Relationship between selected perinatal paratuberculosis management interventions and passive transfer of immunity in dairy calves

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The objective of this cohort study was to assess the relationship between perinatal calf management practices relevant to the control of paratuberculosis and passive transfer of immunoglobulin in calves born in an endemically infected Irish dairy herd. Data from 176 calves were used to assess the effect of time spent in the calving area, individual versus non-designated calving and colostrum pasteurisation on serum total protein, zinc sulphate turbidity, globulin and γ-glutamyltransferase. In addition, the effects of colostrum quality, volume of colostrum fed, method of colostrum administration and calving season on passive transfer were quantified. Serum samples were collected as part of routine herd health monitoring from calves aged between one and seven days. Multivariate linear and logistic regression models were used to assess the effect of each variable on the test result and failure of passive transfer as determined using a cut-off point for each diagnostic test. Colostrum pasteurisation and calving area were not significantly associated with passive transfer, whereas increased time spent in the calving pen was consistently associated with a detrimental effect. In addition, a strong seasonal effect was apparent, which appeared to be unrelated to colostrum quality and calf management. The authors are unaware of published studies documenting such a significant seasonal effect on passive transfer.

Bovine paratuberculosis is a disease characterised by chronic granulomatous enteritis, which manifests clinically as a protein-losing enteropathy causing diarrhoea, hypoproteinaemia, emaciation and, eventually, death (Sweeney 2011). Calves are recognised as being most susceptible to infection (Windsor and Whittington 2010), and protective calf management is regularly advised as part of national control programmes (Geraghty and others 2014). Common ‘protective calf management’ interventions advocated in order to reduce transmission of paratuberculosis in infected herds include the use of individual calving pens, prompt removal of the calf from the calving environment and feeding of low-risk feeds with the aim of reducing exposure of calves to the aetiological agent, Mycobacterium avium subspecies paratuberculosis (MAP).

The use of an individual calving pen over a group calving pen has been associated with reduced transmission of paratuberculosis in endemically infected herds (Pithua and others 2013) or reduced number of seropositive animals in positive herds (Tiwari and others 2009). In addition, during the course of the calving season on a commercial farm, a small number of cows are often not moved to the calving pen in time and calves may be born in ‘non-designated’ calving areas such as close-up or far-off dry pens. While there is no direct evidence to suggest these animals are at a greater risk of infection, environmental samples from adult cow areas are often more likely to be positive than those collected from calving areas (Raizman and others 2004), suggesting a greater risk of exposure to MAP for calves born in these areas.

Prompt separation of the calf from the dam and removal from the calving area is commonly advocated as part of a Johne’s Disease control programme. The probability of testing positive has been reported to be higher in herds where calving was not supervised (Cashman and others 2008) or in herds where there was late separation from the dam with possible suckling (Beaudeau and others 2005).

MAP has also been isolated from milk and colostrum of sub-clinical animals (Sweeney and others 1992, Streeter and others 1995) and the feeding of milk replacer has been advocated as a result. More recently, the use of on-farm pasteurisers has gained popularity as an intervention for the control of paratuberculosis. While a reduction in levels of MAP in milk (Stabel 2001) and colostrum (Godden and others 2006) has been shown, a definitive
effect on within-herd transmission is yet to be demonstrated (Godden and others 2015). Separation of the calf from the dam within two hours is also commonly advocated in order to promote passive transfer and calf health (McGuirk and Collins 2004). Bovine neonates are born virtually agammaglobulinaemic (Klaus and others 1969) and successful passive transfer of maternal immunoglobulin depends on efficient absorption of an adequate volume of colostrum of sufficient quality. Immunoglobulin absorption by enterocytes in the neonatal calf is greatest for the first four hours of life and declines rapidly from 12 hours of age (Weaver and others 2000). Similarly, in the dam, colostrum immunoglobulin is highest immediately after calving and progressively declines from six hours post calving; the mechanism for this decline is unclear (Moore and others 2005).

Recently, colostral bacterial count has also been shown to negatively impact the efficiency of immunoglobulin absorption (Gelsinger and others 2015). Consequently, colostrum pasteurisation has been developed as a method of reducing bacterial counts with limited effect on immunoglobulin content (Donahue and others 2012). Heat treatment of colostrum has also been studied as a method of significantly reducing the level of MAP in colostrum (Godden and others 2006).

Therefore, considerable crossover exists between recommendations for control of paratuberculosis in infected dairy herds and practices advocated in order to promote calf health. However, while there is some anecdotal evidence to suggest that the implementation of a paratuberculosis control programme is associated with a reduced number of difficult requiring veterinary assistance; however, given the small number of difficult calvings recorded on the farm, this was subsequently simplified to a two-point scale; non-assisted and assisted calvings.

A total of eight individual calving pens were present on the farm to which cows were moved immediately prior to calving. Each pen was cleaned out and bedded with straw following every calving. Calvings occurring accidentally in areas other than these calving pens, such as the far-off or close-up dry cow pen, were recorded as non-designated calvings. Calves were removed from these calving pens or non-designated calving area as soon as possible after calving to a pre-weaning calving shed where they were grouped in batches of eight until weaning. Heifer and bull calves were reared in separate pens within the same shed. From day 3 of life, heifers were fed a commercial milk replacer (Triple A Golden Maverick, Volac Ireland, Cavan, Ireland) until weaning, whereas bulls were reared on waste milk.

All calves in the herd were fed low-risk donor colostrum. Each calf was fed one feed of the first milk from a donor cow, followed by two feeds from the second milking. Risk status of animals in the herd was assigned based on ongoing paratuberculosis testing and the ID of the donor was recorded for each calf.

Colostrum quality was measured before and after pasteurisation using an on-farm portable brix refractometer with a range of 0–52 per cent Brix. All colostrum and transition milk intended for heifer calves was pasteurised using a commercial colostrum pasteuriser (MilkWorks GOLD, DairyTech, Greely, Colorado, USA), frozen for storage and thawed when required. All colostrum and transition milk used for bull calves was frozen on collection and thawed before use. Calves were fed from a milk bottle fitted with a teat and those not ingesting sufficient quantities were tube fed via oesophageal tube feeder.

Routine evaluation of passive transfer on the farm was conducted by the farm’s private veterinary practitioner as a part of routine herd health diagnostics. Blood samples were collected from all calves from one to seven days of age at the time of the practitioner’s visit. Samples were transported to the local regional veterinary laboratory. Samples were centrifuged on arrival and the tests for Failure of Passive Transfer (FPT) performed without delay. The ZST test used the standard operating procedure in place at Limerick Regional Veterinary Laboratory, as described by McEwan and others (1970) with the modification that the concentration of the zinc sulphate solution used was 250 mg/l rather than 208 mg/l (Hudgens and others 1996). Testing for GGT, STP and albumin was carried out using an Rx Daytonia autoanalyser; globulin levels were then determined by subtracting albumin levels from STP. GGT levels were evaluated by a colorimetric method where the L-γ-glutamyl-S-carboxy-4-nitroanilide is converted in the presence of glycyglycine by GGT to 5-amino-2-nitro-benzoate, which absorbs at 405 nm (Szasz 1974). Total protein levels were determined by formation of a coloured complex between protein and cupric ions in an alkaline medium (Weichselbaum 1946). Albumin levels were determined by quantitative binding to the indicator 3,3′,5,5′-tetrabromo-m cresol sulphophthalein (bromoresol green) (Doumas and others 1971).

Materials and methods

One hundred and seventy-six calves born between September 2014 and June 2015 were monitored in a 350-cow, split (autumn and spring) seasonal calving dairy herd in southwest Ireland. The average 305-day yield of lactating cows in the herd was approximately 5900 litres. Considerable data regarding the perinatal management of individual calves in the herd were available due to the aim of reducing the spread of paratuberculosis, affected passive transfer as measured by serum total γ-glutamyltransferase (GGT).

Statistical analysis

Paper records were collected from the farm at the end of the calving season and transferred to an Excel spreadsheet (Microsoft Corporation, USA), statistical analysis was conducted using MLwiN (version 2.29, Centre for Multilevel Modelling, University of Bristol 2013) and Stata (V13.1, StataCorp, College Station, Texas, USA).

Four outcomes of interest were evaluated; STP, ZST, globulin and GGT. Each outcome was investigated as a continuous outcome and as a binary outcome (success or failure of passive transfer).

Univariate linear regression was first used to evaluate the effect of each explanatory variable on each continuous outcome. Serum GGT was not normally distributed and was natural log transformed to meet the assumptions of the linear model. All explanatory variables with a P value <0.2 were carried forward to a multivariate linear regression and a backwards
stepwise elimination was conducted to fit the final model. Variables remained in the final model when $P<0.05$.

Logistic regression was used to evaluate the association between the measured variables and the outcome failure of passive transfer as determined by the cut-off points selected for each outcome. Cut-off points of 52 mg/ml (Calloway and others 2002), 20 units (McEwan and others 1970), 20 mg/ml (Garry and others 1993) and 100 IU/l (Parish and others 1997) were selected for STP, ZST, globulin and GGT, respectively.

Results

Data were available for 176 calves including 102 females and 74 males. Mean STP, ZST and globulin were 57.1, 22.8, 28.8 and 360.6, respectively. Using the cut-off points identified in the literature, the prevalence of FPT in the herd was 32.4, 42.0, 8.5 and 22.5 per cent when using STP, ZST, globulin and GGT, respectively.

Calf serum markers of passive transfer increased from less than 3 to 3.5 litres; however, passive transfer declined when the volume of colostrum administered increased from 3 to greater than 4 litres. Tube feeding of colostrum was significantly associated with poorer passive transfer compared with bottle and tube feeding.

Table 2: Season was identified as a significant factor across three of the outcomes assessed. Markers of passive transfer were consistently higher in autumn-born calves even when volume and quality of colostrum administered were corrected for. The amount of time spent in the calving pen was also significant across three of the outcomes assessed, and markers of passive transfer declined with increasing time spent in the calving pen. Colostrum quality as measured on farm by means of a Brix refractometer was associated with improved passive transfer across two of the outcomes assessed. Volume of colostrum administered was associated with improved passive transfer across all four outcomes. Calf serum markers of passive transfer increased from less than 3 to 3 litres and from 3 to 3.5 litres; however, passive transfer declined when the volume of colostrum administered increased from 3.5 to greater than 4 litres. Tube feeding of colostrum was significantly associated with poorer passive transfer compared with bottle and tube feeding.

Multivariate analysis

The results of the multivariate analysis are displayed in Table 2. Season was identified as a significant factor across three of the outcomes assessed. Markers of passive transfer were consistently higher in autumn-born calves even when volume and quality of colostrum administered were corrected for. The amount of time spent in the calving pen was also significant across three of the outcomes assessed, and markers of passive transfer declined with increasing time spent in the calving pen. Colostrum quality as measured on farm by means of a Brix refractometer was associated with improved passive transfer across two of the outcomes assessed. Volume of colostrum administered was associated with improved passive transfer across all four outcomes. Calf serum markers of passive transfer increased from less than 3 to 3 litres and from 3 to 3.5 litres; however, passive transfer declined when the volume of colostrum administered increased from 3.5 to greater than 4 litres. Tube feeding of colostrum was significantly associated with poorer passive transfer compared with bottle and tube feeding.

Logistic regression model

Univariate analysis

Results of the univariate analysis with failure of passive transfer as a binary response variable are displayed in Table 3. Season, time spent in calving area and method of colostrum administration were significantly associated with failure of passive transfer as determined by STP, globulin and GGT. Volume of colostrum administered was significantly associated with FPT as identified by ZST and GGT. Calving area and level of calving assistance and time spent in calving pen were considered significant when FPT was evaluated by globulin. Colostrum quality and feeding of pasteurised colostrum were significantly associated with ZST assessment of FPT. In addition, calving area, time spent in calving pen and time until colostrum administration were considered significant when FPT was evaluated by GGT.

Linear regression model

Univariate analysis

Results of the univariate analysis are shown in Table 1. Season, time spent in calving pen, time until administration of colostrum and volume of colostrum administered were identified as P<0.05 across three of the methods of assessing passive transfer. Method of colostrum administration yielded P values of 0.162, 0.157 and 0.118 when passive transfer was assessed by STP, ZST and globulin, respectively. Colostrum quality was associated with elevated STP and globulin, pasteurisation was associated with an elevated globulin and volume of colostrum administered was associated with elevations across all four measures of passive transfer.

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Table 1: Univariate linear regression of the effect of measured variables on serum total protein (STP), zinc sulphate turbidity (ZST), globulin and log transformed γ-glutamyltransferase (ln GGT)
Multivariate analysis

Results of logistic regression are shown in Table 4. Season had a significant effect on the OR for FPT. The OR (95% CI) ranged from 3.00 (1.40 to 6.41) for STP to 5.3 (1.86 to 15.22) for GGT (P<0.05). The seasonal effect size for FPT when determined by globulin was also large (OR 4.23, 95% CI 0.90 to 19.83); however, this association was not significant (P=0.067).

Increased time spent in the calving area was associated with increased odds of FPT as evaluated by STP, globulin or GGT. Tube feeding of colostrum rather than feeding from bottle and teat was significantly associated with FPT; this observation was also observed with STP but the effect did not quite reach significance (P=0.053). Volume of colostrum administered was significantly associated with FPT risk as assessed by ZST; ORs were lowest for 3.5 litres, followed by 3 litres and greater than 4 litres; all of these categories were significantly better than feeding less than 3 litres.

Discussion

Estimation of the prevalence of FPT in this herd varied considerably from 8.5 per cent as identified by serum globulin to 42 per cent as measured by ZST. However, 17 per cent of all samples

| TABLE 2: Multivariate linear regression models of the effect of measured variables on serum total protein (STP), zinc sulphate turbidity (ZST), globulin and log transformed γ-glutamyltransferase (ln GGT) |
|-----------------------------------------------|
| Variable                              | STP | ZST | Globulin | ln GGT |
|----------------------------------------|-----|-----|----------|--------|
|                                       | β   | se  | P value  | β     | se  | P value  | β     | se  | P value |
| Season                                |     |     |          |       |     |          |       |     |          |
| Autumn                                |     |     |          |       |     |          |       |     |          |
| Spring                                | −5.82 | 1.34 | <0.001   | −6.55 | 1.39 | <0.001   | −0.83 | 0.17 | 0.000   |
| Time spent in calving pen (minutes)   |     |     |          |       |     |          |       |     |          |
| Continuous                            | −0.05 | 0.03 | 0.046    | −0.06 | 0.03 | 0.024    | −0.01 | 0.03 | 0.020   |
| 3.0                                    |     |     |          |       |     |          |       |     |          |
| Continuous                            | 0.75 | 0.25 | 0.003    | 0.73  | 0.26 | 0.005    |        |     |          |
| Method                                 |     |     |          |       |     |          |       |     |          |
| Teat                                   |     |     |          |       |     |          |       |     |          |
| Tube                                  | −3.43 | 1.96 | 0.080    | −3.70 | 2.04 | 0.069    |        |     |          |

β, coefficient of variable; Ref, referent category

| TABLE 3: Univariate logistic regression of the effect of measured variables on failure of passive transfer as determined by serum total protein (STP), zinc sulphate turbidity (ZST), globulin and γ-glutamyltransferase (GGT) |
|-----------------------------------------------|
| Variable                              | STP | ZST | Globulin | GGT |
|----------------------------------------|-----|-----|----------|-----|
|                                       | β   | se  | P value  | β   | se  | P value  | β   | se  | P value |
| Season                                |     |     |          |     |     |          |     |     |          |
| Autumn                                |     |     |          |     |     |          |     |     |          |
| Spring                                | 1.08 | 0.37 | 0.004    | 0.21 | 0.32 | 0.502    | 1.44 | 0.77 | 0.062   |
| Calving area                          |     |     |          |     |     |          |     |     |          |
| Individual                            |     |     |          |     |     |          |     |     |          |
| NonDes                                | 0.14 | 0.33 | 0.670    | 0.11 | 0.32 | 0.729    | 0.76  | 0.54 | 0.161   |
| Assisted calving                      |     |     |          |     |     |          |     |     |          |
| No                                    | 0.34 | 0.46 | 0.459    | −0.35 | 0.47 | 0.451    | 1.00  | 0.63 | 0.114   |
| Yes                                   |     |     |          |     |     |          |     |     |          |
| Time spent in calving pen (minutes)   |     |     |          |     |     |          |     |     |          |
| Continuous                            | 0.01 | 0.01 | 0.086    | 0.00 | 0.01 | 0.462    | 0.02  | 0.01 | 0.024   |
| 0-10                                  | −0.08 | 0.45 | 0.868    | 0.41 | 0.43 | 0.337    | 1.12  | 1.09 | 0.304   |
| 10-60                                 | −0.05 | 0.59 | 0.927    | −0.33 | 0.58 | 0.570    | 0.00  | 0.90 | 1.000   |
| 60+                                   | 0.58 | 0.50 | 0.248    | 0.41 | 0.48 | 0.463    | 1.95  | 1.10 | 0.079   |
| Colostrum quality (%)                 | −0.02 | 0.06 | 0.747    | −0.11 | 0.06 | 0.072    | −0.06 | 0.10 | 0.586   |
| Time until colostrum admin (minutes)  |     |     |          |     |     |          |     |     |          |
| Continuous                            | 0.00 | 0.00 | 0.968    | 0.00 | 0.00 | 0.699    | 0.00  | 0.00 | 0.757   |
| 0-30                                  | 0.29 | 0.46 | 0.530    | 0.01 | 0.45 | 0.977    | −0.94 | 1.14 | 0.409   |
| 61-120                                | 0.28 | 0.43 | 0.516    | 0.54 | 0.41 | 0.186    | 0.53  | 0.70 | 0.451   |
| 121+                                  | 0.32 | 0.44 | 0.468    | 0.34 | 0.42 | 0.421    | 0.64  | 0.71 | 0.365   |
| Volume of Colostrum (litres)          |     |     |          |     |     |          |     |     |          |
| Continuous                            |     |     |          |     |     |          |     |     |          |
| <3.0                                  | −0.11 | 0.67 | 0.869    | −2.06 | 0.84 | 0.014    | 0.63  | 1.13 | 0.575   |
| 3.5                                   | −0.74 | 0.65 | 0.253    | −2.26 | 0.82 | 0.006    | −0.36 | 1.16 | 0.757   |
| 4+                                    | −0.27 | 0.65 | 0.674    | −1.83 | 0.82 | 0.026    | −0.13 | 1.17 | 0.913   |
| Method                                |     |     |          |     |     |          |     |     |          |
| Teat                                  |     |     |          |     |     |          |     |     |          |
| Tube                                 | 0.78 | 0.44 | 0.076    | 0.66 | 0.44 | 0.131    | −0.08 | 0.79 | 0.920   |
| Pasteurised                           |     |     |          |     |     |          |     |     |          |
| No                                    | 0.21 | 0.33 | 0.521    | 0.50 | 0.31 | 0.115    | 0.41  | 0.57 | 0.477   |
| Yes                                   |     |     |          |     |     |          |     |     |          |

β, coefficient of variable; NonDes, non-designated calving area; Ref, referent category
tested were classified as having an FPT on ZST, despite being negative on all three of the remaining tests. ZST is commonly associated with comparably poor specificity for the detection of FPT (Hogan and others 2015). It therefore seems likely that the true prevalence of FPT in the herd was lower than that as estimated by ZST. There are limited published data regarding the prevalence of FPT in commercial Irish dairy herds; however, a recent UK study found that this prevalence varied from 5 to 51 per cent across seven commercial dairies, which was in agreement with similar estimates from North America (MacFarlane and others 2015).

The present study found that there was no difference in passive transfer between calves born in individual calving pens compared with those born in non-designated calving areas. This contrasts with a Swedish study, which found that calf plasma IgG was greatest in calves born in individual calving pens compared with group pens (Michanek and Ventorp 1993). However, a US study found no difference in calf health between calves born in individual calving pens and those born in group calving pens (Pithua and others 2009).

Calving difficulty was not significantly associated with FPT in any of the models. However, there was a tendency for those calves that required some degree of farmer intervention during parturition to have a greater chance of FPT as determined by serum globulin (P=0.051). Dystocia is often commonly cited as a reason for FPT; however, the biological mechanism behind this finding is somewhat unclear and may be related to the fact that calves suffering from combined respiratory and metabolic acidosis as a result of dystocia are less likely to get up and suckle rather than any inability to absorb immunoglobulin per se (Weaver and others 2000).

Increased time spent in the calving pen was consistently associated with a lower assessment of passive transfer and an increased risk of FPT when assessed by methods other than ZST. This finding is somewhat unsurprising as time spent within the calving pen is likely to be related to time from birth to colostrum administration, which has a well-defined role in the efficiency of immunoglobulin absorption. In this data set, time spent in the calving pen and time until administration of colostrum were moderately correlated (r=0.476). However, it is interesting to note that the majority of calves in this study were removed from the dam within one hour of birth and that a significant effect of time spent in calving pen was observed even within the relatively small spread of removal times. Feeding of colostrum shortly after birth may result in earlier intestinal closure in the neonate than if feeding is delayed (Stott and others 1979). Calves that have opportunity to suckle in the calving pen may therefore experience earlier cessation of absorption and a poorer efficiency of absorption of subsequent colostrum feeds.

Colostrum quality as determined by Brix refractometer was significantly associated with passive transfer in the linear analysis for all four evaluation methods; however, logistic regression identified this factor as being only significant when evaluated by ZST. Improvement in passive transfer increased when volume of colostrum increased from less than 3 litres to 3.5 litres. However, the coefficient for feeding greater than 4 litres was consistently less than 3.5 litres across all models, although the difference between these two groups was not statistically significant. Interestingly, a recent Irish study found that feeding colostrum at 8.5 per cent bodyweight resulted in better passive transfer than 10 per cent bodyweight (Conneely and others 2014), although the biological mechanism behind this observation is somewhat unclear.

Colostrum pasteurisation produced contradictory results from the two statistical analyses conducted. In the linear models, there was no significant effect of pasteurisation though the model coefficients suggested a non-significant positive effect of pasteurisation. However, in the logistic regression, pasteurisation was significantly associated with an increased risk of FPT as determined by ZST; this may be the result of poor specificity associated with ZST for the diagnosis of STP.

Feeding of colostrum by tube was generally associated with poorer passive transfer when assessed by STP and globulin and an increased risk of FPT as determined by STP. This observation has been made before (Adams and others 1985) and has been attributed to closure of the oesophageal groove with earlier delivery of colostrum to the abomasum and small intestine. However, the magnitude of this effect is generally considered to be small and not clinically significant (Godden 2008). A recent randomised control trial found that this effect was only significant when small (1.5 litres) volumes of colostrum were administered (Godden and others 2009). In the present study, calves were preferentially fed colostrum by bottle and teat and only

### Table 4: Multivariate logistic regression of the effect of measured variables on failure of passive transfer as determined by serum total protein (STP), zinc sulphate turbidity (ZST), globulin and γ-glutamyltransferase (GGT)

| Variable | STP | | | ZST | | | Globulin | | | GGT | | |
|----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|          | OR  | 95% CI | P value | OR  | 95% CI | P value | OR  | 95% CI | P value | OR  | 95% CI | P value |
| Season   |     |        |         |     |        |         |     |        |         |     |        |         |
| Autumn   | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    |
| Spring   | 3.00| 1.40 to 6.41 | 0.005 | 4.23| 0.90 to 19.83 | 0.067 | 5.33| 1.86 to 15.22 | 0.002 |
| Assisted calving | | |         |     |        |         |     |        |         |     |        |         |
| No       | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    |
| Yes      | 4.08| 0.99 to 16.76 | 0.051 | 4.08| 0.99 to 16.76 | 0.051 | 4.08| 0.99 to 16.76 | 0.051 |
| Time spent in calving pen (minutes) | | |         |     |        |         |     |        |         |     |        |         |
| Continuous | 1.01| 1.00 to 1.03 | 0.049 | 1.03| 1.00 to 1.05 | 0.018 | 1.03| 1.01 to 1.04 | 0.002 |
| Volume of colostrum (litres) | | |         |     |        |         |     |        |         |     |        |         |
| <3.0     | 0.86| 0.76 to 0.98 | 0.022 | 0.86| 0.76 to 0.98 | 0.022 | 0.86| 0.76 to 0.98 | 0.022 |
| 3        | 0.10| 0.02 to 0.56 | 0.009 | 0.10| 0.02 to 0.56 | 0.009 | 0.10| 0.02 to 0.56 | 0.009 |
| 3.5      | 0.08| 0.02 to 0.44 | 0.003 | 0.08| 0.02 to 0.44 | 0.003 | 0.08| 0.02 to 0.44 | 0.003 |
| 4+       | 0.15| 0.03 to 0.81 | 0.027 | 0.15| 0.03 to 0.81 | 0.027 | 0.15| 0.03 to 0.81 | 0.027 |
| Method of colostrum admin | | |         |     |        |         |     |        |         |     |        |         |
| Teat     | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    |
| Tube     | 2.61| 0.99 to 6.91 | 0.053 | 2.61| 0.99 to 6.91 | 0.053 | 2.61| 0.99 to 6.91 | 0.053 |
| Pasteurised | | |         |     |        |         |     |        |         |     |        |         |
| No       | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    | 1.00|        | 1.0    |
| Yes      | 2.22| 1.09 to 4.53 | 0.029 | 2.22| 1.09 to 4.53 | 0.029 | 2.22| 1.09 to 4.53 | 0.029 |

Note: We refer to the online version of the paper for the full table.
tube fed when they did not drink a sufficient quantity of colostrum. Therefore, it is possible that these calves may have been suffering from acidosis as a result of unobserved or undocumented dystocia, which may have affected efficiency of absorption.

An interesting outcome of this study was the strong seasonal effect on passive transfer. Spring-born calves had significantly poorer passive transfer and a greater risk of FPT compared with autumn-born herdmates. Poorer calf health is often observed in the spring-born population of calves in Irish dairy herds compared with autumn-born herdmates. The most likely explanation for this is that the proportion of cows calving in autumn in a split calving season dairy herd is usually smaller than the proportion calving in the spring. Higher numbers of calves born in spring may result in strains on farm labour, and a delay in the average time from calving to colostrum administration may occur as a result. In addition, an increase in stocking density may also result in poorer hygiene and increased pathogen exposure.

The dry period diet of spring calving cows is likely to differ substantially from those calving in the autumn; body condition scores were also not available for autumn and spring calving cows. However, the role of the dry cow diet in determining colostrum quality is somewhat unclear and studies have generally shown that colostrum quality is relatively insensitive to manipulation of the dry cow diet (Godden 2008). Similarly, the relationship between BCS and colostrum quality and passive transfer is also unclear with studies often finding a lack of association between Body Condition Score (BCS) at calving and passive transfer (Lake and others 2006); others have found increases in colostrum quality only when BCS increased from dry-off to calving, but not the BCS at calving per se (Shearer and others 1992). However, the dry cow diet and BCS could only be expected to affect passive transfer in autumn-born calves by affecting colostrum quality, whereas in the present study both the quality of colostrum as assessed by refractometer and the time from calving to colostrum administration were recorded and included in the final models when appropriate. Therefore, it was expected that both the quality of colostrum and the length of time until colostrum was administered would have had a limited effect on this particular finding in the final model. Indeed, the average refractometer reading for colostrum was higher in spring (27.2 per cent) than in autumn (26.1 per cent), whereas poorer passive transfer was observed in the spring-born calves. These findings would suggest that on this particular farm there was an unidentified factor affecting apparent efficiency of absorption resulting in increased time spent in the calving pen which was unrelated to colostrum quality and calf health. Poorer passive transfer in autumn-born calves as opposed to spring-born calves was not accounted for in this study as they were not measured in the present study. However, amongst other factors, the relative delay in colostrum administration would have had a significant effect on passive transfer in autumn-born calves. In conclusion, this study used detailed data on the perinatal management of calves born in a herd endemically infected with paratuberculosis. The effect of management practices on calf passive transfer was assessed. Increased time spent in the calving pen was consistently associated with a detrimental effect on passive transfer. In addition, a strong seasonal effect was apparent, which was unrelated to colostrum quality and calf management.

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