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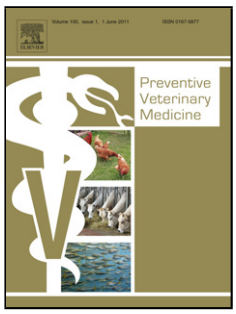


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Preventive Veterinary Medicine – Original Research Paper

**Title: An observational study on passive immunity in Irish suckler beef and dairy calves: Tests for failure of passive transfer of immunity and associations with health and performance**

Authors: C.G. Todd[*], M. McGee[*], K. Tiernan[*†], P. Crosson[*], E. O'Riordan[*], J. McClure[‡], I. Lorenz[†‖], B. Earley[*1]

[*]Animal & Grassland Research and Innovation Centre, Teagasc, Grange, Dunsany, Co. Meath, Ireland

[†] School of Veterinary Medicine, University College Dublin, Belfield, Dublin 4, Co. Dublin, Ireland

[‡] Irish Cattle Breeding Federation, Bandon, Co. Cork, Ireland

[‖] Bavarian Animal Health Service, Poing, Germany

[1] **Corresponding author**: Bernadette Earley, Tel: +353469061166, Fax: +353469026154, Email: Bernadette.Earley@teagasc.ie

## Highlight

- Suckler beef calves had lower passive immunity compared to dairy calves
- 20% of suckler beef and 30% of dairy calves were treated for at least one disease event by 6 mo. of age.
- Calves with lower passive immunity were at greater risk of a negative health event or poor growth
- Test cut-offs for failure of passive transfer risk, based on health and growth outcomes, varied

## Abstract

The study objectives were to: 1) evaluate the diagnostic performance of passive immunity tests for classification of failure of passive transfer (FPT) risk, based on their relationships with calf health and performance, and 2) describe the epidemiology of morbidity and mortality in suckler beef and dairy calves under Irish conditions. A total of 1,392 suckler beef calves (n = 111 farms) and 2,090 dairy calves (84 farms) were included in this observational study. Blood samples were collected by jugular venipuncture. Serum samples were analysed for total IgG concentration using an ELISA assay, total protein concentration by clinical analyser (TP – CA), globulin concentration, zinc sulphate turbidity (ZST) units, total solids percentage by Brix refractometer (TS – BRIX), and total protein concentration by digital refractometer (TP – DR). Crude and cause-specific morbidity, all-cause mortality, and standardised 205-days body weight (BW) were determined. Generalised linear mixed models were used to evaluate associations between suckler beef and dairy calves for morbidity, mortality, growth and passive immunity. Receiver operating characteristic (ROC) curves were constructed to determine optimal test cut-offs for classification of health

and growth outcomes. Overall, 20% of suckler beef and 30% of dairy calves were treated for at least one disease event by 6 mo. of age. Suckler beef calves had greater odds of bovine respiratory disease (BRD; odds ratio (OR), 95% confidence interval (CI): 2.8, 1.2 – 6.5, $P$ = 0.01), navel infection (5.1, 1.9 – 13.2, $P < 0.001$), and joint infection/lameness (3.2, 1.3 – 7.8, $P$ = 0.01) during the first 6 mo. of life than dairy calves. In addition, from birth to 6 mo. of age, suckler beef calves had greater rates of navel infection (incidence rate ratio (IRR), 95% CI: 3.3, 1.3 – 8.4, $P$ = 0.01), but decreased rates of diarrhoea (0.9, 0.2 – 0.9, $P$ = 0.03) compared to dairy calves. Optimal test cut-offs for classification of morbidity and mortality outcomes in suckler beef calves ranged from 8 to 9 mg/ml ELISA, 56 to 61 g/l TP – CA, 26 to 40 g/l globulin, 12 to 18 ZST units, 8.4% TS – BRIX, and 5.3 to 6.3 g/dl TP – DR. Optimal test cut-offs for classification of morbidity and growth outcomes in dairy calves ranged from 10 to 12 mg/ml ELISA, 57 to 60 g/l TP – CA, 29 to 34 g/l globulin, 19 ZST units, 7.8 to 8.4% TS – BRIX, and 5.7 to 5.9 g/dl TP – DR.

**Abbreviations**

AIM = Animal Identification and Movement; AUC: area under curve; BRD = bovine respiratory disease; BW1 = first body weight; BW2 = second body weight; CI = confidence interval; DAFM = Department of Agriculture, Food and the Marine; ELISA = enzyme-linked immunosorbent assay; FPT = failure of passive transfer; ICBF = Irish Cattle Breeding Federation; Ig = immunoglobulin; IgG = immunoglobulin G; IRR = incidence rate ratio; KT = knowledge transfer; NPV = predictive value of negative test; OR = odds ratio; PAR = population at risk; PPV = predictive value of positive test; Q1BW = lower quartile for standardised 205-day body weight; RID = radial immunodiffusion; ROC = receiver operating characteristic; SE = sensitivity; SP = specificity; TP = total protein; TP – CA = total protein concentration by clinical analyser; TP – DR = total protein concentration by digital

refractometer; TS – BRIX = total solids percentage by Brix refractometer; ZST= zinc sulphate turbidity

**Keywords**

Calf, suckler beef, dairy, morbidity, mortality, passive immunity

## 1. Introduction

Failure of passive transfer (FPT) of immunity occurs when the calf does not absorb sufficient colostral immunoglobulin (Ig) in the immediate post-natal period. Testing calves for FPT is an important step in monitoring the successfulness of colostrum management programmes and resolving on-going calf health problems (Godden, 2008; McGuirk, 2008). Assessments of FPT are usually completed during the first week of life, and calves should be at least 24 hours old before blood sample collection (McGuirk, 2005; Godden, 2008). Radial immunodiffusion (RID) is considered the gold standard test for determining immunoglobulin G (IgG) concentration in calf serum; however, it is a labour-intensive and expensive test to perform (Tyler et al., 1996; Godden, 2008). Several other laboratory-based or on-farm tests are available for FPT assessment. Some of these tests directly measure IgG concentration (Lee et al., 2008; Elsohaby et al., 2015; Gelsinger et al., 2015; Dunn et al., 2018); whereas, other tests indirectly estimate IgG content by measuring protein levels, other components in serum, or turbidity reactions (Tyler et al., 1996; Calloway et al., 2002; Deelen et al., 2014; Hernandez et al., 2016; Dunn et al., 2018).

Passive immunity test results are generally categorised for FPT using test-specific cut-off values. Serum IgG and total protein (TP) cut-off values most commonly used to classify dairy calves for FPT are 10 g/l (Gay, 1983) and 5.2 g/dl (Tyler et al., 1996; Calloway et al., 2002). Other research groups have, however, examined associations between serum IgG or TP concentration with health outcomes, such as BRD and mortality risk, and proposed that higher cut-off values for FPT in dairy calves should be adopted (Virtala et al., 1999; Windeyer et al., 2014; Chigerwe et al., 2015). There is less of a consensus on the cut-off values for FPT classification in beef calves, with multiple IgG thresholds, ranging between 8 and 27 g/l, being applied to describe varying levels of passive immunity (Wittum and Perino, 1995; Filteau et al., 2003; Dewell et al., 2006). Moreover, cut-offs for tests that indirectly

estimate IgG concentration are most often established by simply identifying the test equivalent for 10 g/l serum IgG (Deelen et al., 2014; Hogan et al., 2015; Hernandez et al., 2016; Cuttance et al., 2017a). More research is needed to validate test cut-off values, based on their relationships with key health and performance outcome measures, such as morbidity, mortality and growth.

In Ireland, the most recent large-scale study on FPT in calves was conducted more than 3 decades ago (Fallon and Harte, 1987). With this earlier work, a sample of 4,130 purchased Friesian male calves were assessed for FPT using the zinc sulphate turbidity (ZST) test, and 52 and 34 % of calves had less than 20 and 15 ZST units, respectively. More recently, O'Shaughnessy et al. (2015) documented that 22% of calves on 16 Irish suckler beef farms had FPT, which was defined as less than 20 ZST units. In addition, the All-Island Animal Disease Surveillance Programme has reported that between 38 and 66.5% of calf serum samples submitted annually to the regional veterinary laboratories in the Republic of Ireland and Northern Ireland have less than 20 ZST units (Department of Agriculture, Food and the Marine (DAFM) and Agri-Food and Biosciences Institute, 2010-2015). These passive surveillance estimates on FPT may not, however, truly reflect the overall national herd status because they are drawn from voluntary submissions, often from clinically ill calves or animals from herds with recurring calf health problems. Furthermore, there is no recent published information on the passive immune status of calves from modern genotypes in commercial Irish suckler beef and dairy farms. Hence, there is a need for updated information on the FPT status of Irish calves. The primary objective of this study was to evaluate the diagnostic performance of passive immunity tests for FPT classification by identifying test cut-off values associated with increased risk of calf morbidity, mortality, or poor growth. A secondary objective was to describe the epidemiology of morbidity and mortality in suckler beef and dairy calves.

## 2. Materials and methods

### *2.1. Ethical approval*

Project and individual authorisations, in accordance with European Union (Protection of Animals used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012) as amended and Directive 2010/63/EU, were obtained (Health Products Regulatory Authority, Dublin, Ireland (AE19132-P006)). All study procedures were also reviewed and approved by the Teagasc Animal Ethics Committee (TAEC-97).

### *2.2. Data source*

Data were obtained from two studies: 1) a longitudinal study on herd-level factors associated with the health and survival of calves on Irish farms (hereafter referred to as the herd-level study) and 2), a longitudinal study on individual calf-level risk factors for morbidity in spring-born calves (hereafter referred to as the calf-level study. The herd-level study was conducted between July 1, 2014 – December 31, 2015 and the calf-level study was conducted between January 1 – December 31, 2016.

### *2.3. Farmer recruitment and participation*

Recruitment of farmers for the herd-level study occurred throughout spring 2014. Farmers volunteered to participate after learning about the study while attending a national knowledge transfer (KT) event or they were contacted directly by their Teagasc KT advisors. At the end of the recruitment efforts, 230 suckler beef and 103 dairy farmers expressed interest in participating in the herd-level study. Interested suckler beef farmers were stratified by location and a random number sequence was used to select 150 farms, proportional to the provincial distribution of Irish suckler beef herds (DAFM, 2013). All dairy farmers that expressed interest were selected to participate. Sample size calculations were not completed for the herd-level study; final sample size was determined based on logistical and financial resources.

A total of 9 suckler beef and 8 dairy farms from the herd-level study were selected to participate in the calf-level study. These farms were selected based on the following criteria: 1) herd had a spring calving pattern, 2) farmers had demonstrated their willingness and ability to maintain accurate project records during the herd-level study, and 3) some calf morbidity or mortality had been reported between 2012 and 2015. Sample size calculations were completed for the calf-level study in Stata ® 13.0 (StataCorp, College Station, Texas, USA) using preliminary data from the herd-level study to determine expected differences in morbidity. A final sample size of 450 suckler beef calves was determined, based on the following assumptions: occurrence of disease was expected to be 3-times greater among suckler beef calves with vs. those without the risk factor (54 vs. 18%), power of 80%, confidence of 95%, average of 50 suckler beef calves per herd, and adjustments for within-herd clustering (intra-class correlation) and confounding of 0.1 and 15%, respectively. A final sample size of 880 dairy calves was determined, based on the following assumptions: occurrence of disease was expected to be 3-times greater among dairy calves with vs. those without the risk factor (51 vs. 17%), power of 80%, confidence of 95%, average of 100 dairy calves per herd, and adjustments for within-herd clustering (intra-class correlation) and confounding of 0.1 and 15%, respectively.

*2.4. Classification of calving pattern*

Herd calving pattern was classified as either autumn, spring, or split calving. Cows in the autumn and spring calving herds were due to calve from July to December, and January to June, respectively. Cows in the split calving herds were due to calve any time during the year, but generally within two distinct calving periods. Of the suckler beef herds enrolled in the herd-level study, 7 were classified as autumn calving, 83 were classified as spring calving, and 60 were classified as split calving. Of the dairy herds enrolled in herd-level study, 82 were classified as spring calving and 21 were classified as split calving. All herds

enrolled in the calf-level study had a spring calving pattern. Data on all animal births and movements that occurred on the farms during herd-level and calf-level studies were retrieved from the Animal Identification and Movement (AIM; DAFM, Co. Dublin, Ireland) and Irish Cattle Breeding Federation (ICBF; Bandon, Co. Cork, Ireland) databases to verify the calving pattern for each herd.

*2.5. Farm visits and blood sample collection*

Farm visits were completed over two time periods: July 1, 2014 – June 30, 2015 for the herd-level study and January 1 – June 30, 2016 for the calf-level study (Fig. 1). Autumn and spring calving herds enrolled in the herd-level study were visited once between July 1 – December 31, 2014 and January 1 – June 30, 2015, respectively. Split calving herds enrolled in the herd-level study were visited once between July 1 – December 31, 2014 and then a second visit was arranged between January 1 – June 30, 2015. Each farm visit for the herd-level study was scheduled to coincide with a time when calves would be available for blood sample collection. Female and male calves between 1 and 21 days of age were eligible for blood sampling. A maximum of 12 calves were blood sampled at the farm visit. In the event that more than 12 calves within the sampling age range were available, the youngest calves over 24 hours of age were blood sampled. Herds enrolled in the calf-level study were visited every 2 weeks during the 2016 spring calving season. At each farm visit, any calf that was at least 24 hours old, and had been born since the previous visit, was blood sampled.

Blood samples were collected by jugular venipuncture into 8.5 ml vacutainers (BD Vacutainer Serum Separator Tube II Advance 367958 no anticoagulant, Unitech, Dublin, Ireland) using an 18-gauge needle. Samples were

allowed to clot and stored at 4ºC for 24 hours. Serum was harvested following centrifugation (1600 × g for 10 minutes at 4ºC) and then frozen at -20ºC.

*2.6. Serum sample analyses*

Serum samples were analysed using direct and indirect tests for assessment of passive immunity. Total IgG concentration was directly measured in the serum samples using a commercial ELISA (BIO K165 test kit, BioX Diagnostics, Jemelle, Belgium), as described by Dunn et al. (2018). A clinical chemistry analyser (Olympus AU400, Tokyo, Japan) and test reagent kits (OSR6132 and OSR6102, Beckman Coulter Ireland Inc., Lismeehan, Co. Clare, Ireland) were used to quantitatively determine serum total protein (TP – CA) and albumin concentrations, as described by Earley et al. (2015). Globulin concentration was calculated for each serum sample as the difference between TP – CA and albumin concentration. Serum samples were analysed for ZST units, as described by McEwan et al. (1970). An optical Brix refractometer with automatic temperature compensation (RSG-100ATC, Grand Index Solution Enterprise Limited, Hong Kong, China) was used to determine total solids percentage by Brix refractometer (TS – BRIX). A digital hand held refractometer with automatic temperature compensation (DR-303, Index Instruments Ltd, Cambridgeshire, UK) was used to determine total protein concentration by digital refractometer (TP – DR).

*2.7. Collection of health and growth data*

Farmers enrolled in the herd-level and calf-level studies recorded birth, disease, health treatment, and death information on their calves using standardised recording sheets. Case definitions (Table 1) were provided to the farmers to assist with the classification of disease. Farmers were responsible for detecting, diagnosing, and administering treatment to any calf exhibiting clinical signs of disease, and encouraged to consult with their veterinarian when making health treatment decisions. The research team contacted the farmers every 2 to 4

weeks and reminded them to complete the project recording sheets. Nonetheless, despite this regular follow-up, health data were only available for calves on 84 suckler beef and 55 dairy farms from the herd-level study. All farmers for the calf-level study provided health data on their calves. Calves enrolled in the calf-level study were weighed twice using an electronic scale. The first body weight (BW1) was obtained at the first farm visit after birth. The second body weight (BW2) was obtained during a farm visit in autumn 2016. Animals were on pasture during this time. All BW2 measurements for suckler beef and dairy calves were collected before and after weaning, respectively.

### *2.8. Data handling and statistical analyses*

All data were analysed using SAS 9.4 (SAS Institute Inc., Cary, North Carolina, USA). The experimental unit of interest in all analyses was the individual calf.

#### *2.8.1. Passive immunity test results*

Passive immunity test results were initially examined on a continuous scale. Descriptive statistics, including medians, minimum and maximum values, and interquartile range, were generated (UNIVARIATE Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Correlations between test results were assessed using Pearson correlation coefficients. Generalised linear mixed models were constructed to evaluate associations between calf type (suckler beef vs. dairy) and the passive immunity test results. These data were modelled with a normal distribution, an identity link function, and a random effect to account for within-farm correlation (MIXED Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Calf type and sampling age were included as dichotomous and continuous explanatory variables, respectively, in each of the passive immunity test models. The assumption of linearity between sampling age and test results was assessed through the introduction of a quadratic term. The assumption of homoscedasticity was assessed by visually examining scatter-plots of the residuals against predicted values. Normality was

assessed using histogram and normal probability plots, and checking the residuals for skewness and kurtosis. A natural logarithm transformation was applied to help normalize the distribution of residuals for the TP – CA and TS – BRIX models. A square root transformation was applied for the globulin model. The Bonferroni adjustment was specified to account for multiple comparisons.

*2.8.2. Morbidity calculations and analyses*

Crude and cause-specific morbidity were determined using the health data collected from the project recording sheets. All health treatment data were reviewed and the following criteria applied to differentiate between disease events: long-acting antibiotics administered more than 7 days apart, or other medications administered more than 3 days apart were classified as separate disease events (Windeyer et al., 2014). Crude morbidity was defined as calves being treated for at least one disease event, attributed to any cause, excluding injury. Calves treated for illnesses other than diarrhoea, BRD, navel infection, or joint infection/lameness were categorised as receiving treatment for other disease events.

Cumulative incidence and incidence rate of crude and cause-specific morbidity were calculated for the following age categories: birth to 1 mo. of age, 1 to 3 mo. of age, 3 to 6 mo. of age, and birth to 6 mo. of age. Both cumulative incidence and incidence rate were calculated as measures of disease frequency because the blood sampled calves represented a relatively dynamic population, with calves being lost to follow-up (ie. sold off the home farm, exported from Ireland, death, etc.) throughout the study period. Cumulative incidence was calculated as the number of calves treated for disease within each age category, relative to the number of calves at risk of disease (Dohoo et al., 2009). Incidence rate was calculated as the number of disease events (all occurrences) treated within each age category, relative to the total animal-time at risk (Dohoo et al., 2009). Animal-time at risk was calculated for each individual calf as the number of days from birth until it was either sold off the home farm,

died, or the observation period ended. Birth, movement, and death dates for the animal-time at risk calculations were retrieved from the project recording sheets, as well as the AIM (DAFM, Co. Dublin, Ireland) and ICBF (Bandon, Co. Cork, Ireland) databases. Total animal-time at risk for all calves included within each age category was determined.

Generalised linear mixed models were constructed to evaluate associations between calf type and morbidity within each age category. Initially, each morbidity response was treated as a dichotomous outcome variable (disease occurred or not) and these data were modelled with a binomial distribution, a logit link function, and a random effect to account for within-farm correlation (GLIMMIX Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Subsequently, each morbidity response was treated as a count outcome variable (number of disease events) and these data were modelled with a Poisson distribution, a log link function, offset as the natural logarithm of animal-time at risk, and a random effect to account for within-farm correlation (GLIMMIX Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Calf type was included as a dichotomous explanatory variable in each of the morbidity models. Unadjusted means and variance of the disease counts were examined for overdispersion.

*2.8.3. Mortality calculations and analyses*

All-cause mortality was determined using the death information collected on the project recording sheets. Moreover, since every Irish farmer is required to register each animal that dies on their farm, death data were also retrieved from the AIM (DAFM, Co. Dublin, Ireland) and ICBF (Bandon, Co. Cork, Ireland) databases. Therefore, mortality data were available for all calves that were blood sampled, except those that were exported out of the country within the first 6 mo. of life. Cumulative incidence and incidence rate of mortality for each age category was calculated. Associations between mortality within each

age category and calf type were evaluated using generalised linear mixed models. Methods used to construct the mortality models were the same as described above for morbidity.

*2.8.4. Growth calculations and analyses*

Standardised 205-day BW was calculated for each calf using the following formula, which was adapted from industry guidelines for standardising weaning weights (Beef Improvement Federation, 2016).

$$Standardised\ 205-day\ BW = \left[\left(\frac{(BW2-BW1)}{(Age\ at\ BW2-Age\ at\ BW1)}\right) * 205\ days + BW1\right]$$

An adjustment factor for dam age was not included. Descriptive statistics, including medians, minimum and maximum values, and interquartile range, were generated (UNIVARIATE Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). A generalised linear mixed model was constructed to evaluate associations between calf type and standardised 205-day BW. These data were modelled with a normal distribution, an identity link function, and a random effect to account for within-farm correlation (MIXED Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Calf type and BW1 were included as dichotomous and continuous explanatory variables, respectively, in the standardised 205-day BW model. A quadratic term was offered into the model, but not retained, to verify the assumption of linearity between BW1 and standardised 205-day BW. Homoscedasticity was checked using a scatter-plot of the residuals against the predicted values. The distribution of residuals was inspected using histogram and normal probability plots; no transformation was applied.

*2.8.5. Passive immunity test cut-off analyses*

The diagnostic performance of each test for classification of FPT risk in calves, based on relationships with morbidity, mortality and growth outcomes, was evaluated. In each of the test cut-off models, the odds of a negative health event or poor growth was the outcome

of interest and passive immunity test results were explanatory variables. Health and growth outcomes were as follows: morbidity (crude, diarrhoea, BRD, and other causes), mortality (all-cause) and growth. Other causes morbidity included navel infection, joint infection/lameness, and other disease events. A new dichotomous outcome variable for growth was created to identify calves that were within the lower quartile for standardised 205-day BW (Q1BW). With the test cut-off analyses, morbidity and mortality outcomes for the following three time periods were evaluated: birth to 1 mo., birth to 3 mo., and birth to 6 mo. of age. Only those calves that were followed for the entire time period or lost to follow-up because of death were included in the morbidity and mortality test cut-off analyses. Any calf that was sold off the home farm or exported from Ireland was excluded from the corresponding morbidity and mortality analyses, respectively. For example, if a calf was sold during the second time period and exported during the third time period then it would have been excluded from the following test cut-off analyses: morbidity from birth to 3 mo., morbidity from birth to 6 mo., mortality from birth to 6 mo. An assumption was made that the loss of calves to follow-up occurred randomly, independent of passive immunity or health status.

Receiver operating characteristic (ROC) curves were generated for each health and growth outcome variable (GLIMMIX and LOGISTIC Procedures, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Test cut-off analyses were not completed for any passive immunity test and outcome where the 95% confidence interval (CI) for area under the curve (AUC) included 0.5. Passive immunity test results were subsequently dichotomised as either ≤ cut-off or not for each of the following: ELISA cut-offs from 5 to 25 mg/ml in 1 mg/ml increments, TP – CA cut-offs from 50 to 70 g/l in 1 g/l increments, globulin cut-offs from 20 to 40 g/l in 1 g/l increments, ZST cut-offs from 5 to 25 units in 1 unit increments, TS – BRIX cut-offs from 7 to 11 % in 0.2 % increments, and TP – DR from 5 to 7 in 0.1 g/dl increments.

A series of generalised linear mixed models were constructed, with each morbidity, mortality and Q1BW outcome variable being modelled with a binomial distribution, a logit link function, and a random effect to account for within-farm correlation (GLIMMIX Procedure, SAS 9.4, SAS Institute Inc., Cary, North Carolina, USA). Separate models were constructed for suckler beef and dairy calves. Optimal test cut-offs for classification of health and growth outcomes were determined using maximum Youden index, which is calculated as sensitivity (Se) + specificity (Sp) – 1 (macro %ROCPLOT, SAS Institute Inc., Cary, North Carolina, USA). Epidemiologic test characteristics (Se and Sp) and predictive values were calculated for test cut-offs (Dohoo et al., 2009).

## 3. Results

### *3.1. Study population*

An overview of the herd-level and calf-level studies is presented in Fig. 1. Initially, 150 suckler beef and 103 dairy farms were enrolled in the herd-level study; however, 34 farmers decided at a later date to withdraw from the study. Reasons provided for withdrawing included lack of time to complete project recording sheets (n = 8), leaving farming or no longer rearing calves (n = 3), off-farm work obligations (n = 2), personal reasons (n = 2), no handling facilities available (n = 1), and undisclosed reasons (n = 18). A total of 111 suckler beef and 84 dairy farms were visited during the herd-level study and blood samples were collected (Fig. 1). An additional 24 farms were to be visited; however, the research team was unable to coordinate these visits because no calves were available within the blood sampling age range, lack of farmer availability, or time constraints. With the calf-level study, 9 suckler beef and 8 dairy farms were visited every 2 weeks throughout the spring calving season so that calves could be blood sampled and weighed.

Median herd size for the suckler beef farms included the herd-level and calf-level studies was 33 (min. = 5, Q1 = 21, Q3 = 49, max. = 127) and 50 (min. = 16, Q1 = 31, Q3 =

67, max. = 95), respectively. Median herd size for the dairy farms included the herd-level and calf-level studies was 106 (min. = 39, Q1 = 73, Q3 = 151, max. = 370) and 138 (min. = 88, Q1 = 111, Q3 = 161, max. = 277), respectively. Herd size was indirectly estimated using the total number of calves born on the farm during each study period. Herd mortality to 6 mo. of age (including perinatal deaths) on the suckler beef farms ranged from 0 to 31.6% (Q1 = 0, median = 4.7, Q3 = 9.8) and 0 to 13.3% (Q1 = 1.7, median = 6.0, Q3 = 7.4) during the herd-level and calf-level studies, respectively. Herd mortality to 6 mo. of age (including perinatal deaths) on the dairy farms ranged from 0.9 to 50.5% (Q1 = 5.8, median = 8.9, Q3 = 12.7) and 2.1 to 9.0% (Q1 = 4.1, median = 6.7, Q3 = 7.5) during the herd-level and calf-level studies, respectively.

*3.2. Passive immunity test results*

Passive immunity test results for 1,392 suckler beef and 2,090 dairy calves were available for analysis (Fig. 1). Overall, 56.2% (1,958/3,482) and 43.8% (1,524/3,482) of these samples were collected as part of the herd-level and calf-level studies, respectively. Median age at blood sample collection for suckler beef and dairy calves was 10 (min. = 1, Q1 = 6, Q3 = 14, max. = 21) and 9 (min. = 1, Q1 = 5, Q3 = 13, max. = 21) days, respectively. Suckler beef calves tended to have lower TP – DR results than dairy calves ($P = 0.07$; Table 2). On all other tests for passive immunity, suckler beef calves had significantly lower mean values, as compared to dairy calves ($P < 0.05$; Table 2). There was variation in test results, with large ranges between minimum and maximum values. Passive immunity tests results were positively correlated, with Pearson correlation coefficients ranging from 0.53 to 0.96 (ELISA vs. TP – CA: $r = 0.82$, ELISA vs. globulin: $r = 0.85$, ELISA vs. ZST: $r = 0.65$, ELISA vs. BRIX – TS: $r = 0.77$, ELISA vs. TP – DR: $r = 0.64$, TP – CA vs. globulin: $r = 0.96$, TP – CA vs. ZST: $r = 0.71$, TP – CA vs. BRIX – TS: $r = 0.93$, TP – CA vs. TP – DR: $r = 0.77$, globulin vs. ZST: $r = 0.72$, globulin vs. BRIX – TS: $r = 0.88$; globulin vs. TP – DR: $r$

= 0.73, ZST vs. BRIX – TS: $r$ = 0.65, ZST vs. TP – DR: $r$ = 0.53, BRIX – TS vs. TP – DR: $r$ = 0.76).

*3.3. Morbidity*

Morbidity data were available on 1,192 suckler beef and 1,733 dairy calves, but only for the period of time that they remained on their home farm. Crude and cause-specific morbidity for calves' blood sampled on 84 suckler beef and 55 dairy farms are summarised in Table 3. In the first 1 mo. of life, suckler beef calves had greater cumulative incidence and incidence rates of navel ($P < 0.001$ and $P < 0.001$, respectively) and joint infection/lameness ($P < 0.01$ and $P < 0.01$, respectively) compared to dairy calves. Moreover, the odds and rate of suckler calves being treated for BRD ($P < 0.01$ and $P = 0.02$, respectively) between 1 and 3 mo. of age were greater than that of dairy calves. Overall, from birth to 6 mo. of age, suckler beef calves had greater odds of BRD ($P = 0.01$), navel ($P < 0.001$) and joint injection/lameness ($P = 0.01$), as well as increased rate of navel infections ($P = 0.01$), over dairy calves. Conversely, the incidence rate of diarrhoea among dairy calves in the first 6 mo. of life was greater than that of suckler beef calves ($P = 0.03$).

Median age at first treatment for crude morbidity in suckler beef and dairy calves was 14 (min. = 0, Q1 = 8, Q3 = 43, max. = 155) and 13 (min. = 0, Q1 = 7, Q3 = 20, max. = 145) days, respectively. Median age at first treatment for diarrhoea in suckler beef and dairy calves was 13 (min. = 0, Q1 = 8, Q3 = 23, max. = 83) and 12 (min. = 0, Q1 = 7, Q3 = 19, max. = 117) days, respectively. Median age at first treatment for BRD in suckler beef and dairy calves was 48 (min. = 0, Q1 = 31, Q3 = 96, max. = 155) and 20 (min. = 0, Q1 = 11, Q3 = 30, max. = 145) days, respectively. Median age at first treatment for navel infection in suckler beef and dairy calves was 7 (min. = 2, Q1 = 5, Q3 = 12, max. = 30) and 18 (min. = 0, Q1 = 6, Q3 = 27, max. = 35) days, respectively. Median age at first treatment for joint infection/lameness in suckler beef and dairy calves was 24 (min. = 5, Q1 = 11, Q3 = 52, max.

= 174) and 37 (min. = 7, Q1 = 20, Q3 = 91, max. = 93) days, respectively. Median age at first treatment for other disease events in suckler beef and dairy calves was 49 (min. = 1, Q1 = 16, Q3 = 73, max. = 153) and 27 (min. = 0, Q1 = 12, Q3 = 88, max. = 139) days, respectively.

*3.4. Mortality*

All calves, with the exception of 103 dairy calves that were exported from Ireland, were followed for mortality until 6 mo. of age (Fig. 1). All-cause mortality for calves' blood sampled between July 2014 and June 2016 is presented in Table 4. The odds of mortality between 1 and 3 mo. of age tended to be 1.8-times greater in suckler beef vs. dairy calves ($P$ = 0.09). Suckler beef and dairy calves did not differ for cumulative incidence of mortality in any of the other age categories ($P > 0.05$). Median age at death for suckler beef and dairy calves was 51 (min. = 9, Q1 = 30, Q3 = 74, max. = 169) and 27 (min. = 6, Q1 = 18, Q3 = 74, max. = 170) days, respectively. More than half of the dairy calf deaths occurred within the first 1mo. of life; whereas, the majority of suckler beef calves died between 1 and 3 mo. of age. All suckler beef calf deaths occurred on the calves' home farm; whereas 23% (16/69) of dairy calf deaths occurred after they had left the home farm.

*3.5. Growth*

Growth data were collected for 450 suckler beef and 480 dairy calves enrolled in the calf-level study. Median age at BW1 for suckler beef and dairy calves was 9 (min. = 0, Q1 = 5, Q3 = 13, max. = 21) and 9 (min. = 0, Q1 = 5, Q3 = 12, max. = 21) days, respectively. Median age at BW2 for suckler beef and dairy calves was 193.0 (min. = 113, Q1 = 177, Q3 = 223, max. = 318) and 233 (min. = 152, Q1 = 211, Q3 = 244, max. = 265) days, respectively. Suckler beef calves had standardised 205-day BW ranging from 119.1 to 396.4 kg (Q1 = 262.4, median = 289.2, Q3 = 317.3). Dairy calves had standardised 205-day BW ranging from 112.4 to 316.3 kg (Q1 = 175.6, median = 194.3, Q3 = 211.4). Suckler beef calves had significantly greater standardised 205-day BW, after controlling for BW1 and within-farm

correlation, than dairy calves (LSM, 95% CI: 268.4 kg, 253.3 – 283.4 vs. 202.8 kg, 187.0 – 218.7, $P < 0.001$).

*3.6. Passive immunity test cut-offs*

Optimal test cut-offs for suckler beef and dairy calves, associations with health and growth, and diagnostic performance measures are presented in Tables 5 and 6. Test cut-off analyses for all time points and outcomes are summarised in Supplementary Tables 1 and 2. Overall, Se and Sp of the passive immunity tests for classification of calves for health and growth performance varied, depending on the outcome of interest (Tables 5 and 6). Predictive values of positive tests (PPV) were relatively poor, ranging from 2.5 to 28.6% in suckler beef calves and 3.9 to 40.5% in dairy calves. Predictive values of negative tests (NPV) were generally good, ranging from 82.2 to 99.7% in suckler beef calves and 62.8 to 98.6% in dairy calves. Moreover, three-quarters of the optimal test cut-offs were associated with a PPV < 10% and half had a NVP > 90%.

*3.6.1. ELISA cut-offs*

The ELISA cut-off values that optimised classification of suckler beef calves for subsequent morbidity and mortality were 8 and 9 mg/ml, respectively (Table 5). Suckler beef calves with ELISA ≤ 8 mg/ml had 4.5-times greater odds of BRD ($P = 0.01$) and 1.8-times greater odds of other causes morbidity ($P = 0.05$) in the first 1 mo. of life, as well as two-fold the odds of being treated for at least 1 disease event by 3 mo. of age ($P < 0.001$), as compared to those with ELISA > 8 mg/ml (Table 5). Moreover, the odds of suckler beef calves dying by 6 mo. of age were 2.8-times greater for those with ELISA ≤ 9 mg/ml vs. those above this threshold ($P < 0.01$; Table 5).

Dairy calves with ELISA ≤ 10 mg/ml had more than two-fold the odds of Q1BW than dairy calves with ELISA > 10 mg/ml (OR = 2.2, $P < 0.01$; Table 6). Dairy calves with ELISA ≤ 11 mg/ml, as compared to those with a test result above this cut-off, had more than

threefold the odds of being treated for other causes morbidity by 1 mo. of age (OR = 3.3, $P < 0.01$; Table 6). The odds of BRD treatment in the first 6 mo. of life were 2.4-times greater for dairy calves with ELISA ≤ 12 mg/ml vs. ELISA > 12 mg/ml ($P < 0.01$; Table 6). Conversely, dairy calves with ELISA ≤ 13 mg/ml had lower odds of diarrhoea between birth and 6 mo. of age than dairy calves with ELISA > 13 mg/ml (OR = 0.6, $P < 0.01$; Table 6).

*3.6.2. TP – CA cut-offs*

Optimal TP – CA cut-offs for classification of health and growth performance in suckler beef calves ranged from 56 to 61 mg/ml (Table 5). Suckler beef calves with TP – CA ≤ 56 g/l had more than 6-times greater odds of BRD by 1 mo. of age compared to those with TP – CA above this cut-off (OR = 6.2, $P < 0.01$; Table 5). The odds of mortality between birth and 6 mo. of age for suckler beef calves with TP – CA ≤ 60 g/l was 4.3-times greater than that of calves with TP – CA > 60 g/l ($P < 0.01$; Table 5). In addition, suckler beef calves with TP – CA ≤ 61 g/l had 1.5-times greater odds of crude morbidity within 3 mo. of birth ($P = 0.03$) and 2.1-times greater odds of other causes morbidity by 6 mo. of age ($P < 0.01$) compared to suckler beef calves with TP – CA > 61 g/l (Table 5).

Dairy calves with TP – CA ≤ 57 g/l, relative to those with > 57 g/l, had almost two-fold the odds of Q1BW (OR = 1.9, $P < 0.01$) and threefold the odds of other causes morbidity (OR = 2.9, $P < 0.01$) by 1 mo. of age (Table 6). Moreover, dairy calves with TP-CA ≤ 60 g/l had 2.1-times greater odds of being treated for BRD within the first 6 mo. of life than those with TP – CA > 60 g/l ($P = 0.02$; Table 6). The odds of diarrhoea between birth and 6 mo. of age were 30% lower in dairy calves with TP – CA ≤ 66 g/l vs. TP – CA > 66 g/l (OR = 0.7, $P = 0.04$; Table 6).

*3.6.3. Globulin cut-offs*

Globulin cut-offs that optimally categorised suckler beef calves for morbidity and mortality risk included 26, 32 and 40 g/l (Table 5). Suckler beef calves with globulin ≤ 26 g/l

had 1.6-times greater odds of crude morbidity by 3 mo. of age, as compared to those with globulin > 26 g/l ($P$ = 0.02; Table 5). Globulin ≤ 32 g/l was associated with 6.3-times greater odds of BRD in the first 1 mo. of life ($P$ = 0.02) and 3.4-times greater odds of dying by 6 mo. of age ($P$ < 0.01) in suckler beef calves (Table 5). The odds of other causes morbidity by 1 mo. of age were 3.1-times greater in suckler beef calves with globulin ≤ 40 g/l vs. those with greater concentrations of globulin ($P$ = 0.02; Table 5).

The odds of Q1BW in dairy calves with globulin ≤ 29 g/l were more than two-fold that of dairy calves with globulin > 29 g/l (OR = 2.2, $P$ < 0.01; Table 6). Dairy calves with globulin ≤ 31 g/l, compared to those with globulin concentrations above this threshold, had 2.8-times greater odds of other causes morbidity within 1 mo. of birth ($P$ < 0.01; Table 6). In addition, dairy calves with globulin ≤ 34 g/l had 2.2-times greater odds of receiving BRD treatment by 6 mo. of age than dairy calves with globulin > 34 g/l ($P$ = 0.02; Table 6). Furthermore, globulin ≤ 36 g/l was associated with lower odds of diarrhoea in dairy calves from birth to 6 mo. of age (OR = 0.6, $P$ = 0.01; Table 6).

*3.6.4. ZST cut-offs*

The odds of suckler beef calves with ZST ≤ 12 units being treated for at least 1 disease event by 3 mo. of age were almost two-fold that of calves with > 12 ZST units (OR = 1.8, $P$ < 0.01; Table 5). Suckler beef calves with ≤ 14 ZST units had 11.2 and 3.4-times greater odds of BRD by 1 mo. of age ($P$ < 0.01) and dying within 6 mo. of birth ($P$ < 0.01), respectively, relative to those with ZST > 14 units (Table 5). Moreover, ZST ≤ 18 units was associated with 2.2-times greater odds of other causes morbidity in suckler beef calves up to 1 mo. of age ($P$ = 0.02; Table 5).

Dairy calves with ZST ≤ 19 units had almost threefold the odds of being treated for BRD in the first 6 mo. of life compared to dairy calves with > 19 ZST units (OR = 2.8, $P$ < 0.01; Table 6). In contrast, dairy calves with ZST ≤ 23 units had significantly lower odds of

diarrhoea from birth to 6 mo. of age than dairy calves with greater ZST (OR 0.6, $P = 0.02$; Table 6).

*3.6.5. TS – BRIX cut-offs*

The optimal TS – BRIX cut-off for classifying the health status of suckler beef calves was 8.4% (Table 5). Suckler beef calves with TS – BRIX ≤ 8.4% had 7.2-times greater odds of BRD in the first 1 mo. of life ($P < 0.01$), and at least 1.5-times greater odds of crude morbidity (OR = 1.5, $P = 0.02$) and other causes morbidity (OR = 1.7, $P = 0.03$) by 6 mo. of age, as compared to suckler beef calves with a TS – BRIX > 8.4% (Table 5). The odds of suckler beef calves with TS – BRIX ≤ 8.4% dying within 6 mo. of birth were almost threefold that of suckler beef calves with TS – BRIX > 8.4% (OR = 2.8, $P < 0.01$; Table 5

Dairy calves with TS – BRIX ≤ 7.8% had almost 5-times greater odds of other causes morbidity in the first 1 mo. of life than those with TS – BRIX > 7.8% (OR = 4.7, $P < 0.001$, Table 6). The odds of dairy calves with TS – BRIX ≤ 8.4% being treated for BRD by 6 mo. of age (OR = 1.9, $P = 0.05$) or being classified as Q1BW (OR = 2.3, $P < 0.01$) were approximately twice that of calves with TS – BRIX > 8.4% (Table 6). In addition, TS – BRIX ≤ 9.4% was associated with 40% lower odds of diarrhoea in dairy calves between birth and 6 mo. of age (OR = 0.6, $P = 0.03$; Table 6).

*3.6.6. TP – DR cut-offs*

The TP – DR cut-off values that optimised classification of suckler beef calves for morbidity and mortality ranged from 5.3 to 6.3 g/dl (Table 5). Suckler beef calves with TP – DR ≤ 5.3 g/dl had almost 4-times greater odds of death by 6 mo. of age than calves with TP – DR > 5.3 g/dl (OR = 3.9, $P < 0.01$; Table 5). Suckler beef calves with TP – DR ≤ 5.8 g/dl, as compared to those with test results above this threshold, had 1.6-times greater odds of crude morbidity ($P < 0.01$) and 2.3-times greater odds of BRD ($P = 0.01$) in the first 6 mo. of life (Table 5). The odds of other causes morbidity by 3 mo. of age were also 2.5-times greater

among suckler beef calves with TP – DR ≤ 6.3 g/dl compared to those with > 6.3 g/dl ($P$ = 0.02; Table 5).

Dairy calves with TP – DR ≤ 5.7 g/dl, relative to those with test results above this cut-off, had 2.5-times greater odds of other causes morbidity in the first 1 mo. of life ($P$ = 0.01; Table 6). The odds of dairy calves with TP – DR ≤ 5.9 g/dl being treated for BRD within 3 mo. of birth (OR = 1.9, $P$ = 0.04; Table 6) or exhibiting poor growth performance during the first 6 to 7 mo. of life (OR = 1.6, $P$ < 0.01; Table 6) were almost twice that of dairy calves with TP –DR > 5.9 g/dl. Meanwhile, dairy calves with TP – DR ≤ 6.7 g/dl had 50% lower odds of being treated for diarrhoea by 6 mo. of age than those with TP – DR > 6.7 g/dl (OR = 0.5, $P$ = 0.01; Table 6).

## 4. Discussion

### *4.1. Passive immunity and test cut-offs*

Overall, results of this study provide further evidence that calves with lower passive immunity test results are at greater risk of experiencing a negative health event or poor growth performance. This is in agreement with several other studies on passive immunity in suckler beef (Wittum and Perino, 1995; Dewell et al., 2006; Waldner and Rosengren, 2009; Homerosky et al., 2017) and dairy calves (Robison et al., 1988; Donovan et al., 1998; Virtala et al., 1999; Pithua and Aly, 2013; Windeyer et al., 2014).

In the present study, when interpreted on a continuous scale, passive immunity test results for suckler beef calves were significantly lower than that of dairy calves. This response was unexpected, yet consistent across each test except TP – DR. Suckler beef cows generally produce higher quality colostrum, containing as much as 2.5-times more IgG/l, compared to dairy cows (Guy et al., 1994; Dunn et al., 2018). In addition, results from comparative studies have shown that beef calves typically achieve greater transfer of passive

immunity, with mean serum IgG concentration approximately two-fold that of dairy calves (Earley et al., 2000; Suh et al., 2003). These comparative studies were, however, conducted in research centres, where recommended best practices are likely to be adopted, and this may not reflect management conditions on some commercial farms. Pre-calving and colostrum management practices implemented on commercial farms vary, as well as there is large variation in colostrum quality between individual cows and by farm (Gulliksen et al., 2008; Morrill et al., 2012a; Cummins et al., 2016; Dunn et al., 2017). Several management practices and animal factors, including the timing and amount of colostrum fed, colostrum feeding method, time spent in the maternity area, breed, twin birth, dystocia, dam parity and health status, and herd size are known to be associated with the acquisition of passive immunity in calves (Perino et al., 1995; Trotz-Williams et al., 2008; Beam et al., 2009; Waldner and Rosengren, 2009; Vogels et al., 2013; Cuttance et al., 2017b). A risk factor analysis needs to be conducted to investigate which animal and herd-level factors potentially contributed to the observed differences in passive immunity between suckler beef and dairy calves in the present study.

The most commonly used cut-off for classifying dairy calves for FPT is 10 mg/ml serum IgG (Gay, 1983). Surprisingly, despite widespread adoption of this threshold, it was not derived empirically, but rather, based on field experience and a review of published literature. Similarly, McGuire and Adams (1982) reviewed the literature and subsequently proposed the following classification, which is often adopted to characterise the passive immune status of suckler beef calves: FPT < 8 mg/ml serum $IgG_1$, partial FPT ≥ 8 to 16 mg/ml serum $IgG_1$, and normal > 16 mg/ml serum $IgG_1$. These FPT definitions have been useful in guiding interpretation of passive immunity test results; however, in recent years, growing evidence has suggested that test cut-offs for FPT may need to be reviewed, with more emphasis on deriving thresholds based on associations with calf health and performance

outcomes (Virtala et al., 1999; Waldner and Rosengren, 2009; Windeyer et al., 2014; Chigerwe et al., 2015).

Several test cut-offs were identified in the present study that optimised the classification of suckler beef and dairy calves for subsequent health and growth performance. Optimal test cut-offs were selected as the value that minimised the number of misclassification errors. Test cut-offs associated with diarrhoea have to be disregarded because some calves may have received metaphylactic treatment for diarrhoea. The Se, Sp, PPV, NPV estimates reported in the present study are in line with what one would expect based on results from other studies (Virtala et al., 1999; Courtney et al., 2000; Windeyer et al., 2014). Overall, even though the optimal test cut-offs were significantly associated with health and performance outcomes, the PPV were low. This highlights that many factors, besides FPT, contribute to health and performance responses, and suggests that the tests are not particularly useful as individual animal diagnostic tools. As such, it is most often recommended that these tests be used as part of a herd or group-based testing approach for FPT (McGuirk, 2005; Godden, 2008). Predictive values are known to be primarily influenced by disease frequency and test characteristics (Dohoo et al., 2009), suggesting that these tests may be more or ptentially less predictive in other populations depending on prevalence.

ELISA cut-offs of ≤ 8 and ≤ 9 mg/ml were associated with greater odds of morbidity and mortality in suckler calves, respectively. Dairy calves with ELISA test results ranging from ≤ 10 to ≤ 12 mg/ml had greater odds of BRD, other causes morbidity or poor growth compared to those with greater test results. Thus, if FPT was defined based on the optimal ELISA cut-offs, upwards of 31% of suckler beef and 36% of dairy calves would have been classified as having FPT. Beef calves with serum IgG concentrations ≤ 24 mg/ml have been shown to be more likely to require health treatment or die before weaning compared to calves with higher concentrations (Dewell et al., 2006; Waldner and Rosengren, 2009). Moreover,

beef calves with serum $IgG_1 \leq 27$ mg/ml weighed on average 3.4 kg less at 205 days of age than calves with greater $IgG_1$ (Dewell et al., 2006). Virtala et al. (1999) reported that 12 mg/ml IgG optimally classified dairy calves for BRD, with calves below this threshold having more than two-fold the odds of BRD than those with higher IgG concentrations, which is in agreement with the results of the present study. More recently, Chigerwe et al. (2015) recommended that serum IgG test values between 20 and 25 mg/ml, which favoured the absence of mortality, should be used to indicate adequate passive transfer in dairy calves.

Serum TP – CA and TP – DR test cut-offs that optimally classified suckler beef calves for health outcomes ranged from 56 to 61 g/l and 5.3 to 6.3 g/dl, respectively. Serum TP – CA and TP – DR test cut-offs that optimally classified dairy calves for health and growth outcomes ranged from 57 to 66 g/l and 5.7 to 6.7 g/dl, respectively. Thus, if FPT was defined based on the optimal TP – CA cut-offs, upwards of 53% of suckler beef and 39% of dairy calves would have been classified as having FPT. In addition, if FPT was defined based on the optimal TP – DR cut-offs, upwards of 68% of suckler beef and 40% of dairy calves would have been classified as having FPT. The TP – CA and TP – DR cut-offs identified in the present study are greater than the widely used serum TP threshold of ≤5.2 g/dl (Tyler et al., 1996; Calloway et al., 2002), but this is not the first study to propose the adoption of greater serum TP cut-offs. Serum TP has been validated against RID and 5.2 g/dl was determined to be equivalent to 10 g/l of IgG (Tyler et al., 1996). The diagnostic performance of TP thresholds from 5.0 to 5.5 g/dl for detection of FPT, based on 10 g/l serum IgG, have been shown to be good (Tyler et al., 1996; Calloway et al., 2002; Cuttance et al., 2017a). In a large cohort of almost 3,500 calves at a contract heifer rearing facility in Washington State, USA, the lowest risk of mortality was observed among calves with serum TP > 5.5 g/dl; whereas, calves with TP concentration < 5.0 g/dl were more than twice as likely to die in the first 4 mo. of life (Tyler et al., 1998). At three beef research centres in South Dakota, USA,

calves with serum TP < 5.5 g/dl were identified as having FPT because they were more than 3-times as likely to be treated for morbidity prior to weaning than calves with serum TP concentration of at least 5.5 g/dl (Courtney et al., 2000). Windeyer et al. (2014) reported that a serum TP cut-off of < 5.2 g/dl could be used to optimally classify pre-weaned dairy calves for mortality risk. This research group also documented that a higher serum TP cut-off of < 5.7 g/dl needed to be applied to identify calves at increased risk of BRD by 5 weeks of age. Moreover, Chigerwe et al. (2015) reported that calves with serum TP concentrations of 5.8 to 6.3 g/dl were less likely to die by 4 mo. of age than calves with lower serum TP.

Globulin cut-offs that optimally classified suckler beef and dairy calves for the outcomes of interest ranged from 26 to 40 g/l and 29 to 36 g/l, respectively. Thus, if FPT was defined based on the optimal globulin cut-offs, upwards of 78% of suckler beef and 49% of dairy calves would have been classified as having FPT. Serum globulin concentrations have not been widely used to detect FPT in calves.

Optimal ZST units for classification of health outcomes in suckler beef and dairy calves ranged from 12 to 18 units and 19 units, respectively. Thus, if FPT was defined based on the optimal ZST cut-offs, upwards of 64% of suckler beef and 65% of dairy calves would have been classified as having FPT. The ZST test is the most frequently used test in Ireland, with serum samples submitted to the regional veterinary laboratories being analysed using this test. The most commonly applied cut-off for diagnosing FPT in calves is 20 ZST units (McEwan et al., 1970; Radostits et al., 2000). White and Andrews (1986) reported that the morbidity and mortality risks for calves with < 20 vs. ≥ 20 ZST units were 35 and 12%, respectively, vs. 22 and 3.5%, respectively. Hogan et al. (2015) recently documented that the ZST threshold of 20 units is likely too high. In a comparison against IgG ≤ 10 mg/ml using RID, this research group proposed a cut-off of 11 ZST units, which resulted in improved Sp for the test. Results of the present study also suggest that a lower ZST cut-off is warranted.

Fallon and Harte (1987) estimated that 52 and 34% of Irish Friesian male calves purchased over a 9 year period had less than 20 and 15 ZST units, respectively. In the present study, 74 and 46% of suckler beef and 68 and 54% of dairy calves had less than 20 and 15 ZST units, respectively. Thus, it is evident that there are still opportunities for improvement in colostrum management on Irish farms.

Optimal test cut-offs for TS – BRIX was 8.4% for suckler beef calves and between 7.8 to 8.4% for dairy calves. Thus, if FPT was defined based on the optimal TS – BRIX cut-offs, upwards of 39% of suckler beef and 30% of dairy calves would have been classified as having FPT. The diagnostic performance of Brix refractometry has previously been evaluated against the RID in dairy calves (Deelen et al., 2014; Elsohaby et al., 2016; Hernandez et al., 2016; Cuttance et al., 2017a). Correlation between Brix results and serum IgG measured by RID has generally been very good, ranging from 0.71 to 0.93 (Deelen et al., 2014; Thornhill et al., 2015). Brix cut-offs for detecting IgG ≤ 10 mg/ml based on RID in dairy calves have included 7.8% (Morrill et al., 2012b), 8.3% (Elsohaby et al., 2016), 8.4% (Deelen et al., 2014), 8.5% (Hernandez et al., 2016), 8.8% (Cuttance et al., 2017a), and 10% (Thornhill et al., 2015). The TS – BRIX cut-offs determined in the present study are in line with these other reports. This is the first study to evaluate associations between TS – BRIX cut-offs and health and performance parameters in calves, as well to use the Brix refractometer to assess FPT in suckler beef calves.

*4.2. Morbidity and mortality*

This is the first observational study to characterise the epidemiology of morbidity and postnatal mortality in calves, from modern genotypes, reared on commercial suckler beef and dairy farms in Ireland. Overall, 20% of suckler beef calves and 30% of dairy calves exhibited clinical signs of disease and were treated for at least one disease event by 6 mo. of age. Incidence rates of crude morbidity for suckler beef and dairy calves from birth to 6 mo. of

age were 4.1 and 8.7 disease events per 100 calf-mo. at risk, respectively. In total, 2.7% of suckler beef and 3.3% of dairy calves died in the first 6 mo. of life. Incidence rates of mortality from birth to 6 mo. of age were 0.5 and 0.6 deaths per 100 calf-mo. at risk for suckler beef and dairy calves, respectively. The highest risk period for disease in the present study was between birth and 1 mo. of age, with approximately two-thirds of all disease events occurring during this time period. The first 1 mo. of life, generally referred to as the neonatal period in calves, is known to be associated with high levels of morbidity and mortality (Wittum and Perino, 1995; Sivula et al., 1996; Slavík et al., 2009; Windeyer et al., 2014). Almost 90% of calves enrolled in the present study were born between January and May. This is consistent with seasonal calving pasture-based production systems in Ireland, where most animals would be housed for the winter and then calve during the spring months (DAFM, 2013). Thus, many of the calves in the present study would have been born and spent at least the first 1 mo. of life indoors, most often managed in group housing systems, and potentially sharing air space with older animals, which are risk factors for calf morbidity (Gulliksen et al., 2009a; Gulliksen et al., 2009c; Bartels et al., 2010; Klein-Jöbstl et al., 2014).

Suckler beef calves in the present study were more frequently treated for BRD in the first 6 mo. of life, relative to dairy calves. Cumulative incidence and incidence rate of BRD in suckler beef calves were greatest between 1 and 3 mo. of age, which would have likely coincided with autumn born calves being moved indoors to winter housing and spring born calves being turned out to pasture. Cumulative incidence and incidence rate of BRD in dairy calves was greatest during the neonatal period, which would have likely coincided with calves being introduced to group housing during the indoor milk feeding period. Navel infection and joint infection/lameness occurred more frequently in suckler beef calves than dairy calves. The odds and incidence rate of navel infection or joint infection/lameness in

suckler beef calves during the neonatal period were approximately 5-times greater than that of dairy calves. Only a few cases of navel infection occurred after the neonatal period; whereas, almost half of the cases of joint infection/lameness were diagnosed and treated in calves older than 1 mo. of age. These results suggest that navel care practices, and perhaps the frequency of disinfection could have differed between suckler beef and dairy calves, but this needs to be investigated further. The incidence rate of diarrhoea from birth to 6 mo. of age in dairy calves was greater than that of suckler calves, with 6.7 and 1.9 disease events per 100 calf-mo. at risk, respectively. A review of the health records, however, suggested that these incidence estimates may be unreliable because they likely include calves that were treated in response to clinical signs, as well as some calves that received metaphylactic treatment for diarrhoea.

*4.3. Validity of results*

The present study allowed for a large sample of calves to be followed from birth until 6 mo. of age, and relationships between passive immunity, morbidity, mortality and growth to be explored. This is also one of the first studies where the passive immune status and health of both suckler beef and dairy calves have been evaluated. The authors, however, acknowledge that there were some limitations with the design and execution of this observational study. The methods used to recruit farmers may have introduced a selection bias, which could limit the generalisability of the results. Farmers were primarily recruited through KT activities and participation in the study was voluntary. One can speculate that individuals who attend KT events and engage advisory services may be more progressive farmers and more likely to implement best management practices. In addition, farmers that enrolled in the study had to commit to recording birth and health information, which may have dissuaded some farmers from participating. Moreover, farmers included in the calf-level study were purposively selected based on their recording abilities. These farmers had herds

that were on average, larger than those enrolled in the herd-level study. Herd mortality to 6 mo. of age varied widely, suggesting that calves on the study farms were likely exposed to a range of calf health management practices and environmental conditions. Herd sizes for the study farms reflect the distribution of the national herd relatively well (DAFM, 2013).

Right censoring, resulting from non-response of farmers and loss to follow-up of calves, may have led to selection bias. Even though farmers were regularly contacted about completing and submitting their project recordings sheets, 56 farmers from the herd-level study did not provide birth and health information for their calves. This non-response resulted in 200 suckler beef and 357 dairy calves being excluded from the morbidity analyses. Moreover, 99 suckler beef and 821 dairy calves were sold off their home farm or lost for other reasons. Calves that were lost to follow-up were excluded from those morbidity test cut-off analyses where they were not observed for the entire time period. In addition, 103 dairy calves were exported from Ireland before 3 mo. of age and subsequently excluded from the mortality test cut-off analyses. In the end, 78.5 and 99.8% of suckler beef calves were included in the birth to 6 mo. test cut-off analyses for morbidity and mortality, respectively. Conversely, only 43.6 and 95.0% of dairy calves were included in the birth to 6 mo. test cut-off analyses for morbidity and mortality, respectively. To address this right censoring, the authors attempted to analyse these data using survival analyses and generate time-dependent ROC curves. This approach was subsequently abandoned because the time-dependent ROC curves did not account for clustering by farm.

The opportunity for misclassification bias must also be considered. Farmers had an integral role in this study, and the research team was reliant on each farmer to detect and diagnosis all disease events in their calves. Case definitions were provided at the outset of the study; however, misclassification of disease status could have occurred for some calves. Unexpectedly, approximately 43% of calves that died on the home farm had no record of

receiving health treatment prior to death. Some of these deaths may have occurred very suddenly and the calf died before treatment could be initiated. Alternatively, farmers may have either failed to observe clinical signs of disease and morbidity was not detected, or treatment was administered but this health information was not recorded on the project recording sheets. Obtaining accurate calf health information based on farmer diagnoses and recording is a challenge. Gulliksen et al. (2009b) evaluated the quality of calf health data retrieved from a Norwegian health recording system for dairy cattle using three different methods of validation, and estimated that approximately 40% of calf disease events were not recorded by farmers into the system. Therefore, in an attempt to increase the likelihood of good quality data collection by farmers, the approach recommended by Busato et al. (1997) was taken in the present study, which included persistent follow-up through a combination of in person farm visits and telephone contact, as well as SMS and postal reminders.

Finally, the age of calves at blood sample collection may be a potential concern. In most on-farm observational studies, calves between 1 and 7 (McGuirk, 2005; Trotz-Williams et al., 2008; Beam et al., 2009; Vogels et al., 2013; Windeyer et al., 2014) or 2 and 8 days (Donovan et al., 1998; Waldner and Rosengren, 2009; Cuttance et al., 2017a) of age are blood sampled for passive immunity assessment. In the present study, however, the upper age limit for blood sampling was extended to 21 days of age because on many farms in Ireland, especially suckler beef farms, only a small number of calves are born within a 1 week period. Serum Ig reach peak concentrations at approximately 24 hours after birth and then as a result of catabolism, will progressively decline with time (Logan, 1972; Logan et al., 1974; Suh et al., 2003). The half-life of colostral IgG has been estimated at 28.5 days in calves, and the majority of Ig present in the serum of calves up to 30 days of age would be derived from colostrum (Murphy et al., 2014). Further research is needed to determine if, and how, the extended blood sampling age range may have affected the study results. It is likely, however,

that the extended sampling age range may have resulted in the passive immunity test results for some of the older calves at blood sample collection being under-estimated.

## 5. Conclusion

Results of this study provide insight into the relationships between passive immunity, morbidity, mortality and growth of suckler beef and dairy calves under field conditions in Ireland. Overall, 20% of suckler beef calves and 30% of dairy calves were treated for at least one disease event by 6 mo. of age. Suckler beef calves had greater odds of BRD, navel infection, and joint infection/lameness, as well as increased rate of navel infections during the first 6 mo. of life compared to dairy calves. Only 2.7% of suckler beef and 3.3% of dairy calves died within the first 6 mo. of life. Test cut-offs that optimally classified suckler beef calves for health outcomes ranged from 8 to 9 mg/ml ELISA, 56 to 61 g/l TP – CA, 26 to 40 g/l globulin, 12 to 18 ZST units, 8.4% Brix, and 5.3 to 6.3 g/dl TP – DR. Test cut-offs that optimally classified dairy calves for health and growth outcomes ranged from 10 to 12 mg/ml ELISA, 57 to 60 g/l TP – CA, 29 to 34 g/l globulin, 19 ZST units, 7.8 to 8.4% Brix, and 5.7 to 5.9 g/dl TP – DR.

## Author Contributions

Conceived and designed the studies: BE, MMcG, PC (herd-level), CT., IL, BE (calf-level). Data collection: CT, BE, KT. Data acquisition and management: CT, JMcC. Data analysis: CT. Contributed reagents/materials/analysis tools: BE, MMcG, EO'R, IL. Drafted the manuscript: CT. Revised the manuscript critically for important intellectual content BE, MMcG, EO'R, PC.

## Declaration of interest

DAFM funded this research, and did not have input into the study design, collection, analysis, or interpretation of the data, drafting of the manuscript, or decisions to submit the manuscript for publication.

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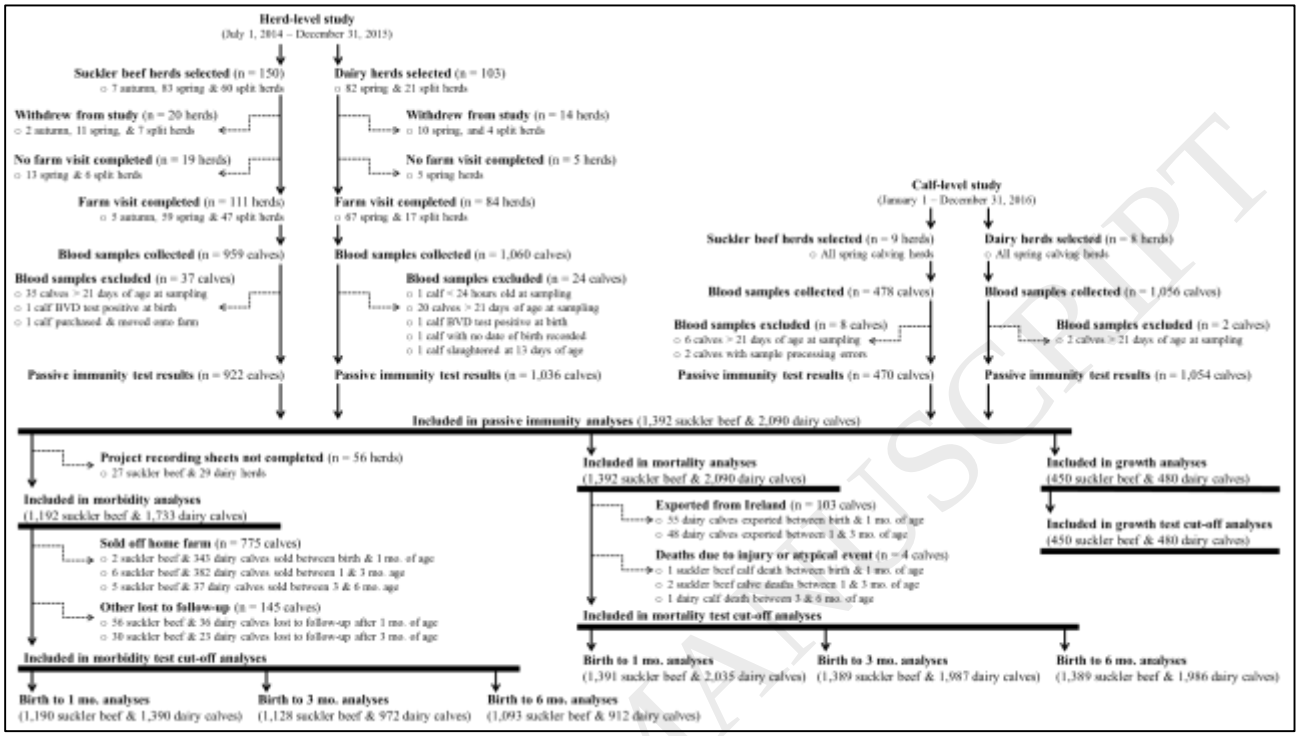
**Figure legend**

Fig. 1. Overview of the herd-level and calf-level studies, including herds selected and withdrawals, blood sample collection, exclusions, and analyses completed



**Table**

Table 1. Case definitions[1] provided to the farmers to assist with classification of disease events

| Disease | Definition |
|---|---|
| Diarrhoea | Repeated passing of loose (soup-like) or watery faeces, of normal or abnormal colour, with or without blood content |
| Bovine respiratory disease (BRD) | One or a combination of the following clinical signs: increased respiratory effort (including increased respiratory rate, laboured breathing, or open mouth breathing), nasal discharge / snotty nose (a considerable amount of cloudy or pus-like discharge), or repeated coughing |
| Navel infection | Warm enlargement of, with or without foul smelling discharge from umbilical structures |
| Joint infection / lameness | One or more swollen joints, resulting in lameness, with or without fever |
| Bloat | Swollen abdomen and exhibited signs of discomfort and / or respiratory distress |
| Dull | Signs of depression, with or without decreased appetite or fever |
| Fever | Temperature of greater than 39.5 ºC / 103 ºF |
| Grass tetany | Combination of the following clinical signs: staggering gait, twitching muscles, collapse, trashing, head thrown back, with or without severe paddling convulsions, and diagnosis preferentially confirmed by veterinarian |
| Meningitis | Combination of the following clinical signs: lack of suckle reflex, head pressing, extended head and neck, star gazing, blindness, over-reactive to stimuli, and / or seizures, and diagnosis preferentially confirmed by veterinarian |
| Mineral / vitamin deficiency | Combination of the following clinical signs: lack of thrive, weight loss, awkward gait, change in hair coat colour, etc., and diagnosis preferentially confirmed by a blood test and / or veterinarian |
| Injury | Physical damage or hurt due to a slip, fall, bump, etc. |

[1] Adapted from Windeyer et al., (2014)

Table 2: Comparison of passive immunity test results for calves' blood sampled between July 2014 and June 2016 on 111 suckler beef and 84 dairy farms

| Test[1] | Suckler beef calves (n = 1,392) | | | | | | Dairy calves (n = 2,090) | | | | | | *P*-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean[2] ± SD | Min | Q1 | Median | Q3 | Max | Mean ± SD | Min | Q1 | Median | Q3 | Max | |
| ELISA, mg/ml | 12.0 ± 5.5 | 1.5 | 8.4 | 11.6 | 15.4 | 47.5 | 14.0 ± 5.9 | 1.5 | 10.3 | 13.9 | 17.6 | 55.5 | < 0.001 |
| TP – CA, g/l | 60.3 ± 8.2 | 36.7 | 55.0 | 59.9 | 65.7 | 87.7 | 62.7 ± 8.3 | 39.8 | 57.1 | 62.6 | 67.9 | 93.0 | < 0.001 |
| Globulin, g/l | 33.1 ± 9.0 | 12.4 | 26.7 | 32.4 | 39.0 | 67.1 | 35.2 ± 9.0 | 13.9 | 29.1 | 34.6 | 41.0 | 68.5 | 0.01 |
| ZST, units | 15.9 ± 7.0 | 0.3 | 11.0 | 15.6 | 20.1 | 52.0 | 17.5 ± 6.9 | 0.5 | 13.2 | 17.0 | 21.5 | 51.4 | < 0.01 |
| TS – BRIX, % | 8.8 ± 0.9 | 6.0 | 8.2 | 8.8 | 9.4 | 13.6 | 9.0 ± 1.0 | 6.0 | 8.4 | 9.0 | 9.6 | 13.2 | < 0.01 |
| TP – DR, g/dl | 5.9 ± 0.9 | 1.5 | 5.4 | 5.9 | 6.5 | 8.7 | 6.2 ± 0.9 | 3.2 | 5.5 | 6.2 | 6.7 | 9.6 | 0.07 |

[1] Serum samples analysed using the following: commercial ELISA assay, total protein concentration by clinical analyser (TP – CA), globulin concentration by clinical analyser, zinc sulphate turbidity (ZST) test, total solids percentage by Brix refractometer (TS – BRIX), and total protein concentration by digital refractometer (TP – DR); [2] Unadjusted mean presented.

Table 3. Comparison of crude and cause-specific morbidity in the first 6 mo. of life for calves' blood sampled between July 2014 and June 2016 on 84 suckler beef and 55 dairy farms

| Morbidity outcome | Suckler beef calves (n = 1,192) | | | | Dairy calves (n = 1,733) | | | | OR[3,4] (95% CI) | IRR[4,5] (95% CI) | *P*-value | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Calves treated, # | Disease events, # | Cumulative incidence[1] | Incidence rate[2] | Calves treated, # | Disease events, # | Cumulative incidence | Incidence rate | | | a[6] | b[7] |
| Birth to 1 mo. of age[8] | | | | | | | | | | | | |
| Crude[9] | 171 | 178 | 14.3 | 15.0 | 478 | 496 | 27.6 | 30.6 | 1.0 (0.5, 1.8) | 1.0 (0.6, 1.6) | 0.90 | 0.88 |
| Diarrhoea | 98 | 103 | 8.2 | 8.7 | 403 | 413 | 23.3 | 25.5 | 0.6 (0.3, 1.8) | 0.6 (0.3, 1.2) | 0.17 | 0.18 |
| BRD[10] | 16 | 16 | 1.3 | 1.3 | 47 | 50 | 2.7 | 3.1 | 0.9 (0.3, 2.4) | 0.8 (0.3, 2.1) | 0.85 | 0.69 |
| Navel infection | 40 | 40 | 3.4 | 3.4 | 20 | 20 | 1.2 | 1.2 | 5.3 (2.1, 13.9) | 4.7 (1.9, 11.9) | < 0.001 | < 0.001 |
| Joint infection / lameness | 14 | 15 | 1.2 | 1.3 | 4 | 4 | 0.2 | 0.2 | 5.0 (1.6, 15.7) | 4.8 (1.5, 15.5) | < 0.01 | < 0.01 |
| Other disease events[11] | 9 | 9 | 0.8 | 0.8 | 17 | 17 | 1.0 | 1.1 | 1.0 (0.4, 2.4) | 0.9 (0.4, 2.2) | 0.91 | 0.78 |
| 1 mo. to 3 mo. of age[12] | | | | | | | | | | | | |
| Crude | 68 | 69 | 6.0 | 3.1 | 46 | 51 | 3.5 | 2.3 | 1.7 (0.8, 3.5) | 1.2 (0.6, 2.2) | 0.16 | 0.60 |
| Diarrhoea | 20 | 20 | 1.8 | 0.9 | 18 | 19 | 1.4 | 0.9 | 0.9 (0.3, 2.6) | 0.6 (0.2, 1.9) | 0.79 | 0.39 |
| BRD | 34 | 35 | 3.0 | 1.6 | 14 | 14 | 1.1 | 0.6 | 4.0 (1.4, 11.4) | 3.2 (1.2, 8.7) | < 0.01 | 0.02 |
| Navel infection[13] | 0 | 0 | 0 | 0 | 4 | 4 | 0.3 | 0.2 | - | - | - | - |
| Joint infection / lameness | 7 | 7 | 0.6 | 0.3 | 3 | 5 | 0.2 | 0.2 | 1.2 (0.1, 22.5) | 0.9 (0.2, 4.7) | 0.91 | 0.89 |
| Other disease events | 8 | 8 | 0.7 | 0.4 | 9 | 10 | 0.7 | 0.5 | 1.0 (0.3, 3.1) | 0.7 (0.2, 2.3) | 0.94 | 0.60 |
| 3 mo. to 6 mo. of age[14] | | | | | | | | | | | | |
| Crude | 23 | 23 | 2.1 | 0.7 | 11 | 11 | 1.2 | 0.4 | 1.2 (0.3, 4.1) | 1.1 (0.3, 3.4) | 0.79 | 0.90 |
| Diarrhoea[13] | 0 | 0 | 0 | 0 | 2 | 2 | 0.2 | 0.1 | - | - | - | - |
| BRD | 16 | 16 | 1.5 | 0.5 | 1 | 1 | 0.1 | 0.04 | 8.1 (0.5, 137.8) | 7.0 (0.5, 92.1) | 0.15 | 0.14 |
| Navel infection[13] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - | - | - |
| Joint infection / lameness | 3 | 3 | 0.3 | 0.1 | 3 | 3 | 0.3 | 0.1 | 1.1 (0.02, 71.6) | 1.1 (0.02, 62.1) | 0.97 | 0.98 |
| Other disease events | 4 | 4 | 0.4 | 0.1 | 5 | 5 | 0.5 | 0.2 | 0.7 (0.02, 27.7) | 0.7 (0.02, 24.2) | 0.85 | 0.84 |
| Birth to 6 mo. of age[15] | | | | | | | | | | | | |
| Crude | 242 | 270 | 20.3 | 4.1 | 521 | 558 | 30.1 | 8.6 | 1.2 (0.6, 2.2) | 0.9 (0.5, 1.4) | 0.59 | 0.57 |
| Diarrhoea | 112 | 123 | 9.4 | 1.9 | 421 | 434 | 24.3 | 6.7 | 0.6 (0.3, 1.2) | 0.9 (0.2, 0.9) | 0.16 | 0.03 |
| BRD | 67 | 67 | 5.6 | 1.0 | 60 | 55 | 3.5 | 0.9 | 2.8 (1.2, 6.5) | 1.9 (0.8, 4.1) | 0.01 | 0.12 |
| Navel infection | 40 | 40 | 3.4 | 0.6 | 24 | 24 | 1.4 | 0.4 | 5.1 (1.9, 13.2) | 3.3 (1.3, 8.4) | < 0.001 | 0.01 |
| Joint infection / | 24 | 25 | 2.0 | 0.4 | 9 | 12 | 0.5 | 0.2 | 3.2 (1.3, 7.8) | 1.7 (0.7, 4.3) | 0.01 | 0.24 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| lameness | | | | | | | | | | | | | |
| Other disease events | 21 | 21 | 1.8 | 0.3 | | 29 | 32 | 1.7 | 0.5 | 1.1 (0.5, 2.3) | 0.7 (0.3, 1.3) | 0.81 | 0.26 |

[1] Cumulative incidence: calves treated for disease within age category / population at risk (PAR), no. per 100 calves; [2] Incidence rate: disease events (all-occurrences) treated within age category / total animal-time at risk, no. per 100 calf-mo. at risk; [3] Odds ratio (95% confidence interval (CI)), adjusted for within-farm correlation using a random effect; [4] Wald CI computed using Taylor-series techniques; [5] Incidence rate ratio (95% CI), adjusted for within-farm correlation using a random effect; [6] *P*-value for cumulative incidence in suckler beef vs. dairy calves; [7] *P*-value for incidence rate in suckler beef vs. dairy calves; [8] PAR of disease from birth to 1 mo. of age: 1,192 suckler beef calves (35,659 calf-days / 1,189 calf-mo.) and 1,733 dairy calves (48,529 calf-days / 1,618 calf-mo.); [9] Crude morbidity: calves treated for at least one disease event, attributed to any cause, excluding injury; [10] Bovine respiratory disease (BRD); [11] Other disease events: calves treated for illness other than diarrhoea, respiratory disease, navel infection, or joint infection / lameness (eg. bloat, eye infection, abscess, etc.); [12] PAR of disease from 1 mo. to 3 mo. of age: 1,126 suckler beef calves (66,894 calf-days / 2,230 calf-mo.) and 1,319 dairy calves (65,378 calf-days / 2,179 calf-mo.); [13] OR, IRR and *P*-value not estimable; [14] PAR of disease from 3 mo. to 6 mo. of age: 1,074 suckler beef calves (96,392 calf-days / 3,213 calf-mo.) and 910 dairy calves (79,771 calf-days / 2,659 calf-mo.); [15] PAR of disease from birth to 6 mo. of age: 1,192 suckler beef calves (198,945 calf-days / 6,632 calf-mo.) and 1,733 dairy calves (193,678 calf-days / 6,456 calf-mo.).

Table 4. Comparison of all-cause mortality in the first 6 mo. of life for calves' blood sampled between July 2014 and June 2016 on 111 suckler beef and 84 dairy farms

| Mortality outcome | Suckler beef calves (n = 1,392) | | | Dairy calves (n = 2,090) | | | OR[3,4] (95% CI) | *P*-value |
|---|---|---|---|---|---|---|---|---|
| | Deaths, # | Cumulative incidence[1] | Incidence rate[2] | Deaths, # | Cumulative incidence | Incidence rate | | |
| Birth to 1 mo. of age[5] | 10 | 0.7 | 0.7 | 35 | 1.7 | 1.7 | 0.6 (0.2, 1.5) | 0.25 |
| 1 mo. to 3 mo. of age[6] | 22 | 1.6 | 0.8 | 18 | 0.9 | 0.5 | 1.8 (0.9, 3.7) | 0.09 |
| 3 mo. to 6 mo. of age[7] | 6 | 0.4 | 0.1 | 16 | 0.8 | 0.3 | 0.6 (0.2, 1.4) | 0.23 |
| Birth to 6 mo. of age[8] | 38 | 2.7 | 0.5 | 69 | 3.3 | 0.6 | 1.0 (0.6, 1.5) | 0.83 |

[1] Cumulative incidence: deaths in age category / population at risk (PAR), no. per 100 calves; [2] Incidence rate: deaths in age category / total animal-time at risk, no. per 100 calf-mo. at risk; [3] Odds ratio (95% confidence interval (CI)), adjusted for within-farm correlation using a random effect; [4] Wald CI computed using Taylor-series techniques; [5] PAR of death from birth to 1 mo. of age: 1,392 suckler beef (41,650 calf-days / 1,388 calf-mo.) and 2,090 dairy calves (61,833 calf-days / 2,061 calf-mo.); [6] PAR of death from 1 mo. to 3 mo. of age: 1,382 suckler beef calves (82,070 calf-days / 2,736 calf-mo.) and 2,000 dairy calves (116,616 calf-days / 3,887 calf-mo.); [7] PAR of death from 3 mo. to 6 mo. of age: 1,360 suckler beef calves (122,400 calf-days / 4,080 calf-mo.) and 1,934 dairy calves (174,060 calf-days / 5,802 calf-mo.); [8] PAR of death from birth to 6 mo. of age: 1,392 suckler beef calves (246,120 calf-days / 8,204 calf-mo.) and 2,090 dairy calves (352,509 calf-days /11,750 calf-mo.)

Table 5: Associations between passive immunity test results and the health of suckler beef calves in the first 6 months of life.

| Test[1] | Time period | AUC[2,3,4] (95% CI) | Optimal cut-off[5] | ≤ Optimal cut-off, % | OR[3,4,6,7] (95% CI) | *P*-value[7] | Se[3,4,8] (95% CI) | Sp[3,4,9] (95% CI) |
|---|---|---|---|---|---|---|---|---|
| ELISA, mg/ml | | | | | | | | |
| Crude[10] | Birth to 3 mo. | 0.57 (0.53, 0.61) | 8 | 22.0 | 2.0 (1.3, 2.9) | < 0.001 | 34.6 (28.1, 41.6) | 80.8 (78.1, 41.6) |
| BRD[11] | Birth to 1 mo. | 0.71 (0.58, 0.84) | 8 | 22.7 | 4.5 (1.4, 14.5) | 0.01 | 56.3 (29.9, 80.3) | 77.8 (75.3, 80.1) |
| Other causes[12] | Birth to 1 mo. | 0.58 (0.51, 0.64) | 8 | 22.7 | 1.8 (1.0, 3.1) | 0.05 | 36.1 (24.2, 49.4) | 78.0 (77.5, 80.4) |
| Mortality | Birth to 6 mo. | 0.64 (0.55, 0.73) | 9 | 31.3 | 2.8 (1.4, 5.8) | < 0.01 | 54.3 (36.7, 71.2) | 69.4 (66.8, 71.8) |
| TP – CA, g/l | | | | | | | | |
| Crude | Birth to 3 mo. | 0.58 (0.54, 0.63) | 61 | 52.8 | 1.5 (1.1, 2.2) | 0.03 | 63.4 (56.4, 70.0) | 49.5 (46.2, 52.8) |
| BRD | Birth to 1 mo. | 0.74 (0.62, 0.85) | 56 | 28.4 | 6.2 (1.7, 22.6) | < 0.01 | 68.8 (41.3, 89.0) | 72.2 (69.5, 74.7) |
| Other causes | Birth to 6 mo. | 0.60 (0.54, 0.67) | 61 | 52.6 | 2.1 (1.2, 3.7) | < 0.01 | 69.3 (57.6, 79.5) | 48.6 (45.5, 51.7) |
| Mortality | Birth to 6 mo. | 0.69 (0.61, 0.77) | 60 | 50.4 | 4.3 (1.8, 10.1) | <0.01 | 80.0 (63.1, 91.6) | 50.4 (47.7, 53.1) |
| Globulin, g/l | | | | | | | | |
| Crude | Birth to 3 mo. | 0.56 (0.52, 0.59) | 26 | 21.1 | 1.6 (1.1, 2.4) | 0.02 | 30.2 (24.0, 37.0) | 80.9 (78.3, 83.4) |
| BRD | Birth to 1 mo. | 0.74 (0.63, 0.84) | 32 | 47.7 | 6.3 (1.3, 29.8) | 0.02 | 87.5 (61.7, 98.5) | 52.8 (49.9, 55.7) |
| Other causes | Birth to 1 mo. | 0.61 (0.54, 0.67) | 40 | 78.2 | 3.1 (1.2, 8.0) | 0.02 | 91.8 (81.9, 97.3) | 22.5 (20.1, 25.1) |
| Mortality | Birth to 6 mo. | 0.66 (0.57, 0.75) | 32 | 48.3 | 3.4 (1.5, 7.5) | < 0.01 | 74.3 (56.7, 87.5) | 52.4 (49.7, 55.1) |
| ZST, units | | | | | | | | |
| Crude | Birth to 3 mo. | 0.57 (0.53, 0.61) | 12 | 29.3 | 1.8 (1.3, 2.6) | < 0.01 | 39.5 (32.8, 46.6) | 73.0 (70.0, 75.9) |
| BRD | Birth to 1 mo. | 0.76 (0.67, 0.85) | 14 | 39.1 | 11.2 (2.1, 60.4) | < 0.01 | 87.5 (61.7, 98.5) | 61.6 (58.7, 64.4) |
| Other causes | Birth to 1 mo. | 0.61 (0.54, 0.68) | 18 | 63.5 | 2.2 (1.1, 4.3) | 0.02 | 78.7 (66.3, 88.1) | 37.3 (34.5, 40.2) |
| Mortality | Birth to 6 mo. | 0.69 (0.61, 0.78) | 14 | 40.3 | 3.4 (1.6, 7.0) | < 0.01 | 68.6 (50.7, 83.2) | 60.4 (57.8, 63.0) |
| TS – BRIX, % | | | | | | | | |
| Crude | Birth to 6 mo. | 0.55 (0.52, 0.59) | 8.4 | 36.7 | 1.5 (1.1, 2.2) | 0.02 | 44.8 (38.2, 51.6) | 65.4 (62.1, 68.6) |
| BRD | Birth to 1 mo. | 0.75 (0.67, 0.83) | 8.4 | 36.7 | 7.2 (1.8, 30.0) | < 0.01 | 81.3 (54.4, 96.0) | 62.9 (60.0, 65.6) |
| Other causes | Birth to 6 mo. | 0.58 (0.52, 0.65) | 8.4 | 36.7 | 1.7 (1.1, 2.9) | 0.03 | 50.7 (38.9, 62.4) | 64.3 (61.3, 67.3) |
| Mortality | Birth to 6 mo. | 0.66 (0.57, 0.74) | 8.4 | 39.2 | 2.8 (1.4, 5.6) | < 0.01 | 62.9 (44.9, 78.5) | 61.5 (58.8, 64.1) |
| TP – DR, g/dl | | | | | | | | |
| Crude | Birth to 6 mo. | 0.58 (0.54, 0.62) | 5.8 | 43.8 | 1.6 (1.1, 2.3) | < 0.01 | 55.6 (48.8, 62.2) | 59.2 (55.9, 62.5) |
| BRD | Birth to 6 mo. | 0.60 (0.53, 0.67) | 5.8 | 43.8 | 2.3 (1.2, 4.3) | 0.01 | 61.7 (48.2, 73.9) | 57.2 (54.1, 60.3) |
| Other causes | Birth to 3 mo. | 0.62 (0.54, 0.69) | 6.3 | 67.6 | 2.5 (1.2, 5.3) | 0.02 | 83.9 (71.7, 92.4) | 33.3 (30.5, 36.2) |
| Mortality | Birth to 6 mo. | 0.69 (0.60, 0.77) | 5.3 | 24.6 | 3.9 (2.0, 7.7) | < 0.01 | 54.3 (36.7, 71.2) | 76.1 (73.8, 78.4) |

[1] Serum samples analysed using the following: commercial ELISA assay, total protein concentration by clinical analyser (TP – CA), globulin concentration by clinical analyser, zinc sulphate turbidity (ZST) test, total solids percentage by Brix refractometer (TS – BRIX), and total protein concentration by digital refractometer (TP – DR); [2] Area under the curve (AUC) for the receiver operating characteristic (ROC) curve; [3] Estimate (95% confidence interval (CI)); [4] Wald CI computed using Taylor-series techniques; [5] Optimal test cut-offs were identified as the test values with maximum Youden index on ROC curves. Only those calves that were observed for the entire period at risk or died before the end of the observation period were included in the test cut-off analyses for morbidity. Only those calves that were observed for the entire period at risk were included in the test cut-off analyses for mortality; [6] Odds ratio; [7] From logistic regression model, adjusted for within-farm correlation using a random effect; [8] Sensitivity (Se): Probability that calves with the outcome of interest had a test result ≤ cut-off value; [9] Specificity (Sp): Probability that calves without the outcome of interest had a test result > cut-off value; [10] Crude morbidity: calves treated for at least one disease event, attributed to any cause, excluding injury; [11] Bovine respiratory disease (BRD); [12] Other causes morbidity: calves treated for navel infection, joint infection/lameness, or other disease events.

Table 6: Associations between passive immunity test results and the health and growth of dairy calves in the first 6 months of life.

| Test[1] | Time period | AUC[2,3,4] (95% CI) | Optimal cut-off[5] | ≤ Optimal cut-off, % | OR[3,4,6,7] (95% CI) | *P*-value[7] | Se[3,4,8] (95% CI) | Sp[3,4,9] (95% CI) |
|---|---|---|---|---|---|---|---|---|
| ELISA, mg/ml | | | | | | | | |
| Diarrhoea | Birth to 6 mo. | 0.58 (0.54, 0.62) | 13 | 43.0 | 0.6 (0.4, 0.9) | < 0.01 | 33.2 (27.1, 39.7) | 53.7 (49.9, 57.5) |
| BRD[10] | Birth to 6 mo. | 0.63 (0.55, 0.71) | 12 | 36.3 | 2.4 (1.3, 4.4) | < 0.01 | 59.6 (44.3, 73.6) | 65.0 (61.7, 68.2) |
| Other causes[11] | Birth to 1 mo. | 0.67 (0.56, 0.77) | 11 | 28.4 | 3.3 (1.6, 6.8) | < 0.01 | 59.4 (40.6, 76.3) | 72.4 (69.9, 74.8) |
| Q1BW[12] | N / A | 0.59 (0.54, 0.65) | 10 | 24.2 | 2.2 (1.3, 3.8) | < 0.01 | 39.2 (30.4, 48.5) | 80.8 (76.4, 84.8) |
| TP – CA, g/l | | | | | | | | |
| Diarrhoea | Birth to 6 mo. | 0.55 (0.51, 0.59) | 66 | 67.5 | 0.7 (0.4, 1.0) | 0.04 | 61.6 (54.9, 67.9) | 30.5 (27.0, 34.1) |
| BRD | Birth to 6 mo. | 0.64 (0.56, 0.72) | 60 | 38.8 | 2.1 (1.1, 3.9) | 0.02 | 61.7 (46.4, 75.5) | 62.4 (59.1, 65.7) |
| Other causes | Birth to 1 mo. | 0.67 (0.57, 0.77) | 57 | 25.4 | 2.9 (1.4, 6.1) | < 0.01 | 53.1 (34.7, 70.9) | 75.3 (72.9, 77.5) |
| Q1BW | N / A | 0.68 (0.63, 0.74) | 57 | 26.7 | 1.9 (1.4, 2.5) | < 0.01 | 40.8 (32.0, 50.2) | 78.1 (73.4, 82.2) |
| Globulin, g/l | | | | | | | | |
| Diarrhoea | Birth to 6 mo. | 0.57 (0.53, 0.62) | 36 | 56.7 | 0.6 (0.4, 0.9) | 0.01 | 48.5 (41.8, 55.2) | 40.6 (36.9, 44.4) |
| BRD | Birth to 6 mo. | 0.62 (0.55, 0.70) | 34 | 48.6 | 2.2 (1.2, 4.3) | 0.02 | 70.2 (55.1, 82.7) | 52.6 (49.2, 56.0) |
| Other causes | Birth to 1 mo. | 0.64 (0.54, 0.74) | 31 | 33.4 | 2.8 (1.4, 5.9) | < 0.01 | 59.4 (40.6, 76.3) | 67.2 (64.7, 69.7) |
| Q1BW | N / A | 0.68 (0.63, 0.74) | 29 | 24.8 | 2.2 (1.3, 3.8) | < 0.01 | 35.8 (27.3, 45.1) | 78.9 (74.3, 83.0) |
| ZST, units | | | | | | | | |
| Diarrhoea | Birth to 6 mo. | 0.57 (0.53, 0.61) | 23 | 83.0 | 0.6 (0.4, 0.9) | 0.02 | 79.9 (74.1, 84.9) | 16.0 (13.3, 18.9) |
| BRD | Birth to 6 mo. | 0.63 (0.55, 0.71) | 19 | 64.5 | 2.8 (1.3, 6.3) | < 0.01 | 83.0 (69.2, 92.4) | 36.5 (33.3, 39.8) |
| TS – BRIX, % | | | | | | | | |
| Diarrhoea | Birth to 6 mo. | 0.57 (0.51, 0.60) | 9.4 | 69.3 | 0.6 (0.4, 1.0) | 0.03 | 61.1 (54.5, 67.5) | 28.0 (24.6, 31.5) |
| BRD | Birth to 6 mo. | 0.62 (0.55, 0.70) | 8.4 | 30.3 | 1.9 (1.0, 3.4) | 0.05 | 51.1 (36.1, 65.9) | 70.9 (67.7, 73.9) |
| Other causes | Birth to 1 mo. | 0.66 (0.56, 0.76) | 7.8 | 10.4 | 4.7 (2.2, 10.2) | < 0.001 | 37.5 (21.1, 56.3) | 90.3 (88.6, 91.8) |
| Q1BW | N / A | 0.68 (0.63, 0.74) | 8.4 | 30.2 | 2.3 (1.3, 3.9) | < 0.01 | 42.5 (33.5, 51.9) | 73.9 (69.0, 78.4) |
| TP – DR, g/dl | | | | | | | | |
| Diarrhoea | Birth to 6 mo. | 0.57 (0.53, 0.60) | 6.7 | 85.0 | 0.5 (0.3, 0.9) | 0.01 | 77.7 (71.8, 83.0) | 12.6 (10.2, 15.3) |
| BRD | Birth to 3 mo. | 0.61 (0.53, 0.69) | 5.9 | 40.1 | 1.9 (1.0, 3.5) | 0.04 | 56.3 (41.2, 70.5) | 60.7 (57.5 ,63.9) |
| Other causes | Birth to 1 mo. | 0.65 (0.56, 0.75) | 5.7 | 31.8 | 2.5 (1.2, 5.2) | 0.01 | 53.1 (34.7, 70.9) | 68.7 (66.2, 17.2) |
| Q1BW | N / A | 0.68 (0.62, 0.73) | 5.9 | 32.3 | 1.6 (1.2, 2.0) | < 0.01 | 44.2 (35.1, 53.5) | 71.7 (66.7, 76.3) |

[1] Serum samples analysed using the following: commercial ELISA assay, total protein concentration by clinical analyser (TP – CA), globulin concentration by clinical analyser, zinc sulphate turbidity (ZST) test, total solids percentage by Brix refractometer (TS – BRIX), and total protein concentration by digital refractometer (TP – DR); [2]

Area under the curve (AUC) for the receiver operating characteristic (ROC) curve; [3] Estimate (95% confidence interval (CI)); [4] Wald CI computed using Taylor-series techniques; [5] Optimal test cut-offs were identified as the test values with maximum Youden index on ROC curves. Only those calves that were observed for the entire period at risk or died before the end of the observation period were included in the test cut-off analyses for morbidity. Only those calves that were observed for the entire period at risk were included in the test cut-off analyses for mortality; [6] Odds ratio; [7] From logistic regression model, adjusted for within-farm correlation using a random effect; [8] Sensitivity (Se): Probability that calves with the outcome of interest had a test result ≤ cut-off value; [9] Specificity (Sp): Probability that calves without the outcome of interest had a test result > cut-off value; [10] Bovine respiratory disease (BRD); [11] Other causes morbidity: calves treated for navel infection, joint infection/lameness, or other disease events; [12] Q1BW: calves within the lower quartile for standardised 205-day BW.