Development of clinical sign-based scoring system for assessment of omphalitis in neonatal calves

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Omphalitis contributes significantly to morbidity and mortality in neonatal calves. Diagnosis of omphalitis is based on the local signs of inflammation—pain, swelling, local heat and purulent discharge. An abattoir trial identified an optimal, sign-based, scoring system for diagnosis of omphalitis. A sample of 187 calves aged between 7 and 15 days old were clinically examined for signs of umbilical inflammation and compared with postmortem examination of navels. On postmortem findings, 64 calves (34.2 per cent) had omphalitis. In the examined omphalitis cases, the most commonly affected umbilical structure was the urachus (78.1 per cent). Multivariable logistic regression revealed that thickening of the umbilical stump over 1.3 cm ($P<0.001$), discharge ($P<0.001$), raised local temperature ($P=0.003$) and the presence of umbilical hernia ($P=0.024$) were correlated and positive predictors of omphalitis. Discharge from the umbilical stump was associated with intra-abdominal inflammation ($P=0.004$). Assigning weights based on the multivariable logistic regression coefficients, a clinical scoring algorithm was developed. The cumulative score ranged from 0 to 9. Using this scoring system, calves were categorised as positive if their total score was ≥2. This scoring method had a sensitivity of 85.9 per cent, specificity of 74.8 per cent and correctly classified 78.6 per cent of all calves.

Introduction

At birth, the calf is sterile and is born in a pathogen-rich environment. The umbilicus is a sensitive porte d'entre for these pathogens to invade the calf's body. Navel ill or inflammation of the umbilicus can remain localised or diffuse into generalised peritonitis. In addition, it can ascend to the liver or be a source of septicaemia.[1,2] Omphalitis has been described as inflammation of any of the three component structures of the umbilicus—the two umbilical arteries, the umbilical veins and the urachus.[2] In omphalitis, the urachus is the most commonly affected structure in calves and the umbilical arteries least frequently affected.[3] Additionally, there may be inflammation or swelling of the surrounding tissues or other intra-abdominal structures may also be involved. The infection of any of these structures will manifest with the overt signs of inflammation—heat, swelling, purulent discharge and pain and could significantly contribute to neonatal morbidity and mortality.[4,5] The common causal agents of omphalitis are opportunistic bacteria[6] and in the past, various figures for incidence or mortality due to omphalitis have been reported. Donovan *et al*[7] reported cumulative incidence of 11 per cent, while Virtala *et al*[4] gave a higher incidence of 14 per cent. In a veal calf system, Pardon *et al*[8] recorded an incidence of 0.01 omphalitis cases per 1000 calf days at risk. Thomas and Jordaan[9] reported omphalitis as the main reason for preslaughter mortality in 23 per cent of calves. According to the same authors, omphalitis was also the most common cause of postslaughter wastage (97 out of 180 calves, i.e., 54 per cent of condemned carcases).

Despite the major impact omphalitis has on neonatal calf health, and consequently, on various production parameters (e.g., growth rates), there is a lack of peer-reviewed research in the area of navel ill diagnostics and specifically on the association between clinical signs and omphalitis. Farmers associate navel ill with the visible swelling of the umbilicus, pain and discharge or delays in drying up.[10] This most common description of navel ill is practical and easy to use on the farm and allows for simple evaluation of navel ill without the need for specialised diagnostic techniques or expensive and complicated equipment. Additionally, it has the benefit of including inflammations affecting all structures of

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the umbilicus, that is, omphalophlebitis, omphaloarteritis and urachitis. Although some neonates could appear completely normal, with dry external navel, they could be severely ill from intra-abdominal inflammation of the urachus, umbilical arteries and/or veins.[1 11] This makes it difficult to rely on topical signs of inflammation only, for reaching a clinical diagnosis and the reliability of these signs has to be further evaluated. Robinson *et al*[12] have published clinical data on the normal umbilicus and its healing rates within the first 24 hours of life. However, no clinical protocol or clinical signs algorithm for detection of navel ill in calves has been assessed or validated in the past.

Considering the importance of early and accurate detection of omphalitis and with the aim to create a scoring system similar to the scoring systems for bovine respiratory disease,[13–15] this paper describes a study that evaluates the reliability of clinical signs used by farmers and vets to assess the umbilicus (and/or the navel stump), with the ultimate goal to present an individual sign approach or a composite algorithm to diagnose omphalitis.

Animals, materials and methods

For the purpose of determining the diagnosis of the navel region, it was decided to evaluate the navel on post mortem. This enabled authors to reach a detailed diagnosis of the navel, as well as the deeper involvement into the abdomen of calves. This study population can be defined as healthy calves suitable for human consumption. However, omphalitis (and specifically omphalitis affecting internal umbilical structures) is frequently unobserved by farmers or omitted on clinical examination and therefore only detected after submission to the abattoir at post mortem. An abattoir in South Wales was recruited that takes young male calves on a commercial basis (approx. age of slaughter 10–14 days), as this type of livestock is not economically viable to rear or fatten. The Buderer's method[16] was used to calculate the sample size and the need for adequate sensitivity (Se) and specificity (Sp) through incorporating the omphalitis prevalence. As previously reported,[4 5] the prevalence of omphalitis ranges between 5 per cent and 15 per cent. The sample size for this study was calculated as 183 calves, based on the higher figure of 15 per cent prevalence.

Antemortem clinical exam

The age of calves in the examined group varied between 7 and 15 days. All calves were Holstein-Friesian bull calves. They originated from local farms and were presented for slaughter on the day of examination. Clinically, omphalitis was defined as 'inflammation of any of the umbilical structures—including the umbilical arteries, umbilical vein, urachus or tissues immediately surrounding the umbilicus'.[2] The calves were examined for the topical clinical signs of omphalitis. The topical signs that were recorded were pain, swelling (thickness) of the umbilical stump, raise in temperature (local heat) and the presence of pus (discharge). Change of tissue colour (redness), even though present in some cases, was omitted as difficult to visualise, due to thick hair coat and therefore less practically relevant.

Additionally, cases of an umbilical hernia, patent urachus, concurrent inflammatory conditions (joint ill and lameness) and concurrent systemic illness (if present) were also recorded for each calf. Kyphosis was recorded as a sign of intra-abdominal pain, and deep abdominal palpation was performed to detect abdominal wall tension and abdominal pain as a distinct entity from umbilical stump pain. Pain was assessed through palpation (firm squeeze) of the umbilical stump (always before abdominal palpation) and the elicited pain response —flinch and kyphosis. Flinch, kyphosis and kicking are subjective behavioural responses to a 'noxious', that is, potentially tissue-damaging stimulus and as such are imperfect indicators of measurable pain response.[17 18] However, similar to other behavioural responses, they have the advantage of occurring immediately after palpation (examination) and can be measured non-invasively.[19]

Heat was measured with a non-contact IR Digital Infrared Thermometer (Standard ST 88618 Dual Laser (N85FR)), and two continuous scanning measurements were taken for each calf: one at the umbilical stump and one at the midpoint of the sternum (as a reference point for external body temperature). Two recordings were made at each location, and the highest reading for each was recorded. Cut-off points for normal stump temperature were explored based on measures of central tendency of the study data set and the highest sensitivity and specificity of elevated temperature as a test determinant for detection of omphalitis. Calves with a stump temperature 0.5°C higher than the referent sternal temperature were considered potentially affected with navel ill.

The thickness of the umbilical stump was measured at midpoint between the base of the stump and the end of the stump using vernier digital callipers and recorded in centimetres with a precision of two decimals. Based on previous normal physiological data reported by Robinson *et al*[12] and the sensitivity and specificity derived from the sample data, swelling over 1.3 cm was considered pathological and therefore calves with swelling over this threshold were positive for navel ill.[12] The presence or absence of umbilical hernia was established through palpation, and any palpable opening was recorded as a positive result.

The discharge was assessed according to its physical characteristics as serous, mucoid, purulent and haemorrhagic (sanguineous) or as a combination of these. The volume and the origin of discharge were also described and recorded. Patent urachus was distinguished from discharge and draining abscesses through evaluation for the origin of the discharge, the depth of the passage or abscess and the presence of urine draining from the umbilical stump.

Postmortem examination

A gross postmortem examination was performed on all calves, and any visible tissue changes due to inflammatory reaction (both extra-abdominally and intra-abdominally) were recorded following the established guidelines of pathological anatomy.[20 21] All navels were sliced, and the appearance of the cut surface was described. Each affected umbilical structure (urachus, umbilical arteries, umbilical veins or surrounding soft tissues) was noted separately and for each individual calf, specifying if the inflammatory reaction was intra-abdominal or extra-abdominal (or both) along with a description of the size and location of the lesions and the severity of the inflammatory process. The presence of any visible (gross) postmortem tissue change (lesion), in any of the umbilical structures, was defined as a case of omphalitis. 'Intra-abdominal' omphalitis was defined as any gross postmortem lesion of the intra-abdominal umbilical structures (artery, veins or urachus), with or without other organs involvement (liver and bladder) but in the absence of externally visible lesions, detectable in the live animal preslaughter.

Statistical analysis and algorithm development

Individual inflammatory signs were assessed as diagnostic tools for detection of omphalitis through calculating percentage agreements and sensitivity and specificity. These were assessed by comparison with the gross postmortem findings of navel ill at the abattoir.

Each clinical sign was dichotomised (present or absent) and univariable logistic regression was used to evaluate the relationship between the main clinical signs and the outcome (the presence or absence of omphalitis at post mortem), that is, to estimate the relative odds of postmortem lesions occurring, with each clinical sign present. The individual clinical signs were investigated for potential collinearity before creating a working model, and once they satisfied this criterion, the five statistically significant clinical signs were fitted in the regression model. Variance inflation factor (VIF) higher than 5.0 was considered a positive indicator for the presence of collinearity.[22]

Multivariable logistic regression[23] was performed to assess the relationship between the main clinical signs combined and the presence of omphalitis at post mortem. After stepwise removal of the non-significant variables, the goodness of fit of the final multivariable logistic model was evaluated by using the Hosmer-Lemeshow test.[24–26]

The final multivariable logistic regression model was used to create a scoring system for omphalitis by taking into account the relative contributions of each of the clinical symptoms. A score weight was assigned to each abnormal clinical sign, and the size of this score was defined as the logarithmic scale value of the corresponding regression coefficient (β or beta weight) rounded to the nearest integer.[15 27] The absence of each sign was assigned 0 points, and the total score value for each individual calf was calculated as the sum of the score weights for each recorded clinical sign. This summed value (i.e., the total score value for each calf) was further used to calculate the probability of positive result for each one of the examined calves.

The score cut-off points were investigated through calculating sensitivity, specificity and positive and negative likelihood ratios for each possible cut-off point of the total score. Receiver operating characteristic (ROC) curve plots were fitted to the total calf scores (i.e., summed values) and overall predictive accuracy (c-statistic) values for all possible cut-off points were calculated.[28] The optimal cut-off point was finally determined as the score that had the highest probability of a correct result, the highest c-statistical value and had correctly identified the greatest proportion of calves over all of the threshold points.[15] This methodology was adapted from previous research.[15 27] Additionally, the same process was applied for intra-abdominal omphalitis. All analyses were conducted using IBM SPSS Statistics 23.0 2015 (IBM Corp., Armonk New York, USA).

Results

In total, 187 calves were evaluated over a period of eight consecutive days. The overall sample prevalence of navel ill in this study was found to be 34.2 per cent at post mortem (64 of all calves). The prevalence of intra-abdominal involvement in the omphalitis cases was 29.7 per cent (19 out of 64 calves). The overall percentage prevalence of omphaloarteritis at post mortem was 7.0 per cent (n=13), of omphalophlebitis −14.4 per cent (n=27) and of urachitis −26.7 per cent (n=50). All three structures were affected in 17.2 per cent (n=11) of omphalitis calves. Omphaloarteritis was, therefore, the least and urachitis the most frequently observed condition. The sample mean for the size of the navel in the current study was 1.3 cm with SD of 0.7 cm.

Of all examined calves, only four presented with joint ill and elevated rectal temperature (over 39.3°C). Three of those were with all four legs affected (multiple joints) and had concurrent omphalitis. One calf had a swelling of a single tarsal joint but had no detectable signs of omphalitis and no umbilical lesions at post mortem. All four calves were with palpably enlarged joints but not severely lame, which explains why they may have failed detection before transport.

Of examined calves, 68.4 per cent presented with at least one of the main clinical symptom (128 calves). A substantial number of calves exhibited both pain and thickened umbilical stump—49 per cent or 26.2 per cent of all calves. Twenty-nine calves (15.5 per cent of all

TABLE 1: Univariable logistic regression parameters for the main clinical signs as indicators of omphalitis							
						95% CI	
Sign	Regression coefficient	se	Wald statistic	P value	OR	Lower	Upper
Pain	1.32	0.32	16.48	0.000	3.74	1.98	7.06
Swelling*	1.60	0.33	23.09	0.000	4.96	2.58	9.53
Heat†	1.54	0.33	21.41	0.000	4.65	2.42	8.91
Discharge‡	3.98	0.76	27.71	0.000	53.38	12.14	234.75
Hernia	1.45	0.63	5.22	0.022	4.25	1.23	14.71
Urachus§	1.37	1.24	1.23	0.267	3.94	0.35	44.25
Palpation¶	−0.48	0.60	0.65	0.420	0.62	0.19	2.00

*Swelling of the umbilical stump over 1.3 cm in diameter.
†Rise of stump temperature with 0.5°C above the reference sternal temperature.
‡Purulent and/or haemorrhagic.
§Patent urachus.
¶Palpation for abdominal pain.

calves) exhibited both thickened umbilical stump and raised local temperature (>0.5°C rise in stump temperature over the referent sternal temperature). Individually, 70 of all calves (37.4 per cent) exhibited pain when firm pressure ('squeeze') was applied at the stump, and 37 of these were found to have omphalitis at post mortem (57.8 per cent of cases). These numbers for swelling were 66 (35.3 per cent of all examined calves) versus 38 (59.4 per cent of omphalitis cases), for local heat 65 (34.75 per cent) versus 37 (57.8 per cent) and for umbilical hernia 12 (6.4 per cent) versus 8 (12.5 per cent).

The majority of evaluated calves with discharge (32 calves or 17.1 per cent) presented with visible fibrino-suppurative (pus-like) discharge. Only three calves presented with a combination of haemorrhagic and purulent discharge (9.4 per cent of all navels with discharge) and no calves presented with clear serous type of discharge. Consequently, these categories were combined into a single value (purulent discharge, i.e., pus) for further analysis. At post mortem, 93.8 per cent of all calves with discharge (n=30) were confirmed with either purulent abscessation along the umbilical cord (intra-abdominal omphalitis; n=9 or 30 per cent) or with an abscess at the umbilical stump (n=21 or 70 per cent of cases with discharge).

Regression modelling for omphalitis

Univariable binary logistic regression revealed a statistically significant association between the main individual clinical signs of pain, swelling, heat, discharge, the presence of umbilical hernia and the presence of omphalitis at post mortem (Table 1). All analysed clinical signs with the exception of umbilical hernia were correlated with omphalitis at the P<0.001 level.

The visible presence of pus (discharge) was ranking highest (β=4.0, P<0.001), followed by swelling (β=1.60, P<0.001), pain (β=3.0, P<0.001) and heat (β=1.5, P<0.001). To a lesser degree, concurrent umbilical hernia was also associated with omphalitis (β=1.5, P=0.022). Patent urachus (P=0.267) and abdominal palpation for abdominal pain (P=0.420) were not associated with omphalitis and excluded from further consideration.

The multivariable logistic regression (Table 2) identified four clinical indicators to be statistically significant and correlated with omphalitis at post mortem. These were swelling, local heat, discharge and umbilical hernia. The most significant contributor in this multivariable model was discharge (β=4.0, P<0.001) and the smallest contributor was local heat (β=1.3, P=0.003).

The model explained 57.0 per cent of the variance in the navel ill sample (R^2=0.57) and correctly classified 65.8 per cent of all studied cases of omphalitis. The Hosmer-Lemeshow test confirmed the goodness of fit of this model (x^2=5.38; P=0.250). There was no multicollinearity detected, with VIF ranging between 1.1 and 1.5 for all clinical signs.

The above four clinical indicators were subsequently used to create a scoring system for omphalitis as described and presented in Table 3. The probability of positive result, the probability of negative result, positive and negative likelihood ratios, the total percentage

TABLE 2: Multivariable logistic regression model parameters for the main clinical signs as indicators of omphalitis							
						95% CI	
Sign	Regression coefficient	se	Wald statistic	P value	OR	Lower	Upper
Swelling*	1.72	0.43	15.73	0.000	5.59	2.39	13.09
Heat†	1.30	0.44	8.98	0.003	3.69	1.57	8.65
Discharge‡	4.14	0.81	26.40	0.000	62.59	12.92	303.22
Hernia	1.73	0.77	5.09	0.024	5.64	1.25	25.38
Intercept	−2.65	0.38	47.53	0.000	0.07	–	–

*Swelling of the umbilical stump over 1.3 cm in diameter.
†Rise of stump temperature with 0.5°C above the reference sternal temperature.
‡Purulent and/or haemorrhagic.

TABLE 3: Summary description of the clinical scoring method for detection of omphalitis based on the binary assessment (present/absent) for swelling of the umbilical cord or stump, local heat, the presence of pus and concurrent umbilical hernia		
Description of the proposed clinical scoring system for detection of omphalitis		
Clinical qualifiers (signs)	Description of qualifiers	Score weights (points)
Swelling	Thickening of the umbilical stump	
Thickened stump	Diameter of the stump is over 1.3 cm	2
No thickening	Diameter of the stump is less than 1.3 cm	0
Local heat	Raised surface temperature of the stump	
Raised stump temperature	Stump temperature 0.5° C higher than the reference sternal temperature	1
Stump temperature not raised	Stump temperature lower than 0.5° C above the reference sternal temperature	0
Discharge (pus)	Pus or abscess on the umbilical stump	
Pus present	Pus can be visibly detected at the stump	4
Pus absent	Pus cannot be visualised at the stump	0
Umbilical hernia	An umbilical hernia with palpable orifice	Score weights (points)
Hernia present	An umbilical hernia can be palpated	2
Hernia absent	An umbilical hernia cannot be palpated	0

of correctly classified calves and the total predictive accuracy values for nine different score cut-off points are presented in Table 4.

The algorithm performed best at a cut-off point 3 classifying correctly 81.8 per cent of all examined calves; however, the c-statistic suggests a slightly better performance at the cut-off point of 2. Binary logistic regression for each score group and assessment of the Wald ratio confirmed that higher scores were associated with higher probability of navel ill.

Regression modelling for intra-abdominal omphalitis

The association of the clinical signs with intra-abdominal inflammation was evaluated following the same methodology, except for the development of the algorithm. The univariable logistic regression revealed that local heat and purulent discharge were individually correlated with internal umbilical inflammation (Table 5). However, the multivariable analysis indicated that only discharge (β=1.7; P=0.001) was significantly correlated with intra-abdominal navel ill. The OR for discharge was 5.67 with a CI between 2.08 and 15.46. The intercept value of the regression model was −2.7. Individually, the presence of discharge predicted 89.8 per cent of the studied intra-abdominal cases of omphalitis (R^2=0.12; P=0.001). Since only one of the clinical signs (discharge) was significant for intra-abdominal navel ill, no scoring system specific for detection of internal omphalitis is proposed here.

Discussion

Previously reported prevalence data on the anatomical structures affected were similar to the current study.[3] The presented data and subsequently suggested clinical scoring algorithm can be a valuable method for veterinary surgeons and farmers to score omphalitis reliably. The findings will make it easier and more accurate to score calves for the presence of omphalitis and possibly affected intra-abdominal structures. The clinical assessment of navel swelling is relatively straightforward and easy to perform and can be effectively applied in clinical practice. Although the assessment of local temperature (heat) may not be as easy to perform or interpret in general practice, availability and affordability of contactless thermometers (or thermal imaging devices) will make these measurements easier in the future.

As individual clinical signs usually have lower sensitivity and specificity as indicators of inflammation, the proposed composite algorithm would be preferred in the clinical examination of calves. At the threshold of 2 or larger, the sensitivity of the ‘all signs’ algorithm (swelling, local heat, purulent discharge and umbilical hernia) was 85.9 per cent and the specificity was 74.8 per cent, suggesting that this algorithm is useful

TABLE 4: Diagnostic performance of the scoring system to correctly identify calves with omphalitis					
Diagnostic performance of the scoring system to correctly identify calves with omphalitis					
Score cut- off point (≥)	Specificity (%)	Sensitivity (%)	Positive likelihood ratio (LR+)	Total % of calves correctly classified (%)	Predictive accuracy (c- statistic)
1	95.3	59.3	2.3	71.7	0.773
2	85.9	74.8	3.4	78.6	0.804
3	67.2	89.4	6.4	81.8	0.783
4	53.1	96.7	16.3	81.8	0.749
5	42.2	99.2	51.9	79.7	0.707
6	23.4	99.2	28.8	73.3	0.613
7	15.6	100.0	–	71.1	0.578
8	3.1	100.0	–	66.8	0.516
9	3.1	100.0	–	66.8	0.516

TABLE 5: Univariable logistic regression parameters for the clinical signs as indicators of intra-abdominal omphalitis

Sign	Regression coefficient	se	Wald statistic	P value	OR	95% CI	
						Lower	Upper
Pain	0.46	0.49	0.88	0.348	1.58	0.61	4.10
Swelling*	0.56	0.49	1.32	0.250	1.75	0.67	4.56
Heat†	1.07	0.49	4.67	0.031	2.90	1.10	7.63
Discharge‡	1.74	0.51	11.52	0.001	5.67	2.08	15.46
Abdominal palpation	0.80	0.69	1.35	0.245	2.24	0.58	8.68
Hernia	1.15	0.83	1.91	0.167	3.16	0.62	16.15
Patent urachus	−19.04	23,205.42	0.00	0.999	0.00	0.00	–

*Swelling of the umbilical stump over 1.3 cm in diameter.
†Rise of stump temperature with 0.5°C above the reference sternal temperature.
‡Serous, mucoid, purulent and haemorrhagic types were combined into single values.

as an initial diagnostic tool in individual animals and on a herd level to underpin veterinary advice on navel hygiene. Omphalitis scoring could also inform on the use of further tests in the clinician's decision-making process, such as ultrasonography, and inform on the prognosis and treatment.[11] Since the choice of tests and prognosis should consider the severity of inflammation and suspicion for the involvement of internal abdominal structures, the presence of discharge (an inflammatory sign that is specifically associated with inflammation of the intra-abdominal structures) can support an early decision for a therapeutic or surgical intervention.[29]

The highest c-statistical value was used to determine the optimal cut-off point in this study; however, the optimum cut-off for a test, based on maximising the proportion of correctly classified individual animals, depends on the prevalence of cases. The authors acknowledge that maximising the c-statistic is equivalent to optimising equally on positive and negative animals, that is, equivalent to a prevalence of 0.5 and therefore the highest c-statistical value may not be the optimum cut-off for the whole population. In future research, the intercept (e^b0) can be chosen instead as a cut-off point, and it would provide the maximum of correctly classified cases and non-cases in a data set with β-weights used as maximum likelihood estimators.

The accuracy of detection is also dependent on cut-off points for the individual clinical signs. These can be validated for the appropriate populations and sensitivities and specificities used according to clinical aims. The method of producing the proposed scoring system for detection of navel ill has been trialled and tested in other areas such as bovine respiratory disease[15] and has a distinct advantage over parallel testing and serial testing. In some clinical circumstances, algorithms consisting of either symptom present (serial testing) as opposed to concurrent symptoms (parallel testing) can raise the sensitivity, whereas second and third assessments of the positives at a later time (sequential clinical assessment) can raise the specificity (with a net loss of sensitivity). Additionally, compared with a single observation, sequential clinical assessment can evaluate the rate of drying up of the umbilical cord[30] and also evaluate the healing and treatment response.[31]

In the present final model, all clinical signs were treated as binary variables (with yes/no result on clinical examination). But if cut-off points are to be defined, these should be re-evaluated under different conditions. Based on a comparison of the median sample estimates, the sensitivity and specificity for swelling and the logistic regression results for this group of calves, the authors recommend a cut-off point of 1.3 cm for swelling (if used alone or in combination for detection of omphalitis). This result is the same as previously suggested by Grover and Godden,[31] but more than the reported healthy mean at 24 hours after birth by Robinson *et al* (7.6 mm).[12] The present data corroborate with these authors that umbilical cord remaining over 1.3 cm, later than 24 hours from birth, is a cause for concern. Umbilical cord drying times are variable, but according to Hides and Hannah,[30] 91 per cent of healthy umbilical cords are considered to have completely shrivelled and dried by four days old. Hence, the authors consider that the measurements of navel thickness, and consequently thickness cut-offs, in calves between 7 and 15 days old are unlikely to be confounded by age.

The high prevalence of omphalitis in this study (34.2 per cent) is probably a result of these being male dairy calves, raised in general, under poorer husbandry conditions than female calves and so this prevalence may not be directly comparable with other populations. Also, this study is based on calves that were healthy enough to be transported to an abattoir, and therefore, some calves with severe omphalitis or unfit for transportation may have been missed. While the present selection criteria may not be applicable to older calves, the goal of the proposed scoring system is early detection and treatment. Examination of older calves would not be useful in achieving this goal.

The UK welfare regulations state that calves should be at least 10 days old before transportation for slaughter. Also, calves cannot be transported if 'the navel has not completely healed'.[32] The presence in this study of calves as young as seven days and with painful, wet or swollen navels indicate possible non-compliance with these standards by local farmers or suppliers. The very small number of calves with joint ill and elevated rectal temperature (four calves) may have escaped detection before transport because they were not severely lame.

In clinical practice, ultrasound examination of the abdomen can be used to detect intra-abdominal navel ill, but this may be impractical on a farm or when the assessment is to be done on many calves. Informed prognosis and early intervention can be crucial to avoid complications and achieve desirable growth rates; the assessment for discharge can be a quick and easy method to predict the presence of intra-abdominal omphalitis.

The next step of the validation of the algorithm is to test its performance in other populations (breed and gender), different climatic conditions and different geographical areas. The other area where further detail would be required is the level of interference for the improvement of umbilical hygiene.

Conclusions

This research is the first of its kind to quantify the magnitude of the association between the clinical signs and omphalitis with or without intra-abdominal involvement. It defines the inflammatory symptoms of swelling, heat and discharge (with the additional assessment for umbilical hernia) as good predictors for omphalitis developing within two weeks from birth. The assessment of these signs in combination can achieve overall accuracy of 81.8 per cent in identifying calves affected with omphalitis. Relevant to omphalitis complications such as bacteraemia, (poly) arthritis and others can be avoided through early detection and treatment, and therefore the scoring algorithm is proposed to improve the detection and early diagnosis of omphalitis. This algorithm facilitates prognosis, informs on subsequent treatment options or necessary prevention measures and therefore it could be judiciously applied in clinical practice as a diagnostic combination for omphalitis.

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Competing interests None declared.

Ethics approval Informed consent was obtained from the Food Standards Agency approved Welsh abattoir to perform the clinical and postmortem examinations. The Clinical Research and Ethical Review Board (CRERB) of the Royal Veterinary College, University of London, has examined and approved the protocol (URN 2016 1484).

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