Mortality and failure of passive transfer of immunity in New Zealand dairy calves

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Abstract

In recent years, there has been a growing interest from consumers globally about the welfare of the animals producing their food. In New Zealand, particular attention has been paid to the treatment of calves though the help of welfare lobbyists bringing certain New Zealand farming practices into the spotlight. Unlike most of the rest of the world, in New Zealand, cattle are born outdoors and are housed only for a short period of time. This has meant that international research on mortality, colostrum management and calf health has been generally not applicable, and that we need New Zealand-based data to be able to benchmark key outcomes.

We had two major objectives for this research. The first was to accurately estimate perinatal and postnatal mortality on New Zealand dairy farms and to identify potential risk factors. The second objective was to focus on one factor that is known to be strongly associated with calf mortality: the failure of the calf to take up sufficient colostral antibodies to provide protective immunity until the calf's antibody-production system becomes fully effective ("failure of passive transfer"; FPT). The study aimed to estimate the prevalence of FPT across New Zealand dairy farms, identify potential risk factors that may be associated with that prevalence and to evaluate the effects of FPT to the end of first lactation.

We found that, despite the significant differences between the New Zealand system and those of the northern hemisphere, the mortality risk of perinatal (5.7%) and postnatal calves up to weaning (4.1%), then weaning to ~27 months (2.7%) was comparable. However, our review of the previously published data highlighted that the quality of data collection, transparency in methods and validation of records in most other studies, particularly retrospective ones, was poor, limiting the validity of such comparisons.

We identified substantial variation between farms in mortality risk (2.2-8.6% perinatal, 0-11% postnatal pre-weaning, 0-7.9% weaning to ~27 months), thus significant reductions in calf mortality may be achievable on many farms. One factor responsible for this variation may be farm-level prevalence of FPT which averaged at 33% and ranged from 5-84%. In intensive systems, separating calves from their dam and feeding high quality colostrum within 4-6 hours of birth reduces FPT. In contrast, our research found no effect of earlier colostrum feeding on FPT prevalence and the only significant herd level risk factors were region and herd size. This may be at least partly due to the difficulty of increasing calf pick-up to the frequency recommended for intensive farms. FPT increased mortality and morbidity

and to a lesser extent decreased weight gain in the first 12 months, however showed no appreciable effect after this time.

Contents

Preface

This body of work was funded by Sustainable Farming Fund, the New Zealand Ministry of Business, Innovation and Employment (Wellington, NZ; contract number DRCX1302) and New Zealand dairy farmers through DairyNZ Inc. (Hamilton, NZ; contract number RD 1405 and 1502) and Veterinary Enterprises Group Ltd.

This thesis has been prepared through publications. As such, each chapter is a section of work that has been published. The supplementary articles are publications from the same body of work but were completed either prior to the PhD enrolment or in parallel alongside other researchers. Each chapter has been prepared in the style and format of the journal they were submitted to or accepted from.

There has been a large focus placed on extension of this body of work to the dairy industry. To date, in addition to the published work, the work on failure of passive transfer and to a lesser extent the work on mortality has been presented to more than 2000 farmers over approximately 60 presentations, at least 200 veterinarians and 150 veterinary students and has been published in DairyNZ technical material, placed on their website and training material and put in multiple newspaper articles. Anecdotally there are now more farmers testing their animals for failure of passive transfer, more consistency in the industry on testing methods and better advice being provided to our dairy farmers. I have had the pleasure of farmers making a point of letting me know that they have never had healthier calves with fewer sicknesses and deaths since paying more attention to their colostrum management. This is by far the most satisfying achievement of this research.

Acknowledgements

I wish to extend my gratitude to Veterinary Enterprises Group Ltd, to whom without their support and ability to afford me total freedom in my career, I would have never gone down this research path, let alone completed a PhD whilst working as well.

Thank you to my amazing VetEnt Research field team, Jane McDermott and Krista Glover. This body of work has really been a team effort and despite some tough time frames we have all managed to stay friends and continue working efficiently together.

I have been very lucky to have the best team of supervisors that all had such an empathy towards the time constraints of doing a PhD whilst working and with three children. I needed a team of supervisors that were quick to reply (like within an hour), could ensure the process was efficiently carried out, but also asked how my family and I were. I hit the jackpot with this team on these requirements. Winston Mason, aside from being one of my longest and loyal friends, we have really done this PhD together. For some reason you have an affinity towards statistical coding and an enthusiasm towards it that I don't think I could achieve in a lifetime. Your involvement has meant that I did not had to spend countless hours finding error codes in R and was able to focus a lot more time on the published content and extension to the industry. Linda Laven, your monthly checks-ups meant a lot and your encouragement was just what I needed. Claire Phyn, our regular catch ups during the trial phase have been so fun. Your writing skills are something to aspire to and I have learnt so much having you involved. Finally, Richard Laven, you have been my supervisor and mentor, but you have also been (and still are) my friend. You work so quickly with your photographic memory and amazing writing skills and are encouraging about everything. You provide plenty of entertainment for the peer review replies which have helped turn a PhD into an enjoyable process.

Last but not least, to my husband William, you never fuss or complain over the hundreds of hours I spend on the computer while you look after our children and the household. You provide unwavering support for everything I do, no matter how ambitious, and I am so thankful to have you.

Finally, I hope that my children will one day be interested enough to read this thesis and be inspired to love learning like I do, understand that quality research is more than Google searches and Facebook blogs and that success is earnt through hard work.

Publications

Chapter	Publication	Status
1	**Cuttance E, Regenerus C, Laven R.** A review of diagnostic tests for diagnosing failure of transfer of passive immunity in dairy calves in New Zealand. *New Zealand Veterinary Journal.*	Published
2	**Cuttance EL, Laven RA.** Literature review of perinatal mortality in dairy calves. *The Veterinary Journal*.	Published
3	**Cuttance EL, Laven RA.** Literature review of perinatal mortality risk factors of dairy calves. *The Veterinary Journal*	Published
4	**Cuttance EL, Mason WA, McDermott J, Laven RA, McDougall S, Phyn CVC.** Calf and replacement heifer mortality from birth until weaning in pasture-based dairy herds in New Zealand. *Journal of Dairy Science* 100, 8347-57, 2017	Published
5	**Mason WA, Cuttance EL, Laven RA, McDougall S, Phyn CVC.** "Short communication:" Replacement heifer mortality from weaning until second mating in seasonal-calving, pasture-based dairy herds in New Zealand. *Journal of Dairy Science*	Published
6	**Cuttance E, Mason W, Laven R, McDermott J, Phyn C.** Prevalence and calf-level risk factors for failure of passive transfer in dairy calves in New Zealand. *New Zealand Veterinary Journal* 65, 297-304, 2017	Published
7	**Cuttance E, Mason W, Laven R, Denholm K, Yang D.** Calf and colostrum management practices on New Zealand dairy farms and their associations with concentrations of total protein in calf serum. *New Zealand Veterinary Journal* 66, 126-31, 2018	Published
8	**Cuttance EL, Mason WA, Laven RA, Phyn CVC.** The relationship between failure of passive transfer and mortality, farmer-recorded animal health events and body weights of calves from birth until 12 months of age on pasture-based, seasonal calving dairy farms in New Zealand. *The Veterinary Journal* 236, 4-11, 2018	Published
9	**Cuttance EL, Mason WA, Laven RA, Phyn CVC.** Relationships between failure of transfer of passive immunity and subsequent mortality, body weights, and lactation performance of heifers between 12 to 36 months of age on pasture-based, seasonal calving dairy farms in New Zealand. *The Veterinary Journal*	Published

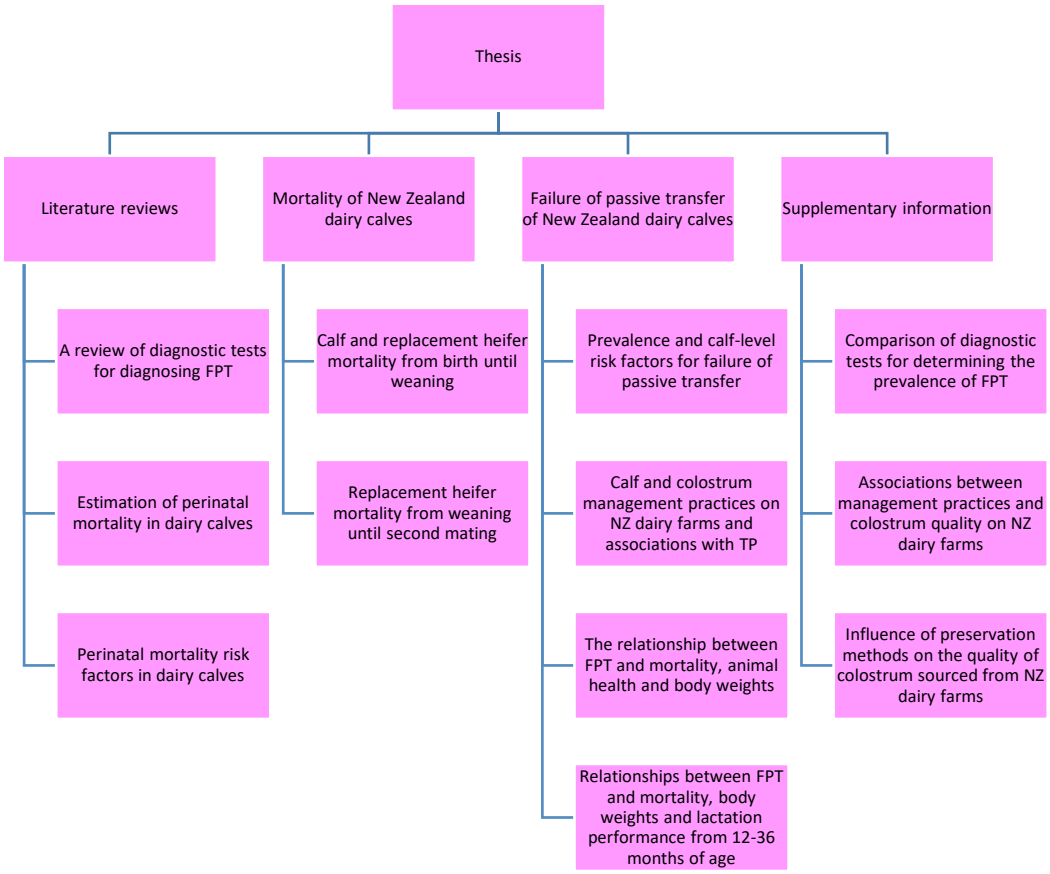
	Supplementary publication	**Status**
10	**Cuttance E, Mason W, Denholm K, Laven R.** Comparison of diagnostic tests for determining the prevalence of failure of passive transfer in New Zealand dairy calves. *New Zealand Veterinary Journal* 65, 6-13, 2017	Published
11	**Denholm KS, Hunnam JC, Cuttance EL, McDougall S.** Associations between management practices and colostrum quality on New Zealand dairy farms. *New Zealand Veterinary Journal* 65, 257-63, 2017	Published
12	**Denholm KS, Hunnam JC, Cuttance EL, McDougall S.** Influence of preservation methods on the quality of colostrum sourced from New Zealand dairy farms. New Zealand Veterinary Journal, 1-6, 2017	Published

Introduction

In recent years, there has been a growing interest from consumers globally about the welfare of the animals producing their food. In New Zealand, particular attention has been paid to the treatment of calves though the help of welfare lobbyists bringing New Zealand farming practices into the spotlight. The dairy industry in New Zealand is committed to world leading on-farm animal care as well as environmental stewardship, competitive and resilient farming businesses and national prosperity (DairyNZ and Fonterra strategy). However, New Zealand farming is unique and, unlike most of the rest of the world, calves are born outdoors, typically spending 1-24 hours with their dam before being housed, and then housed for a short period of time (often just a few weeks) before returning to pasture where they are kept until they calve for the first time. This has meant that a lot of the research completed overseas on the management of calves in the perinatal and postnatal period may not be directly applicable as conditions are so different.

This thesis is set out in four major sections described in figure 1.

Figure 1. Diagram of thesis structure



Literature reviews

The literature reviews purposefully focused on three key areas within the literature on failure of passive transfer. The first literature review focuses on testing methods for failure of passive transfer (FPT). There is a vast amount of literature on this topic, however the purpose of this was to utilise a New Zealand focused literature review to influence current New Zealand practices by veterinarians. Despite the research available, the laboratories were still commonly recommending testing for FPT by using GGT in addition to many vets. Therefore, this literature review was aimed to influence industry change.

In the mortality literature reviews, we focussed on the studies reporting the impacts of FPT in calves pre-weaning and the risk factors for FPT. This was because, although, once again, there is a vast amount of literature on those topics in addition to multiple summary articles, previous summaries have never attempted to draw the reader to the deficiencies in the methods/data collection/data validation. Therefore, the applicability of those results have never been questioned. The reviews presented are centred around assessing the quality of the literature so that the reader may assess how applicable each mortality estimate or risk factors

are to their country or farming practice. This was considered to be of more value to the world literature than further narrative reviews of FPT and colostrum.

Mortality of New Zealand dairy calves

The timing of calf mortality can be categorised into two phases: 1) perinatal mortality, which typically refers to mortality of full-term calves during parturition and up to 24 (or 48 h) after birth, and 2) postnatal mortality, which refers to mortality after the perinatal period, up to a designated time point. Although Compton *et al.*, (2017) reviewed the iterature and available data on calf mortality in New Zealand, the major limitation of this work was the reliance on electronic records (e.g. Minda PRO, LIC, Hamilton). In New Zealand, farmers are not required to ear tag animals that have been born dead, have died shortly after birth or are sent to the processing plant at 4 days of age. Therefore, it is of no surprise that the estimates obtained were very low which prompted the need for accurate data collection in the space.

Although case definitions and data accuracy can vary, estimates of perinatal mortality incidence risk range from 3 to 9% across dairy industries internationally, and the postnatal mortality incidence risk until weaning is reported at between 5 and 11% (Compton *et al.*, 2016).

Although these figures are available across many different publications and even multiple review papers, there are many challenges with utilising these published studies to try and benchmark performance against. Very few studies have estimated the incidence of perinatal and postnatal mortality in herds where cows often calve outdoors and the quality of the data in such studies varies markedly. Mortality throughout all the different definitions is often poorly documented by producers, and there is misclassification of sold, culled, or euthanized animals; all of which are likely to affect mortality estimates. Data validation is also a significant issue across all cow age groups. In a recent review of culling and mortality, Compton *et al.* (2017) reported that data validation was reported in only 24% of the studies they reviewed. In 29 studies that used secondary data, the situation was worse, with only two of these studies including a discussion on data validation.

A wide variety of risk factors have been associated with perinatal and postnatal mortality including dystocia, age of dam, twin calving, year, gender of calf, and first colostrum feeding method, timing and volume. But again these risk factors were almost exclusively identified in systems where cows calved indoors, and there are limited data available in pasture-based

systems where cows calve outdoors during late Winter/early Spring with minimualsupervision.

To develop strategies to reduce calf mortality on pasture-based dairy farms, it is imperative that quality data are collected to make an accurate assessment of perinatal and postnatal mortality and that key calf- and farm-level risk factors are identified.

Failure of passive transfer (FPT)

Many studies have reported that FPT can result in increased mortality rates, disease and ill-thrift in dairy calves (Besser *et al.* 1985; Tyler *et al.* 1999b; Pardon *et al.* 2015). The synepitheliochorial bovine placenta prevents the transfer of immunoglobulins from dam to fetus (Borghesi *et al.* 2014), thus, the neonatal calf is born effectively agammaglobulinaemic (Jones 1967; Merriman 1971). Therefore, calves must ingest and absorb adequate amounts of colostral immunoglobulins (Ig) to acquire sufficient passive immunity to protect them until their own antibody production system becomes properly functional (Weaver *et al.* 2000).

The effectiveness of IgG absorption from colostrum can be measured by the concentration of IgG in the calf's blood, with concentrations <10 g/L most commonly indicating that there has been a failure of passive transfer (FPT) of Ig from dam to calf (Besser *et al.* 1985).

FPT can occur in calves for several reasons: a) they did not receive colostrum early enough (i.e. within the first 12-24 hours of life); b) they received insufficient colostrum during this period; c) the concentration of IgG in the ingested colostrum was too low; or d) the colostrum was contaminated with bacteria that limited the absorption of IgG (Godden *et al.* 2012; Gelsinger *et al.* 2014). In this regard, correct management of calves within the first 12 – 24 hrs is crucial in reducing the occurrence of FPT. To improve calf management in New Zealand, there are a number of key areas that need to be investigated.

Firstly, despite there being several recognised diagnostic tests available for evaluation of FPT in neonatal calves, these have not been thoroughly evaluated in New Zealand. Furthermore, within the New Zealand veterinary industry there is much inconsistency and debate over which tests to use, what age groups to use them on and which cut-offs are most appropriate for a herd-level assessment of FPT. Secondly, there is a lack of good quality, large-scale data on the prevalence of FPT in replacement heifer calves on New Zealand dairy farms. Without an accurate estimate of prevalence, we cannot benchmark farm performance to promote improvement. Thirdly, alongside the lack of prevalence data, there is also a lack of

information on the key calf-level and farm-level risk factors associated with FPT on New Zealand dairy farms. Finally, to make improvements on farm we need to be able to demonstrate to farmers the welfare and financial implications of FPT. There are no studies in New Zealand that have investigated the short and long term effects of FPT.

The chapters of this thesis explore FPT after farmers have provided colostrum or calves have been left in the paddock for up to 24 hours with their dam. At the time this thesis was being designed, the terminology for colostrum was considered loosely by the New Zealand dairy industry. Colostrum was considered as the milk from milk collected from 1-4 days following calving, with some farmers using the terms gold and silver colostrum for day 1 and day 2-4 milk, respectively. In this study, we did not attempt to influence farmers' choice of which milk to feed to newborn calves. It is likely that there would have been differences between farms in the definition of 'colostrum', with some farmers considering colostrum as the first milking only, and some considering milk 'colostrum' until right up to day 4. Thus, when the term colostrum is used in this thesis in relation to the milk that was fed neonatal calves as their first feed after they were separated from their dam, it does not imply that the calves were being fed true day 1 colostrum. It simply means that the calves were fed a milk feed that was what the farmers considered as colostrum on their farm.

Objectives

The first objective of this body of work was to gather an accurate estimate of perinatal and postnatal mortality up to 27 months of age and to identify possible associated risk factors. Secondly, we aimed to estimate the prevalence of FPT across New Zealand dairy farms, possible associated individual and farm risk factors and the effects of FPT to the end of first lactation.

This body of work was designed to deliver improved calf rearing practices for New Zealand dairy farmers that result in improved welfare of all calves born on farm and more productive and efficient replacement cows. The farm management practices investigated were mortality from birth up to ~27 months and failure of passive transfer (FPT) in calves.

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Discussion

The overarching aim of this research project was to deliver improved calf rearing practices for New Zealand dairy farmers that result in improved welfare of all calves born on farm and more productive and efficient replacement cows. Whilst some outcomes of the study were able to be turned into practical and implementable solutions for farmers, we equally unearthed major hurdles and gaps in knowledge that will be necessary to fill before major change can take place.

Mortality

The section of work on mortality was intended for benchmarking, both at the farmer level (allowing within region and within-country comparisons) and at the country level (allowing international comparisons). We had then hoped to take it one step further and find risk factors for the farmer to help improve mortality on their farm.

The data collected for this study was useful to get an idea of how farms were generally performing and to identify the typical range in mortality across farms (Chapter 4 and 5). Putting aside the likely bias in our sample selection (as this sort of study design would not lend itself to farmers who did not have some affinity towards recording), the results of this study provide a useful way to categorise farms into poor or acceptable for both perinatal and postnatal mortality. The problem is that if we then want to take this categorisation and use it to monitor farms, or even in the future provide them with a welfare or performance "grade" like we do with programmes such as "In Calf" it is close to an impossible task. If nothing else, this study highlighted just how difficult it is to obtain accurate records. Over such a busy time of year, farmers simply struggle to commit the time to not just recording mortalities, but the time it takes to equally input calves being sold, euthanased, "bobbied" or moved to their neighbour for a box of beer. Across the farms included in the study, this information took the research team hundreds of hours to extract. These difficulties are not unique to New Zealand farmers. Missing records and poor recording are prevalent in farming systems all over the world. Therefore, unless we can change the culture of recording on New Zealand dairy farms we will not have accurate enough data to use to compare against the benchmarks and therefore making the point of gathering benchmarking data almost redundant.

The study also aimed to gather information on calf and farm level risk factors. We went in with our eyes open, understanding that we were likely underpowered to detect farm level management risk factors, but the survey information itself was of benefit for the industry. The risk factors for perinatal mortality were interesting, and were similar to those identified by international research. However, the identified factors were either not susceptible to farmer action without major changes in the system (e.g. providing large shelters so that animals can avoid the rain) or significant additional resources (to monitor animals a lot closer in the first week of the calving season). Even more importantly, spending significant effort to try and mitigate the effect of time within the calving season on mortality may not be useful, as it is possible that the increase of mortality in the first week was at least partly due to an increased likelihood of late term abortions in that week. Lack of recording and difficulties in data collection mean that we were not able to specifically link calves to their dam to confirm whether they were late term abortions rather than full term calves.

In contrast, the identification of postnatal mortality risk factors, such as in increase in postnatal mortality if farmers were hand feeding colostrum in the first 12 hours of life (assumed to be related to poor colostrum quality), has been more practically useful as it has allowed farmers to see the outcome of poor colostrum practices and the contribution those poor practices are having on mortality in their calves. While this information is not novel (beyond its demonstration on dairy farms in New Zealand), it does supplement the information that came from the FPT section of the research described later.

Ultimately, if we really want to make a real change in the overall level of calf mortality, it is likely that focusing on the clusters of farms that have very high mortality will be the most logical approach. Anecdotally, these farms are often known to the industry and veterinarians, and, despite poor recording, they can still stick out as outliers even when there is major under reporting. Our study showed that if we could focus on the outliers and reduce their mortality to be in line with a more average result, the overall mean mortality changed by 0.4% for perinatal mortality and 1.2% for postnatal mortality. This is a practical solution to start with, and is likely to be more successful than trying to drag ~13,000 farms into the world of accurate recording all at once.

Finally, the mortality research was supposed to allow the New Zealand dairy industry to determine how we are performing against the rest of the world as regards perinatal and postnatal mortality. One year into this study, the New Zealand dairy industry were placed in a

particularly bad light internationally through video footage of poor treatment of bobby calves. In the wake of this publicity, international benchmarking of calf welfare became more important to the New Zealand dairy industry. On the surface, the perinatal and postnatal mortality incidences from this study appear similar to, or even less than those reported in previously published studies. However, accurate comparison with the published data is not as simple as it would appear. Despite numerous authors summarising the data from studies of perinatal and postnatal mortality in multiple reviews over multiple years, there has been very little focus on the underlying quality of the data used to make the estimates. For this thesis, we focused intently on the data quality of published studies. A combination of lack of transparency in reporting the methods, validation of records, analyses, and variation in time frames over which studies were done all contribute to the lack of comparability. Too often the assumption has been made that just because a dataset is large it is accurate and unbiased even when no data quality assessment has been made. This means that ultimately our conclusions as to where New Zealand sits internationally remains a best guess as the number of comparable studies is much less than would be anticipated from a superficial assessment of the literature.

Failure of passive transfer

The work completed on failure of passive transfer in parallel with the supplementary publications had some really interesting and practical findings for the dairy industry.

The first was that testing regimes using GGT to diagnose FPT, which historically have been the most commonly used regimes on New Zealand farms, were really not providing practitioners with the most practical and accurate test. Total protein (TP) (in non-dehydrated animals) is both accurate and practical given that the age of the animal, as long as it is less than 8-days old does not influence test characteristics. Since the completion of this research, the advice provided by laboratories has already changed in favour of recommending total protein. The value of using total protein for diagnosis of FPT instead of GGT was shown both in the literature review (Chapter 1) and in the supplementary paper (Chapter 10) comparing tests of the study animals in this research. The most enlightening part of the research on testing methods was the discovery that an arbitrary “12 sample animals” to detect herd problems with FPT, a number taken as gospel by practitioners all over the world, has major limitations that are simply not understood and/or communicated to farmers. There needs to be a major movement in upskilling practitioners in interpretation of diagnostic tests, especially

when the test results for FPT are indicating a herd level prevalence between 10-40%. Twelve animal results are simply not enough to have confidence in the diagnosis of the herd having an FPT problem (defined as 20% prevalence or above). Practitioners need to understand and have the confidence that either more animals need to be sampled at one time-point or multiple time points need to be utilised (even if it is over a number of years) to gather prior information about the herd.

The prevalence of failure of passive transfer in calves was very similar to the prevalence estimates reported overseas and not surprisingly, hugely variable across farms (Chapter 6). Showing farmers how prevalent it was, despite almost 80% of farmers thinking that they would not have any calves with FPT was the first step in making farmers aware of the problem. The study identified some really practical risk factors that challenged a lot of current thinking on this problem. The most surprising and potentially controversial of those were those associated with colostrum management. Our research identified that calves that were left with the dam for ~24 hours (or once daily pick up from the calving paddock) had lower odds of having FPT. This was not only different to what almost every practitioner has been advising farmers for the past 20 years, but different to all international research. However, when drilling into the likely reason for this, the supplementary paper on colostrum quality, supported by the farm level risk factors, showed that colostrum quality on New Zealand farms was exceptionally poor. This is likely contributed to firstly by the lack of definition of colostrum provided in this study. Colostrum could have been anything from the first milking a few hours after calving to milkings on the 4th day following calving as its definition was determined by what the farmer classified as "colostrum". Secondly, the quality is likely altered by the extended length of time calves are left on the dam to suckle. Therefore, by the time the farmer typically milks the cow, it has been many hours since calving and often she has been fed from multiple times by the calf. Nonetheless, improvement in colostrum quality through clarifying its definition and reducing contamination is a very logical and practical solution for New Zealand dairy farmers and the advice provided on this over the past three years has been very well received with, anecdotally, excellent uptake.

However, we are still left with some major gaps in the research that we feel preclude large leaps in reducing FPT prevalence in New Zealand. While the colostrum quality was undoubtedly horrendous, there was actually no direct association between colostrum quality on the farms and FPT prevalence. Similarly, there was no association with how often calves

were picked up, and volume of colostrum fed on FPT prevalence either. The only association we were able to prove was that if a farm has high quality colostrum, the variability in calf STP concentration decreased. However, other than this, there really were no other major management risk factors that were influencing FPT prevalence. This could be because the study was not powered enough to detect the associations or that the associations were there but just complicated by so many farm interactions. However, it could also be because, in the situation where calves are kept at pasture with their dams for prolonged periods (like in New Zealand), factors which influence how well a cow can feed its calf in the first 12–24 hours are likely to have a larger influence on FPT than the management of calves once they reach the rearing sheds. Our research showed that more than 70% of calves are left with the dam for approximately 24 hours with the remaining 30% still left for up to 12 hours. In contrast, internationally, it is common practice to remove calves off the dam within 1-4 hours of birth and to feed them with a set volume of high quality (often pasteurised) colostrum.

Early removal of calves has long been advocated as a way of ensuring calves are getting adequate volumes of high quality colostrum and as a way of reducing the distress caused for both calf and dam by later removal (Weary and Chua, 2000, Flower and Weary, 2001). Because of this, there has been significant pressure from all veterinarians and advisors to encourage farmers to collect calves from the calving paddock twice or more daily in order to better match what farmers are doing internationally. The key drivers for this have been FPT and mastitis. However, as the results from our research has shown, most dairy farmers are not regularly achieving two pick-ups a day let alone more. This lack of progress and resistance to change from farmers is almost certainly because, from a farm management perspective, there are clear advantages, at an extremely busy time of the year, in not collecting calves more than once a day.

Despite it being a crucial period for the transfer of passive immunity and potentially having a significant welfare impact, there is only one published paper that has provided any New Zealand data on management of calves prior to pick-up and how this impacts on calf welfare (Wesselink *et al.*, 1999). This study included data from 21 calves from one farm in one year. They were able to show that failure to suckle was associated with increased risk of FPT and that calves that were successful in suckling, first suckled within 6 hours of birth. They thus recommended that calves were picked up at least 4 times per day. It is not surprising that 20 years later this recommendation has not had a significant impact on farmer behaviour. Wesselink *et al.*, (1999) were not able to identify how environment and management of cows

and calves in the calving paddock affected the ability of calves to suckle naturally, and thereby ingest colostrum.

The failure of over 20 years of pressure to change calf pick-up management strategies on most farms highlights a failure of research to focus on what is achievable by farmers. There is an opportunity for the New Zealand dairy industry to investigate the advantages and disadvantages of leaving calves on the dam. Perhaps there are ways that farmers can improve the management of cows and calves to enable successful passive transfer or maybe this already is very successful. This may in fact make more of an impact on the industry than simply trying to continually push a more frequent collection of calves in combination with feeding high quality colostrum, confirmed with a Brix refractometer.

We need to be prepared to adapt our research and advice to the current system that the majority of farmers are using. This is particularly so as it is a system that is being marketed by milk suppliers as promoting the highest welfare, rather than continually trying to change it, especially by suggesting management options, that to many farmers are unachievable.

As world interest in animal welfare continues to increase, the management of cow-calf separation is under increasing public scrutiny. The management of cows and calves in the calving paddock is a focus of welfare lobbyist groups such as SAFE, and has become a key area of interest for milk suppliers that are increasingly promoting high welfare standards to their customers. Even more importantly, once they are aware of the process, for the public, cow-calf separation is one of the most contentious practices and a key welfare concern, which cannot be simply changed by increasing the information about this practice and the reasons for doing it (Busch *et al.*, 2017). Therefore, it is logical that the next big opportunity to help farmers achieve the goal of New Zealand dairy farms having the best calf and cow welfare and health in the world is researching how to improve calf management at pasture. This focus on optimising calf management at pasture will allow us to better develop strategies for optimising cow-calf separation and to potentially delay separation to meet consumer demands.

The final and perhaps most important point of the study, is that, regardless of what is found in terms of risk factors or even characterising what is happening in the calving paddock, we need to be able to put the effect of FPT into perspective. It is clear from our research project, international research, anecdotal information from farmers and just plain logic that FPT is

predisposes calves to disease and mortality, at least for the first year of their life. The results are less clear on the effect that FPT has on growth and production (Chapter 8) and effects beyond one year of age (Chapter 9). It seems to be apparent that the severity and prevalence of disease plays a part in how important FPT is for a farmer. In the New Zealand dairy industry, severity of disease before weaning relative to other industries in the Northern Hemisphere is different. Respiratory disease, which causes high mortality in calves if not treated early (McGuirk, 2008; Windeyer et al., 2014), is less common in New Zealand calves pre-weaning (only 0.1% calves had recorded respiratory disease in our study).

What this means is that while working with farmers to improve FPT is an important management tool for improvement of welfare, its effect on farm profitability will be dependent on the type of disease challenge the animals on each farm are exposed to and the current disease and mortality figures the farmer already has. For example, if the farm has a high challenge of cryptosporidium and rotavirus every year, with high morbidity and mortality, it is likely that large changes in farm management to improve FPT are going to be profitable. In contrast, if calf morbidity is low then spending significant effort to improve FPT is unlikely to be beneficial financially. FPT is important, but it is only one part of a complex puzzle that needs to be tackled when improving the welfare and productivity of young stock.

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Minor emendations to published chapters

Chapter 1:

Page 7, paragraph 3, the assumption that >20% of calves had FPT would be wrong 22% of the time should be 17.5% of the time.

Page 7, paragraph 3, However if we use a prior prevalence of 40%, a result of 1/12 positive tests gives a 40% probability should be 37.5% probability.

Page 7, paragraph 3, for 2/12 positive tests, the probability is 60% should be 67.5%.

Page 7 paragraph 4, certainty that the true prevalence is >20% decreases from the 77.5% shown, should be 82.5% shown.

Chapter 3:

Page 3, second paragraph refers to “first calving” which in this context is primiparous animals.

Page 7, final paragraph refers to population attributable factor which should be population attributable fraction.

Chapter 4:

Page 8351, second column, three lines from the top states calves “that had were born”. This should be “that had been born”.

Page 8355, third paragraph, nulliparous should be “nulliparous animals”

Chapter 7:

Page 126, second to last line on the page, should be South West Victorian herds in Australia.