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Clinic for Ruminants with Ambulatory and Herd Health Services, Faculty of Veterinary Medicine, Ludwig-Maximilians-Universität München, Oberschleissheim, Germany

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Influence of dystocia on lamb mortality and postpartal ewe health compared to uneventful vaginal delivery and planned caesarean section

Katja Voigt, Mara Theisges, Viktoria Balasopoulou, Frank Weber, Holm Zerbe, Yury Zablotski

Address for correspondence: katja.voigt@lmu.de

Summary Dystocia has been attributed to a significant percentage of periparturient ewe deaths and is also a major contributor to perinatal lamb mortality. Field data are however commonly confounded by management, husbandry and underlying flock health issues and frequently lack a control group. The true influence of dystocia is therefore difficult to assess from such data. Lambing records (between 2009 and 2023) of a closely-monitored university sheep flock were thus evaluated to assess the influence of dystocia ($n=75$) on lamb mortality and postpartal ewe health compared to uneventful parturition ($n=283$) and elective caesarean sections ($n=218$). Parturition-related postpartal ewe mortality was 0.2% (1/576 lambings), and overall stillbirth and perinatal mortality rates of 3.4% and 7.1% were observed ($n=980$ lambs). The mode of delivery ($p<0.001$) and lamb birth weight ($p<0.001$) were the most influential factors for stillbirth, with increased odds following dystocia and for lambs with low birth weights. Low birth weights ($p<0.001$) were also the most influential factor for perinatal mortality, but increased odds were also associated with dystocia. Retained placenta was the most influential risk factor for postpartal fever episodes ($p<0.001$), but the mode of delivery also showed a tendency ($p=0.058$), with increased odds following dystocia. The high ewe and lamb mortality rates frequently associated with dystocia under field conditions are unnecessary and can be avoided by good management, but dystocia remains an important influential factor for lamb mortality even under best practice conditions. Planned caesarean section in sheep is associated with excellent clinical recovery and ewe and lamb survival.

Keywords birth difficulty, stillbirth, perinatal mortality, sheep

Einfluss von Geburtsstörungen auf Lämmersterblichkeit und postpartale Gesundheit des Muttertieres im Vergleich zu Normalgeburten und geplantem Kaiserschnitt

Zusammenfassung Geburtsschwierigkeiten stehen im Zusammenhang mit einem bedeutenden Anteil peripartaler Todesfälle von Mutterschafen und tragen auch in hohem Maße zur perinatalen Lämmersterblichkeit bei. Felddaten werden jedoch häufig durch Management- und Haltungsfaktoren sowie zugrunde liegende Probleme in der Herdengesundheit beeinflusst und in der Regel fehlt eine Kontrollgruppe. Der wahre Einfluss von Geburtsschwierigkeiten auf die Mutterschaft- und Lämmermortalität ist daher aus derartigen Studien schwer einschätzbar. Die Ablammdaten einer eng überwachten Universitäts-Schafherde wurden daher retrospektiv (2009–2023) ausgewertet, um den Einfluss von Schweregeburten ($n = 75$) im Vergleich zu Normalgeburten ($n = 283$) und geplanten Kaiserschnitten ($n = 218$) auf Lämmersterblichkeit und Gesundheit der Mutterschafe zu untersuchen. Die geburtsbedingte postpartale Mortalität der Mutterschafe lag bei 0,2 % (1/576 Geburten). Die Totgeburtenrate betrug insgesamt 3,4 %, während eine perinatale Lämmermortalität von 7,1 % verzeichnet wurde ($n = 980$ Lämmer). Die Art der Geburt ($p < 0,001$) und das Geburtsgewicht der Lämmer ($p < 0,001$) waren die wichtigsten Einflussfaktoren für Totgeburten mit einer höheren Totgeburtenwahrscheinlichkeit für Schweregeburten und Lämmer mit niedrigem Geburtsgewicht. Ein niedriges Geburtsgewicht ($p < 0,001$) war auch der wichtigste Einflussfaktor auf die perinatale Mortalität. Eine höhere Wahrscheinlichkeit perinataler Mortalität war jedoch auch mit Schweregeburten assoziiert. Nachgeburtshandlung zeigte sich als der wichtigste Risikofaktor für postpartale Fieberepisoden ($p < 0,001$), eine Tendenz wurde jedoch auch für die Art der Geburt beobachtet ($p = 0,058$), mit einem erhöhten Fiebrisiko nach Schweregeburt. Die in der Praxis häufig beobach-

tete hohe Mortalität von Mutterschafen und Lämmern nach Schweregeburten kann durch gutes Management vermieden werden, Geburtsschwierigkeiten bleiben dennoch auch unter optimierten Bedingungen ein wichtiger Risikofaktor für die Lämmersterblichkeit. Geplante Kaiserschnitte zeigen bei Schafen exzellente Heilungsverläufe und Überlebensraten für Muttertiere und Lämmer.

Schlüsselwörter Schweregeburten, Totgeburten, perinatale Sterblichkeit, Schaf

Introduction

Dystocia is relatively common in sheep, and can be an important welfare concern (Scott 2003, 2005, Bruce et al. 2021). The reported frequency of ovine dystocia varies according to a number of factors such as, for instance, breed, lamb birth weight(s), parity and litter size (Speijers et al. 2010, Jacobson et al. 2020). Causes may be of foetal or maternal origin, and foetal causes are generally more common under field conditions (Jacobson et al. 2020). The reported incidence of dystocia is highly variable, and its true incidence in field settings is difficult to assess, as large-scale whole-flock studies are rare. Farmer-recorded dystocia rates in a total of 839 Irish sheep flocks ranged from 1.5% to 1.8% between 2008 and 2014 (McHugh et al. 2016). In contrast, data from the Norwegian sheep recording system, covering 270,850 lambings in 2010, revealed an incidence of 13% for “more severe” dystocia plus an additional 12% of “less severe” cases, accounting for a total of 25% of all recorded parturitions in that year (Waage and Wangensteen 2013).

Strong breed influences have been shown, with reported dystocia rates varying from 4.0% in Merino to 34.0% in Dorset Horn ewes in two studies by the same author (George 1975, 1976). Other authors showed that Texel lambs were three times more likely to require veterinary assistance at birth than lambs of other studied breeds (Scottish Blackface, Mule), with only 44.0% of all Texel lambs born without assistance (Dwyer and Bünger 2012).

Many other studies on ovine dystocia have been conducted in veterinary hospitals or refer to case cohorts presented to veterinary practices. They are thus based on a pre-selected case load and do not allow conclusions regarding the incidence of dystocia in the wider sheep population. In such instances, the proportion of maternal causes of dystocia is commonly over-represented (Scott 1989, Sobiraj 1994, Brounts et al. 2004, Ennen et al. 2013, Voigt et al. 2021).

Dystocia has been attributed to a significant percentage of periparturient ewe deaths and is also a major contributor to perinatal lamb mortality (Bruce et al. 2021). An extended duration of labour prior to presentation for veterinary attention has been shown to significantly increase the odds of stillbirth (Voigt et al. 2021). Stillbirth was also the predominant cause of lamb loss in a field study conducted in 17 large flocks in Germany, and accounted for an average of 45% of lamb losses from birth to sale or retention as breeding animals (Voigt et al. 2019). In a study by Regueiro et al. (2021), 75% of lamb deaths up to the age of 72 hours occurred in

primiparous ewes following a prolonged parturition. In Australia, a recent meta-analysis of 11 studies covering a total of 14,413 lamb post mortem examinations revealed that the overall proportion of lamb mortality attributable to dystocia was 47% in these cases (Bruce et al. 2021). Dystocia was also reported as the most frequent cause of periparturient ewe deaths following 595 post mortem examinations from 40 farms in Australia carried out in 2019 and 2020, identifying 41% (2019) and 29% (2020, respectively) of these deaths as attributable to dystocia (McQuillan et al. 2021).

Whether dystocia results in the death of the ewe and/or the lambs is strongly influenced by the level of husbandry, as well as the adequacy, skill and timescale of potential interventions. Inappropriate treatments and neglect (Scott 2003, 2005) or limited observation in extensive husbandry systems (Bruce et al. 2021) contribute to high mortality. Planned lambing management and increased farmer education have been shown to be associated with lower stillbirth rates in a German study (Voigt et al. 2019).

Current data on dystocia-related ewe and lamb mortality are frequently derived from field situations and thus reflect varying levels of observation and care (Hawkins et al. 2021). Such studies also almost invariably lack a control group. Stillbirth rates can additionally be confounded by infectious causes of abortion as shown by the frequent presence of these agents in stillborn lambs from field submissions (Kirkbride 1993, Clune et al. 2021). The true influence of dystocia on ewe and lamb mortality thus needs to be assessed in well-managed and standardized circumstances providing an optimum level of observation and care, in the absence of other flock health issues and infectious abortion agents. We therefore conducted a retrospective whole-flock study in a closely-monitored university sheep flock in good health and free from infectious abortions to assess the frequency and type of dystocia, and any potential influence of birth difficulties on stillbirth and perinatal lamb mortality as well as postparturient ewe health and survival.

Material and methods

Animals and flock management

An approximately 60 ewe flock of White and Brown Bavarian Alpine sheep (Bayerisches Bergschaf) and their crosses was kept for veterinary educational purposes at the agricultural premises of a veterinary teaching hospital. Following oestrus synchronization of groups of

up to ten animals at a time using intravaginal sponges containing 20mg flugestone acetate (Chronogest®CR, Intervet, UK) for 14 days or two intra-muscular injections of 0.15 mg cloprostenol per animal (Dalmazin SYNCH, Selectavet, Germany) 9 to 10 days apart, the ewes were joined with fertile rams one day after finishing the synchronization protocol and remained with these for three days for natural mating. The second day spent with the ram (i.e. 48–72 h after finishing the synchronization protocol) was defined as the mating day for the purposes of calculating days of gestation. Additional groups of sheep not intended for caesarean section were mated naturally without any prior synchronization. Parturition was expected at around day 149 of pregnancy (Zoller et al. 2015). Late pregnant animals were moved to the hospital facilities for close supervision at lambing time approximately one week prior to this due date and remained there for five to ten days after parturition before being returned to the agricultural facilities. Depending on student numbers, between two and four animals from each group were selected for elective near-term caesarean section. These animals received 2mg dexamethasone (various suppliers) subcutaneously 36 hours prior to the planned operation, followed by 10 mg dexamethasone 12 hours before the procedure to aid foetal lung maturation (Zoller et al. 2015). The caesarean sections were carried out by groups of final year veterinary students no earlier than day 147 of gestation under close guidance by an experienced veterinary surgeon as part of their clinical training in obstetrics. The remainder of the synchronized sheep were left to lamb naturally. All procedures complied with EU Directive 2010/63/EU and German animal welfare legislation and were approved by the Upper Bavarian District Government under licenses number 55.2-1-54-2532.3-23-09 (2009–2012), 55.2.1-54-2532.3-38-13 (2013–2017) and ROB-55.2Vet-2532.Vet_03-17-92 (2018–2023). Parturitions took place throughout the year in a non-seasonal system, with up to eight groups of sheep lambing at different times each year. The animals were kept on deep straw bedding with seasonal access to an outdoor pasture area. They were fed ad libitum hay and mineral supplements, with added concentrate feed during the last trimester of pregnancy and during lactation. The flock health programme included management as a semi-closed flock using only home-bred female replacements, rigorous health checks and a minimum four week quarantine for any bought-in rams. All bought-in animals were routinely tested serologically for Maedi-Visna and caseous lymphadenitis, and the flock was clinically free from these diseases, but did not have official accreditation. The management also involved annual vaccination for clostridial diseases and pasteurellosis (Heptavac P Plus, Intervet, Germany), regular monitoring of body weight, regular faecal examination, antiparasitic treatments if and when required following a targeted treatment approach, post mortem examination of any potential abortions or ewe deaths, and annual vaccination of the initially seronegative flock against *Coxiella burnetii* (Coxevac, CEVA, Germany). The latter formed part of a health and safety risk assessment because of the use in student training and the vicinity to cattle and small ruminant patients of unknown health status at the veterinary hospital.

Caesarean sections were carried out following a standard protocol using a left flank approach under local

anaesthesia with procaine hydrochloride (various suppliers) in right lateral recumbency (Winter 1999, Thorne and Jackson 2000, Khan and Erdogan 2019, Vermunt et al. 2019). Following a left flank incision, the uterus was exteriorized. In case of multiple litters, both horns were incised. Following removal of and contact with the lambs, the ewes were sedated using 0.1 mg/kg body weight (bw) xylazine intramuscularly (various suppliers) because of longer than usual suture times caused by less experienced surgeons (veterinary students). To counter-act uterine contractions induced by the side-effects of xylazine, 0.15 mg clenbuterol (Planipart, Boehringer Ingelheim, Germany) were applied intravenously per animal as approved by the above experimental licenses. The uterine incisions were sutured using a double-layer continuous inverting suture pattern (Cushing suture, Surgicryl monofilament, USP 1 – EP 4, SMI AG, Belgium). A simple continuous suture was applied to jointly close the peritoneum and transverse muscle (Surgicryl monofilament, USP 1 – EP 4, SMI AG, Belgium), followed by a joint simple continuous suture of the two oblique abdominal muscles (Surgicryl PGA, USP 1 – EP 4, SMI AG, Belgium), subcutaneous adaptation (Surgicryl PGA, USP 1 – EP 4, SMI AG, Belgium) and skin closure using metal staples (Manipler AZ – 35W, B Braun, Germany). All ewes received a peri-operative course of at least five days of amoxicillin (15mg/kg body bw, various suppliers) and three days of non-steroidal anti-inflammatory drugs, using either meloxicam (various suppliers, 0.5mg/kg bw subcutaneously) or flunixin-meglumine (various suppliers, 2.2mg/kg bw subcutaneously). From 2018 onwards, additional application of metamizole (20 mg/kg bw intravenously, various suppliers) was required by the experimental license. Immediately after completion of surgery, 70 µg carbetocin (Depotocin, Veyx, Germany) were applied subcutaneously per animal.

All late pregnant ewes were closely monitored continuously between 6.00 and 24.00 h by veterinary students and staff during lambing time. Between 0.00 and 6.00 h, regular observation intervals were extended to 2–3 hours, but whenever a ewe showed signs of imminent parturition at these times, the students on duty kept monitoring the animal until lambing was completed. If a parturition was failing to progress, the ewe was given assistance at lambing by either the student or veterinary surgeon on duty. All cases requiring a higher level of intra-uterine manipulation were given a minimum three day course of amoxicillin at the discretion of the veterinary surgeon. Additional treatments were administered as required on a case by case basis. Any weak lambs were given intensive care including ewe or cow colostrum and assistance with suckling if required, plus additional treatments if necessary depending on their clinical condition(s). Surplus or rejected lambs were bottle-fed or fostered. The ewes and their lambs were placed in individual pens for the first days of life, before being housed together as a group until weaning at around three to four months of age. Detailed clinical and treatment records were kept for all individual animals and were available for retrospective evaluation.

Definitions

The following definitions were used:

1. Dystocia: “failure of transition from stage I to stage II labour or when little to no progress is made for

30 minutes or more after the start of stage II labour" (Anderson 2014).

2. Abortion: the spontaneous delivery of an immature, weak or dead lamb prior to day 142 of gestation (Menziez 2011).
3. Mummification: the delivery of a prematurely perished, dehydrated foetus (Windsor 2019) at term.
4. Stillbirth: the delivery of a dead, fully developed lamb in a fresh state at term (abortions are not included).
5. Perinatal mortality: any stillbirths (see above) plus postnatal lamb deaths up to the age of two days (Wong et al. 2021).
6. Retained foetal membranes: Failure to expel the foetal membranes within 6 hours of delivery of the last lamb (Fthenakis et al. 2000).
7. Fever: Inner body temperature $>40^{\circ}\text{C}$ on two consecutive measurements up to seven days post partum.
8. Metritis: Fever and putrid vaginal discharge and/or reduced general demeanour in the postpartal period, in the absence of other clinical signs (e.g., mastitis) explaining the increased temperature and clinical condition.
9. Wound healing categories
 - Uneventful: no swelling or discharge at any time, first intention healing
 - Minute findings: very slight, short-lived swelling or very slight, short-lived serosanguinous discharge, which fully subsides until removal of skin staples; first intention healing
 - Slight wound healing deficit: slight swelling or seroma still present at time of removal of skin staples; first intention healing
 - Moderate wound healing deficit: swelling or purulent discharge present at time of removal of skin staples, some localized dehiscence, abscess or localized area of discharge; localized second intention healing
 - Severe wound healing deficit: Full-length dehiscence of skin suture, full-length second intention healing

Inclusion criteria

The study reviewed all parturitions taking place between 01.01.2009 and 30.06.2023 and evaluated all planned, elective caesarean sections carried out for teaching purposes, and all full-term vaginal deliveries in healthy animals during this period.

Data management and statistical analyses

Data were gathered from archived paper-based and electronic flock management records (SchafPC, DSP-Agrosoft GmbH, Ketzin, Germany) as well as individual periparturient clinical records. These included the results of a daily clinical examination and postpartal twice-daily temperature measurements while housed at the hospital facilities, details of the course of parturition, any treatments received and individual details of all lambs born.

Data were managed using Microsoft Excel for Macintosh version 16.74 and statistically analysed using R (R version 4.3.1 [2023-06-16]). The data set was checked for completeness, and a total of 51 missing values for lamb birth weight (5.2%) and 40 missing values for lamb sex (4.1%) out of the 980 individual lamb records were imputed via a non-parametric multivariable imputation approach by chained random forest algorithm with 1000 trees (missRanger R package; Mayer 2019). This method

combines random forest imputation (Stekhoven and Bühlmann 2012, Wright and Ziegler 2017) with predictive mean matching (van Buuren and Groothuis-Oudshoorn 2011) and thus iterates multiple times until the average out-of-bag (OOB) prediction error of predictive models stops to improve. The same method was used to impute two missing values of ewe age (0.2%) and one missing value of placental shedding (0.3%) out of the 576 studied parturitions. The OOB prediction error for all four parameters stopped improving at 5.5 to 0%, indicating very accurate predictions. Imputation was therefore accepted.

Parturitions were categorized as follows: parturition at term by either uneventful vaginal delivery (group I; $n=283$), delayed progress at parturition / assisted vaginal delivery (dystocia, group II; $n=75$) or near-term planned caesarean section ($n=218$) on day 147 to 149 of gestation (group III). In case of multiple lambs per litter, this classification was applied to all lambs born on that occasion, irrespective of the number of lambs requiring assistance during one particular parturition. Mummified foetuses were counted for the assessment of litter size and the presence of dead foetuses, but were excluded from analyses regarding stillbirth and perinatal mortality, since their death occurred during the course of pregnancy and was not birth-related. Uni- and multivariable Bayesian logistic regressions (arm package in R; Gelman and Su 2022) were applied to assess a potential association of the mode of delivery (groups I to III) with stillbirth and lamb perinatal mortality, taking into account the potential confounders ewe age and parity (primiparous, secondiparous, parity ≥ 3), litter size (single, twins, multiples ≥ 3), lamb sex, lamb birth weight and lambing season. In addition, a potential association of the mode of delivery with retained foetal membranes and increased body temperature (fever) in the postpartal period was also assessed. Both these analyses included the predictors age, parity, litter size and the presence of dead lambs. For the evaluation of fever, the occurrence of retained foetal membranes (yes/no) was additionally included in the analysis. Not every ewe lambed every year, so parity and age contained different information.

Univariable Bayesian logistic regressions were initially performed for the four response variables and their corresponding predictors. The predictors were subsequently ranked for their relative importance by means of p value and Chi Square Statistics as an effect size. Final multivariable models were selected by the automated brute-force model selection method with multimodel inference for variable importance using the glmulti package in R. The brute-force approach provided the list of models ranked by the Akaike information criterion (AIC), where the model with the lowest AIC contained the most informative combination of predictors. Results showing a p value of $p<0.05$ were considered significant, while $p<0.1$ was considered a tendency.

Results

Descriptive results

A total of 611 lambings took place during the study period. Of these, 576 parturitions (94.3%) by 232 sheep fulfilled the inclusion criteria, with a total of 980 lambs

born on these occasions. Abortions prior to day 142 of gestation (n=3; 0.5%), induced parturitions (n=2) or a pre-term salvage caesarean section (n=1) on medical grounds (total: n=3; 0.5%), caesarean sections due to dystocia (insufficient cervical dilatation unresponsive to manual dilation attempts, n=1; 0.2%), parturitions with insufficient records (n=1; 0.2%) and induced pre-term parturitions forming part of a previous research project (Zoller et al. 2015; n=27, 4.4%) were excluded from the analyses. All aborted fetuses were submitted for post mortem examination, with no infectious causes of abortion diagnosed.

Near-term elective caesarean section was performed in 218 cases on days 147 (n=129), 148 (n=87) or 149 of gestation (n=2). Uneventful lambing was recorded in 283 cases, while 75 parturitions were classified as dystocia (20.9% of the studied 358 vaginal deliveries). The average gestational period in these cases was 150.2 days (median: 150; range: 145–158 days) based on 252 pregnancies with a known mating date following oestrus synchronization.

Four ewes died or were euthanized within 14 days of giving birth (4/576; 0.7%). These included two cases (2/218; 0.9%) following elective caesarean section, one case following assisted delivery (1/75; 1.3%) and one case after uneventful parturition (1/283; 0.4%). The causes of death included gangraenous mastitis (n=1), perforating abomasal ulcers (n=1), euthanasia due to traumatic leg injury (n=1) and one case of metritis and peritonitis following elective caesarean section and retained foetal membranes. The uterine suture was intact in this animal. Only the latter case was considered directly related to parturition.

The overall stillbirth rate was 3.4% of all lambs born, while overall perinatal mortality was 7.1%; An additional 2.1% of the lambs were born at term in a mummified state, predominantly as part of multiple litters. Retained placenta was diagnosed in 74 of the 576 cases (12.8%), and metritis was present on 7 occasions (1.2%). Fever was observed in the postpartal period in 66 cases (11.5%). These included the seven cases diagnosed with clinical metritis. Table 1 shows the descriptive results and further characteristics of the cases by mode of delivery for the three parturition categories.

The vast majority (84%) of the 75 vaginal deliveries classified as dystocia were of foetal origin. Only 12% of the cases were attributed to maternal dystocia, with delays in the birth process/uterine inertia the most frequently observed maternal cause. Table 2 shows details of the causes of dystocia diagnosed in the 75 assisted vaginal deliveries and their frequency in relation to dystocia cases and all examined vaginal deliveries.

Uneventful wound healing was recorded in 131 of the performed 218 elective caesarean sections (60.1%), while minute findings such as short-lived swelling or minimal, short-lived serosanguinous discharge were noted in 69 cases (31.7%). These were still considered part of a normal healing process, since no abnormal findings were present at the time of removal of the skin staples. Normal wound healing therefore occurred in 200 of the 218 cases (91.7%). In the 18 animals diagnosed with wound healing disorders, twelve (5.5%) were categorized as slight, five (2.3%) as moderate and one (0.5%) as severe (full-length dehiscence of the skin suture). All animals with wound healing disorders made a full recovery.

TABLE 1: *Lamb mortality parameters and postpartal ewe health indicators following uneventful vaginal delivery (uneventful), assisted vaginal delivery (dystocia) and near-term elective caesarean section (planned C section), and descriptive characteristics of the studied parturitions (576 parturitions of 232 Bavarian Alpine sheep, delivering 980 lambs).*

| | Uneventful (n=283) | Dystocia (n=75) | Planned C section (n=218) |
|--|--------------------|--------------------|---------------------------|
| Total number of lambs delivered | 461 | 135 | 384 |
| Stillbirth rate | 3.9% | 11.1% | 0% |
| Mummified lambs | 0.9% | 4.4% | 2.9% |
| Perinatal mortality | 6.7% | 14.1% | 5.2% |
| Retained foetal membranes | 2.5% | 4.0% | 29.4% |
| Fever >40°C (including clinical metritis cases) | 8.5% | 17.3% | 13.3% |
| Metritis | 0.4% | 4.0% | 1.4% |
| Parturition-related ewe mortality within 14 days post partum | 0% | 0% | 0.5% |
| Mean litter size (median; range) | 1.8 (2; 1–3) | 2.1 (2; 1–3) | 2.1 (2; 1–7) |
| Mean lamb birth weight (kg) (median; range) | 3.9 (3.9; 0.9–6.9) | 3.9 (4.0; 1.3–7.2) | 4.0 (4.1; 0.4–6.8) |
| Mean parity (median; range) | 1.9 (2; 1–5) | 2.5 (3; 1–5) | 2.4 (2; 1–6) |
| Mean ewe age (years) (median; range) | 2.7 (3; 1–7) | 3.4 (4; 1–6) | 3.6 (4; 1–8) |

TABLE 2: *Causes of dystocia in assisted vaginal deliveries between January 2009 and June 2023 in a flock of Bavarian Alpine sheep.*

| Cause | Number cases | Proportion of dystocia cases (n=75) | Proportion of all vaginal deliveries (n=358) |
|---|--------------|-------------------------------------|--|
| Foetal maldisposition | 45 | 60% | 12.6% |
| Large lambs | 14 | 18.7% | 3.9% |
| Simultaneous presentation of more than one lamb | 4 | 5.3% | 1.1% |
| Uterine inertia / delayed parturition | 5 | 6.7% | 1.4% |
| Foetomaternal disproportion (vaginal) | 2 | 2.7% | 0.6% |
| Insufficient cervical dilatation | 2 | 2.7% | 0.6% |
| Details insufficiently recorded | 3 | 4% | 0.8% |
| Total | 75 | 100% | 20.9% |

Statistical analyses

Lamb mortality parameters

In addition to the mode of delivery, ewe age and parity, litter size, birth weight, lamb sex and lambing season were evaluated using univariable Bayesian logistic regression regarding their potential association with stillbirth and perinatal mortality. For stillbirth, the mode of delivery ($p<0.001$) and lamb birth weight ($p<0.001$) were significant in univariable analyses, while season showed a tendency ($p=0.078$). The other studied parameters were not significant. Brute force selection however ranked season as the least important factor (Fig. 1) and determined a final best model by means of AIC to include birth weight, mode of delivery, ewe age, litter size and lamb sex. The mode of delivery and lamb birth weight remained significant ($p<0.001$) in the multivariable analysis, while ewe age ($p=0.051$) and litter size ($p=0.085$) showed a tendency. Lamb sex was

identified as non-significant (Fig. 2). The odds of stillbirth decreased with increased birth weights (OR=0.26; 95% confidence interval (CI) 0.17–0.39; $p<0.001$) and increased with increased dam age (OR=1.32; 95% CI 1.03–1.68; $p=0.028$). Pairwise comparison of the modes of delivery showed significantly increased odds of stillbirth for dystocia in comparison to elective caesarean section (OR=77.3; 95% CI 5.85–1,021; $p<0.001$) as well as increased odds for uneventful vaginal deliveries in comparison to planned caesarean section (OR=26.1; 95% CI 2.02–338; $p=0.008$), while there were decreased odds for uneventful vaginal deliveries compared to dystocia (OR=0.34, 95% CI 0.12–0.94; $p=0.035$). Upon pairwise comparison of litter size categories, the only tendency was seen for decreased odds of stillbirth for multiples compared to singles (OR=0.22, 95% CI 0.04–1.09; $p=0.069$). Figure 1 illustrates the model-averaged importance of terms of the originally studied seven predictors (Fig. 1A), and the predicted probabilities of

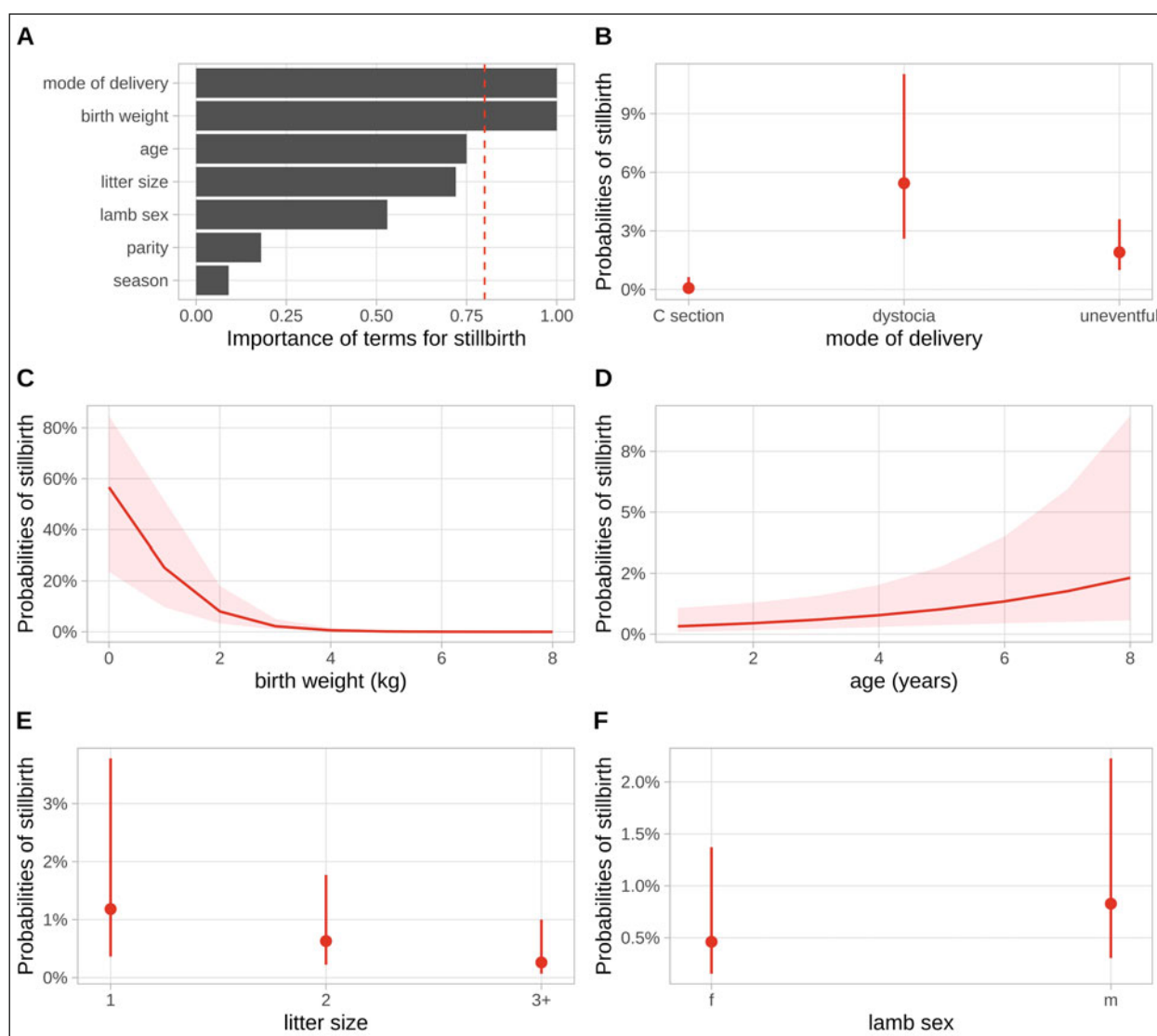


FIGURE 1: A: Model-averaged importance of terms for the prediction of stillbirth ranked by brute force selection of models. Predictors reaching a value >0.8 (red vertical broken line) are considered of high importance. B to F: Predicted probabilities of stillbirth determined by the final multivariable model following brute force selection of predictors. The mode of delivery and lamb birth weight were significant, while ewe age and litter size showed a tendency. Lamb sex was not significant. Error bars or shadows indicate the 95% confidence intervals; $n=980$ lambs from 576 studied parturitions.

stillbirth for the selected final five predictors following the multivariable best model approach (Fig. 1B to 1F).

Similarly, only birth weight ($p<0.001$) and mode of delivery ($p=0.006$) were initially significant for perinatal mortality in univariable analyses, with no additional tendencies identified for any of the other studied predictors. Brute force selection retained birth weight, litter size, mode of delivery, lamb sex and ewe age in the final multivariable model for perinatal mortality, and ranked their relative importance in that order, while parity and season were ranked as least important and thus dismissed from the final model (Fig. 2). In the multivariable model, birth weight ($p<0.001$) was the most significant factor, with decreased odds of perinatal mortality associated with an increased birth weight (OR=0.30, 95% CI 0.23–0.40; $p<0.001$). All other predictors also showed varying levels of significance in the following order: Litter size ($p=0.005$), mode of delivery ($p=0.015$), lamb sex ($p=0.020$) and ewe age ($p=0.022$). Upon pairwise com-

parison of the delivery categories, a significant difference was seen between dystocia and planned caesarean section, with increased odds of perinatal mortality for dystocia (OR=2.81; 95% CI 1.19–6.63; $p=0.014$), and between uneventful deliveries and dystocia, with decreased odds following uneventful parturitions (OR=0.42; 95% CI 0.18–0.98; $p=0.042$), but no significant difference was observed in this context between planned caesarean section and uneventful vaginal delivery ($p=0.863$). Lower odds of perinatal mortality were seen for lambs from higher litter sizes, lambs from younger ewes and female lambs (Table 3). Figure 2 illustrates the model-averaged importance of terms and the predicted probabilities of perinatal mortality following the final multivariable model.

Ewe health indicators

Since only one parturition-related ewe death occurred in the studied cases, statistical assessment of a potential

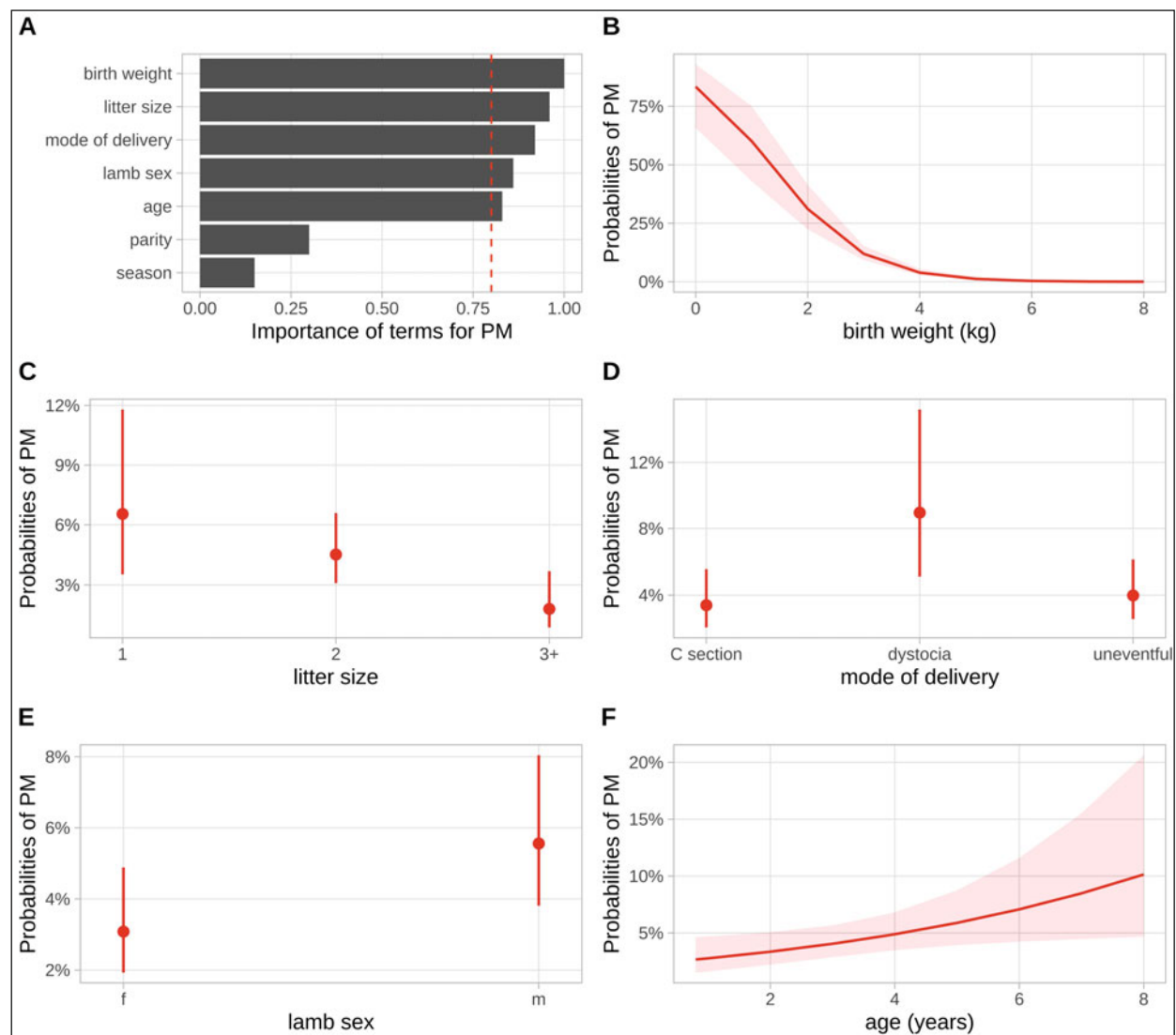


FIGURE 2: A: Model-averaged importance of terms for the prediction of perinatal mortality (PM) ranked by brute force selection of models. Predictors reaching a value >0.8 (red vertical broken line) are considered of high importance. B to F: Predicted probabilities of PM determined by the final multivariable model following brute force selection of predictors. All five studied predictors showed various levels of significance in this context. Error bars or shadows indicate the 95% confidence intervals; $n=980$ lambs from 576 studied parturitions.

association of the mode of delivery with ewe mortality was not possible. The very low number of clinical metritis cases (n=7) also hindered statistical analyses on this matter.

The percentage of retained placenta following near-term elective caesarean section was considerably higher than following the two vaginal delivery categories, and the mode of delivery was significant in the univariable analysis ($p<0.001$). Ewe age showed a tendency ($p=0.077$), while parity, litter size and the presence of dead lambs were not significant in univariable analyses. Brute force selection retained the mode of delivery and the presence of dead lambs in the final model and ranked their importance in this order, while age, parity and litter size were ranked as less important and thus not included in the final model (Fig 3). In the multivariable analysis, the mode of delivery remained highly significant ($p<0.001$), with decreased odds of retained placenta following uneventful vaginal delivery (OR=0.06, 95% CI 0.02–0.16; $p<0.001$) or dystocia (OR=0.09, 95% CI 0.02–0.35; $p<0.001$) in comparison to near-term elective caesarean section, and no significant difference between the two vaginal delivery categories ($p=0.848$). The presence of a dead (mummified or stillborn) foetus showed a tendency ($p=0.054$), with increased odds of retained foetal membranes in cases carrying a dead foetus (OR=2.77; 95% CI 0.96–7.95; $p=0.059$). Figure 3 illustrates the model-averaged importance of terms and the predicted probabilities of retained placenta following the final multivariable model.

The mode of delivery showed a tendency ($p=0.060$) for the development of postpartal fever episodes $>40^{\circ}\text{C}$ in univariable analyses, while the presence of retained foetal membranes was significant ($p<0.001$) in this context. In the majority of cases (59/66, 89.4%), these fever episodes were not associated with any compromised clinical condition of the affected animals, but clinical metritis was diagnosed in the remaining seven cases. Age, parity, litter size and the presence of dead lambs were not significant in this context in univariable analyses. Brute force selection retained the presence of retained foetal membranes and the mode of delivery in the final multivariable model, with retained placenta remaining significant ($p<0.001$) and the mode of delivery remaining a tendency ($p=0.094$) (Fig 4). There were increased odds of developing fever episodes following retained placenta (OR=3.92, 95% CI 1.98–7.76; $p<0.001$). Pairwise comparison of the modes of delivery only showed a tendency between uneventful vaginal delivery and dystocia, with decreased odds for uneventful parturitions (OR=0.46, 95% CI 0.19–1.10; $p=0.094$). There was no significant difference between planned caesarean section and uneventful vaginal delivery ($p=0.998$), or between caesarean section and dystocia ($p=0.131$). Figure 4 illustrates the model-averaged importance of terms and the predicted probabilities of postpartal fever episodes following the final multivariable model.

Discussion

Despite the study being limited to a single flock and breed, the data provide valuable insights into the nature and impact of dystocia by comparing assisted and uneventful vaginal deliveries to near-term elective caesar-

TABLE 3: Results of pairwise comparisons of predictors for perinatal mortality following multivariable linear regression

| Predictor | OR ¹ | 95% CI ¹ | p-value |
|-------------------------|-----------------|---------------------|---------|
| litter_size | | | |
| 2 / 1 | 0.68 | 0.28–1.65 | 0.561 |
| (3+) / 1 | 0.26 | 0.08–0.82 | 0.017 |
| (3+) / 2 | 0.39 | 0.16–0.90 | 0.024 |
| mode_of_delivery | | | |
| dystocia / C_section | 2.81 | 1.19–6.63 | 0.014 |
| uneventful / C_section | 1.18 | 0.55–2.52 | 0.863 |
| uneventful / dystocia | 0.42 | 0.18–0.98 | 0.042 |
| age | 1.22 | 1.03–1.44 | 0.023 |
| birth_weight | 0.30 | 0.23–0.40 | <0.001 |
| lamb_sex | | | |
| m / f | 1.85 | 1.09–3.15 | 0.023 |

OR = Odds Ratio, CI = Confidence Interval

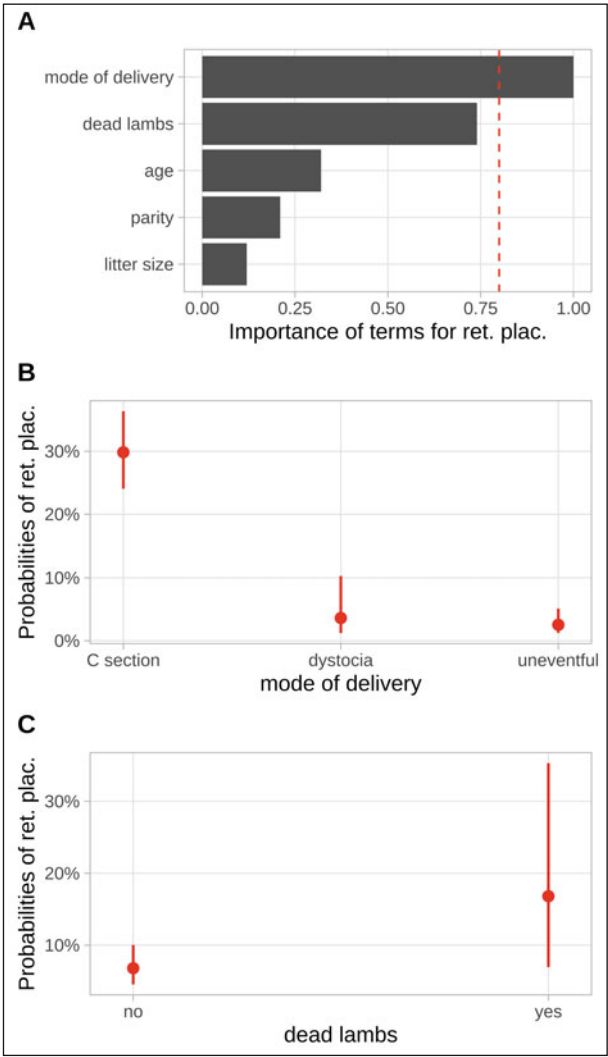


FIGURE 3: A: Model-averaged importance of terms for the prediction of retained placenta (ret. plac.) ranked following brute force selection of models. Predictors reaching a value >0.8 (red vertical broken line) are considered of high importance. B and C: Predicted probabilities of retained foetal membranes determined by the final multivariable model following brute force selection of predictors. The mode of delivery was significant in this context, while the presence of dead lambs showed a tendency. Error bars and shadows indicate the 95% confidence intervals. n=980 lambs from 576 studied parturitions.

ean sections, a delivery technique entirely avoiding any potential foetal stress caused by a vaginal birth process. Standardized lambing management and supervision, high flock health and the absence of infectious abortions further minimised confounding factors for stillbirth commonly present in field situations. Confounding factors for perinatal mortality such as, for instance, insufficient colostrum intake, mismothering or exposure were ruled out by the high level of care provided to any vulnerable lambs. The nature of the study therefore allows conclusions to be made as to the true impact of dystocia and other predictors on lamb mortality parameters and postpartal ewe health.

A previous case control study compared elective caesarean sections with uneventful vaginal deliveries, but did not assess any potential impact of dystocia on ewe and lamb health and survival (Waage and Wangenstein 2013). The brute-force approach for automated model selection and multimodel inference represents a significant advancement over this approach or the commonly employed backward or forward variable selection methods. Unlike these sequential methods, the brute-force approach systematically assesses all possible combinations of predictors to identify the optimal model that provides the most accurate representation of the data. Given the frequent disagreement regarding the 'final optimal' models obtained through forward and backward variable selections, the brute-force approach ranks the models and suggests not only a single "best model" but also a set of qualitatively similar models. These models typically fall within 2 units of AIC and feature different combinations of predictors, irrespective of the classical significance of those predictors. Moreover, similar to the Random Forest algorithm, the brute-force approach generates variable importance plots, but based on distinct decision criteria. While neither backward nor forward selections can produce variable importance plots, and the Random Forest algorithm cannot suggest an "optimal" model, the brute-force approach enhances both the quality and quantity of inferences drawn from the data.

The causes of dystocia observed in the studied flock largely confirm the results of previous whole-flock studies, with foetal causes by far outnumbering maternal causes of dystocia in field situations, and foetal maldisposition the most frequently observed condition (Grommers et al. 1985, Dwyer and Bünger 2012). Only one case of caesarean section due to dystocia was observed in the 14.5-year study period, accounting for 0.3% of deliveries not intended for the elective procedure, making clinical obstetrical indications for caesarean section a very rare event in the studied flock. Comparison of dystocia rates between published studies is difficult, as case definitions and breed characteristics vary. The breed used in the present study typically produces lambs with a lean body conformation. The observed dystocia rate of nearly 21% of all litters therefore seems relatively high. Close and frequent observation and early assistance at lambing following the definition of dystocia as no progress being made within 30 minutes or more (Anderson 2014) were aimed at maximizing lamb survival, but may have led to some potential over-diagnosis in contrast to other publications, which used, for instance, a definition of one to two hours (Grommers et al. 1985) or simply "when assistance was required" (Holst et al. 1997). In

some cases classified as dystocia, the ewe may thus still have lambd without assistance, even though this may have further compromised lamb viability. This potential over-diagnosis most likely applies to some of the cases classified as uterine inertia or a delay in the birth process with no other obvious problems, since frequent observation itself and thus possible interruption of the birth process may have been the cause of the delay on some occasions.

Despite early intervention in cases showing delays in the birth process, dystocia was highly significant for the occurrence of stillbirth, with significantly increased odds of stillbirth for dystocia in comparison to elective caesarean section as well as uneventful vaginal delivery. The difference in stillbirth rates between planned

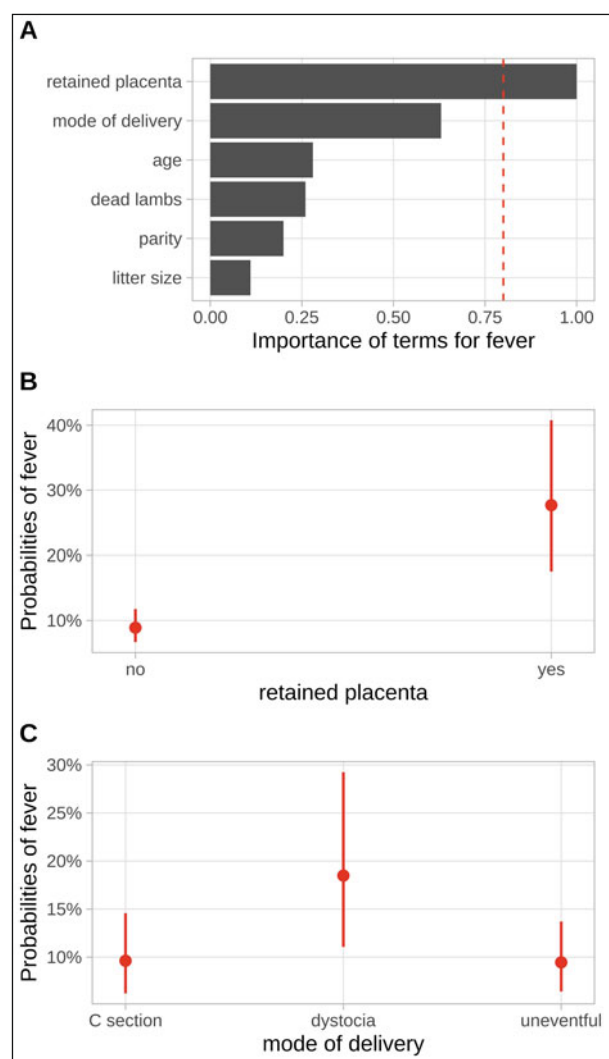


FIGURE 4: A: Model-averaged importance of terms for the prediction of postpartal fever episodes (fever) ranked following brute force selection of models. Predictors reaching a value >0.8 (red vertical broken line) are considered of high importance. B and C: Predicted probabilities of postpartal fever episodes determined by the final multivariable model following brute force selection of predictors. The presence of retained foetal membranes was significant in this context, while the mode of delivery showed a tendency. Error bars and shadows indicate the 95% confidence intervals. $n=980$ lambs from 576 studied parturitions.

caesarean section (0%) and uneventful vaginal delivery (3.9%) was also statistically significant. Even if classified as uneventful, the vaginal birth process itself thus increases the stillbirth risk to the lamb. Birth weight was an equally significant predictor in this context, but contrary to expectations the risk did not increase with increased birth weight. While heavier lambs are more likely to require assistance at birth (Dwyer and Bünger 2012) and are thus more likely to be exposed to the effects of dystocia, it was particularly low birth weights that were associated with higher odds of stillbirth in our study population. This phenomenon is therefore most likely unrelated to parturition difficulties but associated with factors affecting foetal development such as, for instance, placental insufficiency leading to underweight lambs, which are then less viable than lambs with normal or high birth weights. For perinatal mortality, i.e. cumulative deaths to include stillbirth and any postnatal mortality up to the second day of life (Wong et al. 2021), low birth weights outweighed the other predictors in relative importance, but all studied parameters also showed different levels of significance. For litter size and ewe age, the results interestingly indicated better perinatal survival for lambs from triplet or multiple litters in comparison to singles and twins, and poorer perinatal survival for lambs born to older ewes. This observation contradicts previous studies such as, for instance, Holst et al. (1997), which indicate inferior survival rates for triplets, and the common assumption that older, more experienced ewes are more successful at raising their lambs than younger sheep. These observations most likely reflect the high standards of care given to each and every live-born lamb, and successful hand-rearing and fostering practices for surplus and rejected lambs, and show that field data are most likely frequently confounded by a ewe's over-stretched mothering capability, or husbandry and management factors. Lambs born following dystocia still showed decreased odds of perinatal survival in comparison to the other two delivery groups, but, in contrast to stillbirth alone, there was no longer a significant difference between uneventful delivery and planned caesarean section. This can be explained by the fact that an even slightly pre-term caesarean section carries a risk of prematurity in the delivered lambs (Zoller et al. 2015). While all non-mummified lambs were delivered alive by planned caesarean surgery, sequels of prematurity were the predominant cause of death or reason for euthanasia in lambs delivered this way despite the application of dexamethasone prior to the procedure to aid foetal lung maturation. The perinatal mortality rate of 5.2% following planned caesarean section was, however, still numerically lower but very similar to the 6.7% seen following uneventful vaginal delivery.

In field situations, the effect of dystocia goes far beyond the direct effect of a delayed vaginal delivery causing lamb asphyxia, hypoxic damage or birth injuries. Recent studies have shown that postpartal maternal grooming behaviour and the ewe-lamb bond are negatively affected in dystocic ewes (Regueiro et al. 2021, Redfearn et al. 2023), most likely triggered by exhaustion or pain following a difficult or traumatic parturition. Shortening the birth process by early, pre-planned assistance immediately after the start of the expulsion phase significantly increased lamb viability and had a positive

effect on maternal behaviour (Regueiro et al. 2023), and is thus advisable to limit these negative behavioural effects. In the current study, the negative behavioural impact of dystocia was minimized by early intervention, close supervision of neonatal lambs and by the high level of care given to all cases where the ewe-lamb bond or ewe and lamb health appeared compromised. The effects of dystocia on stillbirth and perinatal mortality seen in the current study are therefore largely restricted to direct effects of the duration and difficulty of the vaginal birth process on the lamb and are not confounded by reduced maternal care, as all lambs rejected by their dams or otherwise requiring assistance were given adequate colostrum, shelter and care and were subsequently hand-reared or fostered. It is therefore highly likely that cumulative effects of dystocia on lamb vigour and maternal behaviour will lead to more pronounced differences in perinatal mortality between eutocic and dystocic ewes in field situations, with mismothering and subsequent starvation and exposure further adding to perinatal mortality following dystocia (Regueiro et al. 2021).

Of the four ewe fatalities occurring within 14 days post partum, only one case was birth-related, with a diagnosis of retained foetal membranes, metritis and subsequent peritonitis in a ewe 6 days after elective caesarean section. This death accounted for 0.2% of the studied 576 parturitions. Parturition-related ewe mortality can thus be considered very low in healthy animals under close observation and good management conditions, and this is a standard that should be strived for. In field situations, high periparturient ewe mortality is frequently associated with underlying health issues (Sobiraj 1994, Voigt et al. 2021), inappropriate treatments or poor hygiene (Scott 2005), or limited observation in extensive farming systems (Bruce et al. 2021). Labour shortage or the nature of extensive farming are quite often limiting factors for optimal flock surveillance at lambing time. Efforts have therefore recently been made to use animal-fitted sensor technology and artificial intelligence algorithms to identify and ultimately predict the time of parturition in ewes (Smith et al. 2020, Fogarty et al. 2021). While there are currently still limitations to this technique, precision livestock farming approaches hold great promise for improving individual sheep welfare at lambing time.

Even under the given conditions of the operations being performed by inexperienced veterinary students leading to prolonged surgery times, caesarean section was associated with excellent clinical recovery, survival rates and wound healing. The surgical protocol described here is also suitable for operations under field conditions, with the exception that sedation with xylazine is not usually necessary, and the use of clenbuterol in sheep is prohibited in field cases under German law. Its use in this study was thus only possible due to the experimental status of the animals.

The results following caesarean delivery are in accordance with the findings previously reported for ewes undergoing elective caesarean surgery (El-Guindy and El-Ghannam 1973, Thurley 1973, Waage and Wangenstein 2013, Paping et al. 2023). Higher post-surgical mortality in field cases carried out following dystocia (Scott 1989, Sobiraj 1994, Brounts et al. 2004, Voigt et al. 2021) or a high incidence of wound healing disorders seen by some authors (Ennen et al. 2013) are thus attrib-

utable to the effects of prolonged labour, contamination of uterine contents by prior delivery attempts, underlying health issues or, possibly, differences in suture material or suture techniques.

Under the circumstances of elective procedures and timely intervention in dystocic ewes, retained placenta can be seen as the most important risk factor for immediate postpartal ewe health as determined by fever episodes, although the majority of these cases were not associated with a compromised general condition. Only seven animals were diagnosed with clinical metritis, precluding reliable statistical analyses, but five of these cases were preceded by retained foetal membranes. One of these animals died after developing subsequent peritonitis. The two remaining metritis cases had undergone a very difficult assisted delivery following simultaneous presentation of multiple lambs but had subsequently cleansed normally.

The high frequency of retained foetal membranes in the cases undergoing near-term elective surgical delivery (29.4%; n=218) by far exceeded the rate seen in dystocic field cases following emergency caesarean section (12.6%; n=206) by the same group of authors (Voigt et al. 2021). Recognized factors predisposing to the condition in cattle include insufficient placental maturation associated with premature delivery or shortened gestations (Sheldon 2019). The premature delivery after an average gestational length of 147.4 days as opposed to 150.2 days for natural deliveries in the same flock is thus an obvious explanation for this high incidence in our study. It is interesting to note that the antepartal application of dexamethasone lead to enhanced placental maturation in cattle, but did not reduce the incidence of retained foetal membranes following induced parturitions in this species (Hartmann et al. 2013). A similar phenomenon is likely in the ovine cases described here although no histological examinations were carried out to assess the process of placental maturation. In contrast to our results, a much lower percentage of placental retention was observed following elective caesarean section by other authors: Waage and Wangensteen (2013) only report a single case of retained placenta in 162 ewes undergoing elective caesarean surgery. The authors however do not provide a case definition, so the time allowed for placental shedding prior to classification as retention may have been longer. Also, elective surgery was carried out much closer to term, with caesarean sections performed on day 146.7 (± 1.7), which was very similar to the average gestational length of 146.4 days (± 1.7) in the same flock (Waage and Wangensteen 2013).

A study involving dairy ewes from Greece suggested a four-fold increased risk for retained placenta following assisted deliveries, and a linear increase of risk with litter size (Leontides et al. 2000). We could, however, not find a statistically significant difference in the odds of developing retained placenta between parturitions classified as dystocic or eutocic, or associated with litter size in our data set.

Conclusions

Even under best practice conditions, dystocia is an important factor contributing to stillbirth and perinatal

mortality. The high ewe and lamb mortality rates associated with dystocia under field conditions are, however, unnecessary and can be reduced by improved surveillance during lambing time, early intervention in dystocic ewes, optimizing post-natal lamb care and good general flock health management. Caesarean section is well tolerated by sheep and should be performed early when dealing with dystocia in the ewe. Stillbirth and perinatal mortality are, however, not entirely avoidable, but the high ewe and lamb survival rates seen under best practice circumstances can aid in formulating achievable goals for flock health management. The study also shows that planned caesarean sections are justifiable in the training of veterinary students in terms of animal welfare aspects, as ewe and lamb survival rates as well as clinical recovery are excellent. Further research is desirable to develop technical solutions for improved observation of lambing flocks and, ideally, automated parturition alert systems to overcome practical restrictions to round-the-clock surveillance associated with staffing levels or particular husbandry conditions.

Conflict of interest

The authors hereby declare that they have no proprietary, professional or other personal interests in any product, service and/or company that could have influenced the contents or opinions expressed in this publication.

Ethical approval

The authors hereby declare that they have followed the accepted guidelines of good scientific and good veterinary practice while preparing the present paper. All relevant international, national and institutional ethical guidelines for the handling of the animals used in the study were followed. Details of the animal welfare applications and their approval are given in the Materials and Methods section of the published text.

Author contributions

Conceptualization and study design: KV; Data acquisition: MT, FW; Data analysis and interpretation: KV, YZ, MT; First draft of manuscript: KV, VB, YZ; Critical revision and final approval of manuscript: KV, VB, HZ, YZ, MT, FW.

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Address for correspondence:

Katja Voigt
Clinic for Ruminants with Ambulatory and Herd Health Services
Faculty of Veterinary Medicine
Ludwig-Maximilians-Universität München
Sonnenstr. 16
85764 Oberschleissheim
Germany
katja.voigt@lmu.de