concentration in colostrum (Gilbert *et al.*  
306 1988).

307

308 *Nutritional factors influencing neonatal survival*

309 Adequate nutrition of the ewe or goat during pregnancy is essential to produce viable  
310 offspring which can thrive in the post-natal environment. Extensive research (see recent  
311 reviews for individual studies: Kenyon and Blair, 2014, Rooke *et al.* 2015) has described how  
312 changes in nutrition, both total and specific nutrient supply, impact on neonatal lamb  
313 characteristics relevant to survival. Since, in temperate regions, the ewe is a seasonal  
314 breeder, and pregnancy in these climatic zones coincides with winter when nutrient  
315 availability from grazing is limited, an annual cycle approach to feeding the ewe has long  
316 been advised (Russell, 1985: Figure 3). Lactation, the period of maximum nutrient demand,  
317 normally occurs in spring when pasture growth and quality are at a maximum. After weaning  
318 lambs in mid/late summer, the ewe is able to replenish body reserves mobilised during  
319 gestation and lactation. Subsequently, deficits in feed nutrient supply, primarily energy,  
320 during gestation are balanced by mobilisation of adipose tissue. Thus undernutrition (UN) is  
321 the nutrient imbalance most commonly encountered by the pregnant ewe. This imbalance is  
322 also seen in pregnant goats although, in tropical regions, this results from the annual cycle of  
323 rain and dry rather than day length as in temperate zones.

324 Maternal UN can influence neonatal lamb mortality in several ways. Directly, UN may reduce  
325 lamb birth-weight and thereby increase mortality risk. Maternal UN can also adversely affect  
326 lamb neonatal behaviour and the ability of the lamb to thermoregulate. UN also influences  
327 mothering ability of the ewe, hence the establishment of the ewe-lamb bond (Dwyer *et al.*  
328 2003), and the amount and quality of colostrum produced by the ewe. Similarly in goats, UN  
329 in the last third of gestation is associated with altered maternal care and impaired recognition  
330 abilities of mothers. However, the extent to which UN influences mortality through each of  
331 these routes has not been thoroughly investigated. Rooke *et al.* (2015) found, across all  
332 studies reviewed, that UN consistently reduced birth-weight only in the last third of ovine  
333 pregnancy with the reduction in birth-weight being related both to the length and severity of  
334 UN. In the first two-thirds of pregnancy, UN only reduced birth-weight in specific  
335 circumstances. These included severity of UN: feeding only 0.15 of requirement between

336 gestation days 0 and 60 reduced birth-weight and increased mortality. Breeds more adapted  
337 to adverse conditions (e.g. Scottish Blackface) partitioned more nutrients to the foetus and  
338 thereby maintained birth-weight in response to early gestational UN challenge whereas birth-  
339 weight was reduced in breeds selected for more rapid growth (e.g. Suffolk). Ewes in good  
340 body condition were better able to withstand the challenge of UN than ewes in poorer body  
341 condition. Decreased birth-weight, however, is only a risk factor for increased lamb  
342 mortality. Where both lamb birth-weight and mortality were recorded (Rooke *et al.* 2015), in  
343 only half the studies was a decrease in birth-weight accompanied by increased mortality.  
344 Contributory factors will be how large the decrease in birth-weight was, the physical  
345 environment and the amount and quality of husbandry. Importantly, feeding the ewe  
346 nutrients in excess of requirements for foetal growth and ewe maintenance was not  
347 associated with improvements in lamb survival; in fact negative outcomes were more  
348 common than positive ones. This is supported by studies that show a U-shaped relationship  
349 between lamb birth-weight and survival (Figure 4).

350 In relation to specific nutrients, most research has focussed on trace elements and vitamins  
351 where deficiency is a practical problem, and linked to increased mortality (e.g. deficiencies of  
352 copper, cobalt or iodine). Interpretation of many studies is difficult because the baseline  
353 status of ewes (deficient, marginal or adequate) prior to the study is frequently not well-  
354 defined. Where the status of ewes was marginal, supplementation improved survival, or  
355 associated measures, for cobalt, selenium and vitamin E (reviewed by Rooke *et al.* 2008).  
356 Responses where pre-experiment ewe status was adequate have been more equivocal and  
357 there is little evidence for any benefits to supplying trace nutrients in excess of requirement  
358 but short of toxicity (Rooke *et al.* 2008).

359 In summary, providing there are no chronic deficiencies in trace element and vitamin supply,  
360 UN is the main nutritional risk to neonatal lamb survival, particularly in the last trimester. As  
361 long as ewes have adequate body reserves at mating (Figure 3), loss of body condition over  
362 the first 100 days of pregnancy does not impose a markedly increased risk of lamb mortality.

363 Where ewes are housed in late pregnancy, loss of body condition can be avoided by  
364 adequate feeding. Ewes kept outside on pasture are probably more at risk either from  
365 chronic UN from lack of grass growth or acute UN from adverse weather, for example,  
366 snowfall.

367

### 368 *Genetic aspects of neonatal survival*

369 Selecting for improved lamb survival both reduces 'wastage' whilst improving animal welfare,  
370 whereas selection for higher litter size inevitably increases lamb losses as lambs from  
371 multiple births have higher risk of mortality. Considering lamb survival 'as a trait of the lamb'  
372 in the context of a multi-trait breeding index, is predicted to improve lamb survival at a faster  
373 rate than if it is considered as being a 'trait of the ewe' (Conington *et al.* 2002).

374

375 The heritability of lamb survival is generally low with most published estimates being less  
376 than 0.1 (e.g. Safari *et al.* 2005; Brien *et al.*, 2014 and see Supplementary Material) although  
377 higher heritability estimates in experimental flocks have been documented (e.g. 0.13-0.33:  
378 Sawalha *et al.* 2007). Low heritability can in part be explained because farmers often do not  
379 record lambs born dead; and because the multifactorial nature of lamb mortality may mean  
380 that genetic variation in different causes of mortality may differ. Also, where flocks have a  
381 high degree of human intervention, lambs that would otherwise have died are often kept  
382 alive, thus the degree of human intervention may be an additional variable. It seems logical  
383 that extensively-managed flocks, with low or no human intervention at the time of lambing,  
384 rely greatly on the expression of ewe and lamb behaviours that contribute to higher rates of  
385 survival. For these systems the definition of the breeding goal can be relatively  
386 straightforward. Recent analyses (for details see Supplementary Material) for Scottish  
387 Blackface sheep estimate heritability for survival at 0.05 and 0.09, with lamb birth weight  
388 being the most important predictor of survival.



389

390 The use of 'component' traits for lamb survival such as aspects of lamb vigour and ability to  
391 reach critical 'survival milestones' (e.g. sucking) have been suggested (Matheson *et al*  
392 2012). For farmers that are keen to reduce reliance on human intervention around lambing  
393 time and to identify families of more vigorous lambs, then using such 'indicators' of  
394 propensity to have higher survival make good sense. Unfortunately, the time required to  
395 implement some of the measures is prohibitive and so alternatives to behavioural  
396 observational milestones are preferable.

397

398 It is likely that the molecular basis to lamb survival is highly polygenic, i.e. many different  
399 gene variants are involved in the complex biological mechanisms associated with survival.  
400 Some key mechanisms, such as ability to generate heat through non-shivering  
401 thermogenesis, have been described above and the genetic basis to cold resistance  
402 documented (Also see Supplementary Material). There is evidence that a variant of the  
403 ovine  $\beta$ 3-adrenergic receptor gene (ADRB3) is associated with higher risk of cold-related  
404 mortality in Merino sheep in New Zealand (Forrest *et al.* 2006). However, when extended to  
405 13 other NZ breeds and crosses, the frequency of that gene variant was low or non-existent,  
406 suggesting that it may already have been selected against in the breeds tested. It also  
407 highlights the inherent risks associated with translating results of gene associations found for  
408 one breed to all genotypes. Gene discovery for specific components of lamb survival will  
409 continue although the application of genomic breeding values: integrating single nucleotide  
410 polymorphism data with good survival phenotypes with lamb birth-weight is perhaps more  
411 realistic.

412

#### 413 *Practical applications*

414 Can the scientific knowledge outlined above lead to practical solutions to lamb mortality?

415 The critical role of birth-weight as a risk factor for neonatal mortality has been emphasised

416 throughout: lamb vigour, udder-seeking and thermoregulatory ability are impaired in low  
417 birth-weight lambs, and heavy lambs are vulnerable to dystocia and birth injury. Thus,  
418 ensuring an optimal intermediate birth-weight (within breed), rather than maximising birth-  
419 weight, is a key goal to increase survival. This requires attention to detail in feeding ewes,  
420 some mechanism for checking that nutrition is optimal (such as regular body condition  
421 scoring or assessing circulating  $\beta$ -hydroxybutyrate), and use of ultrasound scanning to  
422 determine litter size to tailor nutritional strategies appropriately. However, the interacting  
423 factors of litter size and ewe age still make this difficult to achieve practically. Defining the  
424 intermediate weight as a breeding goal will also help to ensure neonatal birth-weights are  
425 targeted correctly.

426 Neonatal hypothermia is a significant cause of lamb mortality in many environments.  
427 Although heat loss and heat production can be influenced by birth-weight, lambs can also be  
428 protected by provision of shelter, particularly those that are born outdoors, to limit the impact  
429 of evaporative heat loss. Research has investigated the impact of type and placement of  
430 different shelters in lambing paddocks (Pollard, 2006; and see Supplementary Material), but  
431 the factors determining birth site selection by ewes, and thus the likelihood of births  
432 occurring in shelter, has not received much attention. Familiarity with the terrain, such as  
433 may be achieved with set stocking, influences shelter use, which suggests that permanent  
434 structures, or temporary features that are introduced well before lambing, may increase their  
435 use. Providing a sufficient number of appropriate birth sites for flock size is also important to  
436 prevent contamination of preferred sites, and to minimise the likelihood of mismothering if  
437 maternal ewes are forced to lamb in close contact with one another.

438 An adequate intake of colostrum is a fundamental component of lamb survival. Many of the  
439 risk factors for lamb mortality (Figure 2) have their root in preventing or reducing the uptake  
440 of sufficient colostrum by the lamb. Although the biological impact of sucking colostrum on  
441 neonatal responses has not been fully elucidated, ensuring that neonatal ruminants gain  
442 access to the udder and ingest colostrum as soon as possible after birth is probably the

443 single most important factor in their subsequent survival. Although some newborns may  
444 require the provision of supplementary colostrum, it is preferable for neonates to find the  
445 udder of their mother and suck themselves if this can be achieved within a reasonable  
446 timescale (ideally within 2 hours of birth). Lambs tube-fed colostrum are less active and are  
447 licked less frequently by their mothers in comparison to naturally suckled lambs (Garcia  
448 Gonzalez and Goddard, 1998), which may indicate disrupted bonding.

449 Although the genetic component to lamb survival may be small, or difficult to measure  
450 accurately, there is opportunity to improve lamb survival by genetic means. In addition,  
451 appreciation that birth difficulty can impair lamb behaviour and survival, and thus selecting  
452 sires on the basis of lambing ease, should also improve lamb survival.

453

#### 454 **Farm and management influences affecting survival**

455 Most knowledge on lamb and kid mortality is from biological studies carried out on  
456 experimental farms. How this might be translated into management practices and how  
457 applicable it may be to the diverse production and farming systems for sheep and goats  
458 remains to be addressed. Participative studies, which directly involve farmers, or  
459 epidemiological studies can help to identify the needs of farmers for better control of  
460 neonatal mortality. Here we consider knowledge about farm practices and control points  
461 from a participative sheep farm study conducted in France, and epidemiological studies in a  
462 number of sheep-farming countries. Similar studies are not available for goat farms. These  
463 studies will address whether the same issues, risk factors and causes are apparent on farm  
464 as have been addressed in experimental studies. Neonatal lamb mortality differs  
465 considerably among flocks (Binns *et al.* 2002; Forrest *et al.* 2006; Holmøy *et al.* 2012), with  
466 variations between 0% and 20% seen between flocks. Flock mortality rates were strongly  
467 correlated between years (Binns *et al.* 2002; Holmøy and Waage, personal communication),  
468 suggesting that flock level risk factors are important.

469

470

471 *On farm data collection*

472 In France, a participative study generated detailed on farm knowledge from 'real farm'  
473 situations and disseminated best practice. Data were collected on farms using one of three  
474 different farming systems: one lambing period per year, pastoral system and accelerated  
475 system (3 lambing in two years) to understand factors associated with lamb mortality (for  
476 details see Supplementary Material). Overall mortality was 13.4%, but varied across farms  
477 from 3.6% to 31.2%. Lamb mortality followed a similar pattern to experimental studies, with  
478 54% of mortality occurring within the first 2 days of life. However, the farmers in the study felt  
479 that they had little or no ability to influence lamb mortality during this period, and had more  
480 control over mortality occurring after the first 2 days. The main causes of mortality were very  
481 small lambs or sucking problems, although a large number of mortalities were of unknown  
482 cause.

483 Farms were very variable in the distribution of risk factors for lamb mortality. However, the  
484 main risk factors regularly observed were: ewes lambing with low body condition scores and  
485 deficient selenium status (as defined by selenium concentration of below 60µg/l in at least 3  
486 ewes), impaired colostrum intake, poor hygiene in the lambing sheds and mixed flocks with  
487 lambs of different ages.

488

489 *Flock and management factors*

490 Intensive lamb rearing is associated with increased mortality (Binns et al., 2002), although  
491 deaths from stillbirths are reduced. For indoor flocks, lamb mortality rates are lower where  
492 there is continuous monitoring (Holmøy et al. 2012). Likewise, mortality is higher in larger  
493 flocks (more than 900 lambing ewes; Binns et al. 2002). These authors suggest that the

494 increased risk may not be related to flock size per se, but to the reduced supervision ewes in  
495 larger flocks might receive. The presence of a stockperson allows prompt assistance with  
496 cases of dystocia and reduces deaths associated with difficult births.

497 Active involvement to ensure sufficient colostrum intake improves lamb survival. However,  
498 flocks where tube feeding is routine had increased neonatal mortality compared with flocks  
499 where assistance with suckling was the routine intervention (Holmøy *et al.* 2012). These  
500 differences may be associated with the increased risk of infection with tube-feeding, or the  
501 role of sucking in behavioural interactions as described above. Use of tube feeding may also  
502 be more frequent in flocks where neonatal mortality rates already are high.

503

504 Lambs managed indoors may be exposed to high pathogen burdens in the environment,  
505 especially during peak lambing. Providing new bedding for lambing pens daily influenced  
506 mortality rates in the first 24 h after birth, but not subsequently (Binns *et al.* 2002). Treating  
507 sick lambs with electrolytes was associated with low perinatal mortality rates, whereas  
508 fostering of lambs increased the risk (Binns *et al.* 2002). Fostering of lambs may be an  
509 indicator of a large proportion of multiple births in the flock, and thus the underlying reason  
510 for the increased risk observed. However, housing factors do not appear to be related to  
511 neonatal mortality, indicating that management practices should be the main focus when  
512 preventive flock level factors are addressed.

513 Taken together the participative study and epidemiological analyses suggest that on farm  
514 lamb mortality occurs for similar reasons as shown in the experimental work, and that similar  
515 risk factors are relevant. It should be emphasised that the studies described were  
516 predominantly in ewes housed at lambing time. Some of the practices described above as  
517 important determinants of lamb mortality rates may not be practical in other outdoor  
518 production systems.

519

## 520 **Knowledge Transfer: Challenges and successes**

521 It is clear that there is considerable between-farm variation in neonatal mortality, and that the  
522 reasons for high mortality on one farm may not be the same on another. Although genetic  
523 solutions may be applicable across farms, for management-related actions (which are likely  
524 to be the main factors improving lamb mortality) there is no 'one' solution: individual farms  
525 may require individual solutions to address their own problems. In this section we will  
526 consider point 4 of the introduction to discuss the issues around transfer of specific  
527 knowledge to farmers, and the barriers to uptake of this knowledge.

528

### 529 *Knowledge Exchange*

530 Farmers acquire knowledge from many sources: written resources, farmer-focused events,  
531 discussion groups, and one-to-one interactions with advisers or veterinarians (Dodunski,  
532 2014). Farmers consistently rate face-to-face interactions as their preferred means of  
533 acquiring knowledge (Ingram, 2008), and prefer activities involving practical and hands-on  
534 means of teaching (Dodunski, 2014). In a study of adviser-farmer interactions, Ingram (2008)  
535 characterised different types of knowledge exchange events and concluded that facilitative  
536 encounters, where the advisor and farmer worked together to address the situation, sharing  
537 their knowledge and experience, were the most effective in providing farmer education and  
538 development. This suggests that advisers or veterinarians are an important source of  
539 knowledge for farmers to improve lamb or kid survival, but the nature of this exchange can  
540 have an impact on the uptake and use of the information.

541

### 542 *Decisions regarding management change*

543 As research suggests that management practices are of greater importance than housing,  
544 improvements in neonatal lamb survival rates depend on changes in the farmers' decisions

545 and behaviour. Many approaches to understanding decision-making assume that the  
546 decision-maker is only focused on maximising profit, which may in fact not always be the  
547 case. Farmers, particularly on small farms, tend to value the way of life, independence and  
548 performance above expressive, social and instrumental aspects, such as a high income  
549 (Gasson, 1973; Muri *et al.*, personal communication).

550 The Theory of Planned Behaviour (Ajzen, 1991) suggests that the immediate antecedent of  
551 behaviour is behavioural intention, which is under the influence of attitudes, subjective  
552 norms, and perceived behavioural control. Attitude is the degree to which people evaluate  
553 something with favour or disfavour – in this case lamb mortality rates and the specific  
554 management procedures that may reduce them. Subjective norms are a person's perception  
555 of the extent to which important referents (e.g. other farmers, family members) would  
556 approve or disapprove of particular actions. Perceived behavioural control is a measure of  
557 the extent to which people believe they are able to control the outcome, e.g. whether they  
558 actually think they can reduce lamb mortality through the suggested management change. In  
559 this regard the results from the French participative study, which suggested that farmers felt  
560 they had little control over perinatal lamb mortality, are particularly interesting. Using this  
561 theory in a qualitative approach, Australian sheep farmers were shown to have a positive  
562 attitude to improving lamb survival rates, but differed in their beliefs about how to achieve  
563 this (Elliott *et al.* 2011). Social norms and perceived behavioural control played a significant  
564 role in decision-making, and other farmers appear to be the most important referents.  
565 Furthermore, external factors, such as type of farm, sheep breed etc., also played an  
566 important role, as well as the characteristics of the farmers themselves (Elliot *et al.*, 2011).

567 These data suggest that effective knowledge transfer of the increasing body of scientific  
568 research would be best achieved by one-to-one encounters, using a facilitative approach to  
569 explore the specific farm risk factors and derive workable farm-level solutions. This can help  
570 overcome factors, such as the apparent perception of lack of control over early lamb  
571 mortality, and may also be useful to challenge the perceived norms around neonatal

572 mortality. The within-farm variation in mortality, which is observed in all studies that have  
573 gathered these data, provides evidence from commercial farms, rather than experimental  
574 studies, of what can be achieved. The process of improving on farm mortality may also be  
575 aided by collection of more specific data on farm, such as actual rather than estimated  
576 mortality rates and causes. Where this has been achieved, the rather pessimistic picture  
577 provided in the literature, that mortality rates have remained unchanged over the past 40  
578 years can begin to be challenged.

579

#### 580 *Success stories*

581 An example of successful facilitative knowledge exchange, conducted largely as small-scale  
582 discussion groups with a group of motivated farmers in the UK, has begun to deliver  
583 considerable benefits in terms of knowledge exchange and improvements in lamb mortality.  
584 Relevant to the discussions above about subjective norms are farmers that have chosen to  
585 move away from maximising lambing percentages (which might be viewed by other farmers  
586 as evidence of success but accompanied by higher losses) to achieve similar numbers of  
587 lambs weaned through a lower lambing percentage and lower mortalities. This more  
588 sustainable outcome might provide greater job satisfaction, without necessarily impacting on  
589 farm profitability.

590 Other successful examples include the uptake of behavioural and experimental information  
591 on the importance of lamb behaviour and its genetic components. Although these have not  
592 been used to derive breeding values for animals, improvements in lamb survival have been  
593 reported by culling or not re-breeding animals that have required assistance at lambing,  
594 where lambs required assistance to suck or where ewes have abandoned lambs. Similar  
595 strategies involve only selecting well-grown lambs from a group that produced and reared  
596 twins, thus selection is based on ability to rear two lambs rather than for litter size.



597 On farm nutritional strategies that minimise the seasonal variation in ewe body condition  
598 have also been employed. Often these have not been prescriptive nutritional regimes, but  
599 are based on improved knowledge about the issues and costs to ewe and lamb survival of  
600 poor gestational nutrition, and then a workable solution derived that meets the needs of the  
601 individual farm to optimise the nutritional management of the flock. The adviser's role may  
602 have been to help the farmer to make decisions about behavioural change, as outlined  
603 above, to prioritise nutrition, and then helping to develop a solution that can be achieved on  
604 the farm.

605 Evidence for an improvement in lamb survival in these situations may often be anecdotal, or  
606 reported in trade papers, and may not have been published in scientific journals. However,  
607 farmers either culling or moving to different breeds are reporting improved shelter seeking by  
608 ewes (of wool-shedding breeds), improved lamb thermoregulatory ability, and improved  
609 maternal care leading to better lamb survival.

610

## 611 **Conclusions**

612 At the start of this paper we asked why the considerable amount of research on the causes  
613 of, and risks to, lamb mortality did not appear to have had an impact on improving lamb  
614 survival in practice, and suggested several reasons why this may have occurred. From a  
615 review of the data we conclude that studies focussing on biological knowledge have  
616 produced a large body of information and that this can be used to develop practical solutions  
617 (point 1). It is true that experimental studies apply treatments in very controlled ways, with  
618 ethical endpoints, and may therefore underestimate impacts but the on farm studies quoted  
619 suggest that this has not tended to produce non-viable solutions or information that is not  
620 relevant to commercial situations (point 2). In addition, although experimental studies tend to  
621 only investigate a single factor at a time, the on farm data suggest that, firstly, these single  
622 issues may be those that are most important, and secondly there may be farm-specific

623 single issues that are the main contributors to mortality thus a single issue solution may be  
624 the most useful (point 3). Thus we can conclude that, even though experimental studies may  
625 not exactly replicate commercial farm environments, they do this sufficiently well to produce  
626 relevant data to assist with developing solutions on commercial farms.

627 It is possible that scientific information may not have been translated sufficiently well to  
628 farmers or others who provide on farm advice (point 4). The application of social science  
629 methods to understand barriers to uptake and the best means to deliver information is still  
630 relatively new and more could be done to facilitate this approach. In addition, many sheep  
631 farms still have relatively rudimentary record keeping of lamb mortality, and related data.  
632 Without this information, any progress will be very difficult to achieve. However, there is  
633 some evidence that improvements in lamb survival can be achieved where facilitative  
634 interactions take place between farmers and advisors, and clear management goals are  
635 present, although these improvements have not necessarily been reported in the scientific  
636 literature (point 5).

637 In conclusion, therefore, we suggest that neonatal survival in small ruminants can be  
638 improved on farm, and scientific knowledge of the biological issues can contribute to  
639 providing solutions. The large between-farm variation in lamb survival reported in many  
640 studies suggests that this can be achievable. However, it is clear that some farmers perceive  
641 that they have a lack of control over lamb mortality, and thus may not be motivated to  
642 attempt to improve survival, or have little knowledge of the level of lamb mortality on their  
643 farms as records are not kept. There will not be a single solution that will fit all farm systems,  
644 and determining the best practices to implement will need to be considered on a case by  
645 case basis. Education and training for advisors in the biological knowledge around lamb  
646 mortality, improved record keeping on farm, and advisory support for farmers in developing  
647 solutions that will work within their own farm systems, are key to achieving improved lamb  
648 survival.

649

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652 Association for Animal Production held in Copenhagen, Denmark, August 2014.

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654 Additional references of relevance to this subject area are given in the Supplementary  
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781

## 782 Figure Legends

783 Figure 1. Published average percentage lamb mortality between 1970 and 2014 (references  
784 are given in the text and Supplementary Material) showing no improvement over 40 years.  
785 The dotted line represents an overall average mortality of 15%.

786 Figure 2. The complexity and risk factors influencing the interactions between ewe and lamb  
787 that affect lamb survival for a) behaviour and b) physiology. Abbreviations: ACTH –  
788 adrenocorticotrophic hormone; AF – amniotic fluid; BAT – brown adipose tissue; T3 –  
789 triiodothyronine; T4 – thyroxine; TSH – thyroid-stimulating hormone.

790 Figure 3. Illustration of the optimal changes in ewe weight (as a proportion of her weight at  
791 mating) during the reproductive cycle. Values given on the curve are indicative average body  
792 condition scores.

793 Figure 4. Relationship between lamb mortality rate (proportional mortality) and birth-weight  
794 (in kg) for Scottish Blackface lambs, demonstrating the optimal birth-weight, for this breed,  
795 lies between 3-5 kg.

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