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Lightning related fatalities in livestock: Veterinary expertise and the added value of lightning location data

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ABSTRACT

Although lightning strike is an important cause of sudden death in livestock on pasture and among the main reasons why insurance companies consult an expert veterinarian, scientific information on this subject is limited. The aim of the present study was to provide objective information on the circumstantial evidence and pathological findings in lightning related fatalities (LRF), based on a retrospective analysis of 410 declarations, examined by a single expert veterinarian in Flanders, Belgium, from 1998 to 2012. Predictive logistic models for compatibility with LRF were constructed based on anamnestic, environmental and pathological factors. In addition, the added value of lightning location data (LLD) was evaluated. Pathognomonic singe lesions were present in 84/194 (43%) confirmed reports. Factors which remained significantly associated with LRF in the multivariable model were age, presence of a tree or open water in the near surroundings, tympany and presence of feed in the oral cavity at the time of investigation. This basic model had a sensitivity (Se) of 53.8% and a specificity (Sp) of 88.2%. Relying only on LLD to confirm LRF in livestock resulted in a high Se (91.3%), but a low Sp (41.2%), leading to a high probability that a negative case would be wrongly accepted as an LRF. The best results were obtained when combining the model based on the veterinary expert investigation (circumstantial evidence and pathological findings), together with the detection of cloud-to-ground (CG) lightning at the time and location of death (Se 89.1%; Sp 66.7%).

Introduction

Lightning strike is an important cause of sudden death in cattle on pasture (Finelle and Tartera, 2001). Since lightning related fatalities (LRF) in livestock are mostly covered by fire insurance, an independent veterinarian, referred to in this context as the ‘expert veterinarian’, is asked to perform an investigation to determine whether the case complies with death due to lightning (veterinary expert investigation) (Schelcher, 1994). Over the last 10–15 years the importance of forensic veterinary medicine has increased, mostly because of an increasing tendency for owners to seek compensation for animal losses (Cooper and Cooper, 2008). In practice, LRF is among the most frequent reasons for forensic veterinary medicine, confronting not only veterinary specialists in forensic medicine, but also local veterinary practitioners.

Despite its importance, very little scientific information is available to help expert veterinarians in their judgment of LRF insurance cases (Best, 1967; Appel, 1991; Schelcher and Tartera, 2001; Van Alstine and Widmer, 2003; Zele et al., 2006; Gomes, 2012), with only three studies emphasising the task of the expert veterinarian (Schelcher, 1994; Volat, 1994; Finelle and Tartera, 2001). Lightning related injury or death may occur through five primary mechanisms: (1) direct strikes are the most straightforward; (2) side flashes emanating from tall objects (e.g. trees) hit by lightning are possible; (3) ground currents (step potentials or step voltages) occur with each strike and are the most common mechanism in four-legged species; after injection of current into the earth, a potential gradient develops, which can initiate current entering the animal from one set of feet, leaving the body by the other set of feet; in contrast to human beings, this current crosses essential organs, such as the heart and liver, more frequently causing death (Gomes, 2012); (4) contact, from touching long conductors, such as railings, cables and fences; and (5) upward leaders, which emanate from high ground and tall objects when downward leaders approach ground; even if upward leaders do not connect with a downward leader, they

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can be fatal. More details on the different mechanisms can be found in Cooper (1984, 2002) and Gomes (2012).

Singe lesions (lightning burn lesions) and the presence of feed in the oral cavity as a sign of apoplectic death historically have been reported in >80% of LRF cases (Kahn and Line, 2005). However, in the field, veterinarians are confronted with many LRF declarations which do not show pathognomonic singe lesions. Moreover, some farmers attempt to confuse the investigation by creating false circumstantial evidence, which holds little risk, since penalties for false declarations are usually mild. Also, in many regions, different veterinarians perform a limited annual number of LRF investigations. The consequence is that, in the absence of pathognomonic signs, confirmation or declination of an LRF case by a veterinarian consulted by the insurance company is likely to be an empiric decision, driven to some degree by chance. Also, second opinions by independent assessors are seldom consulted for LRF declarations, at least not in Belgium.

To deal with this issue, several expert veterinarians contact their National Meteorological Service to check whether lightning impacts were detected at the time and location of the suspected death. Lightning data mainly consist of cloud-to-ground (CG) lightning. This information is not used systematically by the expert veterinarian, since consultation implies additional costs for the insurance company. Whether detection or non-detection of CG discharges are reliably associated with LRF in livestock has never been evaluated. Therefore, the primary aim of the present study was to provide objective information on anamnestic, environmental and pathological findings in LRF cases, based on a large data set involving 410 declarations, spread over 15 years of veterinary expert investigation, for insurance companies in Flanders, Belgium. Predictive models for LRF in livestock were constructed and the possible added value of using lightning location data (LLD) to confirm LRF cases was evaluated.

Table 1
Gross postmortem diagnoses in 141 declined (negative) declarations of lightning related fatalities in livestock.

Diagnosis	Number[a]	%[b]
Respiratory system	26	33
Bacterial bronchopneumonia	14	18
Verminous bronchopneumonia	2	3
Aspiration pneumonia	3	4
Pulmonary hemorrhage	3	4
Asphyxiation	2	3
Drowning	2	3
Cardiovascular system	4	5
Cardiomyopathy	3	4
Aortic rupture	1	1
Gastrointestinal system	24	30
Peritonitis post-Caesarian section	9	11
Traumatic reticuloperitonitis	5	6
Perforating abomasal ulceration	4	5
Intestinal volvulus	3	4
Enterotoxaemia	2	3
Iatrogenic ruminal tear	1	1
Urinary system	1	1
Urethral rupture	1	1
Reproductive system	12	15
Toxic mastitis	5	6
Uterine rupture	3	4
Dystocia	3	4
Toxic endometritis	1	1
Miscellaneous	13	16
Bluetongue	2	3
Dehydration	2	3
Taxus baccata intoxication	2	3
Trauma	1	1
Pregnancy toxaemia	1	1
Leucosis	1	1
Abscess with toxaemia	1	1
Septicaemia	3	4
No gross diagnosis	57	
Advanced postmortem decomposition	4	

[a] A final diagnosis could be made in 80/141 cases.
[b] Expressed over the total number of postmortem examinations with a diagnosis ($n = 80$).

Materials and methods

Study design

A retrospective case series of declared LRF cases based on the records available in the archives of a veterinary expertise and advice agency (DEAB, Merelbeke, Belgium) was analysed. In Flanders, the number of specialised expert veterinarians is estimated at 15, based on their regular contact with the Royal Meteorological Institute of Belgium (RMIB) concerning LRF. The available archive represents one of the largest expert practices in Flanders, covering a 15 year period from 1998 to 2012.

The inclusion criterion to determine the relevant cases for analysis was defined as: 'any animal reported to the insurance company with suspicion of death by lightning and subsequently investigated by the expert veterinarian'. The expert investigation in this study was always performed by the same veterinarian following a standardised approach. First, the owner was interviewed to obtain a detailed case history. Next, the environmental conditions in which the animal was found were inspected. Finally, pathological examination of the cadaver was performed. Pathological examination was in most cases, for sanitary reasons and economy, limited to a thorough visual inspection of posture, abdominal distension, eyes, skin and mucosae, combined with palpation. If the expert veterinarian could not base a decision on the information obtained by these methods, a standardised field postmortem examination was performed (Vanneste et al., 2011).

If any doubt remained after the postmortem examination, the RMIB was contacted to confirm whether or not there had been CG activity in the environment at the probable time of death. All cases that remained doubtful after this approach were given the benefit of the doubt and classified as positive for LRF.

In all 410 cases, the Lightning Location System (LLS) of the RMIB (Poelman et al., 2013) was used to check whether CG activity was observed at the location and suspected time of interest; this information was added to the data set. The performance of the LLS has been tested against ground-truth data using high-speed video and electrical field measurements (Poelman et al., 2013), resulting in a median location accuracy (LA) of 1.0 km and a flash detection efficiency (DE) of 92% in Belgium. A time window of 3 days before and 1 day after the suspected time of death was applied, to account for the difficulty in pinpointing the exact moment of death. A radius of 10 km around the indicated location was examined.

The records were checked for 23 parameters potentially associated with LRF (Table 1). The parameters were divided into three sets. The first set consisted of anamnestic parameters involving both the animal and timing of the LRF declaration, the second set included environmental parameters at the time of inspection and the third set consisted of pathological findings. An object (e.g. tree, water) was considered to be in the near surroundings of a suspect case if present within a 10 m radius around the cadaver. The interval from death to expert investigation was calculated by subtracting the date of the reported death by the farmer from the date of the investigation. The occurrence of an LRF declaration within 3 days of another declaration was determined by comparing the date of declaration with the date of the previous and next case in the data set.

Statistical analysis

Significant associations between the predictor variables were determined using the χ^2 test, with significance set at $P < 0.05$. Special attention was paid to parameters associated with the presence of singe lesions, which are regarded as pathognomonic for LRF. To predict which parameters were associated with confirmation of an LRF case by the expert veterinarian, a multivariable logistic regression model was built. Of the 23 parameters, four could not be included in the model building process, since they only occurred in either the positive or negative decisions, leaving 19 parameters for model building purposes (Table 1). These four parameters were the presence of singe lesions, the presence of a tree with signs of recent lightning impact, the presence of a filled gastrointestinal tract or the presence of typical gross lesions at postmortem examination. To estimate the seasonal effect, a binary variable was constructed involving the known risk months for lightning storms (May–September) compared to the other months (Poelman et al., 2012).

In the first step, all factors were tested univariably for their association with 'confirmation as an LRF case by an expert veterinarian' and factors with a P value <0.20 were withheld for the multivariable model. This multivariable model was built stepwise backwards, progressively excluding non-significant predictors. Significance was set at $P < 0.05$ and $P < 0.10$ was considered to be a trend. Associations between significant predictors were tested using the χ^2 test and by Fisher's exact test for small sample sizes. All biologically relevant interactions between two main effects were tested. Model validity was based on the Hosmer–Lemeshow test for logistic models.

To determine the added value of lightning detection data provided by the LLS for the confirmation of LRF cases, the sensitivity (Se) and specificity (Sp) of the basic model (without parameters documenting lightning detection) and models containing CG were compared. The probability that each case would be classified as an LRF case by the expert veterinarian was calculated according to the different models; predicted probabilities ≥0.5 were classified as positive cases (default cut-off value for logistic models). Se, Sp, and positive and negative predictive values were calculated as described by Dohoo et al. (2009). All analyses were performed using SPPS version 21 (IBM).

Results

A total of 410 reports of death by lightning to insurance companies were recorded by the veterinary expert agency from 1998 to 2012. LRF declarations were the main reason for veterinary expert investigation, representing on average of 23% (standard deviation 6.7%; range 11.6–36.6%) of the annual total number of reports from 1998 to 2012 in this agency. Of the LRF declarations, 217/410 (52.9%) were rejected (negative advice) by the expert veterinarian and 194/410 (47.3%) were accepted as an LRF (positive advice). Of these 194 cases, 16 (8.2%) were given the benefit of the doubt and accepted on the basis of a lack of conflicting evidence.

There were no significant differences in the number of positive cases between years ($P = 0.99$). A seasonal incidence of LRF declarations was evident, with most LRF cases occurring from May to September (Fig. 1). The highest number of lightning declarations, both positive and negative, were found from June to August, which coincides with the risk period for lightning storms in Belgium. Most of the cases involved cattle (388/410, 94.6%). Draft horses ($n = 7$), Belgian Warmblood horses ($n = 8$) and donkeys ($n = 2$) accounted for 4.1% of cases, while other species affected were a pig, two deer and two ostriches (1.2%; $n = 5$).

In 208/410 (50.7%) reports, a full postmortem examination was performed in addition to the standard protocol. Of these postmortem examinations, 141 (67.8%) were performed in cases declared as negative (not LRF). Gross diagnoses are provided in Table 1. In the confirmed cases, no gross lesions suggestive of an alternative diagnosis were found, but this was also the case in 40.0% of the negative cases (Table 1). Singe lesions were present in 84/194 (43.3%) confirmed cases, but absent in all but one declined case; this case was fraudulent, since the owner deliberately burned the animal postmortem. Factors which were significantly associated with the presence of singe lesions were the declaration within 3 days of another LRF case ($P < 0.001$), presence of feed in the oral cavity ($P < 0.001$), tympany at postmortem examination ($P < 0.01$) and the detection of CG ($P < 0.001$) by the RMIB at the suspected date and location.

Table 2 provides an overview of the association between the anamnestic, environmental and pathological parameters, and the final classification of the case as consistent (positive) or not consistent (negative) with LRF. Many factors were univariably associated with classification as LRF by the expert veterinarian (Table 2). Several parameters, such as the presence of a tree with signs of a recent lightning impact in the near surroundings, singe lesions, absence of gross lesions at postmortem examination and a filled gastrointestinal tract at postmortem examination could not be used for modelling purposes, since they occurred exclusively in the positive cases.

Model building was limited to cattle, since most cases occurred in this species ($n = 388$). The final multivariable model to predict a positive advice by an expert veterinarian on a declared LRF case consisted of six parameters, as shown in Table 3. The two parameters indicating detection of lightning at the time and location of the declared case, namely 'declaration of an LRF case within 3 days of another' and CG, were highly correlated ($P < 0.001$) and therefore could not be used together in the model. Table 3 shows the logistic regression results for all three parameters. The displayed model contained 'declaration of an LRF case within 3 days of another case'. The contribution of the other five variables in the model did not change substantially when this parameter was replaced by CG. Therefore, the logistic regression results for CG are also shown in Table 3, separated from the full model. This was done to fully illustrate the information available in Table 4.

Table 4 shows the Se, Sp, and positive and negative predictive values, of different logistic models, based on lightning detection and other parameters. A model with only the presence of singe lesions had a low Se (42.9%), but high Sp (100.0%). In contrast, the model only containing CG as the predictor variable resulted in a high Se (91.3%), but low Sp (41.2%). The basic model, with six predictors, as shown in Table 3, displayed a higher Sp compared to the single parameter CG models, but a lower Se. Nevertheless, this basic model classified more cases correctly (71.9% compared to 65.0% for CG). Adding CG to the basic model strongly increased Se (from 53.8% to 89.1%), with a moderate reduction in Sp (from 88.2% to 66.7%).

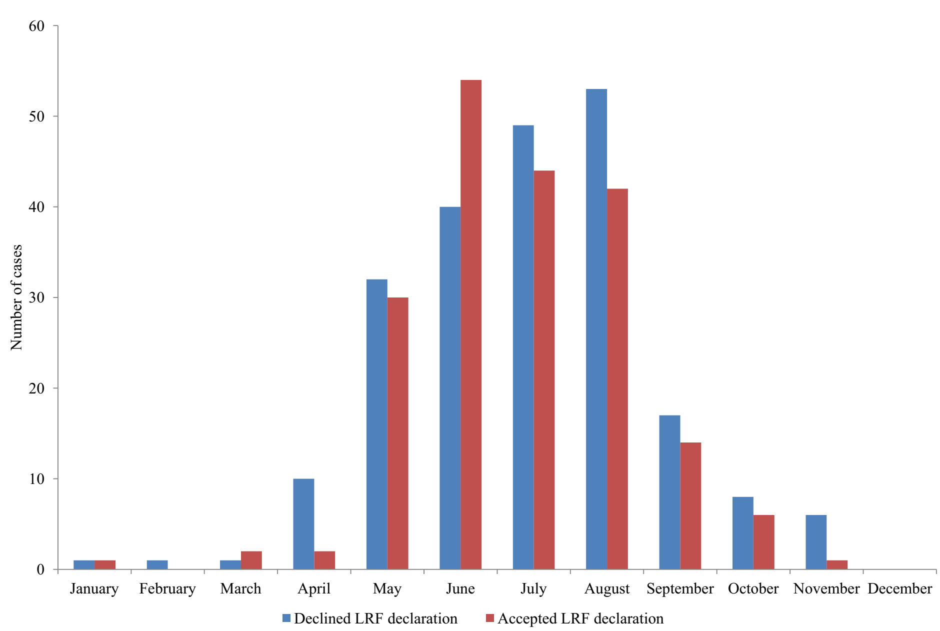

Fig. 1. Monthly distribution of accepted and declined lightning related fatality (LRF) declarations in livestock in a veterinary expert agency in Flanders (1998–2012).

Table 2
Overview of factors potentially associated with confirmation of lightning strike in livestock by an expert veterinarian.

Factor	Category	Negative advice expressed as % of cases (number of cases/total)	Positive advice expressed as % of cases (number of cases/total)	*P* value[a]
Anamnestic factors				
Interval from death to expert visit (days)	Mean (standard deviation) min–max	1.9 (2.3) 0–21	1.9 (2.8) 0–23	0.92
Month of declaration	May, June, July, August or September	51.1% (189/370)	48.9% (181/370)	0.05
	Other months	67.5% (27/40)	32.5% (13/40)	
Animal species	Horses and donkeys	52.9% (9/17)	47.1% (8/17)	0.5
	Bovine	52.6% (204/388)	47.4% (184/388)	
	Other	80.0% (4/5)	20% (1/5)	
Cattle breed	Limousin, Blonde d'Aquitaine	75.0% (18/24)	25.0% (6/24)	0.04
	Belgian Blue	54.4% (142/261)	45.6% (119/261)	
	Holstein–Friesian	44.0% (37/84)	56.0% (47/84)	
	White and Red Eastern Flanders	46.2% (12/26)	53.8% (14/26)	
Sex	Male	58.8% (50/85)	41.2% (35/85)	0.20
	Female	51.1% (166/325)	48.9% (159/325)	
Age	<1 year	60.2% (59/98)	39.7% (39/98)	0.09
	≥1 year	50.3% (157/312)	49.7% (142/312)	
Declaration within 3 days of another lightning strike declaration	No	71.1% (64/90)	28.9 (26/90)	<0.001
	Yes	47.8% (153/320)	52.5 (168/320)	
Cloud-to-ground lightning (CG)	No	84.1% (90/107)	15.9% (17/107)	<0.001
	Yes	41.9% (127/303)	58.4% (177/303)	
Environmental factors				
Location	Stable	61.1% (11/18)	38.9% (7/18)	0.46
	Pasture	52.3% (205/392)	47.7% (187/392)	
Number of affected animals	Single animal	53.4% (207/388)	46.6% (181/388)	0.36
	Multiple animals	45.5% (10/22)	59.0% (13/22)	
Tree in the near surroundings of the animal[b]	No	56.1% (193/344)	43.9% (153/344)	0.02
	Yes	34.8% (23/66)	65.2% (43/66)	
Tree with signs of recent lightning strike in the near surroundings[b]	No	55.1% (216/392)	44.9% (176/392)	<0.001
	Yes	0% (0/18)	100% (18/18)	
Presence of open water in the near surroundings[b]	No	54.2% (200/369)	45.8% (169/369)	0.06
	Yes	39.0% (16/41)	61.0% (25/41)	
Presence of an electric fence in the near surroundings[b]	No	55.4% (153/276)	44.6% (123/276)	0.11
	Yes	47.0% (63/134)	53.0% (71/134)	
High tension power lines crossing pasture	No	53.4% (213/399)	46.6% (186/399)	0.09
	Yes	27.3% (3/11)	72.7% (8/11)	
Pathological factors				
Position	Sternal recumbency	53.8% (14/26)	46.2% (12/26)	0.90
	Lateral recumbency	52.6% (202/384)	47.4% (182/384)	
Presence of tympany	No	88.9% (40/45)	11.1% (5/45)	<0.001
	Yes	48.2% (176/365)	51.8% (189/365)	
Presence of feed in the oral cavity	No	63.4% (211/333)	36.6% (122/333)	<0.001
	Yes	6.5% (5/77)	93.5% (72/77)	
Haemorrhage	No	52.9% (194/367)	47.1% (173/367)	0.83
	Yes	51.2% (22/43)	48.8% (21/43)	
Singe lesions on the skin	No	66.2% (215/325)	33.8% (110/325)	<0.001
	Yes	1.2% (1/85)	98.8% (84/85)	
Presence of gross lesions at postmortem examination	No	34.0% (34/100)	66.0% (66/100)	<0.001
	Yes	99.1% (107/108)	0.9% (1/108)	
Filled gastrointestinal tract at postmortem examination	No	100.0% (28/28)	0% (0/28)	<0.001
	Yes	62.8% (113/180)	37.2% (67/180)	

NA, not applicable, not possible to evaluate in a logistic model because one of the categories does not contain enough observations; max, maximum; min, minimum.
[a] *P* value as determined by univariable logistic regression with confirmation as a case of lightning strike by the expert veterinarian as the outcome variable.
[b] Near surroundings defined as 10 m radius around the animal.

The latter model performed best, classifying up to 77% of cases correctly.

Discussion

Livestock are periodically exposed to CG lightning, albeit at different frequencies in different regions of the world. On the European mainland, there are 0.5–4 lightning flashes/km^2/year, whereas lightning is more frequent in the USA (1–9 flashes/km^2/year) (Finke and Hauf, 1996; Orville and Huffines, 2001; Schulz et al., 2005; Antonescu and Burcea, 2010; Mäkelä et al., 2014). The highest density of lightning flashes in the world is observed in the Congo basin (80 flashes/km^2/year; Christian et al., 2003). Belgium is at moderate risk, with about 35,000 lightning flashes to the ground per year, with a mean flash density of ~1/km^2/year (Poelman et al., 2012). Thunderstorms are more frequent during the summer months, coinciding with an increased incidence of LRF declarations.

In the present study, 217/410 (52.9%) declarations of possible LRF were not consistent with LRF on expert veterinary investigation. Possible explanations are that farmers initially think of LRF when confronted with sudden deaths on pasture in summer, or, less honestly, see the opportunity to fraudulently report dead animals as LRF cases. This observation makes it clear that veterinarians charged with an LRF investigation for an insurance company face a difficult job in many cases and would benefit from a risk model estimating the likelihood of the case being consistent with LRF. Therefore, the aim of the present study was to identify factors contributing to a reliable diagnosis of death by lightning in livestock.

A first important finding was that only 84/194 (43.3%) accepted cases showed pathognomonic singe lesions, in contrast to

Table 3
Multivariable logistic regression model to predict acceptance of a lightning related fatality (LRF) by the expert veterinarian, based on 388 reports of LRF in cattle (1998–2012).

Factor	Level	Number of observations	Odds ratio	95% Confidence interval of odds ratio	*P* value
Age	<1 year (reference)	92			
	≥1 year	296	2.0	1.1–3.6	0.02
Tree in the near surroundings	No (reference)	327			
	Yes	61	2.0	1.0–4.1	0.04
Presence of open water in the near surroundings	No (reference)	354			
	Yes	34	4.5	1.8–11.1	<0.001
Presence of tympany	No (reference)	36			
	Yes	352	8.9	2.7–29.1	<0.001
Presence of feed in the oral cavity	No (reference)	314			
	Yes	74	28.2	9.8–81.2	<0.001
Declaration within 3 days of another LS declaration[a]	No (reference)	84			
	Yes	304	3.9	2.0–7.4	<0.001
Cloud-to-ground lightning[a]	No (reference)	100			
	Yes	288	13.9	6.2–31.1	<0.001

[a] Highly correlated factors documenting the detection of lightning at the time and location of the declaration. These factors cannot be put into the same model. The logistic regression model for 'declaration within 3 days of another lightning strike declaration' is shown. Changing this variable by cloud-to-ground lightning did not substantially change the other parameters in the model. The results for both lightning strike detection factors are displayed in this table in order to provide the reader with the full information to interpret Table 4.

80–90% reported by Kahn and Line (2005). Step potentials are the most common lightning hazard for animals and do not cause burn lesions, in contrast to direct or indirect flashes (Gomes, 2012). In human medicine, Lichtenberg figures (branching reddish-brown cutaneous patterns) are often present, but disappear quickly (Andrews et al., 1992; Lewis, 1997; O'Keefe Gatewood and Zane, 2004). In animals, Lichtenberg figures have rarely been reported (Zele et al., 2006); they were not observed in the present case series.

The presence of feed in the oral cavity was not exclusively found in LRF cases, raising the question as to whether this finding is pathognomonic for LRF. The possibility that farmers deliberately put feed into the mouth of a dead animal cannot be excluded. Other factors were the presence of a tree or water in a 10 m radius around the cadaver, making it more likely that death was due to lightning (Ritenour et al., 2008). The fact that animals ≥1 year were more frequently affected could be explained by their larger size.

As illustrated in this case series, at least some farmers have the intention to confuse the veterinary expert by creating burn marks postmortem in an attempt to reproduce singe lesions. These observations, together with the common occurrence of step potentials (Gomes, 2012), make it clear that confirmation of LRF based only on these signs will not be sufficient. Therefore, the veterinarian has to compare field observations with accurate LLD. Conversely, our study shows that relying solely on detection of CG discharges at the time and location of the case will correctly predict most of the positive cases (high Se; CG detected in 94.3% of positive cases), but performs poorly in the identification of negative cases (low Sp; CG detected in 58.5% of negative cases), resulting in a large number of false positive declarations.

In other words, it is not because lightning has been detected at the time and location of death that the animal truly died from a fatal lightning impact. Possible explanations for these false positive declarations include the likelihood that farmers think of an LRF when a thunderstorm occurred, or see an opportunity for a fraudulent action. The reason why CG lightning was not detected in every positive case (5.7%) might be due to misclassification by the expert veterinarian or because the efficiency of detection of lightning strike by the LLS is <100% (Poelman et al., 2013).

The basic model, constructed on the basis of the veterinary expert investigation, was better at identifying false positive cases than using CG data alone, but lacked the discriminative power for identifying true positive cases. When combining the basic model with CG data, the highest combined Se and Sp was obtained, resulting in a correct prediction in 77.0% of cases. For the insurance company, the real value of the expert visit, in addition to LLD, lies in the analysis of circumstantial evidence and pathological findings, in order to identify false positive declarations.

The main difficulty in the design of the present study was to formulate a correct case definition for an LRF. Since there is no gold standard to diagnose an LRF, a misclassification or systematic bias by the expert veterinarian cannot be excluded completely. However, since all investigations were performed by a single veterinarian using a standardised protocol, all declarations were treated in the same way. Another advantage of the present data set is that the expert veterinarian has extensive experience in LRF declarations, given the high number of annual declarations treated and the many years of experience. If any misclassification occurred, this would only have introduced a systematic error, rather than a random error.

The predictive models constructed in the present study can be used to aid inexperienced evaluators in their decision making process, ensuring a high level of diagnostic consistency, at least within the one agency. Ideally, the models built on the present data should be validated against large data sets from other expert agencies, in order to assure good external validation. Unfortunately, no well-organised data sets large enough were available in Flanders. Nevertheless, the present models form a unique source of information to aid less experienced veterinarians, dealing with few cases each year, in achieving improved diagnosis of LRF in livestock.

According to the present study, the best way to approach an LRF declaration is by first looking for pathognomonic signs of direct or indirect lightning strike (singe lesions or presence of a tree with signs of lightning impact), since they are highly specific (few false positives). If these signs are absent, the presence of the factors mentioned in the basic model should be checked carefully, to ensure the highest specificity in identifying true negative cases. The present study has shown that, in non-pathognomonic cases, it is advisable to obtain

Table 4
Sensitivity and specificity of logistic models with and without lightning location system data to predict a diagnosis consistent with lightning strike in cattle by the expert veterinarian.

Model	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Percentage correct (%)
Singe lesions	42.9	100.0	100.0	66.0	72.9
Cloud-to-ground lightning[a]	91.3	41.2	58.2	84.1	65.0
Basic model (Table 3)	53.8	88.2	88.2	67.9	71.9
Basic model + 'Declaration within 3 days of another lightning strike declaration'	51.6	91.7	84.8	67.8	72.7
Basic model + 'Cloud-to-ground lightning'	89.1	66.7	70.7	87.2	77.3

[a] Lightning location system is represented by the variable 'Cloud-to-ground lightning'.

LLD to increase the rate of detection of true positive cases. This combined approach would be likely to result in the most evidence based decision making process. To further increase the diagnostic accuracy of LRF, systematically performing a postmortem examination should be further encouraged, even though this is not always easy in practice.

Conclusions

The present study has shown that LRF in livestock is relatively frequent in Flanders and is the primary reason for field investigations by a veterinary expert. Pathognomonic signs are not always present and incorrect declarations are frequent. In the absence of pathognomonic signs, the combination of circumstantial evidence, and external and internal pathological findings, collected during the veterinary expert investigation, combined with LLD, results in the highest probability of correctly diagnosing an LRF case. This systematic approach should be encouraged to optimise the correct diagnosis of LRF cases and to ensure correct financial compensation by insurance companies.

Conflict of interest statement

Dr. Weyens has been financially compensated for performing the veterinary expert investigations from 1998 to 2012 for insurance companies. No other authors have a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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