CODE OF PRACTICE FOR THE CARE & HANDLING OF VEAL CATTLE: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

DECEMBER 2016

Veal Cattle Code of Practice Scientific Committee

Anne Marie de Passillé Ph.D. (Co-Chair)
Adjunct Professor, Faculty of Land and Food Systems
University of British Columbia

Michael Cockram Ph.D. (Co-Chair)
Professor, Department of Health Management
Atlantic Veterinary College
University of Prince Edward Island

Derek Haley Ph.D.
Associate Professor, Ontario Veterinary College
University of Guelph

Argenis Rodas-González Ph.D.
Assistant Professor, Faculty of Agricultural and Food Sciences
University of Manitoba

Fernando Borderas Ph.D.
Research Writer

Robert Wynands (ex-officio)
Veal Cattle Code Development Committee Chair
Canadian Veal Association

NATIONAL FARM ANIMAL CARE COUNCIL
CONSEIL NATIONAL POUR LE SOIN DES ANIMAUX D'ÉLEVAGE

ACKNOWLEDGEMENTS

This report was a significant undertaking that benefited from the involvement of several contributors. The Scientific Committee wishes to thank Fernando Borderas for his significant contributions and efforts throughout the development of this report. We also wish to acknowledge Dan Weary who kindly coordinated the peer review. The report benefited from the thoughtful comments brought forward by the following reviewers, and we are very grateful for their time and expertise: Drew Vermeire, Kees van Reenen, Ken Leslie, Laura Webb and Mike Steele. Thank you also to Robert Wynands for his valuable support and expertise throughout the process.

Funding for this project has been provided through the AgriMarketing Program under Growing Forward 2, a federal–provincial–territorial initiative.

Excerpt from Scientific Committee Terms of Reference

Background

It is widely accepted that animal welfare codes, guidelines, standards or legislation should take advantage of the best available knowledge. This knowledge is often generated from the scientific literature.

In re-establishing a Code of Practice development process, NFACC recognized the need for a more formal means of integrating scientific input into the Code of Practice process. A Scientific Committee review of priority animal welfare issues for the species being addressed will provide valuable information to the Code Development Committee in developing or revising a Code of Practice. As the Scientific Committee report is publicly available, the transparency and credibility of the Code is enhanced.

For each Code of Practice being developed or revised, NFACC will identify a Scientific Committee. This committee will consist of a target number of 6 scientists familiar with research on the care and management of the animals under consideration. NFACC will request nominations from 1) Canadian Veterinary Medical Association, 2) Canadian Society of Animal Science, and 3) Canadian Chapter of the International Society for Applied Ethology. At least one representative from each of these professional scientific bodies will be named to the Scientific Committee. Other professional scientific organizations as appropriate may also serve on the Scientific Committee.

Purpose & Goals

The Scientific Committee will develop a report synthesizing the results of research relating to key animal welfare issues, as identified by the Scientific Committee and the Code Development Committee. The report will be used by the Code Development Committee in drafting a Code of Practice for the species in question.

The Scientific Committee report will not contain recommendations following from any research results. Its purpose is to present a compilation of the scientific findings without bias.

The full Terms of Reference for the Scientific Committee can be found within the NFACC Development Process for Codes of Practice for the Care and Handling of Farm Animals, available at www.nfacc.ca/code-development-process#appendixc.

Preface

The following document, compiled by the Veal Cattle Code Scientific Committee, was based on 5 priority welfare issues that were chosen by consensus of the Code Development Committee and Scientific Committee. This slate of issues was narrowed down from a much broader list and is not meant to be an exhaustive review of all of the issues that can affect the welfare of veal calves. Rather, the 5 priority welfare issues were selected because the Code would particularly benefit from a review of the available scientific literature.

In Canada, milk-fed veal is started with calves from dairy farms that are raised primarily on a milk-fed diet and finished to a live weight up to 318 kg. Some calves may also receive solid feed (e.g. grain and/or fibre). Grain-fed veal is started with calves from dairy farms that are fed initially on a commercial milk replacer or whole milk diet before transitioning to a grain ration and finished to a live weight up to 341 kg.

It should also be noted at the outset that in some areas there is a paucity of published research on veal calves. As the behaviour and physiology of young dairy replacement heifers and young beef calves are in many cases similar to those of veal calves, where appropriate, the scientific literature on these types of calves has been included to provide relevant information on veal calves. The report has identified specific gaps in research on veal calves.

CODE OF PRACTICE FOR THE CARE & HANDLING OF VEAL CATTLE: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

Veal Cattle Code of Practice Scientific Committee

December 2016

TABLE OF CONTENTS

Tables and Figures

Introduction: Scope and review process

The scientific evaluation of animal welfare involves the use of empirical methods to obtain information about animals that can be used to inform ethical decision-making regarding their quality of life. One major challenge is that different people often emphasize different kinds of information about the animals in assessing their welfare. People commonly emphasize information under three general categories as being the things that are most important to animal welfare: 1) biological functioning, 2) affective states, and 3) natural living. These form the bases for different approaches to animal welfare research (Fraser et al., 1997). Emphasis on biological functioning considers the basic normal functioning of the animal and includes measures having to do with health and productivity, stress response and normal (or lack of abnormal) behaviour (Broom, 1991). An emphasis on affective states, often referred to as the feelings-based approach, is concerned with the subjective experiences of animals with an emphasis on states of suffering (pain, fear, frustration), states of pleasure (comfort, contentment) and the notion that animals should be housed and handled in ways that minimize suffering and promote positive experiences (Duncan, 1993). Thirdly, some emphasize the naturalness of the circumstances that the animal experiences and the ability of the animal to live according to its nature (Fraser, 2008). While natural living offers another viewpoint on what is important for a good quality of life for animals, evidence from this area is often considered to be more difficult to measure and interpret (Fraser, 2008).

When possible, each section in this review covers research results from all three approaches for assessing veal calf welfare. Many animal welfare issues, especially those impacting the animal over longer periods of time such as housing conditions, or space allowance, etc., have mainly been evaluated in the literature using measures of biological function. Other animal welfare issues have been studied using empirical research about subjective states, for example, cattle preferences for different flooring surfaces. In general, criteria for "naturalness" are less frequently addressed in the scientific literature although considerations for freedom of movement, opportunities to engage in species-typical behaviour and daily activities have been considered here, and in particular when there is evidence that constraining these behaviour patterns results in signs of negative emotional states (e.g., fear or frustration) or results in disruption of biological function.

The mandate of the Scientific Committee was to review pertinent literature dealing with:

- Management of milk feeding
- Reducing the risk of welfare issues associated with iron deficiency anaemia
- Benefits arising from the provision of fibre in the diet
- Risk factors for abomasal damage
- Welfare implications of rearing veal calves in stall, tether and group housing systems
- Flooring and bedding.

The committee was to address the implications for veal calf welfare within the topics identified. Few, if any, references are made to economic considerations or human health and welfare concerns, as these were beyond the scope of the committee's mandate and were rarely addressed in the papers reviewed.

Broom D.M. (1991) Animal welfare: Concepts and measurement. *Journal of Animal Science* 69:4167–4175.

Duncan I.J.H. (1993) Welfare is to do with what animals feel. *Journal of Agricultural and Environmental Ethics* 6(Suppl. 2):8–14.

Fraser D. (2008) *Understanding Animal Welfare: The Science in Its Cultural Context*. Ames IA:Wiley-Blackwell.

Fraser D., Weary D.M., Pajor E.A. & Milligan B.N. (1997) A scientific conception of animal welfare that reflects ethical concerns. *Animal Welfare* 6:187–205.

1. Management of milk feeding

Conclusions

1. **Calves are highly motivated to suck. The ingestion of milk (which in this chapter includes whole milk and milk replacer) increases sucking motivation. Calves that cannot suck a teat for their milk will have a higher level of sucking motivation and reduced signs of satiety after the meal than calves that can. The research to date suggests that calves' sucking motivation is reduced both for calves receiving a larger ration of whole milk or milk replacer, and for calves that can suck a teat.**

2. **Feeding through a teat stimulates the oesophageal groove reflex, preventing milk going into the rumen, and elicits the secretion of hormones that enhance milk digestion and metabolism. Additionally, sucking a teat for milk reduces the speed of milk intake by calves, hastens the signs of satiety and sleep after a meal, and reduces cross-sucking between calves.**

3. **Increasing the frequency of meals improves storage and utilization of glucose, reduces the occurrence of excessive abomasal filling, reduces acidity of the abomasum, reduces the prevalence of abnormal oral behaviours, and increases the efficiency of nutrient utilization.**

4. **Abruptly weaning calves off whole milk or milk replacer and weaning before 8 weeks of age result in many behavioural signs of stress. These can be reduced by gradual weaning (gradually reducing the amount of milk fed over time) and either by adjusting weaning age according to each calf's willingness to eat solid feed or by weaning at a later age (after 8 weeks).**

5. **There is no evidence that feeding large daily amounts of whole milk causes diarrhoea in calves.**

1.1 Introduction

To answer the three main concerns about the welfare of veal calves (impaired biologic functioning, negative affective states, and inability to perform some natural behaviours) the type, amount, and quality of food and water provided during their life cycle are of the utmost importance.

Dairy replacement calves under conventional management systems in North America are usually separated from their mothers within 24h of birth, fed colostrum, and fed $\underset{\sim}{}$ 10% of their body weight in milk by bucket or bottle until they are weaned onto concentrate and forage-based diets at 5 to 10 weeks of age. There is a trend to feed more milk to dairy calves in Canada through, for example, the provision of acidified milk replacer or the use of the automatic milk feeders.

When calves nurse their dam, they have around 10 nursings per day in the first week of life. The nursing frequency gradually decreases up to weaning, and weaning occurs around 9 months of age (Hafez & Lineweaver 1968).

Up to 8 weeks of age, when their ability to eat solid feed is limited, calves will drink an average of 10 L/d when nursed by their dam or when whole milk is available ad libitum (de Passillé et al., 2008; Jasper & Weary, 2002; Sweeney et al., 2010; von Keyserlingk et al., 2004). Benefits of providing calves with amounts of milk that are close to what they would choose to consume include reduced risk of hunger (avoiding a negative affective state), and higher average daily gains (promotion of biological function).

Veal calves are mainly male dairy calves that are reared for the production of white (milk-fed) or pink veal (grain-fed) meat. Calves are raised with high levels of milk replacer as the main component of their diet for the whole growing period in the case of milk-fed veal or in combination with grain in the case of grain-fed veal.

Conventional milk-fed veal calf production practices have been strongly criticized because of alleged physiological and behavioural consequences of an all-liquid diet on calves' welfare. It has been claimed that veal calves raised under intensive confinement with all-liquid diets show a high incidence of stereotypic behaviours (European Food Safety Authority [EFSA], 2006). In addition, a number of health issues have been identified. Gastrointestinal disorders such as low rumen development, rumen mucosa alterations, and abomasal lesions have also been related to this feeding practice in veal calves (Cozzi et al., 2002). See also *Chapter 3 – Behavioural and health benefits arising from the provision of fibre in the diet of veal cattle* and *Chapter 4 – Risk factors for abomasal damage*.

In the European Union (EU), these concerns prompted the introduction of directives (91/629/EC and 97/2/EC) to veal producers by the European Council requiring producers to include forage as a source of fibre (EU Council, 1997; EU Council, 1991).

Veal calves that cannot perform the natural behaviours of chewing and rumination might redirect the resulting frustration by developing abnormal oral behavioural patterns (Veissier et al., 1998; Bokkers et al., 2001), which in veal calves often become readily apparent at about 3 months of age (Kooijman et al., 1991).

1.2 Abnormal oral behaviour

The environmental and management conditions provided to veal calves under conventional production systems may not fulfill all of their behavioural and physiological needs.

Separation from the dam, low frequency of milk meals, feeding milk by bucket without a teat, and inadequate access to fibre may result in an increased frequency of non-nutritive oral behaviours, which include tongue rolling, cross sucking, manipulation (biting/sucking/nibbling) of the substrates of their pen (Leruste et al., 2014) or sham chewing (jaw movements like those shown when chewing food are shown at a time when the animal has no food in its mouth; Broom & Fraser, 2007). These non-nutritive behaviours are considered as abnormal when they are directed toward inappropriate objects, highly repetitive or performed for a long period of time, and where their function is not clear or their performance is harmful to the individual (e.g., by causing injuries) (Mason & Rushen, 2008; Mason, 1991). Abnormal behaviours are mostly performed by animals living in sub-optimal environments and there is evidence that these environments are associated with reduced animal welfare (Mason & Rushen, 2008).

The types of abnormal oral behaviour most closely related to milk feeding are cross-sucking (where a calf sucks at the body of another calf; can include prepuce sucking in male calves wich can be accompanied by urine drinking) or non-nutritive sucking at parts of the pen or other objects (Rushen et al., 2008). These behaviours appear to reflect an inability of the calf to satisfy its sucking motivation during feeding (Rushen et al., 2008).

The provision of larger amounts of fibrous solid feed in addition to the all-liquid diet has been shown to reduce abnormal oral behaviours (Mattiello et al., 2002) and to promote rumen development (Di Giancamillo et al., 2003; Morisse et al., 2000; Suarez et al., 2006). Webb et al. (2013) suggest that the overall effect of fibre on calves' oral behaviour depends on a combination of the type of feed and amount of fibre (see Chapter 3).

In a recent study by Leruste et al. (2014), the prevalence of 3 non-nutritive oral behaviours (manipulating substrates, tongue rolling, and manipulating a pen-mate) in 157 commercial veal farms was measured. Interestingly, the risk of calves manipulating a pen-mate was higher for calves fed with 280 to 380 kg, compared with those fed >380 kg of milk powder in total, for the fattening period. Calves also showed more tongue rolling behaviour when housed in small groups (fewer than 10 calves per pen) than in larger groups, regardless of the type of milk distribution system. A space allowance above the EU legal requirement (>1.8 m^2/calf) was also associated with a reduced risk of tongue rolling, but the reasons for this are unclear.

1.3 Sucking motivation in calves

Although calves naturally get milk by sucking the dam's teat, veal calves are often fed milk replacer from troughs or open buckets; the main advantage of the latter being the ease of milk delivery and cleaning. The main disadvantage of buckets compared to teat feeding is that satiation (feeling of fullness) does not eliminate the motivation for sucking, which is also an important factor in the development of abnormal oral behaviours.

Sucking has often been claimed as a behavioural need for calves (Rushen et al., 2008). Many veal calves are fed by buckets and so cannot perform much of their normal sucking behaviour. This raises concern that calves may be suffering from behavioural deprivation if they are unable to suck to obtain milk. The main functional goal of sucking behaviour is to obtain milk but when young ruminants are raised separately from their mothers, they suck at parts of their pens ("non-nutritive sucking") and at each other ("cross-sucking") despite apparently adequate nutrition. This supports the idea that calves have a need to perform sucking behaviour.

1.3.1 What motivates the calf to do non-nutritive sucking?

de Passillé and Rushen (1997), de Passillé (2001) and Rushen et al. (2008) have reviewed the results of earlier research done to examine the factors that can cause or inhibit non-nutritive sucking by calves.

Non-nutritive sucking is partly dependent on the calf's level of hunger. Non-nutritive sucking is slightly higher in calves receiving a lower ration of milk than when offered a higher ration, e.g., 3 L/d versus about 4 L/d, (Rushen & de Passillé, 1995) indicating that non-nutritive sucking is dependent on daily feed intake in the longer term. Rushen and de Passillé (1995) also found that missing one meal of milk increased the amount of non-nutritive sucking that occurred immediately following the subsequent meal. However, they found that halving the amount of milk the calves drink during a meal (from about 2 L to 1 L) did not increase the amount of non-nutritive sucking that occurs after the meal. In contrast, Jung and Lidfors (2001) found less non-nutritive sucking in calves after they drank a meal of 5 L compared to 2.5 L or 1 L. These results suggest that hunger from an inadequate intake of milk can contribute to an increase in sucking motivation.

However, the relationship between milk ingestion and sucking motivation is complex. For example, non-nutritive sucking is far more common immediately after the meal than before (de Passillé et al., 1992) and largely disappears when calves are weaned off milk (Lidfors, 1993; Krohn et al., 1999). Non-nutritive sucking may also occur during normal nursing in cattle, especially at the end of the meal (Lidfors et al., 2010). These findings suggest that non-nutritive sucking is stimulated, rather than reduced, by the ingestion of milk. de Passillé et al. (1992) found that some non-nutritive sucking occurred when calves did not drink milk at meal time or drank water, but this was considerably less than when the calves drank milk. Simply injecting small volumes of milk (e.g., 10 mL) into the mouth of the calf is sufficient to stimulate considerable sucking (Rushen & de Passillé, 1995), and the amount of non-nutritive sucking increases as the concentration of milk replacer increases, especially with increases in the concentration of lactose (de Passillé et al., 1997). This suggests that it is specifically the taste of milk that is important in eliciting sucking (Rushen & de Passillé, 1998). de Passillé et al. (1992) found that the sucking motivation that was stimulated by the ingestion of the milk waned during the 10 minutes following the meal, and Rushen and de Passillé (1995) found only low levels of sucking motivation forty minutes after a milk meal, even if calves could not suck a teat right after their meal. These results suggest that the elicited motivation to suck eventually wanes even in the absence of opportunities to suck.

Other research suggests that other factors besides hunger and the taste of milk are motivating the calves to do non-nutritive sucking, especially the inability of the calf to perform sucking behaviour itself (Hammell et al., 1988). Rushen and de Passillé (1995) found evidence that sucking at a dry teat itself reduced calves' motivation to suck, even in the absence of milk consumption. Veissier et al. (2002) found that bucket fed calves were more likely to perform non-nutritive sucking at the bars of the pen compared to calves that sucked milk through a teat. Bokkers and Koene (2001) found that on average, calves fed by teat on an automated feeder performed less oral behaviours (15.7 ± 1.6 %) than calves bucket-fed twice a day in group housing (24.2 ± 2.1 %) and individual housing (23.7 ± 2.0 %). Jung and Lidfors (2001) found that reducing the flow rate of milk through a teat (which increased sucking time but did not affect the amount of milk drunk) reduced the amount of non-nutritive sucking that occurred afterwards. The results of Haley et al. (1998) corroborate this and indicate that it is easy to slow down the rate of milk ingestion of calves when feeding milk through a teat. This may help calves better control the oesophageal closure and reduce the incidence of rumen milk that is reported to occur in veal calves when they are fed large amounts of milk (see section 1.3.3 – *Stimulation of the oesophageal groove reflex*). These results support the idea that allowing the calves to perform sucking behaviour reduces sucking motivation.

1.3.2 What are the consequences of sucking?

Some research results show that the performance of sucking behaviour during or after a milk meal has physiological consequences that may be of value to the animal, and in this respect sucking may be very important for calves. For example, de Passillé et al. (1993) found that insulin and cholecystokinin (CCK) in the hepatic portal vein after the meal were higher when the calves sucked a dry teat after the meal. In support of this, Veissier et al. (2002) found that calves were quicker to show signs of satiety and appeared to fall asleep after a meal when they sucked the milk through a teat rather than drinking from a bucket. The evidence of increased satiety from sucking and the widespread metabolic effects of insulin and CCK mean that deprivation of sucking behaviour cannot be assumed to be inconsequential for animal well-being.

Most research (reviewed by Jensen 2003; Jensen & Budde, 2006; Rushen et al., 2008) also shows that allowing calves to suck milk through a teat reduces the amount of cross-sucking (calves sucking each other) that occurs. This is found when comparing calves fed with a teat bucket rather than an open bucket. Only one study reports less cross-sucking among bucket fed calves than those fed with an automated milk feeder (Veissier et al., 2002). Allowing the calves to continue to suck the teat after the meal, or to suck a dry teat after the milk meal, and the use of a floating teat also reduces cross-sucking (Jung & Lidfors, 2001; Loberg & Lidfors, 2001; Rushen et al., 2008). Reducing the milk flow rate through the teat (which prolongs sucking) also reduces cross-sucking (Jensen, 2003).

1.3.3 Stimulation of the oesophageal groove reflex

Failure of the oesophageal (reticular) groove reflex can lead to the accumulation of large amounts of whole milk or milk replacer in the rumen ("ruminal drinking"). Ruminal milk (milk not diverted into the abomasum by the oesophageal groove reflex) may result in several clinical and pathological signs, including lactic acid induced ruminal acidosis, bloat, white and clay-like faeces, low appetite, growth retardation, hyperkeratosis in the rumen, and villus atrophy in the small intestine (Breukink et al., 1988; Van Weeren-Keverling Buisman et al., 1990).

Many factors may influence the efficiency of the oesophageal groove reflex. Diseases, stress, age and breed of the animals, the quality and temperature of the liquid feed, and the method of provisioning milk replacer (e.g., teat vs bucket) are generally considered especially relevant for veal calves (EFSA, 2012).

Labussière et al. (2014) found that ruminal milk could average between 17 to 24% of total milk intake. Berends et al. (2015), using indigestible markers, recovered 20% of the milk replacer marker from the rumen of Holstein calves after each meal. Guilhermet et al. (1975) and Wise et al. (1984) used pre-ruminant calves equipped with a rumen cannula to estimate ruminal milk. These studies showed a large variation in the amount of milk recovered in the rumen between individual calves, which averaged between 7% and 20% of the milk ingested. The amount of milk in the rumen considerably increases with age (Guilhermet et al., 1975) and is related to appetite: dos Santos et al. (1986) reported finding 3% of the milk drunk in the rumen of calves with a good appetite and 57% in calves with a reduced appetite, indicating that milk in the rumen may have serious impacts on the calf's appetite or vice versa.

There is an increased likelihood of ruminal milk following milk meals from bucket (40.7 to 45.3%) compared to a teat (4.9 to 5.2%) (Wise et al., 1942). Ruminal milk hardly occurs when calves suck milk from a teat (< 1% of the milk drunk) but is common when they drink milk from a bucket (~ 40% of the milk drunk) (Guilhermet et al., 1975). Wise et al. (1984) reported that sucking milk from a teat in comparison with drinking from a bucket resulted in longer times to complete first swallows, smaller amounts of milk per swallow, slower rates of milk intake and of swallowing, fewer sequential openings and closings of the groove, lower incidence and shorter duration of groove openings, less spillage into the reticulorumen, and less variability of these reactions among calves. However, the amount of milk in the rumen can vary and may depend on the amount of milk drunk: Abe et al. (1979) found little milk in the rumen of calves that drank only 3L of milk and this did not differ between bucket feeding and teat feeding. This shows that sucking milk from a teat may help with oesophageal groove closure especially when calves are having large milk meals.

Feeding calves through a teat instead of an open bucket has several advantages for the digestive physiology and health of the animal. The virtual elimination of ruminal milk when a teat is used for feeding is particularly important.

1.3.4 Competition at the teat

Group housing affords many advantages for calves: social contact, more space to do exercise (Jensen, 2006), stimulation to learn (Gaillard et al., 2014), and reduced food neophobia (Costa et al., 2014), with some studies even reporting improvements in growth without any greater health issues than seen in individual housing (Costa et al., 2015). These advantages can be accompanied by labour savings, especially in cleaning pens and time spent feeding (de Passillé et al., 2004; Kung et al., 1997). However, competition over the teat can occur (von Keyserlingk et al., 2004; Jensen & Budde, 2006) when calves do not have ad libitum access to milk. Competition leads to displacements from the teat and to a large variation in milk intake between calves. This problem is significant when the calves are fed small amounts of milk, because hungry calves frequently switch from one teat to another (de Passillé & Rushen, 2006), and when fed by computer-controlled milk feeders they are reported to actively compete for access to milk (Jensen, 2006). By contrast, competition by ad libitum fed calves is rare (O'Driscoll et al., 2006; De Paula Vieira et al., 2008).

1.4 Milk quantity and feeding frequency

White veal (milk fed) calves are fed high quantities of milk replacer. They actually are fed higher levels than they drink by choice when milk is offered ad libitum via an automated feeder (Webb et al., 2014). Feed intake elevates plasma glucose concentrations, and insulin release is subsequently initiated to maintain glucose homeostasis; however, calves fed 8 L/d in 2 meals do not show signs of insulin sensitivity (MacPherson et al., 2016). Insulin resistance and impaired glucose metabolism (impaired glucose storage and utilization) has been diagnosed in veal calves fed high levels of milk replacer in 2 meals/d. These calves show the following signs:

hyperglycemia (elevated glucose levels in blood), glucosuria (elevated glucose levels in urine), and excessive insulinemia (elevated insulin levels in blood), all of which are energy-draining processes, i.e., processes that reduce feed efficiency (Hostettler-Allen et al., 1994; Blum & Hammon, 1999; Hugi et al., 1998). Moreover, breed-specific differences in glucose partitioning and insulin sensitivity have been reported between Holstein-Friesian and Belgian Blue calves, which may put Holstein calves at increased risk (Bossaert et al., 2009).

Kaufhold et al. (2000) found lower plasma concentrations of glucose, lactate, urea, somatostatin, glucagon, and insulin in calves fed 6x/d by an automatic milk feeder compared to calves fed the same amount of milk replacer in two meals/d with buckets. Nussbaum et al. (2002) found minor postprandial changes in glucose concentration in calves fed milk replacer and averaging 10 meals/d on automatic milk feeder, while they found rapidly increased concentrations were observed after feeding similar calves the same amount and type of diet by bucket twice a day.

Vicari et al. (2008) found that veal calves fed non-clotting milk replacer 4 times a day showed lower post-prandial glucose and insulin blood levels and a quicker return to pre-prandial glucose and insulin blood levels than calves fed the same replacer two times a day. Additionally, van den Borne et al. (2006) found that calves fed high levels of non-clotting milk replacer (2.5 × metabolizable energy requirements for maintenance) 4 times a day increased (11%) the efficiency with which digestible protein (whey protein) was utilised compared to calves fed the same milk replacer but only 2 times per day. This digestible protein utilization efficiency was increased by only 5% in calves fed 4 times compared to 2 times a day when calves were fed lower levels of milk replacer (1.5 × metabolizable energy requirements for maintenance). This indicates that feeding large amounts of milk twice a day leads to lower protein utilization efficiency than feeding 4 times a day. These results on the effects of feeding frequency indicate that calves have a limited capability to metabolically handle great amounts of highly digestible nutrients in 1 meal (Blum & Hammon, 1999). In conclusion, the efficiency of digestible protein utilization is higher in calves fed 4 small meals compared to calves fed 2 large meals for the same total daily milk intake.

The source of protein in milk replacer is also important. More rapidly hydrolyzable (i.e., non-clotting) protein sources such as vegetable proteins and whey are the current nitrogen compounds in milk replacers. These protein sources, coupled with a high milk feeding level and low feeding frequency (two meals a day is common practice), results in rapid absorption of nutrients such as amino acids, glucose, and galactose soon after ingestion (Van der Borne et al., 2007).

Additionally, Ahmed et al. (2002) demonstrated that increasing the frequency of milk replacer meals by teat from 2 to 3/d leads to a higher mean 24-h abomasal luminal pH (as high as with a feeding frequency of 4 or 8 meals/d) and a higher percentage of the 24-h period with pH > 3.0 (not different from 4 or 8 meals/d). Consequently, feeding milk 3 times vs 2 times a day via sucking can lower the risk of abomasal acidosis.

Furthermore, providing milk replacer to veal calves in large volumes of liquid in 2 meals per day could be the main critical point for excessive abomasal distension, potentially resulting in ulceration of the abomasum (Brscic et al., 2011) regardless of the type of milk replacer (see *Chapter 4 – Risk factors for abomasal damage*).

The use of automatic milk feeders for group-housed veal calves enables an increase in the frequency of meals without increasing labour. The feeder allows the calf to mimic natural nursing; calves allowed 12 L/d have at least 5 milk meals per day (Borderas et al., 2009; von Keyserlingk et al., 2009; De Paula Vieira et al., 2008; Webb et al., 2014) and so drink in many meals and satisfy their sucking motivation. Calves spend 52-64 min/d suckling their mothers (Day et al., 1987) while time sucking per day, for calves on an automated milk feeding system, is around 47-57 min (Jensen & Holm, 2003). As the calf grows older, the feeding station may be adapted so the calf takes fewer but larger meals as in natural conditions (Jensen & Holm, 2003).

An effect of feeding more frequently on grain intake at weaning was reported by Kmicikewycz et al. (2013), who found that feeding calves milk replacer 4 times a day resulted in an increased starter grain intake in the two weeks after weaning, compared to calves fed the same amount of milk replacer in 2 meals/d.

In summary, increasing the frequency of milk meals improves glucose utilization and storage, reduces the degree of abomasal filling, reduces the amount of milk in the rumen, and increases the efficiency of nutrient utilization.

1.5 Weaning calves off milk

Calves are born as pre-ruminants and rely on milk or milk replacer as their main source of nutrition. The amounts of solid feed that the calves will eat before 4 weeks of life are very small compared with subsequent intake. Calves will gradually increase the amount of solid feed that they willingly eat. In a study in which calves had free access to milk replacer, concentrates, silage and hay, Webb et al. (2014) found that at 3 months of age, calves ingested twice as much dry matter from the milk replacer than from the concentrates, but at 6 months of age, this was reversed. Weaning calves off milk before they are able or willing to eat sufficient solid feed will lead to a number of signs of poor welfare.

Feral calves raised by their mothers are weaned off milk over a period of several months, with the number of nursings decreasing gradually (Vitale et al., 1986; von Keyserlingk & Weary, 2007). Weaning is usually completed after 8–12 months (Reinhardt & Reinhardt, 1981). Thus, calves in grain-fed veal production are weaned off milk more quickly (abruptly or over a few days) and at a younger age (6 to 8 wks) than occurs naturally. On the other hand, white veal are not weaned off milk, but continue to receive milk at higher levels than they would normaly drink by choice when milk is offered ad libitum via an automated feeder (Webb et al., 2014).

Weaning calves off milk can be a stressful time (Weary et al., 2008). A stress response in calves is apparent in increased vocalizations, behavioural signs of hunger, increased cross-sucking, increased activity, and reduced locomotor play, as well as a reduction in growth or even loss of weight (Budzynska & Weary, 2008; Krachun et al., 2010; Nielsen et al., 2008a; Sweeney et al., 2010; de Passillé et al., 2011a), and some evidence of immunosuppression (Hulbert et al., 2011; Johnston et al., 2016) or altered immune-responsiveness (Pollock et al., 1992). Weaning stress can be particularly evident for calves receiving large amounts of milk (> 8 L/d), since these large amounts decrease the solid feed that the calves will eat before weaning as well as the calves' ability to digest the concentrate (Terré et al., 2007; Borderas et al., 2009; Hill et al., 2016). A considerable amount of research now shows that these signs of stress can be reduced in a number of ways.

1.5.1 Gradual weaning

Gradual weaning has been shown to be superior to abrupt weaning in a number of studies. Weaning calves off milk over a period of 10 d or 22 d resulted in increased energy intakes, better weight gains, and prevented weight loss during the period of weaning and during the week after as compared to calves weaned abruptly (overnight) (Sweeney et al., 2010). Weaning calves over a 2-week period (completed at 8 weeks of life) was found to reduce cross-sucking and reduce behavioural signs of hunger during weaning compared to abrupt weaning over 1 d (Nielsen et al., 2008a). Gradually reducing the amount of milk allowed at each meal reduced behavioural signs of hunger more than reducing the number of meals allowed (Jensen, 2006) and more than gradually diluting the milk with water (Nielsen et al., 2008b).

However, increasing the duration of weaning may have negative effects if this reduces the age at which weaning is initiated. de Passillé et al. (2010) found more cross-sucking among calves weaned over a 22 d period which began at 19 d of age compared to calves weaned over shorter periods (0–10 d) that began at a later age. Quigley

(1996) found calves weaned abruptly at 35 d of age improved final body weight compared to calves that were weaned by halving the milk replacer allowance from 25 d to 35 d. However, in this case calves were fed a low allowance of milk replacer (10% body weight).

1.5.2 Age at weaning

Weaning calves at a later age can also reduce weaning stress. Completing weaning (done over 7 d) at 8 weeks of age for calves fed a large volume of milk replacer was found to lead to increased weight gain over the weaning period, higher body weights at the end of weaning, less time performing non-nutritive oral behaviour, more time ruminating, and more time lying down compared with calves weaned at 6 weeks of age (Eckert et al., 2015). Calves weaned at 8 weeks also showed signs of a more developed digestive tract than those weaned at 6 weeks (Eckert et al., 2015), and those weaned at 12 weeks rather than 8 weeks had a smoother development of digestive functionality (Meale et al., 2015). In contrast, Hopkins (1997) found no differences in weight gain or final body weight between calves weaned at 28 d compared to those weaned at 56 d, although these calves were on a very low milk allowance (3.8 L/d). Similarly, Kehoe et al. (2007) found no differences in growth or health among calves (fed milk replacer at 10 % BW) weaned at 3, 4, 5, or 6 weeks of age. These conflicting studies suggest that the effects of early weaning may depend upon the amount of liquid feed the calves are receiving, with less effects of weaning age apparent in calves fed lower amounts of milk or milk replacer.

In contrast, there are clearer effects of delaying the age of weaning beyond 8 weeks for calves fed larger amounts of milk. Completing gradual weaning (over 10 d) at 12–13 weeks resulted in better energy intakes, fewer signs of hunger, and better weight gains in calves fed 12 L /d of milk compared to completing weaning at 8 weeks of age (Krachun et al., 2010; de Passillé et al., 2011a). These results reflect the fact that the later weaned calves were more able to increase their intakes of starter in response to a reduced milk allowance. There were no differences found in the amount of cross-sucking. However, calves fully weaned at 12 weeks of age had better weight gains over weaning and were heavier after weaning than calves weaned at 8 weeks (de Passillé et al., 2011b); but, in another study, there were no differences between calves weaned at 8 weeks and 10 weeks (Meale et al., 2015). Calves weaned at or prior to an average age of 44.7 d showed some evidence of suppression of some components of the immune system, and this was more marked for calves weaned at an average age of 23.7 d (Hulbert et al., 2011).

1.5.3 Other weaning methods

Weaning calves by reducing the milk allowance according to the amount of solid feed the calves eat appears promising as a way of reducing weaning stress, particularly where this is done using automated feeders. This has been found to reduce cross-sucking and avoid weight loss during weaning (Roth et al., 2008; de Passillé & Rushen, 2012).

Some other methods have been shown to reduce some of the signs of distress at weaning. For example, Jasper et al. (2008) found that allowing the calves to drink warm water through the milk feeding equipment reduced vocalizations when calves were abruptly weaned.

1.6 Milk feeding and diarrhoea

There has been concern that feeding calves large amounts of milk may increase diarrhoea, but there is no real evidence for this. While increased whole milk or replacer levels may lead to looser faeces, there is no strong evidence that this increases the incidence of clinical diarrhoea (Lorenz et al., 2011).

Most studies show no difference in scour score (a common measure of diarrhoea) between calves fed high or low quantities of milk (Nocek et al., 1984; Appleby et al., 2001; Jasper & Weary, 2002; Diaz et al., 2001; Uys et al., 2011; Bach et al., 2013). Hammon et al. (2002) found more loose faeces in restricted fed calves than in ad libitum fed calves. A study by Quigley et al. (2006) showed that calves fed additional amounts of milk replacer had longer duration of diarrhoea episodes. However, this finding should be viewed with caution, as calves that refused milk during the experiment were force fed any remaining milk, independently of their health status. Force feeding has been previously demonstrated to aggravate disease. Murray and Murray (1979) showed that force fed mice showed a 50% increase in mortality and a shortened survival time when compared to ad libitum fed mice.

In most studies, diarrhoea is assessed using a scour score on a scale of 1 (normal), 2 (soft), 3 (runny), and 4 (watery) (Kertz & Chester Jones, 2004). However, it seems reasonable that when calves are drinking large amounts of milk their faeces will be more liquid (Osorio et al., 2012; Hengst et al., 2012), without this being a clinical sign of diarrhoea indicating an illness (Lorenz et al., 2011).

In general, there does not appear to be an established link between ad libitum milk feeding and the incidence and severity of diarrhoea. A common practice in treating diarrhoea in milk restricted calves is to further reduce the calves' intake. Garthwaite et al. (1994) showed that withholding milk actually negatively affects recovery. However, the maximum quantity of milk offered in this study was low (10% of BW). Unfortunately, no studies have been reported on milk withdrawal during diarrhoea episodes (or a restriction to 10% BW) on scouring comparing responses of restricted and ad libitum fed calves.

1.7 References

Abe M., Iriki T., Kondoh K. & Shibui H. (1979) Effects of nipple or bucket feeding of milk-substitute on rumen by-pass and on rate of passage in calves. *British Journal of Nutrition* 41:175–181.

Ahmed A.F., Constable P.D. & Misk N.A. (2002) Effect of feeding frequency and route of administration on abomasal luminal pH in dairy calves fed milk replacer. *Journal of Dairy Science* 85:1502–1508.

Appleby M. C., Weary D. M. & Chua B. (2001) Performance and feeding behaviour of calves on ad libitum milk from artificial teats. *Applied Animal Behaviour Science* 74:191–201.

Bach A., Terré M. & Pinto A. (2013) Performance and health responses of dairy calves offered different milk replacer allowances. *Journal of Dairy Science* 96:7790–7797.

Berends H., van den Borne J.J.G.C., Stockhofe-Zurwieden N., Gilbert M.S., Zandstra T., Pellikaan W.F., van Reenen C.G., Bokkers E.A.M. & Gerrits W.J.J. (2015) Effects of solid feed level and roughage-to-concentrate ratio on ruminal drinking and passage kinetics of milk replacer, concentrates, and roughage in veal calves. *Journal of Dairy Science* 98:5621–5629.

Blum J.W. & Hammon H.M. (1999) Endocrine and metabolic aspects in milk-fed calves. *Domestic Animal Endocrinology* 17:219–230.

Bokkers E.A.M. & Koene P. (2001) Activity, oral behaviour and slaughter data as welfare indicators in veal calves: a comparison of three housing systems. *Applied Animal Behaviour Science* 75:1–15.

Borderas T.F., de Passillé A.M.B. & Rushen J. (2009) Feeding behavior of calves fed small or large amounts of milk. *Journal of Dairy Science* 92:2843–2852.

Bossaert P., Leroy J.L.M.R., De Campeneere S., De Vliegher S. & Opsomer G. (2009) Differences in the glucose-induced insulin response and the peripheral insulin responsiveness between neonatal calves of the Belgian Blue, Holstein-Friesian, and East Flemish breeds. *Journal of Dairy Science* 92:4404–4411.

Breukink H.J., Wensing T., van Weeren-Keverling Buisman A., van Bruinessen-Kapsenberg E.G. & de Visser N.A.P. (1988) Consequences of failure of the reticular groove reflex in veal calves fed milk replacer. *Veterinary Quarterly* 10:126–135.

Broom D.M. & Fraser A.F. (2007) Domestic Animal Behaviour and Welfare. 4th Edition. Wallingford. CABI.

Brscic M., Heutinck L.F.M., Wolthuis-Fillerup M., Stockhofe N., Engel B., Visser E.K., Gottardo F., Bokkers E.A.M., Lensink B.J., Cozzi G. & Van Reenen C.G. (2011) Prevalence of gastrointestinal disorders recorded at postmortem inspection in white veal calves and associated risk factors. *Journal of Dairy Science* 94:853–863.

Budzynska M. & Weary D.M. (2008) Weaning distress in dairy calves: Effects of alternative weaning procedures. *Applied Animal Behaviour Science* 112:33–39.

Costa J.H.C., Meagher R.K., von Keyserlingk M.A.G. & Weary D.M. (2015) Early pair housing increases solid feed intake and weight gains in dairy calves. *Journal of Dairy Science* 98:6831–6836.

Costa J.H.C., Daros R.R., von Keyserlingk M.A.G. & Weary D.M. (2014) Complex social housing reduces food neophobia in dairy calves. *Journal of Dairy Science* 97:7804–7810.

Cozzi G., Gottardo F., Mattiello S., Canali E., Scanziani E., Verga M. & Andrighetto I. (2002) The provision of solid feeds to veal calves: I. Growth performance, forestomach development, carcass and meat quality. *Journal of Animal Science* 80:357–366.

Day M.L., Imakawa K., Clutter A.C., Wolfe P.L., Zalesky D.D., Nielsen M.K. & Kinder J.E. (1987) Suckling behavior of calves with dams varying in milk production. *Journal of Animal Science* 65:1207–1212.

de Passillé, A. M. (2001) Sucking motivation and related problems in calves. *Applied Animal Behaviour Science* 72:175–187.

de Passillé A.M., Borderas T.F. & Rushen J. (2011a) Weaning age of calves fed a high milk allowance by automated feeders: Effects on feed, water, and energy intake, behavioral signs of hunger, and weight gains. *Journal of Dairy Science* 94:1401–1408.

de Passillé A.M., Borderas F. & Rushen J. (2011b) Cross-sucking by dairy calves may become a habit or reflect characteristics of individual calves more than milk allowance or weaning. *Applied Animal Behaviour Science* 133:137–143.

de Passillé A.M., Christopherson R. & Rushen J. (1993) Nonnutritive sucking by the calf and postprandial secretion of insulin, CCK, and gastrin. *Physiology & Behavior* 54:1069–1073.

de Passillé A.M., Marnet P.G., Lapierre H. & Rushen J. (2008) Effects of twice-daily nursing on milk ejection and milk yield during nursing and milking in dairy cows. *Journal of Dairy Science* 91:1416–1422.

de Passillé A.M. & Rushen J. (2012) Adjusting the weaning age of calves fed by automated feeders according to individual intakes of solid feed. *Journal of Dairy Science* 95:5292–5298.

de Passillé A.M. & Rushen J. (1997) Motivational and physiological analysis of the causes and consequences of non-nutritive sucking by calves. *Applied Animal Behaviour Science* 53:15–31.

de Passillé A.M., Rushen J. & Weary D.M. (2004) Designing good environments and management for calves. *Advances in Dairy Technology* 16:75–89.

de Passillé A.M., Sweeney B. & Rushen J. (2010) Cross-sucking and gradual weaning of dairy calves. *Applied Animal Behaviour Science* 124:11–15.

de Passillé A.M.B., Metz J.H.M., Mekking P. & Wiepkema P.R. (1992) Does drinking milk stimulate sucking in young calves? *Applied Animal Behaviour Science* 34:23–36.

de Passillé A.M.B. & Rushen J. (2006) Calves' behaviour during nursing is affected by feeding motivation and milk availability. *Applied Animal Behaviour Science* 101:264–275.

De Paula Vieira A., Guesdon V., de Passillé A.M., von Keyserlingk M.A.G. & Weary D.M. (2008) Behavioural indicators of hunger in dairy calves. *Applied Animal Behaviour Science* 109:180–189.

Di Giancamillo A., Bosi G., Arrighi S., Savoini G. & Domeneghini C. (2003) The influence of different fibrous supplements in the diet on ruminal histology and histometry in veal calves. *Histology and Histopathology* 18:727–733.

Diaz M.C., Van Amburgh M.E., Smith J.M., Kelsey J.M. & Hutten E.L. (2001) Composition of growth of Holstein calves fed milk replacer from birth to 105-kilogram body weight. *Journal of Dairy Science* 84:830–842.

dos Santos G.T., Toullec R., Roger R., De la Grange H. & Guilloteau P. (1986) Caractéristiques digestives des veaux de boucherie s'adaptant mal en atelier d'engraissement. *Reproduction Nutrition Development* 26:1217.

Eckert E., Brown H.E., Leslie K.E., De Vries T.J. & Steele M.A. (2015) Weaning age affects growth, feed intake, gastrointestinal development, and behavior in Holstein calves fed an elevated plane of nutrition during the preweaning stage. *Journal of Dairy Science* 98:6315–6326.

EU Council (1991) *Directive 91/629EC*. Official Journal of the European Communities. No. 340/28. EC, Brussels, Belgium.

EU Council (1997) *Directive 97/2/EC*. Official Journal of the European Communities. Vol. 20. EC, Brussels, Belgium.

European Food Safety Authority (2012) Scientific Opinion on the welfare of cattle kept for beef production and the welfare in intensive calf farming systems. *The EFSA Journal* 10(5):2669.

European Food Safety Authority (2006) The risks of poor welfare in intensive calf farming systems. An update of the Scientific Veterinary Committee Report on the Welfare of Calves. *The EFSA Journal* 366:1–36.

Gaillard C., Meagher R.K., von Keyserlingk M.A.G. & Weary D.M. (2014) Social housing improves dairy calves' performance in two cognitive tests. *PLoS ONE* 9(2):e90205.

Garthwaite B.D., Drackley J.K., McCoy G.C. & Jaster E.H. (1994) Whole milk and oral rehydration solution for calves with diarrhea of spontaneous origin. *Journal of Dairy Science* 77:835–843.

Guilhermet R., Mathieu C.M. & Toullec R. (1975) Transit des aliments liquides au niveau de la gouttière œsophagienne chez le veau préruminant et ruminant. *Annales de Zootechnie* 24:69–79.

Hafez E.S.E & Lineweaver J.A. (1968) Suckling behaviour in natural and artificially fed neonate calves. *Zeitschrift fur Tierpsychologie* 25:287–298.

Haley D.B., Rushen J., Duncan I.J.H., Widowski T.M. & de Passillé A.M. (1998) Effects of resistance to milk flow and the provision of hay on nonnutritive sucking by dairy calves. *Journal of Dairy Science* 81:2165–2172.

Hammel K.L., Metz J.H.M. & Mekking P. (1988) Sucking behaviour of dairy calves fed milk *ad libitum* by bucket or teat. *Applied Animal Behaviour Science* 20:275–285.

Hammon H.M., Schiessler G., Nussbaum A. & Blum J.W. (2002) Feed intake patterns, growth performance, and metabolic and endocrine traits in calves fed unlimited amounts of colostrum and milk by automate, starting in the neonatal period. *Journal of Dairy Science* 85:3352–3362.

Hengst B.A., Nemec L.M., Rastani R.R. & Gressley T.F. (2012) Effect of conventional and intensified milk replacer feeding programs on performance, vaccination response, and neutrophil mRNA levels of Holstein calves. *Journal of Dairy Science* 95:5182–5193.

Hill T.M., Quigley J.D., Bateman H.G., Suarez-Mena F.X., Dennis T.S. & Schlotterbec R.L. (2016) Effect of milk replacer program on calf performance and digestion of nutrients in dairy calves to 4 months of age. *Journal of Dairy Science* 99:8103–8110.

Hopkins B.A. (1997) Effects of the method of calf starter delivery and effects of weaning age on starter intake and growth of Holstein calves fed milk once daily. *Journal of Dairy Science* 80:2200–2203.

Hostettler-Allen R.L., Tappy L. & Blum J.W. (1994) Insulin resistance, hyperglycemia, and glucosuria in intensively milk-fed calves. *Journal of Animal Science* 72:160–173.

Hugi D., Tappy L., Sauerwein H., Bruckmaier R.M. & Blum J.W. (1998) Insulin-dependent glucose utilization in intensively milk-fed veal calves is modulated by supplemental lactose in an age-dependent manner. *Journal of Nutrition* 128:1023–1030.

Hulbert L.E., Cobb C.J., Carroll J.A. & Ballou M.A. (2011) The effects of early weaning on innate immune responses of Holstein calves. *Journal of Dairy Science* 94:2545–2556.

Jasper J., Budzynska M. & Weary D.M. (2008) Weaning distress in dairy calves: Acute behavioural responses by limit-fed calves. *Applied Animal Behaviour Science* 110:136–143.

Jasper J. & Weary D.M. (2002) Effects of ad libitum milk intake on dairy calves. *Journal of Dairy Science* 85:3054–3058.

Jensen M.B. (2006) Computer-controlled milk feeding of group housed calves: the effect of milk allowance and weaning type. *Journal of Dairy Science* 89:201–206.

Jensen M.B. (2003) The effects of feeding method, milk allowance and social factors on milk feeding behaviour and cross-sucking in group housed dairy calves. *Applied Animal Behaviour Science* 80:191–206.

Jensen M.B. & Budde M. (2006) The effects of milk feeding method and group size on feeding behavior and cross-sucking in group-housed dairy calves. *Journal of Dairy Science* 89:4778–4783.

Jensen M.B. & Holm L. (2003) The effect of milk flow rate and milk allowance on feeding related behaviour in dairy calves fed by computer controlled milk feeders. *Applied Animal Behaviour Science* 82:87–100.

Johnston D., Earley B., Cormican P., Kenny D.A., McCabe1 M.S., Kelly A.K., McGee M. & Waters S.M. (2016) Characterisation of the whole blood mRNA transcriptome in Holstein-Friesian and Jersey calves in response to gradual weaning. *PLoS ONE*. 11(8):e0159707.

Jung J. & Lidfors L. (2001) Effects of amount of milk, milk flow and access to a rubber teat on cross-sucking and non-nutritive sucking in dairy calves. *Applied Animal Behaviour Science* 72:201–213.

Kaufhold J.N., Hammon H.M., Bruckmaier R.M., Breier B.H. & Blum J.W. (2000) Postprandial metabolism and endocrine status in veal calves fed at different frequencies. *Journal of Dairy Science* 83:2480–2490.

Kehoe S.I., Dechow C.D. & Heinrichs A.J. (2007) Effects of weaning age and milk feeding frequency on dairy calf growth, health and rumen parameters. *Livestock Science* 110:267–272.

Kertz A.F. & Chester-Jones H. (2004) Invited Review: Guidelines for Measuring and Reporting Calf and Heifer Experimental Data. *Journal of Dairy Science* 87:3577–3580.

Kmicikewycz A.D., da Silva D.N.L., Linn J.G. & Litherland N.B. (2013) Effects of milk replacer program fed 2 or 4 times daily on nutrient intake and calf growth. *Journal of Dairy Science* 96:1125–1134.

Kooijman J., Wierenga H.K. & Wiepkema P.R. (1991) Development of abnormal oral behaviour in group-housed veal calves. In: Metz J.H.M. & Groenestein C.M. (eds) *New Trends in Veal Calf Production*. EEAP Publication No. 52, Pudoc, Wageningen, The Netherlands, pp. 54–58.

Krachun C., Rushen J. & de Passillé A.M. (2010) Play behaviour in dairy calves is reduced by weaning and by a low energy intake. *Applied Animal Behaviour Science* 122:71–76.

Krohn C.C., Foldager J. & Mogensen L. (1999) Long-term effect of colostrum feeding methods on behaviour in female dairy calves. *Acta Agricolae Scandinava Section A: Animal Science* 49:57–64.

Kung L., Demarco S., Siebenson L.N., Joyner E., Haenlein G.F. & Morris R.M. (1997) An evaluation of two management systems for rearing calves fed milk replacer. *Journal of Dairy Science* 80:2529–2533.

Labussière E., Berends H., Gilbert M.S., van den Borne J.J.G.C. & Gerrits W.J.J. (2014) Estimation of milk leakage into the rumen of milk-fed calves through an indirect and repeatable method. *Animal* 8:1643–1652.

Leruste H., Brscic M., Cozzi G., Kemp B., Wolthuis-Fillerup M., Lensink B.J., Bokkers E.A.M. & van Reenen C.G. (2014) Prevalence and potential influencing factors of non-nutritive oral behaviors of veal calves on commercial farms. *Journal of Dairy Science* 97:7021–7030.

Lidfors L.M., Jung J. & de Passillé A.M. (2010) Changes in suckling behaviour of dairy calves nursed by their dam during the first month post partum. *Applied Animal Behaviour Science* 128:23–29.

Lidfors L.M. (1993) Cross-sucking in group-housed dairy calves before and after weaning. *Applied Animal Behaviour Science* 38:15–24.

Loberg J. & Lidfors L. (2001) Effect of milkflow rate and presence of a floating nipple on abnormal sucking between dairy calves. *Applied Animal Behaviour Science* 72:189–199.

Lorenz I., Mee J.F., Earley B. & More S.J. (2011) Calf health from birth to weaning. I. General aspects of disease prevention. *Irish Veterinary Journal* 64:10.

Mason G.J. & Rushen J. (2008) *Stereotypic Animal Behavior: Fundamentals and applications to Welfare*. CAB International, Wallingford, UK.

Mason G.J. (1991) Stereotypies: a critical review. *Animal Behaviour* 41:1015–1037.

Mattiello S., Canali E., Ferrante V., Caniatti M., Gottardo F., Cozzi G., Andrighetto I. & Verga M. (2002) The provision of solid feeds to veal calves: II. Behaviour, physiology and abomasal damage. *Journal of Animal Science* 80:367–375.

Meale S.J., Leal L.N., Martín-Tereso J. & Steele M.A. (2015) Delayed weaning of Holstein bull calves fed an elevated plane of nutrition impacts feed intake, growth and potential markers of gastrointestinal development. *Animal Feed Science and Technology* 209:268–273.

MacPherson J.A.R., Berends H., Leal L.N., Cant J.P., Martín-Tereso J. & Steele M.A. (2016) Effect of plane of milk replacer intake and age on glucose and insulin kinetics and abomasal emptying in female Holstein Friesian dairy calves fed twice daily. *Journal of Dairy Science*. 99:8007–8017.

Morisse J.P., Huonnic D., Cotte J.P & Martrenchar A. (2000) The effect of four fibrous feed supplementations on different welfare traits in veal calves. *Animal Feed Science and Technology* 84:129–136.

Murray M.J. & Murray A.B. (1979) Anorexia of infection as a mechanism of host defense. *American Journal of Clinical Nutrition* 32:593–596.

Nielsen P.P., Jensen M.B. & Lidfors L. (2008a) Milk allowance and weaning method affect the use of a computer controlled milk feeder and the development of cross-sucking in dairy calves. *Applied Animal Behaviour Science* 109:223–237.

Nielsen P.P., Jensen M.B. & Lidfors L. (2008b) The effects of teat bar design and weaning method on behavior, intake, and gain of dairy calves. *Journal of Dairy Science* 91:2423–2432.

Nocek J.E., Braun D.G. & Warner R.G. (1984) Influence of neonatal colostrum administration, immunoglobulin and continued feeding of colostrum on calf gain, health and serum protein. *Journal of Dairy Science* 67:319–333.

Nussbaum A., Schiessler G., Hammon H.M. & Blum J.W. (2002) Growth performance and metabolic and endocrine traits in calves pair-fed by bucket or by automate starting in the neonatal period. *Journal of Animal Science* 80:1545–1555.

O'Driscoll K., von Keyserlingk M.A. & Weary D.M. (2006) Effects of mixing on drinking and competitive behavior of dairy calves. *Journal of Dairy Science* 89:229–233.

Osorio J.S., Wallace R.L., Tomlinson D.J., Earleywine T.J., Socha M.T. & Drackley J.K. (2012) Effects of source of trace minerals and plane of nutrition on growth and health of transported neonatal dairy calves. *Journal of Dairy Science* 95:5831–5844.

Pollock J.M., Rowan T.G., Dixon J.B., Carter S.D. & Fallon R. (1992) Effects of weaning on antibody responses in young calves. *Veterinary Immunology and Immunopathology* 33:25–36.

Quigley J.D. (1996) Influence of weaning method on growth, intake, and selected blood metabolites in Jersey calves. *Journal of Dairy Science* 79:2255–2260.

Quigley J.D., Wolfe T.A. & Elsasser T.H. (2006) Effects of additional milk replacer feeding on calf health, growth, and selected blood metabolites in calves. *Journal of Dairy Science* 89:207–216.

Reinhardt V. & Reinhardt A. (1981) Natural sucking performance and age of weaning in zebu cattle (*Bos indicus*). *The Journal of Agricultural Science* 96:309–312.

Roth B.A., Hillmann E., Stauffacher M. & Keil N.M. (2008) Improved weaning reduces cross-sucking and may improve weight gain in dairy calves. *Applied Animal Behaviour Science* 111:251–261.

Rushen J. & de Passillé A.M. (1998) Behavior, welfare and productivity of dairy cattle. *Canadian Journal of Animal Science* 78(Supplement):3–21.

Rushen J. & de Passillé A.M. (1995) The motivation of non-nutritive sucking in calves, Bos taurus. *Animal Behaviour* 49:1503–1510.

Rushen J., de Passillé A.M., von Keyserlingk M.A.G. & Weary D.M. (2008) *The Welfare of Cattle*. Springer, Dordrecht, The Netherlands.

Suárez B.J., Van Reenen C.G., Gerrits W.J.J., Stockhofe N., van Vuuren A.M. & Dijkstra J. (2006) Effects of supplementing concentrates differing in carbohydrate composition in veal calf diets: II. Rumen development. *Journal of Dairy Science* 89:4376–4386.

Sweeney B.C., Rushen J., Weary D.M. & de Passillé A.M. (2010) Duration of weaning, starter intake and weight gain of dairy calves fed large amounts of milk. *Journal of Dairy Science* 93:148–152.

Terré M., Devant M. & Bach A. (2007) Effect of level of milk replacer fed to Holstein calves on performance during the preweaning period and starter digestibility at weaning. *Livestock Science* 110:82–88.

Uys J.L., Lourens D.C. & Thompson P.N. (2011) The effect of unrestricted milk feeding on the growth and health of Jersey calves. *Journal of the South African Veterinary Association* 82:47–52.

Van den Borne J.J.G.C., Lobley G.E., Verstegen M.W.A., Muijlaert J.M., Alferink S.J.J. & Gerrits W.J.J. (2007) Body fat deposition does not originate from carbohydrates in milk-fed calves. *Journal of Nutrition* 137:2234–2241.

Van den Borne J.J.G.C., Verdonk J.M.A.J., Schrama J.W. & Gerrits W.J.J. (2006) Reviewing the low efficiency of protein utilization in heavy preruminant calves: a reductionist approach. *Reproduction Nutrition Development* 46:121–137.

Van Weeren-Keverling Buisman A., Mouwen J.M., Wensing T. & Breukink H.J. (1990) Intraruminal administration of milk in the calf as a model for ruminal drinking: morphological and enzymatical changes in the jejunal mucosa. *Veterinary Research Communications* 14:129–140.

Veissier I., de Passillé A.M., Després G., Rushen J., Charpentier I., Ramirez de la Fe A.R. & Pradel P. (2002) Does nutritive and non-nutritive sucking reduce other oral behaviors and stimulate rest in calves? *Journal of Animal Science* 80:2574–2587.

Veissier I., Ramirez de la Fe A.R. & Pradel P. (1998) Nonnutritive oral activities and stress responses of veal calves in relation to feeding and housing conditions. *Applied Animal Behaviour Science* 57:35–49.

Vicari T., van den Borne J.J.G.C., Gerrits W.J.J., Zbinden Y. & Blum J.W. (2008) Postprandial blood hormone and metabolite concentrations influenced by feeding frequency and feeding level in veal calves. *Domestic Animal Endocrinology* 34:74–88.

Vitale A.F., Tenucci M., Papini M. & Lovari S. (1986) Social behaviour of the calves of semi-wild Maremma cattle, *Bos primigenius taurus*. *Applied Animal Behaviour Science* 16:217–231.

von Keyserlingk M.A.G., Brusius L. & Weary D.M. (2004) Competition for teats and feeding behavior by group housed dairy calves. *Journal of Dairy Science* 87:4190–4194.

von Keyserlingk M.A.G., Rushen J., de Passillé A.M.B. & Weary D.M. (2009) Invited review: The welfare of dairy cattle – Key concepts and the role of science. *Journal of Dairy Science* 92:4101–4111.

von Keyserlingk M.A.G. & Weary D.M. (2007) Maternal behavior in cattle. *Hormones and Behavior* 52:106–113.

Weary D.M., Jasper J. & Hötzel M.J. (2008) Understanding weaning distress. *Applied Animal Behaviour Science* 110:24–41.

Webb L.E., Bokkers E.A.M., Heutinck L.F.M., Engel B. & Buist W.G. (2013) The effect of roughage type, amount and particle size on veal calf behavior and gastrointestinal health. *Journal of Dairy Science* 96:7765–7776.

Webb L.E., Engel B., Berends H., van Reenen C.G., Gerrits W.J.J., de Boer I.J.M. & Bokkers E.A.M. (2014) What do calves choose to eat and how do preferences affect behaviour? *Applied Animal Behaviour Science* 161:7–19.

Wise G.H., Anderson G.W. & Linnerud A.C. (1984) Relationship of milk intake by sucking and by drinking to reticular-groove reactions and ingestion behavior in calves. *Journal of Dairy Science* 67:1983–1992.

Wise G.H., Anderson G.W. & Miller P.G. (1942) Factors affecting the passage of liquids into the rumen of the dairy calf. II. Elevation of the head as milk is consumed. *Journal of Dairy Science* 25:529–536.

2. Optimal management strategies to reduce the risk of welfare issues associated with iron deficiency anaemia

Conclusions

1. **Reports on the prevalence of iron deficiency in Canadian milk-fed and grain-fed calves were not identified in the scientific literature.**

2. **Veal calves that do not receive sufficient iron from their diet are at risk of developing iron deficiency and iron deficiency anaemia.**

3. **The risk of iron deficiency is greater in calves that receive only milk replacer than in calves that receive solid feed with or without milk replacer.**

4. **Calves that are only offered milk replacer show clear signs of iron deficiency anaemia when the iron concentration in the milk replacer is ≤ 20 mg iron/kg DM.**

5. **In milk-fed veal calves, the veal meat does not become appreciably darker until the iron concentration in the milk replacer is > 40 mg iron/kg DM.**

6. **Measurement of blood haemoglobin concentration is a useful way of monitoring whether the amount of iron in the diet is too low and whether the calves are at risk of iron deficiency anaemia. However, it might be too insensitive to detect the early stages of iron deficiency.**

7. **Calves might experience some effects of iron deficiency before a reduction in blood haemoglobin concentration occurs.**

8. **Groups of calves with a mean blood haemoglobin concentration ≤ 4.8 mmol/L (7.7 g/dL) show effects of iron deficiency anaemia (including inappetence, reduced growth, fatigue after exercise, and impaired immunity) that are likely to affect their welfare. In any group of calves, there will be some calves that have a blood haemoglobin concentration lower than the group mean and this has to be considered when setting thresholds for intervention based on mean values. For example, in one study the mean haemoglobin concentration of the group was 5.3 mmol/L (8.5 g/dL), but 13% of the calves had a blood haemoglobin concentration ≤ 4.3 mmol/L (6.9 g/dL).**

9. **Management strategies to maintain blood haemoglobin concentrations include (a) supplementation of milk replacer with iron sulphate, (b) provision of solid feed, and (c) administration of iron dextran by intra-muscular injection.**

10. **Further research is required on optimal management strategies for blood sampling of calves as well as appropriate intervention thresholds for iron supplementation at the individual calf level.**

2.1 Introduction

Calves are born with some iron stores, but as the concentration of iron in whole milk is low (about 3 mg iron/kg DM) (National Research Council [NRC], 2001), calves reared on whole milk alone are at risk of developing iron deficiency anaemia. However, if calves are suckled at pasture or have access to preserved forages, such as hay or grass silage, when they start to consume forages and associated soil, this provides an essential intake of iron, and iron deficiency anaemia does not develop (Egli & Blum, 1998). Although the recommended iron concentration in milk replacer for rearing dairy calves is 100 mg iron/kg DM (NRC, 2001), in traditional milk-fed veal systems, the milk replacer has a low iron concentration to produce pale meat. Milk replacer used for milk-fed veal calves normally has ≤ 50 mg iron/kg DM (NRC, 2001), but the iron content can be considerably lower. Although iron can be present in both drinking water and air (Government of Canada, 2009), milk-fed veal calves do not have access to solid feed containing iron; in consequence, if they do not receive supplemental iron they are at risk of developing iron deficiency anaemia. Veal calves with iron deficiency anaemia can experience inappetence, fatigue after exercise and have reduced immunity to infection.

Iron is important for several essential functions within the body. Most iron within a calf is used for haemoglobin formation in red blood cells. Although anaemia is the main outcome of iron deficiency, it is not the only consequence of iron deficiency. After blood haemoglobin, the next major use of iron is for myoglobin within muscle. If the muscle contains a normal concentration of myoglobin, the meat produced is red in colour, but if the concentration is reduced, such as in milk-fed veal calves, the meat is pale. As a calf grows, the blood volume and the number of red blood cells requiring iron for the production of haemoglobin increases. If the diet does not contain sufficient iron, the iron stores present at birth are utilised and not replaced, and the concentration of haemoglobin in the blood and the concentration of myoglobin in the muscle decrease. To reduce the risk of anaemia developing in milk-fed veal calves (where the only source of iron is the milk replacer), the milk replacer is supplemented with iron, the blood haemoglobin concentration is monitored, and individual calves at risk receive an injection of iron. Due to the greater iron concentration in solid feeds, such as grain and roughage (e.g., corn 55 mg iron/kg DM, SD=43, n=1738; straw 200 mg iron/kg DM, SD=72, n=20; National Research Council, 2000), the risk of grain-fed veal calves and milk-fed veal calves offered solid feed developing anaemia is reduced.

The prevalence of calves developing iron deficiency and iron deficiency anaemia in current management practices used in Canada to rear veal calves is not known. However, the literature suggests that dietary management practices that restrict iron intake to produce pale meat increase the risk of veal calves developing iron deficiency anaemia. Further work on veal calves is required to study adverse welfare outcomes arising from iron deficiency. As anaemia is only one consequence of iron deficiency, consideration has to be given to whether the laboratory test used to identify anaemia in veal calves, namely blood haemoglobin concentration, is sensitive enough to identify other effects of iron deficiency in veal calves that might occur before anaemia is identified. Evaluation of laboratory methods to identify iron deficiency in veal calves and the setting of appropriate threshold values requires consideration of the physiology underlying iron metabolism. “Understanding the homeostatic regulation of iron is important to understand the pathogenesis of diseases associated with iron metabolism and the limitations on different assays of iron status” (Bohn, 2015).

The scientific literature provides information that can be used to identify some absolute thresholds for minimal dietary iron intake and therapeutic intervention. As long as the iron concentration in milk replacer is no greater than 2 g iron/kg DM, the risk of iron toxicity from supplementing milk replacer with iron up to the normal concentration used to rear dairy calves (i.e., 100 mg iron/kg DM) is low (Jenkins & Hidiroglou, 1987). Therefore, if the only criterion for the development of recommended requirements for daily iron intake for calves was the provision of sufficient iron to ensure the health and welfare of the calves, a very wide safety margin for supplementation of milk replacer with iron could be used to avoid the risk of iron deficiency with low risk of iron toxicity. However, the provision of additional iron in the diet increases the myoglobin concentration in the meat and this affects the colour of the veal meat (Abdelrahim et al., 1983; Wensing et al., 1986). As the colour of veal can have economic consequences for producers rearing milk-fed veal calves, iron intake is restricted to produce pale coloured veal. Therefore, there is a narrow safety margin between ensuring that the calves receive sufficient iron for their health and welfare and the veal is sufficiently pale in colour to meet the market demands for milk-fed veal.

2.2 Iron deficiency anaemia

Anaemia is a clinical condition in which the capacity of the blood to transport oxygen is decreased because there are too few red blood cells and/or their haemoglobin concentration is too low. There are several causes of anaemia, only one of which is iron deficiency. In severe form, anaemia is characterised by some overt and characteristic clinical signs, but in sub-clinical or mild forms it can cause some detrimental effects that could have arisen from several other causes and a laboratory test is required to assist with diagnosis. As anaemia is a clinical condition that can vary quantitatively according to the degree of disruption to the number or integrity of the red blood cells, a laboratory test of various haematological variables (measurements of the form, structure, and physiology of blood) will require interpretation before a diagnosis of anaemia can be reached. There are some haematological changes that only occur during anaemia, such as some changes in the structure and form of red blood cells. However, for most values, such as the blood haemoglobin concentration (routinely used by the veal industry to identify calves at risk of anaemia), that vary quantitatively in a continuous manner according to the severity of the anaemia, it is a question of setting threshold values or a cut-off point to differentiate between healthy calves and calves with anaemia. As the threshold value determines the point at which therapeutic intervention occurs, it is important that the threshold value is set at a level that will detect potential health and welfare issues in veal calves before suffering occurs and that the appropriate laboratory test is used that is capable of detecting early signs of iron deficiency anaemia.

Iron deficiency anaemia is not common in adult cattle, but it is seen in milk-fed veal calves that do not have access to solid feed (Andrews, 2004). Iron deficiency anaemia occurs when the balance of iron intake, iron stores, and the loss of iron from the body is insufficient to support the optimal production of normal red blood cells that contain sufficient haemoglobin (Miller, 2013). Red blood cells (erythrocytes) and their precursors (erythroblasts and then reticulocytes) have a large requirement for iron (Miltenburg et al., 1991; Harvey, 2008a). The most immediate source of iron for erythroblasts is plasma transferrin (Miller, 2013). Erythropoiesis (production of red blood cells) occurs in the bone marrow and involves a series of cell divisions from haematopoietic stem cells that take place over about 4 days with increasing haemoglobin synthesis at each stage (Harvey, 2008a). A normal red blood cell has a lifespan of 156 days, but in calves with anaemia this can decrease to 144 days (Valli et al., 1971) due to their increased fragility (Naigamwalla et al., 2012). Anaemic calves have a greater utilisation of supplemental iron than normal calves (Valli et al., 1971), and calves offered milk replacer containing low iron concentration (19 mg iron/kg) have an increased plasma iron clearance rate after an intravenous injection of iron than calves offered concentrates and hay in addition to milk replacer (Möllerberg et al., 1975b).

Normally, if there is sufficient iron, when the concentration of haemoglobin in an immature red blood cell reaches a certain level, cell division stops and the cell nucleus is extruded, and a normal immature red blood cell (reticulocyte) enters the circulation and subsequently matures into a red blood cell. In laboratory tests of whole blood, early signs of iron deficiency anaemia are decreases in the number of reticulocytes and the haemoglobin concentration within the reticulocytes (Archer & Brugnara, 2015). As the anaemia progresses, the size of the red blood cells decrease (microcytic anaemia) and this is reflected in a low mean corpuscular (cell) volume (a haematological measurement of the size of the red blood cells). In severe iron deficiency anaemia, some of the red blood cells may retain a nucleus. The red blood cells can appear paler than normal (hypochromic) due to reduced haemoglobin concentration, but this may not always be seen in anaemic veal calves (Bremner & Dalgarno, 1973a). The red blood cells can show variations in both shape (poikilocytosis) and size (anisocytosis)

(Blaxter et al., 1957). The haematological measurement of the range of variation in the size of the red blood cells is the red blood cell distribution width. As there are many physiological and pathological influences on individual haematological measurements, such as the red blood cell count and the packed cell volume, the following two derived measurements are used to quantify the haemoglobin content within red blood cells. The *mean corpuscular haemoglobin* is the average amount of haemoglobin in the average red blood cell. The mean corpuscular haemoglobin is derived from the blood haemoglobin concentration divided by the red blood cell count. The *mean corpuscular haemoglobin concentration* is a measure of the concentration of haemoglobin in a given volume of packed red blood cells. It is calculated by dividing the blood haemoglobin concentration by the packed cell volume.

In iron deficiency anaemia, the reduction in the blood haemoglobin concentration results in a decrease in oxygen carrying capacity of red blood cells (Jonker & Boele van Hensbroek, 2014). The primary purpose of red blood cells is to carry haemoglobin. Haemoglobin binds with oxygen to form oxyhaemoglobin to transport oxygen to the tissues, removes carbon dioxide by potentiating the formation of bicarbonate (that transports the carbon dioxide), and binds with carbon dioxide to form deoxyhaemoglobin (Harvey, 2008a).

The clinical signs of severe iron deficiency anaemia in calves are pale mucous membranes, reduced feed intake, and reduced growth (Webster et al., 1975; Reece & Hotchkiss, 1987; Andrews, 2004). Matrone et al. (1957) reported that calves that developed anaemia due to an iron deficient diet and had a blood haemoglobin concentration of about 4 mmol/L (6.4 g/dL) at 2 months of age and 2.7 mmol/L (4.3 g/dL) at 8.5 months of age showed signs of fatigue and difficulty breathing upon physical examination. In three calves offered whole cow's milk (about 0.3 mg iron/L, equivalent to about 2 mg iron/kg DM), Blaxter et al. (1957) observed the following signs of anaemia: inappetence, pale mucous membranes, smooth papillae on the tongue, and reluctance to move. Between 16 and 27 weeks of age, the clinical signs in these calves were so severe that they were euthanised.

2.2.1 Identification of abnormal values indicative of iron deficiency anaemia

Iron deficiency anaemia cannot be identified from clinical signs alone and requires haematological tests. When anaemia is associated with specific haematological changes and the diet is deficient in iron, a diagnosis of iron deficiency anaemia can be made. The difficulty is identifying what qualitative and/or quantitative changes in the haematological variables constitute anaemia. For measurements such as blood haemoglobin concentration that exist as a continuous variable, it is necessary to define the range of values that are found in a normal healthy calf and the range of abnormal values found in a calf with anaemia. Unfortunately, in many cases the distribution of values in normal and abnormal animals overlaps. Several approaches can be used to classify abnormal values. The following modified criteria based partly on those first developed for adult cattle could potentially be used to identify anaemia in calves (Holman, 1955, 1956).

A. Unusual values

(i) Identification of values that fall outside of the normal range on the basis of the statistical distribution.

If the measurement follows an approximate normal or Gaussian distribution, 95% of the values would fall within 1.95 standard deviations of the mean. The critical or cut-off values could then arbitrarily be defined by this distribution, i.e., normal values could be the 95% of the population within two standard deviations of the mean. For example, the blood haemoglobin concentration could be defined as abnormally low if it was lower than a multiple of the standard deviation below the mean concentration or below a certain percentile distribution, if not normally distributed (Farver, 2008). This approach was used by Lindt and Blum (1994a), who considered that veal calves that had been offered milk replacer containing 53 mg iron/DM kg had a mean "normal" blood haemoglobin concentration of 6.5 mmol/L (10.5 g/dL) with a standard deviation of 0.87 mmol/L (1.4 g/dL).

Then, in a survey of calves from 28 veal units in Switzerland that had been reared until 16 to 30 weeks of age on milk replacer containing 32 mg iron/kg DM, they reported the percentage of veal calves that had a blood haemoglobin concentration lower than the mean - [2 × standard deviation] (i.e., those less than 4.8 mmol/L [7.7 g/dL]) as 18% (range 13–31%). Similarly, for packed cell volume or PCV (i.e., the percentage by volume of red and white cells in the circulation compared with the volume of plasma), they reported a "normal" mean of 28%, standard deviation 4, and the percentage of calves with a PCV lower than the mean - [2 × standard deviation] (i.e., less than 20%) as 23% (range 5–47%). For the total red blood cell count, the normal was reported as 8×10^{12}/L, standard deviation 1 and the percentage of calves with a red blood cell count lower than the mean - [2 × standard deviation] (i.e., less than 6×10^{12}/L) as 3% (range 0–10%).

(ii) Classification of values as abnormal based on a percentage reduction from the mean value.

For example, Holman (1955) considered that if the blood haemoglobin concentration is reduced to half the normal value, this could somewhat arbitrarily be classified as moderate anaemia, concentrations below this could be classified as severe anaemia, and concentrations "just above" this as mild anaemia. Similarly, if the mean corpuscular haemoglobin concentration is reduced by 24%, this could be classified as hypochromia, 18% as moderate hypochromia, and 14% as severe hypochromia (Holman, 1955).

B. Values associated with clinical signs of disease

If the blood haemoglobin concentration is sufficiently low that health, productivity, or essential physiological functions are affected (Holman, 1955), this would be classified as abnormally low.

C. Values that respond to treatment/supplementation

If the blood haemoglobin concentration in an apparently healthy calf could be increased by changes in diet that increase the intake of iron or by administration of iron (Holman, 1955), this would be classified as abnormally low.

2.2.2 Characteristic haematological changes in calves with anaemia

Unless a rapidly growing calf can supplement their iron intake from sources other than milk, it is only born with sufficient iron in the liver to support iron metabolism for about 3 weeks (Andrews, 2004; Heidarpour Bami et al., 2008). After that time, signs of iron deficiency can occur. In rapidly growing veal calves that are offered milk replacer with an inadequate concentration of iron to support the increased production of haemoglobin required for an expanded blood volume, the blood haemoglobin concentration will fall. For example, Abdelrahim et al. (1983) described a fall from 6.6 mmol/L (10.6 g/dL) at 7 weeks of age to 5.1 mmol/L (8.2 g/dL) at 15 weeks of age, but then it stabilised at 5.5 mmol/l (8.9 g/dL) until 21 weeks of age. As veal calves grow, (a) their consumption of milk replacer also increases resulting in a greater daily iron intake, and (b) the increase in red cell mass constitutes a progressively smaller component of weight gain, and the net result is that the rate of decrease in the blood haemoglobin concentration can stabilise (Suttle, 2010).

Although the ages of the calves were not always the same, Table 2.1 shows that calves with clinical signs of anaemia had associated haematological changes that were not found in calves that received a milk replacer diet containing supplemental iron (100 mg iron/kg DM) or in those calves weaned at 1 month of age onto grain and hay. The effect of providing milk replacer for about 4 months compared with calves weaned at 1 month onto grain and hay (with greater iron intake) was to lower blood haemoglobin concentration (4.5 and 7.0 mmol/L, respectively [7.2 and 11.3 g/dL]), PCV, the number of red blood cells, mean corpuscular haemoglobin, and mean corpuscular volume. Although numerically smaller, there was no significant effect on the mean corpuscular haemoglobin concentration, i.e., no indication of hypochromia (Reece & Hotchkiss, 1987). The blood haemoglobin concentration, red blood cell count, and PCV decreased in the veal calves offered milk replacer from 7.1 mmol/L (11.4 g/dL), 8.4 × 10^{12}/L, and 35%, respectively, at 1 week of age, to 3.8 mmol/L (6.1 g/dL), 5.2 × 10^{12}/l, and 22%, respectively, at 15 weeks of age. In calves offered milk replacer and weaned at 1 month of age onto grain and hay, the blood haemoglobin concentration, red blood cell count, and PCV remained at about 7.01 mmol/L (11.3 g/dL), 8.3 × 10^{12}/L, and 34%, respectively (Reece & Hotchkiss, 1987).

Table 2.1 Effect of diet on haematological measurements

Variable	Units	Whole cow's milk	Milk replacer	Milk replacer	Milk replacer	Milk replacer	Milk replacer and weaned at 1 month of age onto grain and hay	Suckled calves with access to straw, hay, and grass silage
Iron concentration in milk replacer	mg iron/kg DM	2	10	Not stated	40	100	Not stated	Not stated
Blood haemoglobin concentration	mmol/L g/dL	3.4[†] 5.5	4.0[†] 6.4	4.9[§] 7.9	6.6[†] 10.6	6.9[†] 11.1	7.0[§] 11.3	6.5[†] 10.5
Red blood cell count	no. × 10^{12}/L	8.1[†]	5.6[†]	6.4[§]	8.0[†]	7.2[†]	8.8[§]	10.2[†]
Mean corpuscular volume	femtolitre or μm^3	21[‡]	36[†]	38[§]	41[†]	42[†]	39[§]	29[†]
Mean corpuscular haemoglobin	femtomol/cell or mol × 10^{-15}/cell	0.04[‡]	0.7[†]	0.8[§]	0.8[†]	0.9[†]	0.8[§]	0.6[†]
Mean corpuscular haemoglobin concentration	mmol/L g/dL	17[‡] 27.4	19[†] 30.6	20[§] 32.2	20[†] 32.2	21[†] 33.8	21[§] 33.8	21[†] 33.8
Reference		Blaxter et al. (1957)	Bremner & Dalgarno (1973b)	Reece & Hotchkiss (1987)	Bremner & Dalgarno (1973b)	Bremner & Dalgarno (1973b)	Reece & Hotchkiss (1987)	Egli & Blum (1998)

† measured at 12 weeks
‡ measured at 18 weeks
§ mean of 15 weekly samples from 1 week of age

2.3 Iron metabolism and iron deficiency

2.3.1 Iron metabolism

The metabolism of iron is complex, and not all iron is in a form that can be fully utilised by a calf. Very little iron is present in the circulation, and the small amount that is present is not directly from ingestion but from recycled iron from old red blood cells. As such, the serum iron concentration does not provide a good indication of the amount of iron present in the body (Bohn, 2015).

Iron absorbed from feed is transported in the blood bound to a protein called transferrin. Most iron is transported to the bone marrow and incorporated into the production of haemoglobin within red blood cells (Harvey, 2008a). Iron is also present in muscles as myoglobin and is an important component of many enzymes and other compounds. Iron is stored bound to protein in a soluble form (ferritin) or an insoluble form (haemosiderin, found mainly in macrophages and hepatocytes). Iron that is not required for immediate physiological functions is stored in the liver, but it is also stored in the bone marrow and spleen (Jenkins & Hidiroglou, 1987; Bremner & Dalgarno, 1973b; Naigamwalla et al., 2012). The small quantity of ferritin that is released into the blood is a reflection of the amount of total iron stored in the body. When available iron is insufficient to meet requirements, iron stores are depleted and ferritin concentration decreases. Iron storage and ferritin concentration increase when more iron is absorbed than the body needs, and excess iron is excreted in the faeces.

2.3.2 Iron deficiency

Iron deficiency can progress through several stages (Halwachs-Baumann, 2012; Archer & Brugnara, 2015):

Stage 1. Storage iron depletion: Iron is not stored and iron storage is below normal, plasma ferritin concentration is decreased, but there is no change in haematological variables.

Stage 2. Iron deficiency with no anaemia: Blood haemoglobin concentration is normal or slightly reduced, but other biochemical and haematological measurements indicate that iron availability for the production of red blood cells by the bone marrow is no longer fully met.

Stage 3. Iron deficiency anaemia: There is a restriction in haemoglobin production leading to distortion of red blood cells.

2.3.2.1 Measurements of iron deficiency

Laboratory tests can be used to assess whether iron metabolism has been affected by iron deficiency either due to inadequate stores or inadequate dietary intake. The amount of transferrin that is available to bind to and transport iron is reflected in laboratory tests of the total iron binding capacity (TIBC), unsaturated iron binding capacity (UIBC), and transferrin saturation.

- The total iron binding capacity measures the total amount of iron that can be bound by proteins in the blood. As transferrin is the primary iron-binding protein, the total iron binding capacity is a good indirect measurement of transferrin availability. In iron deficiency, the total iron binding capacity is increased as there is insufficient iron to bind with transferrin.
- The unsaturated iron binding capacity determines the reserve capacity of transferrin, i.e., the portion of transferrin that has not yet been saturated with iron. It is increased in iron deficiency.

- Transferrin saturation represents the percentage of the transferrin that is saturated with iron (serum iron concentration/total iron binding capacity × 100). It is decreased in iron deficiency.
- The serum iron concentration is a measure of the total amount of iron in the blood, nearly all of which is bound to transferrin. It is decreased in iron deficiency.

In humans, a low serum ferritin concentration is considered the most sensitive and specific test for the identification of iron deficiency (Peyrin-Biroulet et al., 2015). In calves, Miyata et al. (1984) found that serum ferritin concentration was more responsive after iron supplementation than other haematological and biochemical measurements of iron metabolism. In iron deficiency that develops into anaemia, the serum ferritin concentration is even lower, and the transferrin saturation percentage is low and indicative of insufficient iron to support normal production of red blood cells (Camaschella, 2015).

Summary of characteristic biochemical and haematological changes in iron deficiency anaemia (Archer & Brugnara, 2015):

Biochemical changes in the serum or plasma
↓ iron, ferritin, transferrin saturation

Haematological changes in the blood
↓ blood haemoglobin concentration, mean corpuscular volume, mean corpuscular hemoglobin, reticulocyte haemoglobin content
↑ red cell distribution width.

2.4 Iron concentration in milk replacer

As calves that have access to only milk replacer have a lower intake of iron than those that have access to either concentrates and/or straw bedding (Welchman et al., 1988), they are at greater risk of developing iron deficiency. For example, veal calves reared for 15-17 weeks on a diet of only milk replacer (19 mg iron/kg) had lower serum iron concentration and transferrin saturation and greater total iron binding capacity and unsaturated iron binding capacity than those with access to grain and hay (Möllerberg et al., 1975b; Reece & Hotchkiss, 1987).

Iron sulphate is absorbed readily from a milk replacer diet (Miltenburg et al., 1993), and it is used to supplement milk replacer. Figure 2.1 shows that without adequate iron supplementation, milk-fed veal calves show signs of iron deficiency.

2.4.1 Effects on plasma/serum iron concentration

Figure 2.1A shows that, as the concentration of iron in a milk replacer diet increases, the concentration of iron in the plasma or serum increases.

2.4.2 Effects on liver iron concentration

Although the concentration of iron in the milk replacer diet can affect the concentration of iron stored in the liver, the studies included in Figure 2.1B did not show an obvious effect of the concentration of iron in a milk replacer diet on the concentration of iron stored in the liver. Bremner and Dalgarno (1973b) found no effect of increasing the concentration of iron in a milk replacer diet on the liver concentration of total iron, non-haem iron, ferritin iron, or haemosiderin iron. Although the total iron concentration in the spleen was not significantly affected by the iron intake, the concentrations in the spleen of non-haem iron, ferritin iron, and haemosiderin iron increased with increasing iron intake. In veal calves aged between 8 and 25 weeks of age, the liver iron concentration falls when they are offered a milk replacer with an iron concentration of less than 20 mg iron/kg DM (Miltenburg et al., 1992a,b). Veal calves that had been offered milk replacer containing 45 mg iron/kg for 6 weeks and then a milk replacer containing 8-10 mg iron/kg had a lower liver iron concentration at 21 weeks of age than those had been offered 15 mg iron/kg after 6 weeks of age (Wensing et al., 1986).

2.4.3 Effects on Total Iron Binding Capacity (TIBC)

Increasing concentrations of iron in the milk replacer do not have a clear effect on the total iron binding capacity (TIBC), but some calves offered milk replacer with a very low iron concentration show increased capacity due to insufficient iron to bind with transferrin (Figure 2.1C).

2.4.4 Effects on blood haemoglobin concentration

When calves are offered a milk replacer containing less than 30 mg iron/kg DM, there is a clear reduction in the blood haemoglobin concentration. Figure 2.1D shows that at milk replacer iron concentrations of 30 mg iron/kg DM or greater the mean blood haemoglobin concentration did not fall below 5 mmol/l (8.1 g/L). Whereas, at 10–20 mg iron/kg DM, especially in calves 8 weeks of age and older, the mean blood haemoglobin concentration recorded in most studies was between 3.6 and 4.4 mmol/L (5.8 and 7.1 g/dL).

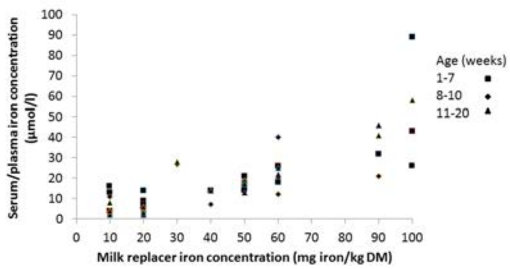
2.4.5 Effects on red blood cell count

Similarly, Figure 2.1E shows that at milk replacer iron concentrations of 30 mg iron/kg DM or greater, the mean total red blood cell count did not fall below 6×10^{12}/L. Whereas at 10-20 mg iron/kg DM, especially in calves 8 weeks of age and older, some studies reported red blood cell counts as low as 4×10^{12}/L.

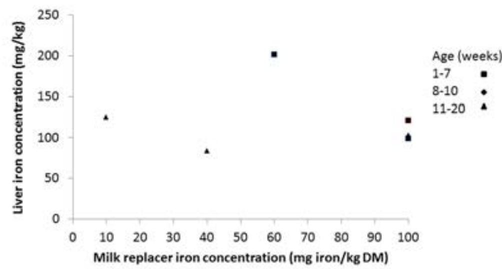
2.4.6 Effects on Packed Cell Volume (PCV)

There was a clear effect of the concentration of iron in a milk replacer diet on the PCV. Figure 2.1F shows that at milk replacer iron concentrations of 30 mg iron/kg DM or greater the PCV did not fall below 27%. Whereas at 10-20 mg iron/kg DM, especially in calves 8 weeks of age and older, most studies reported a mean PCV of 19 to 25%.

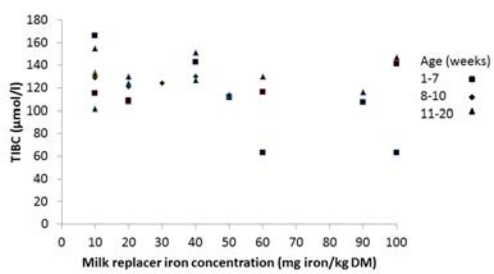
Figure 2.1 Effect of concentration of iron in milk and milk replacer on measurements of iron metabolism†



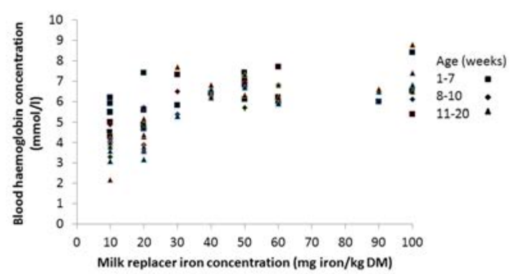
A. Plasma/serum iron concentration



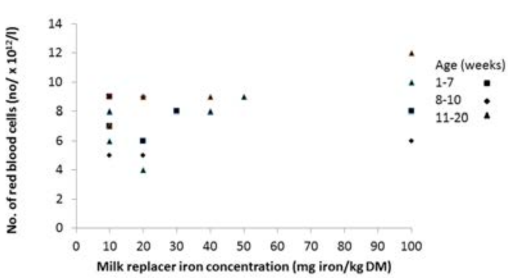
B. Liver iron concentration



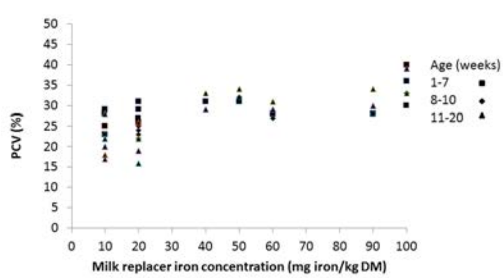
C. TIBC concentration



D. Blood haemoglobin concentration



E. Total red blood cell count



F. Packed Cell Volume (PCV)

† Mean values grouped by age and milk replacer iron concentration categories that were derived from multiple publications (Bernier et al., 1984; Blaxter et al., 1957; Bremner & Dalgarno, 1973a; Gygax et al., 1993; Hostettler-Allen et al., 1993; Jenkins & Hidiroglou, 1987; Lindt & Blum, 1993, 1994a, b; Matrone et al., 1957; McFarlane et al., 1988; Miltenburg et al., 1992b; Möllerberg et al., 1975a,b; Moser et al., 1994; Webster et al., 1975; Wensing et al., 1986).

2.4.7 Blood haemoglobin concentration in veal calves offered milk replacer

As shown above, the blood haemoglobin concentration is sensitive to the level of iron provided in milk replacer. No recent surveys of the blood haemoglobin concentration in calves on commercial veal units were found in the scientific literature. In this review, mean values are used for simplicity, however, as stated by the European Food Safety Authority (EFSA) (2012), there will, of course, be many calves that have a blood haemoglobin concentration lower than the mean, and this has to be considered when setting thresholds based on mean values. As shown by the surveys described below, there is variation in blood haemoglobin concentration within calves kept under similar management practices, and at the times of the surveys there were some veal calves with low blood haemoglobin concentrations.

In a survey of 10 commercial veal units in the USA in 1990 and 1991 that provided calves with a milk replacer that contained 209 mg iron/kg on arrival at 1 week of age but with decreasing iron concentration until at 17 weeks it contained 32 mg iron/kg (to reduce the red colour of the veal at slaughter), the percentages of calves with a blood haemoglobin concentration < 4.3 mmol/L (6.9 g/dL) were 2, 0.5, 0.8, 0.8, 3 and 10 % at 1, 3, 5, 9, 13 and 17 weeks of age, respectively. The percentages of calves with a blood haemoglobin concentration 4.3–4.9 mmol/L (6.9–7.9 g/dL) were 6, 2, 4, 6, 17 and 26 % at 1, 3, 5, 9, 13 and 17 weeks of age, respectively (Stull & McDonough, 1994).

In a survey, published in 1994 (Lindt & Blum, 1994a), of calves aged 3 to 15 weeks on commercial veal units in Switzerland, when the iron concentration in (a) whole milk (14 farms) was 1.6 mg iron/kg DM, the blood haemoglobin concentration was 6.6 mmol/L (10.6 g/dL); (b) milk replacer (8 farms) was 32 mg iron/kg DM, the blood haemoglobin concentration was 6.8 mmol/L (10.9 g/dL); and (c) supplemented whole milk (7 farms) was 32 mg iron/kg DM, the blood haemoglobin concentration was 5.9 mmol/L (9.5 g/dL). Three percent of veal calves had a blood haemoglobin concentration of 3.1–3.7 mmol/L (5.0–5.9 g/dL), 5% 4.3 mmol/L (6.9 g/dL), 12% 5.0 mmol/L (8.0 g/dL), 16% 5.6 mmol/L (9.0 g/dL), 20% 6.2 mmol/L (10.0 g/dL), 17% 6.8 mmol/L (10.9 g/dL), and 27% 7.4 to 9.3 mmol/L (11.9 to 15.0 g/dL).

In a survey, published in 1994 (Wilson et al., 1994), of four commercial veal units in the USA that provided calves with a milk replacer that contained 21 to 51 mg iron/kg until week 7, when the iron content of the milk replacer was decreased to between 5 and 12 mg iron/kg but supplemented with about 8.5 mg iron/kg, the blood haemoglobin concentration was 6.9, 6.6, 5.7, and 4.8 mmol/L (11.1, 10.6, 9.2, and 7.7 g/dL) after 0, 2, 7, and 16 weeks, respectively.

In a survey, published in 1999 (Klont et al., 1999), of 14 commercial veal units in The Netherlands that reared their calves on milk replacer containing 56 mg iron/kg for 8 weeks, then 8 mg iron/kg until slaughter at 25–29 weeks, the mean blood haemoglobin concentrations of the veal calves, 2 weeks before slaughter, destined for two slaughter plants were 4.8 (standard deviation 0.7, n=760) and 6.0 (standard deviation 1.2, n=505) mmol/L, respectively (7.7 [standard deviation 1.1, n=760] and 9.7 [standard deviation 1.9, n=505] g/dL).

In a survey, published in 2000 (Wilson et al., 2000), on five commercial veal units in the USA that provided calves with a milk replacer that contained 21 to 51 mg iron/kg until week 7, when the iron content of the milk replacer was decreased to 5 to 12 mg iron/kg but supplemented with about 8.5 mg iron/kg depending on the monthly blood haemoglobin concentration, the blood haemoglobin concentration was 6.4, 5.9, 5.9, and 5.3 mmol/L (10.3, 9.5, 9.5, and 8.5 g/dL) after 0, 4, 12, and 18 weeks, respectively. The percentages of calves with a blood haemoglobin concentration ≤ 4.3mmol/L (6.9 g/dL) were 5, 2, 4, and 13% after 0, 4, 12, and 18 weeks, respectively. The percentages of calves with a blood haemoglobin concentration 4.3 to 5.5 mmol/L (6.9 to 8.9 g/dL) were 23, 34, 31, and 49% after 0, 4, 12, and 18 weeks, respectively. The PCV was 33, 30, 27, and 26% after 0, 4, 12, and 18 weeks, respectively. The percentages of calves with a PCV ≤ 20.9 were 2, 0.5, 11, and 6% after 0, 4, 12, and 18 weeks, respectively.

2.5 Solid feeds

Calves that consume solid feed are at lower risk of iron deficiency than those that do not have access to solid feed. Cereal grains contain 30 to 60 mg iron/kg DM, but most forages contain 70 to 500 mg iron/kg DM. Soil contamination of forages increases the iron content of the feed, and water can also be a source of iron (NRC, 2000). Not all of the iron in forages is readily available for absorption (NRC, 2000). The amount of iron available for absorption by the intestine depends on the amount of iron in the diet and its bioavailability (Smith, 1997). Iron is complexed with the feed, and the nature of the feed determines its bioavailability. For example, phytates, tannins, and phosphates in the diet can bind iron into insoluble complexes that cannot be absorbed (Harvey, 2008b). In most cases, iron within a diet has to be dissociated and made soluble before the iron can be absorbed (Garcia & Diaz-Castro, 2013). The haeme form of iron is absorbed readily and independently of the composition of the diet. Nonhaeme iron is largely unavailable and its absorption is affected by other ingredients in the diet (Smith, 1997).

In suckled calves with access to straw, hay, and grass silage, the calves start to develop early signs of iron deficiency anaemia while they are suckling, but when they start to consume solid feed they show signs of recovery. The following haematological variables decreased from birth to 4 weeks and then increased to week 12: at 0, 4, and 12 weeks, the blood haemoglobin concentration was 8.5, 5.2, and 6.5 mmol/L, respectively (13.7, 8.4, and 10.5 g/dL, respectively), PCV was 42, 26, and 31%, respectively, and the red blood cell count was 9, 8, and 10×10^{12}/L, respectively. The plasma iron concentration decreased from birth (15 µmol/L) to 4 weeks (6 µmol/L) and then increased to week 12 (22 µmol/L) (Egli & Blum, 1998).

As shown in Table 2.2, the provision of solid feed to calves on a milk replacer diet can increase iron intake and improve the blood haemoglobin concentration compared with calves on a milk replacer diet alone.

Table 2.2 Effects of solid feed on mean blood haemoglobin concentration and other measurements of iron metabolism

	Feed iron concentration (mg iron/kg DM)			Blood haemoglobin concentration (mmol/L) *(g/dLl)*			Other measurements			Reference
Approximate age (weeks)	1-7	8-10	11-20	1-7	8-10	11-20	1-7	8-10	11-20	
Milk replacer		20		7.4 *11.9g/dL*	5.7 *9.2 g/dL*	5.3 *8.5 g/dL*	PCV 31%	25%	26%	Moser et al. (1994)
Milk replacer Straw		20 39		7.6 *12.2 g/dL*	5.8 *9.3 g/dL*	5.0 *8.1 g/dL*	PCV 31%	25%	24%	
Milk replacer		NS								Lapierre et al. (1990)
Corn and barley concentrate	200	100				7.4 *(11.9)*			PCV 37%	
		150				7.4 *(11.9)*			PCV 37%	
		200				7.5 *(12.1)*			PCV 37%	
Milk replacer		28				5.4 *(8.7)*				Beauchemin et al. (1990)
Milk replacer Barley concentrate	28	37				6.8 *(10.9)*				
Milk replacer Corn Soybean meal	28	4 640				6.7 *(10.8)*				
Milk replacer	40-50	10				4.0 *(6.4)*			PCV 22%	Morisse et al. (1999)
Milk replacer Cereal and straw pellets	40-50	182				4.5 *(7.2)*			PCV 24%	
Milk replacer Ground barley	53	15 50		7.3 *(11.8)*		5.3 *(8.5)*			PCV 28%	Cozzi et al. (2002b)
Milk replacer Ground straw	53	15 68		8.3 *(13.4)*		5.5 *(8.9)*			PCV 29%	
Milk replacer Corn	6-8	8 20		6.2 *(10.0)*		4.9 *(7.9)*			% of calves given iron injections 32	Prevedello et al. (2012)
Milk replacer Corn and straw	6-8	8 36		6.7 *(10.8)*		5.2 *(8.4)*			22	
Milk replacer Corn, straw, and soybean	6-8	8 46		6.6 *(10.6)*		5.1 *(8.2)*			28	
Milk replacer	55-20	20		6.8 *(10.9)*		5.1 *(8.2)*				Cozzi et al. (2002a)
Milk replacer Straw	55-20	20 79		7.1 *(11.4)*		5.0 *(8.1)*				
Milk replacer Corn and straw	6-8	8 30		6.7 *(10.8)*	6.4 *(10.3)*	5.6 *(9.0)*				Brscic et al. (2014)
Milk replacer Corn, straw, and extruded pea	6-8	8 36		6.4 *(10.3)*	6.1 *(9.8)*	5.5 *(8.9)*				
Milk replacer Corn, straw, and urea	6-8	8 36		6.3 *(10.2)*	6.0 *(9.7)*	5.1 *(8.2)*				
Milk replacer and corn		33			5.8 *(9.3)*	4.7 *(7.6)*				Prevedello et al. (2009)
Milk replacer, corn, straw, and soybean		100			5.9 *(9.5)*	5.3 *(8.5)*				
Milk replacer	45-10	4				5.2 *(8.4)*			Plasma iron 16 µmol/L	Pommier et al. (1995)
Milk replacer Corn-based concentrate Corn grain, soybean, and canola concentrate	45 217	77				6.9 *(11.1)*			Plasma iron 31 µmol/L	
Milk replacer Corn-based concentrate Corn grain, soybean, and canola concentrate	45-10 217	4 77				6.8 *(10.9)*			Plasma iron 37 µmol/L	
Milk replacer	35	6				6.8 *(10.9)*				Scheeder et al. (1999)
Milk replacer Corn silage Concentrates	35 675	 275 313				8.0 *(12.9)*				

2.6 Consequences of iron deficiency

Proteins containing iron are essential for oxygen transport and storage, respiration, DNA synthesis, and many enzymatic reactions (Harvey, 2008b). The effects of iron deficiency are therefore only partly due to a compromised delivery of oxygen to the tissues caused by decreased haemoglobin concentration. In addition, as stores of iron within the body are preferentially utilised for erythropoiesis, there can be adverse effects of iron deficiency before a reduction in blood haemoglobin concentration occurs (Naigamwalla et al., 2012). In humans, negative consequences of iron deficiency have been observed in patients before the development of clinical anaemia or a reduction in the blood haemoglobin concentration (Murray-Kolb, 2013; Archer & Brugnara, 2015). Therefore, the development of anaemia should not be used as the sole determinant of the consequences of iron deficiency.

2.6.1 Enzymes

Iron is a component of many enzymes, including cytochromes, necessary for energy generation and as such is essential for many biochemical processes, including electron transfer reactions, gene regulation, binding and transport of oxygen, and regulation of cell growth and differentiation (Naigamwalla, et al., 2012; Jonker & Boele van Hensbroek, 2014). Many cellular oxidative reactions are catalysed by enzymes that contain iron or need iron as a cofactor.

In calves that received milk replacer containing either 10, 40, or 100 mg iron/kg DM for 14 weeks, the cytochrome c oxidase concentration in the heart increased with increasing iron intake (Bremner & Dalgarno, 1973b). As this enzyme requires iron and is involved in energy production, these results suggest that there was insufficient iron intake at 10 mg iron/kg DM to support normal metabolism. At 12 weeks, the blood haemoglobin concentration in the calves offered milk replacer containing either 10, 40, or 100 mg iron/kg DM was 4.0, 6.6, and 6.9 mmol/L (6.4, 10.6, and 11.1 g/dL), respectively (Bremner & Dalgarno, 1973b).

Although iron does not have a direct role in the activity of the liver enzyme aspartate transaminase, in calves about 9 days of age, offered milk replacer containing either 10 mg iron/kg DM from week 1 to week 14 or supplemented with iron sulphate at 30 mg iron/kg DM from week 1 to 6 and then 50 mg iron/kg DM from week 7 to 14, those supplemented with extra iron had greater activity of aspartate transaminase. Although the activity of aspartate transaminase can increase if the liver is damaged, the activity in iron supplemented calves was similar to other published values for normal calves and, therefore, was probably not indicative a raised activity associated with liver damage caused by iron toxicity (Bernier et al., 1984).

2.6.2 Glucose metabolism

An increased sensitivity to insulin and an increased glucose utilisation was found in calves that were offered milk replacer containing 19 compared with those offered 50 mg iron/kg. This was interpreted as a reduction in the capacity for aerobic glucose oxidation that could result in an increase in anaerobic catabolism and/or glycogen storage. At the times of the glucose tests, the blood haemoglobin concentration in the 19 and 50 mg iron/kg groups was 5.5–6.1 mmol/L (8.9–9.8 g/dL) and 6.8–7.2 mmol/L (11.0–11.6 g/dL), respectively, and the plasma iron concentration was lower in those that received 19 mg iron/kg than in those that received 50 mg iron/kg (Hostettler-Allen et al., 1993).

2.6.3 Immunity

Mortality as a direct consequence of iron deficiency anaemia is rare, but there can be increased susceptibility to infectious diseases due to reduced immunity. Iron deficiency is associated with impaired cell-mediated immunity and impaired ability of polymorphonuclear granulocytes (mainly neutrophil white blood cells) to kill ingested bacteria. Neutrophils have many iron-containing compounds (Smith, 1997). Iron is required for the bactericidal activity of macrophages (a type of white blood cell); iron is a critical component of peroxide and nitrous oxide generating cellular enzymes and also for T-cell numbers and function (white blood cell lymphocytes involved in cell-mediated immunity) (Jonker & Boele van Hensbroek, 2014). In addition, "during the acute phase of an infection a pro-inflammatory cytokine response causes a decrease in intestinal iron absorption and decreased release from body iron stores" (Jonker & Boele van Hensbroek, 2014).

In calves offered whole milk for 1 week and then milk replacer containing either 10 or 50 mg iron/kg, feed refusals and numbers of calves with a fever and requiring antibiotics were greater, and growth rate and feed conversion efficiency over a 13 week period were lower, in those offered 10 than in those offered 50 mg iron/kg. The blood haemoglobin concentration in the group offered 10 mg iron/kg fell from 6.8 to 4.0 mmol/L (11.0 to 6.4 g/dL) over this period, but in those offered 50 mg iron/kg it only varied between 6.2 and 6.8 mmol/L (10.0 and 11.0 g/dL). There was no significant effect of diet on antibody responses or lymphocyte stimulation tests undertaken on weeks 1, 5, and 10. However, cell-mediated immunity (measured as a cutaneous delayed-type hypersensitivity reaction, and, in week 10, the number of neutrophils with phagocytic capacity and the myeloperoxidase activity of neutrophils) was lower in those offered 10 than in those offered 50 mg iron/kg (Gygax et al., 1993).

Between 9 and 28 days, the antibody response to vaccination in calves offered milk replacer containing 15 mg iron/kg DM and corn-based concentrate containing 32 mg iron/kg DM was significantly lower than in calves offered milk replacer containing 85 mg iron/kg DM and corn-based concentrate containing 100 mg iron/kg DM. At 28 days, the blood haemoglobin concentration was 4.9 and 6.4 mmol/L, respectively (7.9 and 10.3 g/dL). The growth rate between 14 and 90 days was significantly lower in the calves with the lower compared with those with the higher iron intake (Sarkozy et al., 1985).

Unfortunately, iron is also an essential nutrient for many pathogens and, therefore, increased availability of iron might increase the risk of infectious disease. The risk depends on how the pathogen sequesters iron, including factors such as whether it is mainly an intracellular or extracellular pathogen and its preferred source of iron (Jonker and Boele van Hensbroek, 2014). There are some reports of adverse effects of iron supplementation on infectious disease in human neonates (Weinberg, 2009). No equivalent literature on calves was identified. However, there is evidence of the beneficial effects of iron supplementation on diarrhoea in calves. Veal calves (3 to 15 weeks of age) that received iron dextran injections (blood haemoglobin concentration 6.9 mmol/L [11.1 g/dL]) had fewer days with diarrhoea than those that did not receive iron supplementation (blood haemoglobin concentration 3.4 to 5.6 mmol/L [5.5 to 9.0 g/dL]) (Möllerberg et al., 1975a).

2.6.4 Growth

Veal calves with a blood haemoglobin concentration of about 3.0 mmol/L (4.83 g/dL) can show inappetence (Reece & Hotchkiss, 1987). Calves offered a milk replacer containing 10 mg iron/ kg DM, compared with those offered 40 or 100 mg iron/kg DM, had a lower blood haemoglobin concentration at 3 months of age, 3.85, 6.33, and 6.52 mmol/L (6.2, 10.2 and, 10.5 g/dL), respectively, showed signs of inappetence, and had a lower growth rate over this period (Webster et al., 1975).

Two-day-old calves offered milk (1 mg iron/kg DM) without iron supplementation (blood haemoglobin concentration was about 6.8 mmol/L [11.0 g/dL] at the start of the trial, 4 mmol/L [6.4 g/dL] after 8 weeks, and 2.7 mmol/L [4.35 g/dL] after 34 weeks) had a lower growth rate over a 9 month rearing period than calves that received whole milk supplemented with either 30 or 60 mg/d of iron (blood haemoglobin concentration of between 6.2 and 8.1 mmol/L [10.0 and 13.1 g/dL] throughout a 36-40 week period) (Matrone et al., 1957).

2.6.5 Behaviour

Behavioural changes can occur in humans as a result of iron deficiency, and potentially a similar response might occur in calves. In humans, there is evidence that iron deficiency with or without anaemia is linked with cognitive impairment (Jáuregui-Lobera, 2014). In humans, the changes in behaviour and cognition caused by iron deficiency are thought not to be simply due to hypoxia from iron deficiency anaemia (Murray-Kolb, 2013). In iron deficiency, aldehyde oxidase, a key enzyme in serotonin degradation, is decreased and serotonin concentration is elevated (Smith, 1997). These examples from human research suggest that iron deficiency might conceivably affect brain function in calves, and these effects might have welfare implications. For example, changes in cognitive function could affect the ability of calves to learn how to use feeding equipment (Jensen & Holm, 2003), or they might affect the emotional state of the calf (Duncan & Petherick, 1991; Désiré et al., 2002). Serotonin is involved in the regulation of many behavioural and neuropsychological processes (Berger et al., 2009).

2.6.6 Fatigue

In calves offered milk replacer containing 5 mg iron/kg DM, after week 7, the blood haemoglobin concentration was lower (week 7, 4.3 mmol/L [6.9 g/dL] and week 16, 3.8 mmol/L [6.1 g/dL]) than in those offered 105 mg iron/kg DM (week 7, 5.4 mmol/L [8.7 g/dL] and week 16, 8.8 mmol/L [14.2 g/dL]), but the low iron concentration in the diet did not appear to have caused extreme fatigue as there was no effect of diet on the duration that the calves spent lying down (McFarlane et al., 1988).

Iron deficiency anaemia can cause exercise intolerance. There is reduced synthesis of haemoglobin and reduced activity of most enzymes of the respiratory chain. This results in reduced oxygen capture in the lung and reduced oxygen delivery and utilisation by tissues. There can be an increased load on the cardiorespiratory systems and insufficient oxygen consumption and utilisation, which can lead to metabolic acidosis due to increased lactate formation and to a reduced buffering effect by the blood (Piguet et al., 1993).

In calves about 4 weeks of age, that had been offered milk for 1 week and then milk replacer containing either 8, 18, 52, or 86 mg iron/kg, then after 8 weeks, exercised (walked) on a treadmill (1 m/s, 7.5% incline for 10 minutes) when their blood haemoglobin concentrations were 4.4, 4.4, 6.5, and 7.4 mmol/L (7.1, 7.1, 10.5, and 11.9 g/dL), respectively:

- the blood lactate concentration, heart rate, fractional oxygen extraction rate were greater in calves offered 8 or 18 mg iron/kg than in those offered 52 or 86 mg iron/kg
- respiration rate was greater in those offered 8, 18, or 52 mg iron/kg than in those offered 86 mg iron/kg
- oxygen consumption was lower in those offered 8 or 18 mg iron/kg than in those offered 86 mg iron/kg and was lower in those offered 8 mg iron/kg than in those offered 52 mg iron/kg (Lindt and Blum, 1993).

In calves, 4–5 weeks of age, that had been offered milk for 1 week and then milk replacer containing either 24, 32, 40 or 52 mg iron/kg, then after 8 weeks, exercised (walked) on a treadmill (1 m/s, 10% incline for 15 minutes) when their blood haemoglobin concentrations were 4.5, 5.2, 6.0, and 6.5 mmol/L (7.3, 8.4, 9.7 and 10.5 g/dL), respectively, there was no significant effect on the blood lactate concentration (Lindt and Blum, 1994b).

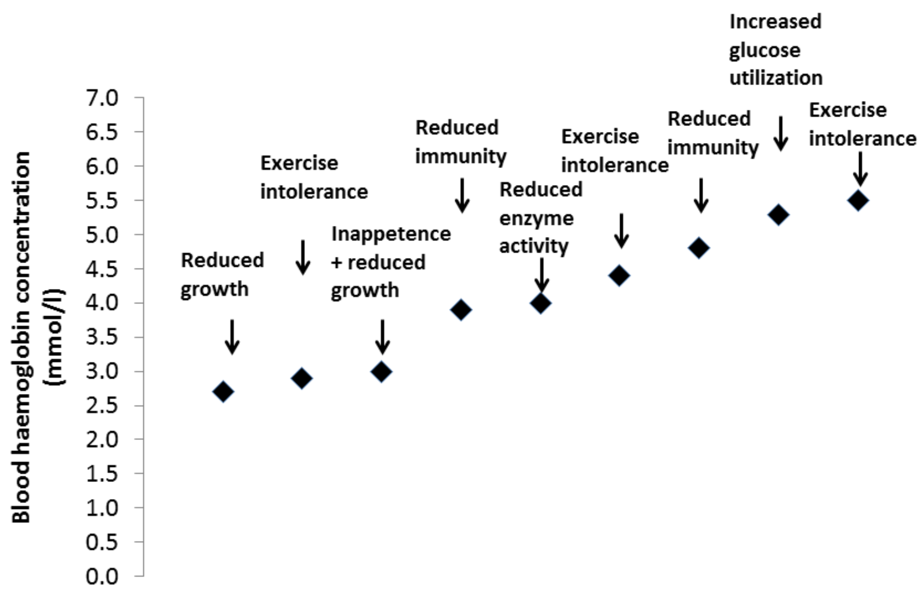
Two groups of calves with a mean blood haemoglobin concentration of 2.9 and 4.1 mmol/L (4.7 and 6.6 g/dL) that had been reared on milk replacer until 16 weeks of age and then exercised showed increased heart rate, greater decreases in venous blood partial pressure of oxygen, arterial blood partial pressure of carbon dioxide, and arterial blood pH than a group reared on milk replacer until 5 weeks of age and then hay and grain until 16 weeks of age (blood haemoglobin concentration 6.8 mmol/L [11.0 g/dL]). The increase in respiration rate was greater in the calves with a blood haemoglobin concentration of 2.9 mmol/L (4.7 g/dL) than in those with a blood haemoglobin concentration of 6.8 mmol/L [11.0 g/dL) (Reece, 1984).

In veal calves (180 kg) exercised for 0.25 h on a treadmill after 9 and 12 weeks of milk replacer containing either 21, 37, or 52 mg iron/kg, with blood haemoglobin concentrations of 5.5 (SD=0.33), 6.6 (SD=0.49), and 6.9 (SD=0.66) mmol/L (8.9 [SD=0.53], 10.6 [SD=0.79] and 11.1 [SD=1.1] g/dL), respectively, those that had received 21 mg iron/kg had a greater numerical blood lactate concentration after exercise at 0.8 to 1.3 m/s than those that had received 52 mg iron/kg, but this difference was not statistically significant. Oxygen consumption after exercise at 1.1 m/s was significantly lower in those that had received 21 mg iron/kg than in those that had received either 37 or 52 mg iron/kg. There were no significant effects of diet on the heart rate or respiratory rate responses to exercise. The blood lactate concentration, plasma cortisol concentration, and heart rate after exercise were negatively correlated with the blood haemoglobin concentration (Piguet et al., 1993).

Table 2.3 Summary of detrimental responses in calves with low blood haemoglobin concentration

Milk replacer (mg iron/kg DM)	Blood haemoglobin concentration (mmol/L) *(g/dL)*	Relative response compared with calves with a greater blood haemoglobin concentration	Reference
1	2.7 *(4.3)*	↓ growth	Matrone et al. (1957)
Not stated	2.9 *(4.7)*	↑ respiration rate after exercise	Reece (1984)
Not stated	3.0 *(4.8)*	↑ inappetence	Reece & Hotchkiss (1987)
10	3.9 *(6.3)*	↑ inappetence ↓ growth	Webster et al. (1975)
10	4.0 *(6.4)*	↓ cell-mediated immunity	Gygax et al. (1993)
10	4.0 *(6.4)*	↓ cytochrome c oxidase activity	Bremner & Dalgarno (1973b)
8–18	4.4 *(7.1)*	↑ anaerobic metabolism in response to exercise	Lindt & Blum (1993)
15	4.8 *(7.7)*	↓ antibody response	Sarkozy et al. (1985)
19	5.3 *(8.5)*	↑ glucose utilization	Hostettler-Allen et al. (1993)
21	5.5 *(8.9)*	↓ oxygen consumption after exercise	Piguet et al. (1993)

Figure 2.2 Mean blood haemoglobin concentrations that have been associated with ill health, decreased productivity, or affect essential physiological functions



See Table 2.3 for references

2.6.7 Implications for animal welfare

Although it depends on the approach taken to the assessment of animal welfare, effects of reduced iron intake reflected in reduced blood haemoglobin concentration that simply produce statistically significant changes in physiological measurements do not necessarily have major consequences for the welfare of veal calves. However, regardless of the approach taken to animal welfare assessment, some of the effects described above (Table 2.3 and Figure 2.2) can be interpreted as indicative of an effect on animal welfare. The following are indicative of reduced welfare: increased inappetence (likely associated with negative feelings), reduced immunity (has the potential to increase risk of infectious disease, which is likely to be associated with discomfort and suffering), and decreased exercise tolerance (likely associated with fatigue) (Cockram & Hughes, 2011).

2.7 Prevention of iron deficiency

2.7.1 Supplementation of milk replacer with iron

Iron sulphate is normally used to supplement milk replacer. Iron carbonate and iron phytate have lower iron availability (Bremner & Dalgarno, 1973a; McGuire et al., 1985). Bremner and Dalgarno (1973a) compared the effects of providing iron supplementation to milk replacer as either iron sulphate, iron citrate, iron EDTA, or iron phytate (to achieve 40 mg iron/kg DM) with a non-supplemented milk replacer (10 mg iron/kg DM). At 11 weeks, the blood haemoglobin concentrations and the PCV were greater in calves that had received iron as iron sulphate, iron citrate, or iron EDTA, but not in those that had received iron as iron phytate. At 11 weeks, there were no significant effects of type of iron supplementation (40 mg iron/kg DM) compared with no supplementation (10 mg iron/kg DM) on mean corpuscular volume, mean corpuscular haemoglobin concentration, or liver iron concentration (Bremner & Dalgarno, 1973a).

2.7.2 Provision of solid feed

Provision of solid feed to calves on a milk replacer diet can increase iron intake and improve the blood haemoglobin concentration compared with a milk replacer only diet (Table 2.2).

2.7.3 Intramuscular administration of iron dextran

Table 2.4 shows that the intra-muscular administration of iron as iron dextran can improve growth, and if the iron intake of the calves is low it can have marked effects on measurements of iron deficiency anaemia. However, some effects may only be short term. Getty et al. (1968) reported that in calves offered whole milk there was a large peak in the percentage of reticulocytes following iron injections at week 1 and 3, but the percentage of reticulocytes was only numerically greater than in the calves that did not receive iron supplementation during weeks 2 to 5 (Getty et al., 1968).

Wilson et al. (2000) reported the blood haemoglobin concentrations of calves in veal units in the USA after feed company service representatives had blood sampled 10 to 25% of randomly selected calves approximately once per month and used the blood haemoglobin concentration from these calves to determine whether supplemental iron was required either by injection or in the milk replacer. No threshold value for intervention was reported, but a blood haemoglobin concentration of ≤ 4.3 mmol/L (6.9 g/dL) was mentioned as indicative of anaemia. Although the mean blood haemoglobin concentration of the calves at 18 weeks of age was 5.3 mmol/L (8.5 g/dL) (standard deviation 0.83 mmol/L [1.3 g/dL], n=686), 13% of the calves had a blood haemoglobin concentration of ≤ 4.3mmol/L (6.9 g/dL). Forty-nine percent of the calves had a blood haemoglobin concentration of between 4.3 and 5.5 mmol/L (6.9 and 8.9 g/dL).

Table 2.4 Effects of an iron dextran injection on haematological and biochemical variables

Dose g iron		0	1	0	1.5	0	0.5	0	0.4	0	0.8-0.9	0	0.8	1.6
Age at administration (weeks)	week		<1		1,2 and 3		1 and 3		<1 and 2		<1, 3 and 6		1 × 3-6	1 x 3-6
Blood sampled	week	4		12		12		13		12		13		
Milk replacer iron concentration	mg iron/kg DM	110		Whole milk		Whole milk		Whole milk		19		100-52		
Solid feed		Corn, barley and soybean concentrate						Concentrates and hay						
Blood haemoglobin concentration	mmol/L g/dL	4.8 7.7	7.1 11.4	3.0 4.8	4.9 7.9	5.3 8.5	6.4 10.3	6.3 10.2	6.9 11.1	3.1 5.0	6.5 10.5	5.9 9.5	6.6 10.6	7.2 11.6
PCV	%	26	37	18	28	34	36	31	33	15	35	31	36	38
Red blood cell count	No. × 10^{12}/L	8	10	5	6			9	9			10	10	11
Serum iron concentration	µmol/L	17	21			18	35					3	5	5
TIBC	µmol/L	39	28											
Mean corpuscular volume	femtolitre or μm^3	33	38	35	49	40	42	38	37			31	34	35
Mean corpuscular haemoglobin	femtomol /cell	0.7	0.8			0.6	0.7	0.7	0.8			0.6	0.6	0.7
Mean corpuscular haemoglobin concentration	mmol/L g/dL	20 32.2	20 32.2	16 25.8	19 30.6			19 30.6	21 33.8			19 30.6	19 30.6	19 30.6
Growth			↑		↑		↑		0		↑			Non-sign. ↑
Reference		Heidarpour Bami et al. (2008)		Roy et al. (1964)		Getty et al. (1968)		Miyata et al. (1984)		Möllerberg et al. (1975a)		Geisser et al. (1991)		

2.8 Iron intake and meat colour

Myoglobin is the main pigment in red muscles, and its concentration in veal is an important factor responsible for its colour (St-Laurent & Brisson, 1967). Supplementation of milk replacer with iron can make the veal too red to be considered "white veal" (Wensing et al., 1986). Lapierre et al. (1990) reviewed several studies that were not published in English that indicated that if veal calves were reared on milk replacer with greater than 25–30 mg iron/kg DM, the veal was too dark to be considered as "white veal." In 11−14 week old calves that had been offered milk replacer containing either 10, 40, or 100 mg iron/kg DM from 2–3 weeks of age, the blood haemoglobin concentrations were 3.7, 5.4–7.0, and 7.1 mmol/L (6.0, 8.7–11.3, and 11.4 g/dL), respectively. There was no significant difference between the 10 and 40 mg iron/kg DM groups, but the muscle myoglobin concentration was greater and the veal darker in the 100 mg iron/kg DM group than in the 10 and 40 mg iron/kg DM groups (MacDougall et al., 1973). In veal calves reared on milk replacer containing 56 mg iron/kg for 8 weeks then 8 mg iron/kg until slaughter at 25–29 weeks, the mean blood haemoglobin concentration 2 weeks before slaughter ranged from 4.1 to 7.4 mmol/L (6.6 to 11.9 g/dL) and was significantly correlated with measurements of the darkness and redness of the carcasses (Klont et al., 1999).

In veal calves offered milk replacer containing either 60, 100, or 150 mg iron/kg DM for 7 weeks then 15 mg iron/kg DM until slaughter at 29 weeks, the blood haemoglobin concentration was 5.7, 6.0, and 5.9 mmol/L (9.2, 9.7, and 9.5 g/dL), respectively. There were increases in redness and iron concentration in some muscles with increasing iron concentration in the milk replacer, but there was no significant effect of diet on the darkness of the veal (Miltenburg et al., 1992a). In 2 month old calves offered milk replacer containing either 2 mg iron/kg or 50 mg iron/kg from < 1 week of age, the blood haemoglobin concentration fell from 6.5 to 4.3 mmol/L (10.5 to 6.9 g/dL) and 6.8 to 5.4 mmol/L (11.0 to 8.7 g/dL), respectively; there was no effect on the concentration of muscle myoglobin, muscle haemoglobin concentration, or the redness of the veal; but the veal in the group provided with extra iron was darker (St-Laurent & Brisson, 1967, 1968).

In calves offered a milk replacer containing 20 mg iron/kg DM, the provision of straw (39 mg iron/kg DM) had no significant effect on the muscle myoglobin concentration or the veal colour and darkness when slaughtered at 13 weeks (Moser et al., 1994). Similarly, in veal calves offered milk replacer containing 8 mg iron/kg DM and corn (20 mg iron/kg DM), the addition of straw (16 mg iron/kg DM) had no effect on the redness or the darkness of the veal (Prevedello et al., 2012).

The veal produced from milk-fed calves (blood haemoglobin concentration of 5.4 mmol/L [8.7g/dL] at slaughter) is paler than that from grain-fed calves (blood haemoglobin concentration of 6.7 mmol/L [10.8 g/dL] at slaughter) (Beauchemin et al., 1990). In veal calves offered corn and barley based diets supplemented to provide 90, 163, or 219 mg iron/kg DM, there was no effect of the diet on the blood haemoglobin concentration (7.4 to 7.5 mmol/L [11.9 to 12.1 g/dL]) or PCV (37%) at 14 weeks of age. Although, due to the high iron supplementation, the meat was considered to be too dark to be described as "white veal," the darkness of the meat did not increase with the iron content of the diet (Lapierre et al., 1990). In veal calves weaned at 8 weeks and offered corn silage and concentrates with a high iron content, the veal was darker and redder than calves maintained on a milk replacer only diet with an iron concentration of 34 mg iron/kg DM for 8 weeks followed by 6 mg iron/kg DM for weeks 9 to 25 (Scheeder et al., 1999).

2.9 References

Abdelrahim A.I., Wensing T., Franken P. & Schotman A.J. (1983) The influence of an extra supply of iron on some blood components and on meat colour at slaughter in fattening veal calves. *Journal of Veterinary Medicine Series A* 30:325–331.

Andrews A.H. (2004) Other calf problems. In: Andrews A.H., Blowey R.W., Boyd H. & Eddy G. (Eds.) *Bovine medicine: Diseases and husbandry of cattle*. Oxford: Blackwell Publishing, pp. 249–264.

Archer N.M. & Brugnara C. (2015) Diagnosis of iron-deficient states. *Critical Reviews in Clinical Laboratory Sciences* 52:256–272.

Beauchemin K.A., Lachance B. & St Laurent G. (1990) Effects of concentrate diets on performance and carcass characteristics of veal calves. *Journal of Animal Science* 68:35–44.

Berger M., Gray J. A. & Roth B. L. (2009) The expanded biology of serotonin. *Annual Review of Medicine* 60: 355–366.

Bernier J.F., Fillion F.J. & Brisson G.J. (1984) Dietary fibers and supplementary iron in a milk replacer for veal calves. *Journal of Dairy Science* 67:2369–2379.

Blaxter K.L., Sharman G.A.M. & MacDonald A.M. (1957) Iron-deficiency anaemia in calves. *British Journal of Nutrition* 11:234–246.

Bohn A.A. (2015) Diagnosis of disorders of iron metabolism in dogs and cats. *Clinics in Laboratory Medicine* 35:579–590.

Bremner I. & Dalgarno A.C. (1973a) Iron metabolism in the veal calf. The availability of different iron compounds. *British Journal of Nutrition* 29:229–243.

Bremner I. & Dalgarno A.C. (1973b) Iron metabolism in the veal calf. II. Iron requirements and the effect of copper supplementation. *British Journal of Nutrition* 30:61–76.

Brscic M., Prevedello P., Stefani A.L., Cozzi G. & Gottardo F. (2014) Effects of the provision of solid feeds enriched with protein or nonprotein nitrogen on veal calf growth, welfare, and slaughter performance. *Journal of Dairy Science* 97:4649–4657.

Camaschella C. (2015) Iron-deficiency anemia. *New England Journal of Medicine* 372:1832–1843.

Cockram M.S. & Hughes B.O. (2011) Health and disease. In: Appleby M., Hughes B., Mench J. & Olsson A. (Eds.), *Animal Welfare*. 2nd edition. CABI, Wallingford, UK, pp. 120–137.

Cozzi G., Gottardo F., Mattiello S., Canali E., Scanziani E., Verga M. & Andrighetto I. (2002a) The provision of solid feeds to veal calves: I. Growth performance, forestomach development, and carcass and meat quality. *Journal of Animal Science* 80:357–366.

Cozzi G., Gottardo F., Mutinelli F., Contiero B., Fregolent G., Segato S. & Andrighetto I. (2002b) Growth performance, behaviour, forestomach development and meat quality of veal calves provided with barley grain or ground wheat straw for welfare purpose. *Italian Journal of Animal Science* 1:113–126.

Désiré L., Boissy A. & Veissier I. (2002) Emotions in farm animals: A new approach to animal welfare in applied ethology. *Behavioural Processes* 60:165–180.

Duncan I. J. & Petherick J. C. (1991). The implications of cognitive processes for animal welfare. *Journal of Animal Science* 69:5017–5022.

Egli C.P. & Blum J.W. (1998) Clinical, haematological, metabolic and endocrine traits during the first three months of life of suckling Simmentaler calves held in a cow-calf operation. *Journal of Veterinary Medicine Series A* 45*:*99–118.

European Food Safety Authority (2012) Scientific opinion on the welfare of cattle kept for beef production and the welfare in intensive calf farming systems. *The EFSA Journal* 10:2669.

Farver T.B. (2008) Concepts of normality in clinical biochemistry. In: Kaneko J.J., Harvey J.W. & Bruss M.L. (Eds.), *Clinical biochemistry of domestic animals*. Burlington, MA, USA: Elsevier Academic Press, pp. 1–25.

Garcia Y. & Diaz-Castro J. (2013) Advantages and disadvantages of the animal models v. in vitro studies in iron metabolism: A review. *Animal* 7:1651–1658.

Geisser P., Hohl H., Baer M., Heim H. & Fischer W. (1991) Investigation on the dosage/efficacy relationship of iron dextran in veal calves. *Arzneimittel-Forschung/Drug Research* 41:32–37.

Getty S.M., Beck C.C., Brown L.D., Connor G.H., Ellis D.J. & Miller E.R. (1968) Effect of iron on hematology and growth of calves. *Journal of Animal Science* 27:712–717.

Government of Canada (2009) Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Iron. http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/water-iron-fer-eau/index-eng.php

Gygax M., Hirni H., Zwahlen R., Lazary S. & Blum J.W. (1993) Immune functions of veal calves fed low amounts of iron. *Journal of Veterinary Medicine Series A* 40*:*345–358.

Halwachs-Baumann G. (2012) Diagnosis of anaemia: Old things rearranged. *Wiener Medizinische Wochenschrift* 162*:*478–488.

Harvey J.W. (2008a) The erythrocyte: Physiology, metabolism, and biochemical disorders. In: Kaneko J.J., Harvey J.W. & Bruss M.L. (Eds.) *Clinical biochemistry of domestic animals*. Burlington, MA, USA: Elsevier Academic Press, pp. 173–240.

Harvey J.W. (2008b). Iron metabolism and its disorders. In: Kaneko J.J., Harvey J.W. & Bruss M.L. (Eds.) *Clinical biochemistry of domestic animals*. Burlington, MA, USA: Elsevier Academic Press, pp. 259–285.

Heidarpour Bami M., Mohri M., Seifi H.A. & Alavi Tabatabaee A.A. (2008) Effects of parenteral supply of iron and copper on hematology, weight gain, and health in neonatal dairy calves. *Veterinary Research Communications* 32:553–561.

Holman H.H. (1956) Changes associated with age in the blood picture of calves and heifers. *British Veterinary Journal* 112:91–104.

Holman H.H. (1955) The blood picture of the cow. *British Veterinary Journal* 111:440–457.

Hostettler-Allen R., Tappy L. & Blum J.W. (1993) Enhanced insulin-dependent glucose utilization in iron-deficient veal calves. *Journal of Nutrition* 123:1656–1667.

Jáuregui-Lobera I. (2014) Iron deficiency and cognitive functions. *Neuropsychiatric Disease and Treatment* 10:2087–2095.

Jenkins K.J. & Hidiroglou M. (1987) Effect of excess iron in milk replacer on calf performance. *Journal of Dairy Science* 70:2349–2354.

Jensen M. B. & Holm L. (2003). The effect of milk flow rate and milk allowance on feeding related behaviour in dairy calves fed by computer controlled milk feeders. *Applied Animal Behaviour Science* 82:87–100.

Jonker F.A.M. & Boele van Hensbroek M. (2014) Anaemia, iron deficiency and susceptibility to infections. *The Journal of Infection* 69:S23–S27.

Klont R.E., Barnier V.M.H., Smulders F.J.M., Van Dijk A., Hoving-Bolink A. & Eikelenboom G. (1999) Post-mortem variation in pH, temperature, and colour profiles of veal carcasses in relation to breed, blood haemoglobin content, and carcass characteristics. *Meat Science* 53:195–202.

Lapierre H., Lachance B. & Rolland J.R. (1990) Effects of dietary iron concentration on the performance and meat color of grain-fed calves. *Canadian Journal of Animal Science* 70:1053–1062.

Lindt F. & Blum J.W. (1994a) Occurrence of iron deficiency in growing cattle. *Journal of Veterinary Medicine Series A* 41:237–246.

Lindt F. & Blum J.W. (1994b) Growth performance, haematological traits, meat variables, and effects of treadmill and transport stress in veal calves supplied different amounts of iron. *Journal of Veterinary Medicine Series A* 41:333–342.

Lindt F. & Blum J.W. (1993) Physical performance of veal calves during chronic iron deficiency anaemia and after acute iron overload. *Journal of Veterinary Medicine Series A* 40:444–455.

MacDougall D.B., Bremner I. & Dalgarno A.C. (1973) Effect of dietary iron on the color and pigment concentration of veal. *Journal of the Science of Food and Agriculture* 24:1255–1263.

Matrone G., Conley C., Wise G.H. & Waugh R.K. (1957) A study of iron and copper requirements of dairy calves. *Journal of Dairy Science* 40:1437–1447.

McFarlane J.M., Morris G.L. Curtis S.E., Simon J. & McGlone J.J. (1988) Some indicators of welfare of crated veal calves on three dietary iron regimens. *Journal of Animal Science* 66:317–325.

McGuire S.O., Miller W.J., Gentry R.P., Neathery M.W., Ho S.Y. & Blackmon D.M. (1985) Influence of high dietary iron as ferrous carbonate and ferrous sulfate on iron metabolism in young calves. *Journal of Dairy Science* 68:2621–2628.

Miller J.L. (2013) Iron deficiency anemia: A common and curable disease. *Cold Spring Harbor Perspectives in Medicine* 3:1–13.

Miltenburg, G. A., Wensing, T., Smulders, F. J. & Breukink, H. J. (1992a). Relationship between blood hemoglobin, plasma and tissue iron, muscle heme pigment, and carcass color of veal. *Journal of Animal Science,* 70(9):2766–2772.

Miltenburg G.A., Wensing T., van de Broek J., Mevius, D. J. & Breukink, H. J. (1992b) Effects of different iron contents in the milk replacer on the development of iron deficiency anaemia in veal calves. *Veterinary Quarterly* 14:18–21.

Miltenburg G.A.J., Wensing T., Breukink H.J. & Marx J.J.M. (1991) A study of iron metabolism in young veal calves by means of ferrokinetics. *Journal of Animal Physiology and Animal Nutrition* 65:281–287.

Miltenburg G.A.J., Wensing T., Breukink H.J. & Marx J.J.M. (1993) Mucosal uptake, mucosal transfer and retention of iron in veal calves. *Veterinary Research Communications* 17:209–217.

Miyata Y., Furugouri K. & Shijimaya K. (1984) Developmental changes in serum ferritin concentration of dairy calves. *Journal of Dairy Science* 67:1256–1263.

Möllerberg L., Ehlers T., Jacobsson S.O., Johnsson S. & Olsson I. (1975a) The effect of parenteral iron supply on hematology, health, growth and meat classification in veal calves. *Acta Veterinaria Scandinavica* 16:197–204.

Möllerberg L., Ekman L. & Jacobsson S. (1975b) Ferro kinetic studies in normal and iron deficiency anemic calves. *Acta Veterinaria Scandinavica* 16:205–217.

Morisse J.P., Cotte J.P., Huonnic D. & Martrenchar A. (1999) Influence of dry feed supplements on different parameters of welfare in veal calves. *Animal Welfare* 8:43–52.

Moser M., Bruckmaier R.M. & Blum J.W. (1994) Iron status, erythropoiesis, meat colour, health status and growth performance of veal calves held on and fed straw. *Journal of Veterinary Medicine Series A* 41:343–358.

Murray-Kolb L.E. (2013) Iron and brain functions. *Current Opinion in Clinical Nutrition and Metabolic Care* 16:703–707.

Naigamwalla D.Z., Webb J.A. & Giger U. (2012) Iron deficiency anemia. *Canadian Veterinary Journal* 53:250–256.

National Research Council (2000) *Nutrient requirements of beef cattle*. Revised 7th Edition. Washington, D.C.: National Academy Press.

National Research Council (2001). *Nutrient requirements of dairy cattle*. Revised 7th Edition. Washington, D.C.: National Academy Press.

Peyrin-Biroulet L., Williet N. & Cacoub P. (2015) Guidelines on the diagnosis and treatment of iron deficiency across indications: A systematic review. *American Journal of Clinical Nutrition* 102:1585–1594.

Piguet M., Bruckmaier R.M. & Blum, J.W. (1993) Treadmill exercise of calves with different iron supply, husbandry, and work load. *Journal of Veterinary Medicine Series A* 40:456–465.

Pommier S.A., Lapierre H., de Passillé A.M. & Gariepy C. (1995) Control of the bioavailability of iron in heavy veal production by different feeding management systems: Use of ca-EDTA as an iron chelating agent. *Canadian Journal of Animal Science* 75:37–44.

Prevedello P., Brscic M., Schiavon E., Cozzi G. & Gottardo F. (2012) Effects of the provision of large amounts of solid feeds to veal calves on growth and slaughter performance and intravitam and postmortem welfare indicators. *Journal of Animal Science* 90:3538–3546.

Prevedello P., Moro L., Brscic M., Gottardo F. & Stefani A. (2009) Trend overtime of total haemoglobin, iron metabolism and trace minerals in veal calves fed high amounts of two different solid feeds. *Italian Journal of Animal Science* 8(S3):184–186.

Reece W.O. (1984) Response of anemic calves to exertion. *American Journal of Veterinary Research,* 45:437–439.

Reece W.O. & Hotchkiss D.K. (1987) Blood studies and performance among calves reared by different methods. *Journal of Dairy Science* 70:1601–1611.

Roy J.H.B., Gaston H.J., Shillam K.W.G., Thompson S.Y. & Stobo L.J.F. (1964) The nutrition of the veal calf. The effect of anaemia and of iron and chlortetracycline supplementation on the performance of calves given large quantities of whole milk. *British Journal of Nutrition,* 18:467–502.

Sarkozy P., Palfi V., Schultz E., Misley A. & Williams F. (1985) Immune response in anemic calves. *Journal of Veterinary Medicine Series B* 32:317-325.

Scheeder M.R.L., Becker B. & Kreuzer M. (1999) Veal colour and other meat quality characteristics in calves fattened on maize silage and concentrate. *Archiv Tierzucht Dummerstoft,* 6:535–553.

Smith J.E. (1997) Iron metabolism and its disorders. In: Kaneko J.J., Harvey J.W. & Bruss M.L. (Eds.), *Clinical biochemistry of domestic animals*. San Diego, USA: Academic Press, pp. 223–239.

St-Laurent G.J. & Brisson G.J. (1967) Changes in color and pigment content of skeletal muscles of veal calves due to age, and to iron and desferriox amine supplementation when measured by biopsy technique. *Journal of Animal Science* 26:1283–1287.

St-Laurent G.J. & Brisson G.J. (1968) Effect of dietary iron and desferrioxamine on blood hemoglobin and on pigment content and color of muscles in veal calves. *Journal of Animal Science* 27:1525–1526.

Stull C.L. & McDonough S.P. (1994) Multidisciplinary approach to evaluating welfare of veal calves in commercial facilities. *Journal of Animal Science* 72:2518–2524.

Suttle N.F. (2010) *Mineral nutrition of livestock* (4th ed.). Wallingford: CABI.

Valli V.E.O., Mc Sherry B.J., Hulland T.J., Robinson G.A. & Gilman J.P.W. (1971). The kinetics of hematopoiesis in the calf part 2 an auto radiographical study of erythropoiesis in normal anemic and endo toxin treated calves. *Research in Veterinary Science* 12:551–564.

Webster A.J.F., Donnelly H., Brockway J.M. & Smith J.S. (1975) Energy exchanges of veal calves fed a high fat milk replacer diet containing different amounts of iron. *Animal Production* 20:69–76.

Weinberg E. D. (2009). Iron availability and infection. *Biochimica Et Biophysica Acta (BBA) - General Subjects; the Impact of Host Iron Homeostasis on Disease* 1790:600–605.

Welchman D.D., Whelehan O.P. & Webster A.J. (1988) Haematology of veal calves reared in different husbandry systems and the assessment of iron deficiency. *Veterinary Record* 123:505–510.

Wensing T., Abdelrahim A.I. & Schotman A.J.H. (1986) Some aspects of extra iron supply in veal calf fattening. *Veterinary Research Communications* 10:283–296.

Wilson L.L., Egan C.L. & Drake T.R. (1994) Blood, growth and other characteristics of special-fed veal calves in private cooperator herds. *Journal of Dairy Science* 77:2477–2485.

Wilson L.L., Smith J.L., Smith D.L., Swanson D.L., Drake T.R., Wolfgang D.R. & Wheeler E.F. (2000) Characteristics of veal calves upon arrival, at 28 and 84 days, and at end of the production cycle. *Journal of Dairy Science* 83:843–854.

3. Behavioural and health benefits arising from the provision of fibre in the diet of veal cattle

Conclusions

1. **Solid feed is required for ruminal development and rumination. Depending on the level of milk replacer consumed, calves can start to consume fibrous feeds and ruminate as early as 2 weeks of age. Their intake of fibrous feed and rumination activity increases with age.**

2. **There are multiple factors, including diet, housing, and opportunities for sucking during milk replacer delivery that can affect whether or not veal calves show abnormal oral behaviour. Although there is not a simple cause and effect relationship between the lack of fibre in the diet and the occurrence of abnormal oral behaviour in milk-fed veal calves, some veal calves not offered sufficient fibre in their diet show abnormal, oral, stereotyped behaviour (mainly tongue playing and manipulation of pen substrates), and this is indicative of sub-optimal management.**

3. **When provided in sufficient amounts, the types of fibrous feeds that are effective in stimulating chewing and rumination are also those that are effective in reducing abnormal, oral, stereotyped behaviour.**

4. **Tongue playing is reduced, and chewing and rumination increased, by the provision of ad libitum hay or ad libitum straw.**

5. **Oral manipulation of pen substrates (e.g., walls, gates and feeding equipment) is reduced by the provision of ad libitum hay.**

6. **Definitive evidence on which to identify minimum daily requirements of fibre for different ages of veal calves is not readily available. Intakes of solid feed are reduced by high intakes of milk replacer. However, based on the increases in the voluntary intake of fibre with age, and studies of the effectiveness of different types of fibrous feeds on the reduction of tongue playing behaviour in various ages of calves, the following is the best estimate that can be made from the available scientific literature: the provision of (a) a hay intake of 50 g, 500 g, and ≥ 1 kg of DM/calf/d at 1, 3, and 6 months of age, respectively, or (b) a straw intake of 25 g, 300 g, and 0.5 to 1 kg of DM/calf/d at 1, 3, and 6 months of age, respectively, should provide sufficient fibre to satisfy the ad libitum intake of fibre required to reduce the occurrence of tongue playing in milk-fed veal calves.**

7. **The effectiveness of hay or straw in stimulating rumination and reducing abnormal oral behaviour increases with the length of the fibre, but straw chopped to 1 cm in length is still beneficial. Fibre provided as long forage (such as hay or straw) is more effective than non-forage feeds, such as grain, in stimulating chewing and rumination.**

8. **If provided in sufficient amounts, incorporating straw and other fibrous feeds, such as corn silage (roughage), within mixed grain-based diets so that the percentage of fibrous feed (roughage) within the mixed diet is at least 50%, is beneficial in reducing the occurrence of abnormal oral behaviour compared with mixed roughage and grain based diets that contain only 20% roughage.**

9. **Although grain is effective in the stimulation of ruminal papillae, fibrous feeds assist in the development of ruminal musculature and maintenance of ruminal mucosa by removal of excessive keratin, thus avoiding hyperkeratinisation.**

10. **Fibrous feeds that stimulate rumen motility, chewing, and saliva production can be beneficial in avoiding low rumen pH that can lead to acidosis and possibly bloat in grain-fed veal cattle.**

11. **Unfortunately, the provision of hay and straw in the diet of veal calves that consume large amounts of milk replacer can result in increased abomasal damage.**

3.1. Introduction

Traditionally, veal calves reared to produce pale coloured veal have been fed a diet that is substantially different from calves raised on pasture and from those raised for beef or milk production. Veal calves are offered a diet consisting mainly of milk replacer and/or grain to meet the nutritional requirements for growth and the end-product of pale/pink veal meat.

The purpose of this review of the scientific literature is (a) to describe the effects of providing fibre on the behaviour and health of veal calves and (b) to assemble the available evidence on the most effective ways of providing fibre in terms of the type of fibre, the amounts of fibre required, and the most appropriate age at which fibre should be supplied. The review is focussed on the effects of the provision of fibrous feeds rather than on the effects of solid feed in general.

The relationships between the provision of fibre and ruminal development in calves will be described. As a main reason proposed in the literature for the provision of fibre to milk-fed veal calves is to reduce the occurrence of abnormal oral behaviour that has been observed in veal calves that have no or little fibre in their diet, the literature on relationships between abnormal oral behaviour in veal calves and fibre provision will be discussed. Finally, the positive and negative aspects of fibre provision on calf health will be discussed. For a discussion of relationships between the types of health issues discussed and animal welfare, please see Cockram and Hughes (2011).

3.1.1 Fibre

Fibre is the part of the diet that is slowly digestible or is indigestible and occupies space in the gastrointestinal tract (Mertens, 1997). The nutritional content of a diet or dietary ingredient is most frequently expressed as the percentage chemical composition of the dry matter (DM) content (feed residue left after all moisture has been removed by drying of the diet). The most common measure of fibre within a feed analysis is Neutral Detergent Fibre (NDF). It provides a measure of most of the structural components of plant cells (i.e., lignin, hemicellulose, and cellulose); however, NDF only provides a measure of the chemical characteristics of the feed, not the physical characteristics, such as particle size or density (Mertens, 1997). Another measure of the fibre in the diet is Crude Fibre (CF). However, CF underestimates the fibre content in feed (Mertens, 2002). The term roughage is often used interchangeably with fibre or fibrous feed. It refers to a plant based ingredient (forage/herbage) with a high fibre content that is coarse and bulky (Mertens, 2002). Many non-forage fibre sources are high fibre by-products of plants processed for human food. Non-forage sources of fibre include beet pulp, soybean hulls, alfalfa meal, distillers grains, brewers grains, and corn gluten feed.

Solid feeds offered to calves vary in their fibre content and this is reflected in the percentage of DM represented as NDF or CF. In addition to the fibre content, as represented by the percentage NDF or CF, the effect of the provision of fibrous feed in the diet of cattle depends on the amount and the physical properties of the fibrous feed, e.g., the size and physical structure of the fibre. Many fibrous feeds are processed before they are used in the diet of cattle. Processing (e.g., chopping or grinding) of some forages to reduce particle size can increase intake (Leibholz & Russell, 1978). Subsequent pelleting of forages can reduce dust (National Research Council [NRC], 2000). Processing (rolling or grinding) of cereal grain can increase nutritive value by releasing starch (NRC, 2000).

3.1.2 Fibre in the diet of veal cattle

Cattle have a ruminant digestive system that has evolved to use forage and other roughages. A major function of the rumen is the anaerobic fermentation of dietary fibre (Beever, 1993). However, very young calves cannot utilise solid feed and rely on liquid feed that enters the abomasum directly via the oesophageal groove. Therefore, the diet of veal calves consists initially of milk replacer. In calves left with their dam, natural weaning, i.e., when a calf no longer sucks from its dam and consumes only solid feed, has been reported to occur between 7 and 14 months of age (Reinhardt & Reinhardt, 1981). Calves that are offered solid feed from birth do not start to consume appreciable amounts until at least 3 weeks of age (Anderson et al., 1987). In calves offered large volumes of milk replacer (e.g., 8 L/d), appreciable intakes of solid feed may not occur until about 5 weeks of age (Khan et al., 2011). Calves offered 4 L/d of milk replacer can, between 4 days and 3 weeks of age, consume 400 g of either chopped (2 cm length) or long barley straw. During subsequent weeks, the intake increases, and about 3 kg of straw can be consumed between 0 and 9 weeks of age (Thomas & Hinks, 1982). After 3 weeks of age, the increased intake of solid feed together with the presence of microflora required for the digestion of the solid feed in the rumen results in ruminal digestion and increased volatile fatty acid production (Anderson et al., 1987).

In Canada, some veal systems keep calves on milk replacer for the entire rearing period, and these calves are slaughtered at about 5 months of age, whereas grain-fed veal calves are at about 2 months of age weaned onto solid feed consisting of grain (e.g., whole corn), protein supplements, and possibly some roughage, such as hay or straw. Grain-fed veal calves are slaughtered at 6 to 7 months of age (Ngapo & Gariépy, 2006; Veal Farmers of Ontario, 2015). The optimal requirements for fibre in the diet of milk-fed and grain-fed veal cattle are not defined in the nutritional literature. Although there are advantages to offering calves fibrous feeds, from a strictly nutritional perspective, fibre is not a requirement to achieve growth. In addition, negative consequences on growth from increasing the fibre content of the diet have been emphasised (Hill et al., 2005). The energy and protein requirements of the cattle can be met from milk replacer (NRC, 2001) and/or grain. However, the addition of chopped straw, corn silage, and concentrates to the diet of milk-fed veal calves can have a beneficial effect on the ability of the calves to utilise nitrogen sources in their diet (Berends et al., 2012a).

3.2 Fibre and rumen development

3.2.1 Capacity of rumen

At birth, it is the abomasum rather than the rumen that is the largest stomach compartment (over half of the weight and capacity of the other compartments). In calves offered a milk diet, the capacity of the reticulo-rumen and the omasum increases with age. However, in calves offered hay or grain, the size of these compartments increases markedly in proportion to the size of the abomasum (Warner et al., 1956; Braun et al., 2013). A physically and functionally developed rumen is required to digest solid feed. However, the neonatal rumen remains undeveloped if calves are not offered solid feed in addition to milk replacer (Harrison et al., 1960; Tamate et al., 1962). Compared with milk-fed calves not provided with solid feed, diets with a high fibre content offered in addition to milk replacer and based on corn/maize silage, straw or hay, and concentrates, increased empty rumen weight and development (Tamate et al., 1962; Morisse et al., 1999; Berends et al., 2012b; 2014; Webb et al., 2013).

3.2.2 Rumen mucosal development

The provision of fibre in the diet is not as effective as a concentrate/grain diet in the development of ruminal papillae (Stobo et al., 1966; Bertram et al., 2009; Khan et al., 2011). Mucosal development of the rumen is associated with the end-products of the microbial digestion of the feed (Tamate et al., 1962). Solid feed intake stimulates rumen microbial proliferation and production of microbial end products, volatile fatty acids, which initiate rumen epithelial development (Pounden & Hibbs, 1949). The presence of volatile fatty acids (mainly butyrate and propionate) in the rumen stimulates the development of ruminal papillae (Sander et al., 1959; Tamate et al., 1962). Growth and development of ruminal papillae (Steele et al., 2014) are necessary to provide an absorptive surface area to enable the absorption and utilisation of volatile fatty acids produced in the rumen (Heinrichs, 2005). Ruminal papillae do not develop in calves that are only offered milk replacer (Brownlee, 1956; McGavin & Morrill, 1976). In a survey of 170 veal calf farms in the Netherlands, France, and Italy, poor development of rumen papillae was 15 times more likely to occur with provision of ≤ 50 kg of DM/calf per fattening cycle than when 151–300 kg of DM/calf per fattening cycle was provided (Brscic et al., 2011). When corn/maize silage or concentrate pellets/coarse mix were used as the main types of solid feed, the risk of poor development of rumen papillae was 4 times more likely than with the use of barley or corn/maize cereal grains (Brscic et al., 2011). The size of the particles in the diet affects ruminal development. In calves offered a milk replacer diet until about 5 weeks of age and solid feed (NDF 23%) from about 1 week of age, those offered a diet composed of fine particles had a lower rumen pH, the percentage of epithelium from the ruminal wall that was composed of keratin was greater, and the ruminal papillae in the ventral floor of the cranial rumen sac were longer than in those offered a coarser diet (Greenwood et al., 1997). Rumen mucosal development and maintenance is beneficial for optimal rumen function, nutrient uptake and efficiency, and decreases the risk of ruminal disorders.

3.2.3 Rumen muscle development

Milk-fed calves that are offered fibre, such as hay, straw, or corn silage, have a thicker ruminal muscle wall than those offered concentrates (McGavin & Morrill, 1976; Nocek et al., 1984; Suárez et al., 2007). The development of ruminal musculature facilitates rumen function, such as ruminal contractions that initiate rumination. Rumination has behavioural and health benefits (see sections 3.3.2, 3.3.4, 3.5.2, 3.5.3, 3.5.4, and 3.5.5).

3.3 Relationships between fibre and abnormal oral behaviour in veal calves

3.3.1 Abnormal oral behaviour

In this chapter oral behaviours are described as follows:

- Oral behaviour: any movements of the lips, mouth, tongue, and jaw.
- Abnormal oral behaviour: any movements of the lips, mouth, tongue, and jaw that because of their frequency, magnitude, context, or character appear strange and not directly associated with normal feeding activities (Bergeron et al., 2006).
- Stereotyped abnormal oral behaviour: any abnormal oral behaviour that is repetitive and serving no obvious function (Mason, 1991).

Veal calves given all-liquid diets cannot perform the normal behaviours of chewing solid feed and rumination because they do not have access to the substrate that permits these behaviours. The inability of veal calves without access to sufficient fibre to perform these normal behaviours is considered to be an important factor contributing to the development of abnormal oral behaviours, such as tongue playing/rolling, sham ruminating/chewing, and oral manipulation of the pen (Veissier et al., 1998; Bokkers et al., 2009). However, there is not a simple cause and effect relationship between the provision of fibre in the diet and the occurrence of abnormal oral behaviours in veal calves. Further research is required to identify the gaps in our understanding of the motivational/causal factors for the development of abnormal oral behaviours in veal calves. Tongue playing consists of extension of the tongue and swaying it sideways, turning and partly rolling and unrolling it inside and outside of the mouth (Bokkers et al., 2009; Webb et al., 2015). Sham rumination/chewing consists of relatively fast, irregular chewing movements (Bokkers et al., 2009) that are not associated with eating or regurgitation of solid feed. Oral manipulation of the pen involves persistent biting/sucking/licking/nibbling on substrates such as fences/walls, troughs, and buckets (Bokkers et al., 2009). In milk-fed veal calves without access to fibre, abnormal oral behaviours can become readily apparent at about 3 months of age (Kooijman et al., 1991).

There are multiple factors that can affect whether veal calves show abnormal oral behaviours. Housing conditions, such as number of calves per pen and space allowance (Leruste et al., 2014), and opportunities for sucking during milk replacer delivery (Webb et al., 2014a; 2015) affect the performance of abnormal oral behaviour, such as tongue playing. Evidence is discussed below that shows that fibre provides opportunities for chewing and rumination, and the performance of abnormal oral behaviour can be reduced by the addition of certain types and amounts of fibre in the diet (Kooijman et al., 1991). See *Chapter 1 – Management of milk feeding* and *Chapter 5 – Comparison of the welfare implications of rearing veal calves in stall, tether and group housing systems* for a discussion of the relationships between these risk factors and the occurrence of abnormal oral behaviour in milk-fed veal calves.

Research is required to identify the prevalence of abnormal oral behaviours in the systems of veal production used in Canada. In observations on 157 veal units in Europe, where there was variation in management between farms, including the amount and type of solid feed provided, the mean percentages of calves per farm (15 weeks of age) that were observed tongue playing was 2.8 ± 0.18% (range 0.2–14.8) and manipulating substrates was 11.0 ± 0.46% (range 2.2–38.6) (Leruste et al., 2014). As some of the calves would have been receiving fibre this would have reduced the overall prevalence of tongue playing and substrate manipulation. In addition, calves at < 4 months of age would be expected to show a lower prevalence of tongue playing than older calves (Kooijman et al., 1991).

All of the research reviewed on the relationships between fibre and abnormal oral behaviour in veal cattle was undertaken in Europe. This research was conducted on veal calves that continued to receive milk replacer during their entire fattening period. In the European Union, the provision of fibre in the diet of veal calves is a legal requirement ("a minimum daily ration of fibrous food must be provided for each calf over two weeks old, the quantity being raised from 50 g to 250 g per day for calves from eight to 20 weeks old") (Council of the European Union, 2009). A survey of 157 veal fattening units in Europe recorded that the calves received, on average, 500 g DM/calf/d of solid feed during the total fattening period, with the average daily intake ranging from 4 to 1360 g DM/calf/d. On half of the farms that participated in the study, the average daily intake of solid feed ranged between 390 and 660 g DM/calf/d (Leruste et al., 2014). The research in Europe studied the effects of providing a variety of forage and non-forage sources of fibre. These are listed and described in Table 3.1.

Table 3.1 Description of solid feeds used in the diet of veal calves to supplement milk replacer

Fibre source	***Description***
Forage	
Hay	Mainly, cut and dried grass
Straw: long, chopped, pellets, ground	Cut and dried stalks of cereal plants, after the grain and chaff (seed casings) have been removed
Corn/Maize silage: chopped or ground	Whole corn/maize plants cut and ensilaged by a natural “pickling” process that occurs when bacteria ferment sugar within the plant to produce lactic acid and the material is kept sealed from the air (In Canada, the word corn is used as a synonym for maize.)
Corn/Maize cob silage chopped, ground	Normally includes the cob and grain and sometimes part of the husk and shank of the corn/maize plant, but does not include the stalk and most of the leaf material.
Non-forage	
Dried beet pulp	By-product remaining after the extraction of sugar from sugar beet
Barley: grain, pellets, ground	Cereal grain, seed of barley plant
Corn/Maize: grain	Seed of corn plant
Concentrates	Concentrates contain a high density of nutrients, with low fibre content and high digestibility. They can contain a variety of different materials in various proportions such as grains, by-products of crop processing, products of oilseeds, and protein sources such as soybean meal and processed forages. They provide a concentrated source of energy and protein supplemented with vitamins and minerals. Concentrates can be provided as pellets, flakes, mash or meal.

3.3.2 Effect of fibre on oral behaviour in milk-fed veal calves

Veissier et al. (1998) found that the percentage of the daytime that 3-month-old veal calves spent tongue playing was 4.5% in those kept in individual stalls without solid feed, but was only 1.5% in those that were group reared and had access to chopped straw and concentrates from 1.75 months of age. Table 3.2 shows that the provision of ad libitum hay can reduce the occurrence of tongue playing and oral manipulation of substrates by veal calves and increase the times spent chewing and ruminating. Tongue playing can also be reduced and the duration spent ruminating increased by the ad libitum provision of straw. The straw is effective if provided ad libitum as pellets, or if provided at 500 g DM/calf/d in the form of chopped (4–5 cm in length) or ground (1 cm) straw. If provided in sufficient amounts, e.g., 1 kg DM/calf/d, corn/maize silage can reduce tongue playing. However, when corn/maize silage is offered at 250 or 500 g DM/calf/d, either chopped (4–5 cm) or ground (1 cm), it is not effective. Corn/maize cob silage is not effective at reducing tongue playing or oral manipulation of substrates.

The effect of fibrous feed in reducing the occurrence of abnormal oral behaviour is not simply due to the intake of sufficient solid feed. In veal calves offered ad libitum choices of a range of solid feeds (pelleted concentrates, corn/maize silage, long hay, and long barley straw) in addition to milk replacer, Webb et al. (2014a) were not able to demonstrate a significant linear relationship between the total DM intake of veal calves at 3 and 6 months of age and the occurrence of abnormal oral behaviours. In addition, there are many factors that can affect the relationship between the provision of fibre and the occurrence of abnormal oral behaviour in veal calves. In a study of 157 milk-fed veal units in Europe, single penning (during the first 1–2 months of age), group size, and space allowance were identified as significant risk factors (that explained 21% of the variance) affecting the percentage of calves performing tongue playing at about 4 months of age (Leruste et al., 2014). However, the quantity of solid feed offered was not a significant risk factor for either manipulating pen substrates or tongue playing. Although the amount of solid feed offered varied between 0.04 and 1.36 kg DM/calf/d, on half of the farms studied it only varied between 0.39 and 0.66 kg/calf/d. The authors considered that in their survey there might have been too little variation in solid feed intake to have shown an effect. The type of solid feed offered was a significant risk factor affecting the occurrence of manipulation of pen substrates. The occurrence of manipulation of pen substrates was lower on farms where the main solid feed offered was corn/maize silage than on farms where the calves were offered pelleted or flaked concentrates or cereal grain.

The experimental studies summarised in Table 3.3 show that the type of fibre provided in the diet affects the oral behaviour of veal calves. The provision of wheat straw increases the occurrence of chewing and rumination in comparison with the provision of grain. When chopped wheat straw is mixed with concentrates and either grain or corn/maize silage, to increase the time spent ruminating and to achieve a reduction in the occurrence of oral manipulation of substrates a minimal daily DM intake of this ration is required. In calves 4 and 6 months of age, Webb et al. (2015) found that the greatest reduction in the frequency of abnormal behaviour (tongue playing and oral manipulation of the pen) occurred when groups of calves had an intake of 1476-2321 g DM/d of solid feed offered at a roughage to concentrate ratio of 50:50. At a roughage to concentrate ratio of 10:90, provision of chopped hay (3–4 cm length, NDF 58.8%) to calves about 2 months old, is more effective at stimulating rumination (5.9% of observations) and reducing the occurrence of abnormal oral behaviour (19.7% of observations) than the provision of ground hay (2 mm length, NDF 50.8%) (rumination 2.8% of observations and abnormal oral behaviour 28.3% of observations) (Montoro et al., 2013).

The occurrence of tongue playing and oral manipulation of pen substrates (e.g., walls, gates, and feeding equipment) is reduced more if, on a DM basis, 50% of a combined ration of roughage and concentrates is composed of wheat straw and corn/maize silage than if only 20% of the combined ration consists of roughage. If veal calves, in addition to a mixed ration of chopped wheat straw, corn/maize silage and concentrates are provided with ad libitum long wheat straw, in a separate trough, this can reduce the occurrence of tongue playing and oral manipulation of substrates, and increase the time spent ruminating (Webb et al., 2015). Terré et al. (2013) also showed (in calves 1–2 months old), that the provision of forage (chopped oat hay, NDF 63%) in addition to a pelleted concentrate ration (wheat, corn, barley, soybean meal, and wheat middling), was more effective in reducing the occurrence of abnormal oral behaviour and increasing rumination than simply increasing the fibre content of the pelleted ration from 18 to 27% NDF. The percentage of observations during which abnormal behaviour was observed were 2.7 and 3.5% for the low and high fibre pelleted rations, respectively, but when the oat hay was provided in addition to the pellets, the percentage of observations during which abnormal behaviour was observed were reduced to 0.6 and 1.3% for the low and high fibre pelleted rations, respectively. The percentage of observations during which rumination was observed were 4.2 and 1.9% for the low and high fibre pelleted rations, respectively, but when the oat hay was provided in addition to the pellets, the percentage of observations were increased to 12.7 and 11.5% for the low and high fibre pelleted rations, respectively.

The study of milk-fed veal units in Europe conducted by Leruste et al. (2014) did not identify provision of solid feeds as a significant risk factor affecting oral manipulation of other calves amongst group reared calves. However, Mattiello et al. (2002) found that in group reared veal calves at about 4.25 months of age, provision of straw (for details see Table 3.2) can reduce the frequency of social contacts compared with those observed in calves without access to straw, but a low frequency of cross sucking was not affected by straw provision. Webb et al. (2013) found in 3-month-old veal calves that provision of fibrous feeds reduced oral manipulation of other veal calves compared with those that were only offered milk replacer. At 5.5 months of age, provision of either straw, corn/maize silage, or hay (for details see Table 3.2), reduced oral manipulation of other veal calves compared with those that were only offered milk replacer.

Table 3.2 Effects of the addition of fibre in comparison with milk replacer alone on the oral behaviour of veal calves

Age (months)	Solid feed				Effect on oral behaviour in comparison with milk replacer alone					Referer
	Type	Amount (g DM/calf/d) (unless otherwise stated)	NDF %	CF %	Tongue playing	Oral manipulation of substrate	Total abnormal oral behaviour	Chewing	Rumination	
4 to 7	Hay	Ad libitum			↓	↓				Kooijm et al. (1991)
	Straw pellets	200 g/calf/d			0	0				
		Ad libitum			↓	↓				
	Corn/maize silage	1000 g/calf/d			↓	↓				
3.43	Concentrates and straw (chopped 7.5 cm)	Concs 100-150 g/calf/d Straw 450 g/calf/d			↓			↑		Veissie al. (199
1 to 5	Ground straw and concentrate pellets (particle size 1-2 mm)	50 to 300 g/calf/d	26		0	0			0	Morisse al. (199
1 to 5	Ground barley and straw pellets	50 to 300 g/calf/d	26						0	Morisse al. (200
			43						0	
			52						↑	
			78						↑	
1.75	Wheat straw	200	86				↓	↑		Mattiel al. (200
3.25								↑		
4.25								0		
5.75								0		
1.75	Dried beet pulp	210	47				0	↑		
3.25								0		
4.25								0		
5.75								0		
3 to 6	50% concentrates, 25% fresh corn/maize silage, and 25% chopped wheat straw (DM basis)	243-403	-		0	0	0	0		Webb e (2012)
		492-774			0	0	0	0		
		743-1241			0/↓	0	↓/0	0[a]		
3	Hay	Ad libitum		29	↓	↓		↑	↑	Webb e (2013)
	Straw(chopped (4 to 5 cm) or ground (1 cm)	250		42	↓	0		↑	↑	
		500			↓	0		↑	↑	
	Corn/maize silage(chopped (4 to 5 cm) or ground (1 cm)	250		17	0	0		0	0	
		500			0	0		↑	↑	
	Corn/maize cob silage(chopped (4 to 5 cm) or ground (1 cm)	250		10	0	0		0	0	
		500			0	0		0	0	
5.5	Hay	Ad libitum		29	↓	↓		↑	↑	
	Straw (chopped (4 to 5 cm) or ground (1 cm)	250		42	↓	0		↑	↑	
		500			↓	0		↑	↑	
	Corn/maize silage (chopped (4 to 5 cm) or ground (1 cm)	250		17	0	0		0	0	
		500			0	0		0	0	
	Corn/maize cob silage (chopped (4 to 5 cm) or ground (1 cm)	250		10	0	0		0	0	
		500			0	0		0	0	

↑ significant ($P<0.05$) increase relative to milk replacer alone ↓ significant ($P<0.05$) decrease relative to milk replacer alone
0 not significantly different ($P>0.05$) from milk replacer alone
[a] Effect dependent on age and method of observation, see Webb et al. (2012) for details.

Table 3.3 Relative effects of type of fibre provision on the oral behaviour of veal calves offered milk replacer and solid feed

Age (months)	Solid feed			Effect on oral behaviour in comparison with other solid feeds					Reference
	Type	Amount (g DM/calf/d)	NDF %	Tongue playing	Oral manipulation of substrate	Total abnormal oral behaviour	Chewing	Rumination	
5.25	Ground wheat straw	196	78	↓ v barley grain	0 v barley grain		↑ v barley grain		Cozzi et al. (2002b)
	Barley grain	139	47						
1.5 to 2.5	Concentrates (20% wheat, 15% corn, 11% barley, 12% sorghum, 23% soybean meal, 12% wheat middlings, 5% soybean hulls, DM basis)	129	18						Castells et al. (2012)
	Concentrates + chopped alfalfa hay	137	40			↓ v concentrates		↑ v concentrates	
	Concentrates + chopped rye-grass hay	146	59			↓ v concentrates		↑ v concentrates	
	Concentrates + chopped oat hay	167	60			0 v concentrates		0 v concentrates	
	Concentrates + chopped barley straw	155	74			0 v concentrates		0 v concentrates	
	Concentrates + corn silage	148	42			0 v concentrates		0 v concentrates	
1.3 to 6.7	80% corn grain and 20% wheat straw (5 cm length) (as fed-basis)	864	25				↑ v corn grain	↑ v corn grain	Prevedello et al. (2012)
	72% corn grain, 20% wheat straw (5 cm length), and 8% extruded soybean	883	28				↑ v corn grain	↑ v corn grain	
	Corn grain	864	11						
1.8 to 6.2	85% corn grain and 15% 5 cm chopped straw (as fed-basis)	45 to 1330	23			0			Brscic et al. (2014)
	72% corn grain, 15% 5 cm chopped straw, and 13% extruded pea (as fed-basis)		23			0			
	83% corn grain, 16% 5 cm chopped straw, and 1% urea (as fed-basis)		23			0			
3.75 - 6	10% corn/maize silage, 10% chopped wheat straw, and 80% concentrates (36.2% corn, 20.6% lupins, 20.3% barley, 12.5% carob meal, 4.4% corn gluten meal, and 6% premix) (DM basis)	137-190	Conc 13 Corn/maize silage 42 Wheat straw 79						Webb et al. (2015)
		577-910			↓ v 137-190 g DM/calf/d				
		1077-1674			↓ v 137-190 g DM/calf/d				
		1569-2409			↓ v 137-190 g DM/calf/d			↑ v 137-190 g DM/calf/d	
	25% corn/maize silage, 25% chopped wheat straw, and 50% concentrates (DM basis)	132-181		↓ v 20% roughage: 80% concentrate ratio	↓ v 20% roughage: 80% concentrate ratio				
		562-880		↓ v 20% roughage: 80% concentrate ratio	↓ v 20% roughage: 80% concentrate ratio			↑ v 132-181g DM/calf/d	
		916-1510		↓ v 20% roughage: 80% concentrate ratio				↑ v 132-181 g DM/calf/d	
		1476-2321		↓ v 20% roughage: 80% concentrate ratio	↓ v 132 g DM/calf/d ↓ v 20% roughage: 80% concentrate ratio			↑ v 132-1510 g DM/calf/d	
	Corn/maize silage, chopped wheat straw, and concentrates provided separately, ad libitum	368-644 corn/maize silage 134-313 wheat straw 1146-2325 concentrates		↓ v 137-910 g DM/calf/d ↓ v 20% roughage: 80% concentrate ratio	↓ v 137-910 g DM/calf/d ↓ v 20% roughage: 80% concentrate ratio			↑ v 132-2321 g DM/calf/d ↓ v 20% roughage: 80% concentrate ratio	Webb et al. (2015)
3.75 - 6	10% corn/maize silage, 10% chopped wheat straw, and 80% concentrates (DM basis)	577-910							Webb et al. (2015)
	10% corn/maize silage, 10% chopped wheat straw, and 80%	577-910 roughage and concentrate		↓ v 577-910 g DM/calf/d	↓ v 577-910 g DM/calf/d			↑ v 577-910 g DM/calf/d	

	concentrates (DM basis) plus ad libitum long wheat straw	mix plus 650 g/d long wheat straw							

Table 3.4 Effect of age and fibre source on the percentage of time (% of observations) that veal calves spent tongue playing

Type of fibre[a]	Solid feed intake (g DM/calf/d)	Month of age							Reference
		1	2	3	4	5	6	7	
Hay	Intake[a]	-	-	-	-	-	1410	-	Kooijman et al. (1991)
	% of observations[1]	0	0.2	-	0.5	-	0.4	1.0	
Straw pellets	Intake[a]	-	-	-	-	-	1010	-	
	% of observations[1]	0.5	0.2	-	0.4	0	1.4	1.4	
Corn/maize silage	Intake[a]	-	-	-	-	-	-	-	
	% of observations[1]	0	0.2	-	0.5	-	1.0	1.0	
Milk replacer	Intake[a]	0	0	0	0	0	0	0	
	% of observations[1]	0.5	1.4	-	3.8	-	7.1	5.2	
Straw and concentrate pellets	Intake[a]	50	100	200	250	300			Morisse et al. (1999)
	% of observations[2]	3.5	2.8	5.2	8.3	5.2			
	Intake[a]	50	50	100	100	100			
	% of observations[2]	2.0	3.5	6.6	9.7	14.2			
Milk replacer	Intake[a]	0	0	0	0	0			
	% of observations[3]	2.0	2.0	4.8	4.6	6.4			
Ground wheat straw	Intake[b]	141		201		201			Cozzi et al. (2002b)
	% of observations[4]	3		2		5			
Barley	Intake[b]	110		140		175			
	% of observations[4]	3		5		10			
Concentrates, corn/maize silage, and chopped wheat straw	Intake[a]			243-743	286-881	347-1047	403-1241		Webb et al. (2012)
	% of observations[5]			1.1	5.6	4.8	6.0		
Hay	Intake[a]			541			1127		Webb et al. (2013)
	% of observations[6]			0.5			3.2		
Straw	Intake[a]			281			503		
	% of observations[6]			0.9			5.2		
Corn/maize silage	Intake[a]			459			503		
	% of observations[6]			3.9			8.9		
Corn/maize cob silage	Intake[a]			281			503		
	% of observations[6]			4.0			6.6		
Milk replacer	Intake[a]			0			0		
	% of observations[6]			4.8			10.2		

[a] For details on solid feed see Table 3.2 and Table 3.3
- Observations were not made
[1] Observations every 30s for 4 x 0.5-h periods/24 h
[2] Observations every 0.25 h for 4-h period starting 0.5 h after feeding
[3] Observations every 0.25 h for 4-h period starting 1 h after feeding
[4] 1 scan/2 minutes for 14 h starting 1 h before am feeding until 1 h after pm feeding
[5] Observations every 10 minutes/h for 4x1-h periods (during 1 h before and 1 h after the am and pm feeding
[6] 1 scan/2 minutes for 3x2-h periods (starting at 06.30, 11.00 and 15.30 h)

Table 3.5 Effect of age and fibre source on the percentage of time (% of observations) that veal calves spend on oral manipulation of substrates

Type of fibre[a]	Solid feed intake (g DM/calf/d)	Month of age 1	2	3	4	5	6	7	Pen type	Milk delivery system	Reference
Hay	Intake[a]	-	-	-	-	-	1410	-	Group	Bucket	Kooijman et al. (1991)
	% of observations[1]	3.4	4.3	-	6.4	-	4.2	3.8			
Straw pellets	Intake[a]	-	-	-	-	-	1010	-			
	% of observations[1]	4.3	7.3	-	11.1	-	8.5	7.7			
Corn/maize silage	Intake[a]	-	-	-	-	-	-	-			
	% of observations[1]	6.0	6.0	-	9.8	-	9.4	7.5			
Milk replacer	Intake[a]	-	-	-	-	-	-	-			
	% of observations[1]	6.8	12.8	-	19.6	-	23.9	19.6			
Straw and concentrate pellets	Intake[a]	50	100	200	250	300			Individual stalls	Bucket	Morisse et al. (1999)
	% of observations[2]	3.1	5.5	5.1	6.0	7.6					
	Intake[a]	50	50	100	100	100					
	% of observations[2]	2.0	4.8	8.1	7.2	7.2					
Milk replacer	Intake[a]	0	0	0	0	0					
	% of observations[3]	1.6	4.2	3.5	7.2	9.5					
Ground wheat straw	Intake	141		201		201			Group	Bucket with teat	Cozzi et al. (2002b)
	% of observations[4]	23		20		22					
Barley	Intake	110		140		175					
	% of observations[4]	30		20		22					
Concentrates, corn/maize silage, and chopped wheat straw	Intake[a]			243-743	286-881	347-1047	403-1241		Group	Bucket	Webb et al. (2012)
	% of observations[5]			14.2	32.3	35.2	34.8				
Hay	Intake[a]			541			1127		Group	Bucket	Webb et al. (2013)
	% of observations[6]			6.9			4.5				
Straw	Intake[a]			281			503				
	% of observations[6]			9.7			6.8				
Corn/maize silage	Intake[a]			459			503				
	% of observations[6]			9.9			7.5				
Corn/maize cob silage	Intake[a]			281			503				
	% of observations[6]			9.7			8.4				
Milk replacer	Intake[a]			0			0				
	% of observations[6]			11.7			7.0				

[a] For details see Table 3.2 and Table 3.3
- Observations were not made
[1] Observations every 30s for 4 x 0.5-h periods/24 h
[2] Observations every 0.25 h for 4-h period starting 0.5 h after feeding
[3] Observations every 0.25 h for 4-h period starting 1 h after feeding
[4] 1 scan/2 minutes for 14 h starting 1 h before am feeding until 1 h after pm feeding
[5] Observations every 10 minutes/h for 4x1-h periods (during 1 h before and 1 h after the am and pm feeding
[6] 1 scan/2 minutes for 3x2-h periods (starting at 06.30, 11.00 and 15.30 h)

Tables 3.4 and 3.5 show that the durations that veal calves spend performing abnormal oral behaviour tend to increase with age. As the calves grow and develop, the intake of fibre within the solid feed required to reduce abnormal oral behaviour also increases. Definitive scientific evidence to identify minimum daily requirements of fibre for different ages of veal calves is not readily available, and within the first 2 months of age intakes of solid feed are reduced by high intakes of milk replacer (Jasper & Weary, 2002; Webb et al., 2014a). However, based on the increases in the voluntary intake of fibre with age (shown in Table 3.4 and section 3.4.1 below) and studies of the effectiveness of different types of fibrous feeds on the reduction of tongue playing behaviour in various ages of calves (Tables 3.2, 3.3, 3.4, and 3.5), the following is the best estimate that can be made from the available literature: the provision of (a) a hay intake of 50 g, 500 g, and ≥ 1 kg of DM/calf/d at 1, 3, and 6 months of age, respectively, or (b) a straw intake of 25 g, 300 g, and 0.5 to 1 kg of DM/calf/d at 1, 3, and 6 months of age, respectively, should provide sufficient fibre to satisfy the ad libitum intake of fibre required to reduce the occurrence of tongue playing in milk-fed veal calves.

If given the choice, at 3 and 6 months of age, veal calves have a preference for milk replacer followed by concentrates, hay, and then corn/maize or straw. However, there is large individual variation in preference (Webb et al., 2014a). Therefore, depending on the type of fibre provided, young calves offered ad libitum intakes of milk replacer and/or a cereal-based concentrate might not consume sufficient fibre to show some of the behavioural and health benefits of fibre provision that were described above. The study by Webb et al (2014a) showed that in calves given ad libitum access to either milk replacer, a cereal-based pelleted concentrate, maize/corn silage, long hay, or long straw from <1 month to about 6 months of age, the DM intake of the milk replacer from about 1 month of age was maintained at a relatively constant level, but the DM intake of the concentrate pellets increased from about 1 month of age. After about 3 months of age, the DM intake of the concentrate pellets was greater than the DM intake of the milk replacer. After about 1 month of age, the DM intake of hay started to increase, but after about 3 months of age it was maintained at a relatively constant level well below that of the milk replacer or the pelleted concentrates. After about 3 months of age, the DM intake of the maize/corn silage started to increase, and by about 6 months of age was at about the same intake as for hay. The DM intake of the long straw was very low and remained significantly lower than for the other feeds. At 3 months of age, the DM intake of the milk replacer was significantly greater than the DM intake from each of the other feeds. At 6 months of age, the DM intake of the concentrate pellets was greater than that for milk replacer and each of the other feeds, but the DM intake of hay was still lower than that for milk replacer. At 6 months of age, the combined DM intake from the three fibrous feeds was similar to that from the milk replacer.

3.3.3 Effect of fibre on oral behaviour in grain-fed cattle

No specific research on the effects of fibre on oral behaviour in grain-fed veal cattle was identified. However, some relevant research has been conducted on grain-fed cattle and dairy heifers (Table 3.6). Faleiro et al. (2011) found that providing Holstein heifers (reared from 143 to 370 kg) with ad libitum barley straw in a trough alongside the provision of a concentrate diet increased rumination duration (from 14 to 20% of the time observed) and decreased abnormal oral stereotypies (from 5.2 to 2.4% of the time observed) compared with those not offered straw. Iraira et al. (2013) found that the duration that 9-month-old heifers spent tongue playing when either barley straw, soybean hulls, or whole cottonseed was added to a concentrate ration was between 2.2 and 5.5 minutes/d, whereas it was 16.8 minutes/d when beet pulp was added to the diet. There was no effect of diet on the duration that the heifers spent in oral manipulation of the pen (36–47 minutes/d). The percentage of the day that the heifers spent ruminating when either barley straw or whole cottonseed was added to the diet was 17–20%, but this was reduced to 12% if soybean hulls or beet pulp was added to the diet instead.

Table 3.6 Effect of fibre on oral behaviour of grain-fed cattle and dairy heifers

Age (months)	Solid feed				Effect on oral behaviour in comparison with other solid feeds					Reference
	Type	Amount (g DM/calf/d)	NDF %	% of particles > 1.9 cm	Tongue playing	Oral manipulation of substrate	Total abnormal oral behaviour	Chewing	Rumination	
16	Silage and concentrates	310								Redbo & Nordblad (1997)
16	Long straw, silage and concentrates	607					↓ v no straw		↑ v no straw	Redbo & Nordblad (1997)
	Barley straw (7 cm length) 31% barley, 32% corn, 16% beet pulp, 8% soybean meal, and 9% corn gluten feed (DM basis)	Ad libitum	77 20				↓ v no straw		↑ v no straw	Faleiro et al. (2011)
	31% barley, 32% corn, 16% beet pulp, 8% soybean meal, and 9% corn gluten feed (DM basis)		20							Faleiro et al. (2011)
≥ 9	10% barley straw, 34% ground corn, 34% ground barley, 11% soybean meal, 3% sunflower meal (DM basis)	740	18	8		0		↑ v soybean hulls and beet pulp	↑ v soybean hulls and beet pulp	Iraira et al. (2013)
≥ 9	17% soybean hulls, 34% ground corn, 34% ground barley, 7% soybean meal, 2% sunflower meal (DM basis)	740	16	0		0				Iraira et al. (2013)
≥ 9	17% beet pulp, 30% ground corn, 30% ground barley, 7% soybean meal, 8% sunflower meal (DM basis)	723	14	1		0				Iraira et al. (2013)
≥ 9	16% whole cottonseed, 36% ground corn, 36% ground barley, 2% soybean meal, 5% sunflower meal (DM basis)	791	15	0	↑ v other diets but p=0.07	0		↑ v soybean hulls and beet pulp	↑ v soybean hulls and beet pulp	Iraira et al. (2013)

3.3.4 Explanations for the relationships between fibre and abnormal oral behaviour

The causal relationships between fibre provision and abnormal oral behaviour in veal calves have not been fully explained. However, a number of possibilities have been proposed. Tongue-playing is classified as a stereotypy, i.e., a behaviour that can be described as repetitive and serving no obvious function (Mason, 1991). The welfare significance of a calf performing abnormal oral behaviour is a complex topic. The pathological, psychological, and physiological mechanisms underlying this form of stereotypy are not fully understood. However, there is a clear consensus that the performance of oral stereotypies is indicative of sub-optimal management.

The effect of the provision of fibrous feed on the reduction in abnormal oral behaviour does not appear to operate by reducing physiological stress. In veal calves, Veissier et al. (1998) found no evidence that the provision of solid feed had any effect on endocrine measurements used to assess stress, i.e., there were no effects on blood concentrations of ACTH (adrenocorticotropic hormone) during corticotropin-releasing factor challenges or cortisol during dexamethasone/ACTH challenges, and there were no effects on adrenal weights or activities of catecholamine-synthesising enzymes (Veissier et al., 1998). Although tongue playing in cattle can be stopped by the injection of a dopamine receptor antagonist (Sato et al., 1994), the role of dopamine in the development of stereotypies is not clear (Dantzer, 1986).

Consensus scientific opinion is that the occurrence of stereotypies is indicative of a system of management that is not appropriate or is sub-optimal for some or all of the animals. As discussed by Bergeron et al. (2006), a relationship between the occurrence of oral stereotypies and diets low in fibre is seen in several ungulate species. Although in calves, the manipulation of substrates is usually not considered an abnormal behaviour because it is also part of their normal exploratory behaviour, when this behaviour is performed in a rapid, frequent manner and for a significant amount of time, especially around meals, it appears abnormal (Leruste et al., 2014). Tongue playing and oral manipulation of pen substrates by veal calves are therefore described as abnormal because of their strange appearance, temporal characteristics, including frequency and duration, and apparent lack of obvious function (Bergeron et al., 2006). However, they partly resemble feeding activities and tend to occur at high frequency associated with feeding (Bergeron et al., 2006). A psychological explanation for abnormal oral behaviours in veal calves is that they might arise from frustration from the suppression of other oral activities, such as sucking (see *Chapter 1 – Management of milk feeding*), grasping grass, chewing, and rumination. If natural foraging is considered reinforcing, oral stereotypies could be regarded as vacuum or redirected behaviours providing at least some of the feedback normally provided by natural foraging (Bergeron et al., 2006). If they represent thwarted motivations to perform species-specific behaviour, stereotypies are likely to reflect negative feelings (Mason, 2006) and would be indicative of an animal welfare issue.

If veal calves are provided with solid feed, they spend time eating and chewing this feed, and this can probably compensate, in part, for solid feed searching that occurs between milk meals that would be undertaken if the calves were reared under more natural conditions. From about 2 weeks of age, calves at pasture spend about 2% of their day manipulating grass and by about 4 months of age they will spend about 38% of the day grazing (Nicol & Sharafeldin, 1975). Webster et al. (1985) reported that suckler calves at pasture spent 9, 18, 22, and 27 % of their time grazing at 2, 6, 10, and 14 weeks of age, respectively, and veal calves group reared on straw spent 7, 3, 4, and 4 % of their time eating straw at 2, 6, 10, and 14 weeks of age, respectively. Suckler calves at pasture were observed to spend 8, 13, 15, and 14 % of their time ruminating at 2, 6, 10, and 14 weeks of age, respectively, and veal calves group reared on straw spent 5, 9, 6, and 8 % of their time eating straw at 2, 6, 10, and 14 weeks of age, respectively. Veal calves kept in individual stalls with no access to solid feed could not spend any time ingesting solid feed and were unable to ruminate normally. They spent 7% of the time sham ruminating and 16% of the observed time in abnormal oral activity.

The similarities in how the fibre content of a diet affects tongue playing and rumination (although inversely), the age at which calves show rumination behaviour when they have access to fibrous feed and the age at which calves develop abnormal oral behaviour when they do not have access to fibrous feed, and the similarity in timing of these two behaviours throughout the day when the calves have access to fibrous feed and when they do not have access to fibrous feed, suggests that tongue playing might be a consequence of insufficient rumination (Webb et al., 2015).

Oral manipulation of the pen might be related to anticipation (arousal) of an imminent meal, or it could be undertaken to provide positive feedback and reinforcement if the time taken to consume the meal is too short and does not satisfy the feeding motivation of veal calves (Webb et al., 2015).

3.4 Fibre and rumination

3.4.1 Rumination in young calves

Rumination occurs when calves have developed a functional rumen and have consumed feed that requires reduction in particle size by further chewing of the feed following ruminal contractions, mixing of ruminal contents, and regurgitation (Welch, 1986). The performance of rumination has behavioural and health benefits (see sections 3.3.2, 3.3.4, 3.5.2, 3.5.3, 3.5.4, and 3.5.5). If provided with solid feed, e.g., concentrate pellets, hay, and straw, some calves (depending in part on milk replacer intake) can start to ruminate as early as 5–7 days of age, but, if they are consuming sufficient solid feed, many calves will start ruminating by 2 weeks of age (Swanson & Harris, 1958). However, the number of rumination bouts and the duration of rumination are lower than in calves older than 3 weeks of age. This early rumination occurs even when intake is low and only small amounts of solid feed are present in the rumen (Swanson & Harris, 1958). In 1-month-old calves, offered ad libitum hay and grass silage, the pattern of reticular contractions during rumination is similar to those seen in adult cattle (Braun et al., 2012). The time that veal calves spend chewing and eating solid feed increases with age (Veissier et al., 1998), and their intake of fibrous feeds increases with age. For example, Kooijman et al. (1991) found that the intake of hay by veal calves increased from almost zero at 1 week of age to > 2.5 kg/calf/d at about 7 months of age. Khan et al. (2011) recorded intakes of chopped hay (1.2 cm length, NDF 62%) in calves offered milk and concentrate of 33, 41, and 66 g DM/calf/d at 2, 3, and 4 weeks of age, respectively, and this increased to 342 g DM/calf/d at 2 months of age. In veal calves offered concentrates (NDF 17%) in pelleted or extruded form, corn silage (NDF 16%), or dried corn silage (NDF 42%) from about 1 to 5 months of age, rumination was observed from 2 months of age (Di Giancamillo et al., 2003).

Rumen motility is stimulated by the same factors, particle size and effective fibre, in young as in adult cattle. For example, Hodgson (1971) found that weaned calves offered chopped hay (7 cm long, CF 23%) spent more time ruminating than those offered ground and pelleted hay (< 2 cm long, CF 22–27%). Three-month-old veal calves offered milk replacer and concentrate pellets (71% cereal and cereal by-products and 25% lupins, NDF 24%) showed a preference for long (20–30 cm length) hay over chopped (2–3 cm length) hay, for chopped hay (NDF 59%) over chopped barley straw (NDF 79%), but no preference between chopped and long straw (Webb et al., 2014b). In calves offered a high fibre (NDF 27–29%) diet of 20% corn cob meal, 25% crushed oats, 16% beet pulp, 10% brewer's grains, and 18% soybean meal, as fed) compared with those offered a low fibre (NDF 17–20%) diet of 34% cracked corn, 35% crushed oats, and 21% soybean meal, as fed) there was no significant effect on the time spent ruminating, but when these diets were offered as a coarse mash, the time spent ruminating was greater than when the diets were offered in pelleted form (Porter et al., 2007).

3.4.2 Physically effective fibre and rumination

“True rumination consists of a triple contraction of the reticulum, regurgitation of a ‘bolus’ of digesta, a period of chewing and the return of the digesta to the rumen” (Balch, 1971). There has been extensive research in adult dairy cows on the effectiveness of different types of fibre to stimulate rumination.

Although this research cannot be extrapolated directly to veal cattle, there are likely to be many common underlying principles between the influence of fibre on rumination in dairy cows and those in veal cattle. However, more research on what constitutes physically effective fibre in veal calves would be beneficial. The duration that cattle spend chewing during eating and during rumination is related to the fibre content of the diet (Balch, 1971; Grant, 1997).

In adult cattle, increasing the fibre content of the diet increases rumination activity (McLeod & Smith, 1989; Beauchemin & Buchannan-Smith, 1990; Dado & Allen, 1995). For example, in heifers the duration of rumination is longer when offered long straw (CF 43%) than when offered long hay (CF 30%) (Welch & Smith, 1970).

In 3.75-month-old calves that had been offered whole milk until 2 months of age, those that received a diet of 59% concentrates (pelleted cereals and protein) and 41% chopped hay, DM basis (NDF 31%), and a separate portion of chopped hay (NDF 48%), spent more time chewing than those offered a diet of 72% concentrates and 28% chopped hay, DM basis (NDF 26%), and a separate portion of chopped hay (van Ackeren et al., 2009).

In adult cattle, “Physically effective NDF can be defined as the fraction of the feed that stimulates chewing activity and would be expressed as a product of NDF concentration and a physical effectiveness factor determined by total chewing response” (Grant, 1997).

The term physically effective NDF (peNDF) of a feed was proposed by Mertens (1997) as a way of quantifying the physical properties of its fibre (mainly particle size) that stimulates chewing in dairy cows and establishes a biphasic stratification of ruminal contents (consisting of a floating mat of large particles on a pool of liquid and small particles) (Mertens, 2002).

The peNDF of a feed is determined from the product of its NDF concentration and its physical effectiveness factor (pef). The pef varies from 0 when NDF in a feed stimulates no chewing to 1 when NDF promotes maximum chewing activity. A pef of 1 is allocated to long grass hay to provide a reference value (Mertens, 2002). As the peNDF system uses dairy cows to measure the effectiveness of the fibre source to cause chewing, the peNDF requirements for milk-fed and grain-fed veal cattle may be different from those for dairy cows.

However, the peNDF values of dietary ingredients determined for dairy cows would be expected to provide relative information on the effectiveness of different dietary ingredients to stimulate chewing in other types of cattle (Mertens, 2002). Examples of fibre sources that are physically effective in stimulating chewing in dairy cows are shown in Table 3.7.

“Fibre sources, whether of forage or non-forage origin, differ considerably in their effectiveness at stimulating chewing activity because of differences in particle size distributions and ruminal retention of fibre” (Grant, 1997). In adult cattle, the duration of rumination and chewing increased as the percentage of forage (NDF 51%) to concentrate (NDF 14%) in the diet increased from 12 to 40% (Woodford & Murphy, 1988).

The total duration of chewing during eating and rumination increases as the proportion of dietary forage NDF or particle size in the diet increases (Grant, 1997).

To effectively stimulate chewing in dairy cattle, when the percentage of dietary NDF from forage declines to between < 60 and 65%, the residual dietary forage must have sufficient particle size, as most non-forage fibre sources do not stimulate chewing as effectively as long forage (Grant, 1997).

Although grain and concentrates contain fibre, the fibre in grain is not as effective as forages in stimulating chewing and rumination. Sudweeks et al. (1975) and Sudweeks (1977) showed that the durations that steers spent chewing and ruminating were reduced as the percentage of concentrates (ground corn, citrus pulp, or soybean mill) to forage (silage or hay) in the diet increased from 10 to 70% (DM basis).

In Holstein steers, offered 100 g DM/steer/d of straw (NDF 68%), hay (NDF 52%), barley grain (NDF 21%), or oat grain (NDF 56%), the durations of rumination varied between 5.3 and 7.1 h/d and eating varied between 2.1 and 3.9 h/d. The durations spent eating per kg of NDF intake and rumination per kg of NDF intake were lower for the barley and corn diets than for straw and hay diets (Moon et al., 2002).

The small particle size of many non-forage fibre sources may decrease their retention time in the rumen (Grant, 1997; Welch, 1986). Long forage fibres create a floating mat in the rumen where fibres are entangled because they are too long to pass to the lower gut. The rumen mat stimulates reticulo-ruminal contractions, regurgitation, and subsequent chewing.

In adult cattle offered diets that included corn, hay, and straw at different compositions to achieve a NDF percentage of either 26, 32, or 38% and a particle size of 1.0, 1.5, or 2.0 cm, the duration spent eating increased with both NDF% and particle size and the duration spent ruminating increased with NDF% (Moon et al., 2004).

Particles retained on sieves with apertures > 3.2 mm pass out of the rumen slowly and require additional chewing, whereas those < 1.18 mm provide little stimulus for chewing (Mertens, 2002). In adult cattle, if the fibrous feed in diets containing relatively large percentages of concentrates (50 to 60% DM) or corn silage is fine chopped to 4 to 6 mm, rumination duration is reduced (Zebeli et al., 2012).

In young calves, offered a diet with a roughage to concentrate ratio of 10:90, grinding of hay to 2 mm in length reduces the duration spent ruminating compared with providing the forage as chopped hay 3–4 cm in length (Montoro et al., 2013).

Table 3.7 Physically effective fiber

Fibre source	***Physical form***	***NDF%***[bc]	***pef***[b]	***peNDF***[b]	***Chewing duration (minutes/kg DM)***[de]
Forage					
Hay	Long	54	1.00	54	62
	Chopped	54	0.95	51	44
	Pellets				37
Straw	Long	73	1.00	73	160
	Chopped	84	1.00	84	56
	Pellets				18
	Ground	75			18
Corn/Maize silage	Chopped	68	0.90	61	66
	Ground	60	0.80	35	
Corn/Maize cob silage	Chopped				
	Ground	87	0.40	35	
Non-forage					
Dried beet pulp		46	0.40	18	58
Barley	Rolled	18	0.70	13	11
	Pellets		0.40		
	Ground		0.40		15
Corn/Maize	Rolled		0.60		
	Ground	10	0.40	4	5
Concentrates	Pellets		0.30		12
Soybean hulls		67	0.49	27	8
Whole cottonseed		50	0.90	45	

[a]"Physically effective NDF can be defined as the fraction of the feed that stimulates chewing activity and would be expressed as a product of NDF concentration and a physical effectiveness factor determined by total chewing response" (Grant, 1997).
[b]Adapted from Mertens (1997, 2002)
[c]Adapted from National Research Council (2000)
[d]Adapted from Sudweeks et al. (1981)
[e] Adapted from Moon et al. (2002)

3.5. Fibre and health

3.5.1 Diarrhoea

The evidence for an effect of fibre, as compared to an effect of solid feed in general, on the risk of diarrhoea is not strong. Compared with a liquid diet, where the oesophageal reflex directs the milk replacer into the abomasum, the addition of fibrous feed to the diet aids the development of a functional rumen where the microorganisms within the rumen can act as a barrier for the passage of some oral pathogens into the abomasum and small intestine. Although Roy et al. (1971) were not able to show a beneficial effect on the occurrence of diarrhoea of the provision of hay or barley straw to veal calves offered ad libitum milk replacer, if calves are weaned off milk replacer onto solid feed the risk of diarrhoea is reduced (Webster, 1991).

Fibrous feeds might have some influence on faecal consistency. By 4–6 months of age, the addition from 1 month of age of 210 g DM/calf/d of dried beet pulp (NDF 47%) or 200 g DM/calf/d of wheat straw (NDF 86%) to a milk replacer diet resulted in firmer faecal consistency than in veal calves offered only milk replacer (Cozzi et al., 2002a). Webb et al. (2015) found that the prevalence of diarrhoea in calves 3.5 and 6.25 months of age decreased with increasing DM intake of solid feed, but it was not affected by the roughage to concentrate ratio of the solid feed or by the provision of ad libitum straw.

3.5.2 Acidosis

The addition of fibre to a grain diet can reduce the risk of ruminal acidosis. The effect of fibre is to decrease the rate and volume of cereal consumption, and increase rumen motility, chewing duration, and saliva production that acts as a rumen buffer (Owens et al., 1998; Zebeli et al., 2012; Gonzalez et al., 2012). Rumen acidosis is a condition that can affect the health and welfare of cattle in several ways. The severity of rumen acidosis can vary from mild to lethal and the effects can include reduced feed intake, reduced growth, pain and discomfort from rumen inflammation (rumenitis), diarrhoea, bloat, liver abscesses and/or laminititis, and systemic effects due to biochemical imbalances and lipopolysaccaccaride endotoxin release (Xu & Ding, 2011) that have the potential to make cattle feel ill.

3.5.3 Ruminal tympany/bloat

"Bloat" is a serious condition where gas accumulates in the rumen causing excessive stretching of tissues with associated pain and discomfort and can lead to death from respiratory failure. The addition of fibre to a diet containing rapidly fermentable cereal grains, such as barley or wheat, can reduce the occurrence of bloat (Cheng et al., 1998). Fibre decreases the risk of ruminal bloat by reducing the rate of fermentation in the rumen, stimulating both rumen motility and saliva production, thereby increasing ruminal pH and preventing ruminal acidosis that can suppress rumen contractions (Clarke & Reid, 1974; Cheng et al., 1998). Although in milk-fed veal calves the passage of milk replacer into the rumen, i.e., "ruminal drinking," has the potential to cause bloat (Breukink et al., 1988), the occurrence of ruminal drinking is not affected by the amount or the roughage to concentrate ratio of solid feed (Berends et al., 2015).

3.5.4 Rumen hyperkeratinisation/parakeratosis

Hyperkeratinisation or parakeratosis is a condition where the ruminal epithelial squamous cells are covered with a hardened keratin layer. In a survey of slaughtered veal calves that had been reared in the Netherlands, France, and Italy, 6% of the rumens (between farm range 0 to 47% of rumens) were classified as showing hyperkeratinisation (Brscic et al., 2011). Hyperkeratinisation occurs when the physical properties, such as the coarseness, bulkiness, and abrasiveness, of the diet are unable to remove degenerating epithelial cells, feed particles, and hair from the rumen wall (Suárez et al., 2007). The keratin layer creates a physical barrier that reduces the absorptive surface area and volatile fatty acid absorption (Hinders & Owen, 1965; Bull et al., 1965). If this results in a low rumen pH, there is potential for rumen acidosis to develop (Brscic et al., 2011). In severe cases of parakeratosis, papillae degeneration and sloughing of the rumen epithelium can occur. As described below, these changes to the ruminal mucosa can increase the risk of several ruminal disorders. Increased feed particle size, especially from high fibre feeds such as forages or coarsely-ground concentrates, maintains epithelial and papillae integrity and absorptive ability, thus avoiding low ruminal pH by the physical removal of the keratin layer (McGavin & Morrill, 1976; Beharka et al.,1998; Heinrichs & Lesmeister, 2005; Prevedello et al., 2012). In veal calves offered, from about 1 to 5 months of age, concentrates (NDF 17%) in pelleted or extruded form or corn silage (NDF 16%), but not in those offered dried corn silage (NDF 42%), there were signs of chronic catarrhal rumenitis associated with parakeratosis (Di Giancamillo et al., 2003).

In a survey of slaughtered veal calves that had been reared in the Netherlands, France, and Italy, 31% of the rumens (between farm range 0 to 100% of rumens) showed signs of plaque (rumen mucosa containing focal or multifocal patches with coalescing and adhering papillae covered by a sticky mass of feed, hair, and cell debris) (Brscic et al., 2011). The prevalence of plaque in the rumen was lower in veal calves offered milk replacer plus a solid diet of (a) 500 g DM/calf/d of 70% concentrate pellets (30% beet pulp, 16% soybean hulls, 16% corn grits, 16% broken corn, and 16% crushed barley) (NDF 29%) and either 30% chopped barley straw (NDF 81%) or 30% chopped dried grass (NDF 43%), (b) 810 g DM/calf/d of 70% concentrate pellets plus 15% chopped barley straw and 15% chopped dried grass, or (c) 780 g DM/calf/d of 70% concentrate pellets plus corn silage (NDF 34%) than in those just offered the milk replacer plus about 500 g DM/calf/d of solid feed consisting of (a) concentrate pellets or (b) 70% concentrate pellets and 30% corn silage (Suárez et al., 2007). At 7 months of age, veal calves offered milk replacer plus a solid diet of 864 g DM/calf/d of corn grain (NDF 11%) had an increased prevalence of ruminal parakeratosis and ruminal plaques compared with those offered a solid diet of either 864 g DM/calf/d, 80% corn grain, and 20% wheat straw (5 cm length) (as fed-basis) (NDF 25%) or 883 g DM/calf/d 72% corn grain, 20% wheat straw (5 cm length), and 8% extruded soybean (NDF 28%) (Prevedello et al., 2012).

In a survey of 170 veal calf farms in the Netherlands, France, and Italy, the risk of a calf developing parakeratosis or ruminal plaques was decreased if the solid feed intake was > 151 kg DM/calf during the fattening period compared to when it was ≤ 50 kg DM/calf during the fattening period. If the prevalent type of solid feed consisted of barley or corn/maize cereal grains, the risk of a calf developing parakeratosis or ruminal plaques was more likely than when the prevalent type of solid feed consisted of rolled or flaked corn/maize. If the prevalent type of solid feed consisted of corn/maize silage, the risk of a calf developing parakeratosis or ruminal plaques was decreased compared with farms where the prevalent type of solid feed consisted of barley or corn/maize cereal grains (Brscic et al., 2011).

3.5.5 Hairballs/trichobezoars in the reticulo-rumen

In most cases the presence of one or more hairballs in the rumen will not cause any difficulty. In a small number of cases they can cause obstruction of the gastrointestinal tract resulting in severe welfare issues. Hairballs have the potential to cause obstruction of the oesophageal inlet into the rumen resulting in bloat (Herd & Cook, 1989; Schweizer et al., 2005) and obstruction of the small intestine resulting in pain, anorexia, and dehydration (Abutarbusch & Radostitis, 2004). Hairballs are more likely to occur in calves that only receive milk replacer than in calves that are offered fibrous feed in their diet in addition to milk replacer (Morrise et al., 1999; Cozzi et al., 2002a; Webb et al., 2013).

Offering veal calves pellets of ground straw and cereals (particle size ≤ 1–2 mm, NDF 26%) in addition to milk replacer at a rate of 50 g/calf/d from about 1 month of age and then at a rate of either 100 or 200–300 g/calf/d from 3 to 5 months of age resulted in fewer calves with hairballs in the reticulo-rumen (Morrise et al., 1999). At 6 months of age, the addition from 1 month of age of 210 g DM/calf/d of dried beet pulp (NDF 47%) or 200 g DM/calf/d of wheat straw (NDF 86%) to a milk replacer diet resulted in fewer calves with hairballs in the rumen than in those offered only milk replacer (Cozzi et al., 2002a).

At 7 months of age, the prevalence of hairballs in veal calves offered milk replacer and from 1 month of age, solid feed, consisting of ad libitum hay (CF 29%) was 0%. If the solid feed had been provided at either 250 or 500 g DM/calf/d and either in chopped (4 to 5 cm in length) or ground (1 cm in length) form, the prevalence in those offered straw (CF 42%) was 0%, in those offered corn/maize silage (CF 17%) it was 14% and in those offered corn/maize cob silage (CF 10%) it was 30%. The prevalence of hairballs in the rumen (85%) was significantly greater in those calves not offered solid feed compared with those offered solid feed from 1 month of age (Webb et al., 2013).

Cozzi et al. (2002a) considered that in addition to removal of excess keratin, fibrous feed increase ruminal motility and this facilitates the removal of food particles and hairs that can accumulate among matted papillae of the hyperkeratotic mucosa and penetrate the lamina propria. Damage to the rumen mucosa caused by food particles and hair can cause rumenitis, and this could increase the presence of bacteria in the mucosa that have the potential to spread via the blood to the liver resulting in abscesses (Jensen et al., 1954; Nagaraja & Chengappa, 1998; Tadepalli et al., 2009).

Liver abscesses are potentially painful if the abscesses are large and cause distention within the liver or the abdominal cavity (Heneghan et al., 2011), are a potential source of bacterial infection to other parts of the body and release pyrogenic and endotoxic chemicals (Warner et al., 1975; Nagaraja et al., 2005) that have the potential to make cattle feel ill. Although many cattle with liver abscesses do not show any overt clinical signs and growth may or may not be affected (Nagaraja & Lechtenberg, 2007), those with severe liver abscesses can show decreased feed intake and reduced growth (Brink et al., 1990).

3.5.6 Abomasal damage

The abomasal damage that is thought to arise from overfilling of the abomasum with large milk meals causing local ischaemia (loss of blood supply) to the abomasal wall can be increased by the presence of coarse fibrous feed in the abomasum (see *Chapter 4 – Risk factors for abomasal damage*). Table 3.8 shows that hay, straw, dried beet pulp, corn silage, and corn cob silage can cause abomasal damage. For example, the prevalence of abomasal ulcers can be increased from 9% in veal calves offered only milk replacer to 24% in those offered wheat straw (Mattielo et al., 2002). Even if the straw is provided chopped or ground, the prevalence of abomasal ulcers can be substantially greater (73%) than in calves offered milk replacer only (25%) (Webb et al., 2013).

Table 3.8 Effects of type of fibre provision on the risk of abomasal damage in veal calves

Age (months)	Solid feed			Type of abomasal damage						Overall abomasal damage		Reference
	Type	Amount (g DM/calf/d)	NDF %	Ulcer		Erosion		Scar				
				Prevalence	Size	Prevalence	Size	Prevalence	Size	Prevalence	Severity	
1 to 5	Ground straw and concentrate pellets (particle size 1-2 mm)	50 to 300 g/calf/d	26			0 with DM intake						Morisse et (1999)
5.25	Ground wheat straw	196	78	0 v barley grain		0 v barley grain		0 v barley grain		↓ v barley grain		Cozzi et al. (2002b)
	Barley grain	139	47									
5.75	Wheat straw	200	86	↑ v milk replacer only		↑ v milk replacer only						Mattiello et al. (2002)
	Dried beet pulp	210	47	↑ v milk replacer only		0 v milk replacer only						
7	80% corn grain and 20% wheat straw (5 cm length) (as fed-basis)	864	25							0 v corn grain	0 v corn grain	Prevedello al. (2012)
	72% corn grain, 20% wheat straw (5 cm length), and 8% extruded soybean	883	28							0 v corn grain	0 v corn grain	
	Corn grain	864	11									
	25% straw +		76									
	50% concentrate (DM basis)		25									
6	Hay	Ad libitum		0 v milk replacer only	0 v milk replacer only	0 v milk replacer only	0 v milk replacer only	↑ v milk replacer only	↑ v milk replacer only			Webb et al. (2013)
	Straw (chopped (4 to 5 cm) or ground (1 cm)	250 and 500		↑ v milk replacer only	0 v milk replacer only	↑ v milk replacer only	↑ v milk replacer only	↑ v milk replacer only	↑ v milk replacer only			
	Corn/maize silage (chopped (4 to 5 cm) or ground (1 cm)	250 and 500		↑ v milk replacer only	0 v milk replacer only	↑ v milk replacer only	0 v milk replacer only	0 v milk replacer only	↑ v milk replacer only			
	Corn/maize cob silage (chopped (4 to 5 cm) or ground (1 cm)	250 and 500		↑ v milk replacer only	0 v milk replacer only	0 v milk replacer only	0 v milk replacer only	0 v milk replacer only	0 v milk replacer only			
7	10% corn silage +	20 to 248	42								↑ with DM intake	Berends e al. (2014)
	10% chopped wheat straw +		80									
	80% concentrates (DM basis)		13									
	25% corn silage +		42								0 with DM intake	
	25% chopped wheat straw +		80									
	50% concentrates (DM basis)		13									
7	85% corn grain and 15% 5 cm chopped straw (as fed-basis)	45 to 1330	23							0	0	Brscic et a (2014)
	72% corn grain, 15% 5 cm chopped straw and 13% extruded pea (as fed-basis)		23							0	0	
	83% corn grain, 16% 5 cm chopped straw and 1% urea (as fed-basis)		23							0	0	

Ulcer: characterized by focal loss or necrosis of the epithelial layer down to the submucosal or muscular layer of the stomach wall.
Erosion: characterized as inflammation with partial superficial or profound loss of epithelium without clear disruption of the epithelial layer.
Scar: characterized as focal, longitudinal, or round fibrous contractions of the mucosa. (Webb et al., 2013)

3.6 References

Abutarbush S.M. & Radostits O.M. (2004) Obstruction of the small intestine caused by a hairball in 2 young beef calves. *The Canadian Veterinary Journal* 45:324–325.

Anderson K.L., Nagaraja T.G., Morrill J.L., Avery T.B., Galitzer S.J. & Boyer J.E. (1987) Ruminal microbial development in conventionally or early-weaned calves. *Journal of Animal Science* 64:1215–1226.

Balch C.C. (1971) Proposal to use time spent chewing as an index of the extent to which diets for ruminants possess the physical property of fibrousness characteristic of roughages. *British Journal of Nutrition* 26:383–392.

Beauchemin K.A. & Buchanan-Smith J.G. (1990) Effects of fiber source and method of feeding on chewing activities, digestive function, and productivity of dairy cows. *Journal of Dairy Science* 73:749–62.

Beever D.E. (1993) Rumen function. In: Forbes J.M. & France J. (Eds.) *Quantitative aspects of ruminant digestion and metabolism*. Wallingford, UK, CABI, pp. 187–215.

Beharka A.A., Nagaraja T.G., Morrill J.L., Kennedy G.A. & Klemm R.D. (1998) Effects of form of the diet on anatomical, microbial, and fermentative development of the rumen of neonatal calves. *Journal of Dairy Science* 81:1946–1955.

Berends H., van den Borne J.J.G.C., Mollenhorst H., van Reenen C.G., Bokkers E.A.M. & Gerrits W.J.J. (2014) Utilization of roughages and concentrates relative to that of milk replacer increases strongly with age in veal calves. *Journal of Dairy Science* 97:6475–6484.

Berends H., van den Borne J.J.G.C., Stockhofe-Zurwieden N., Gilbert M.S., Zandstra T., Pellikaan W.F., van Reenen C.G., Bokkers E.A. & Gerrits W.J. (2015) Effects of solid feed level and roughage-to-concentrate ratio on ruminal drinking and passage kinetics of milk replacer, concentrates, and roughage in veal calves. *Journal of Dairy Science* 98:5621–5629.

Berends H., van den Borne J.J.G.C., Alferink S. J. J., van Reenen C. G., Bokkers E. A. M. & Gerrits W. J. J. (2012a). Low-protein solid feed improves the utilization of milk replacer for protein gain in veal calves. *Journal of Dairy Science* 95:6654–6664.

Berends H., van Reenen C.G., Stockhofe-Zurwieden N. & Gerrits W.J.J. (2012b) Effects of early rumen development and solid feed composition on growth performance and abomasal health in veal calves. *Journal of Dairy Science* 95:3190–3199.

Bergeron R., Badnell-Waters A.J., Lambton S. & Mason G. (2006) Stereotypic oral behaviour in captive ungulates: Foraging, diet and gastrointestinal function. In: Mason G. & Rushen J. (Eds.), *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare.* Wallingford, UK, CABI, pp. 19–57.

Bertram H.C., Kristensen N.B., Vestergaard M., Jensen S.K., Sehested J., Nielsen N.C. & Malmendal A. (2009) Metabolic characterization of rumen epithelial tissue from dairy calves fed different starter diets using H-1 NMR spectroscopy. *Livestock Science* 120:127–134.

Bokkers E.A.M., Leruste H., Heutinck L.F.M., Wolthuis-Fillerup M., van der Werf J.T.N., Lensink B.J. & van Reenen C.G. (2009) Inter-observer and test-retest reliability of on-farm behavioural observations in veal calves. *Animal Welfare* 18:381–390.

Braun U., Gautschi A., Tschuor A. & Haessig M. (2012) Ultrasonography of the reticulum, rumen, omasum and abomasum before, during and after ingestion of hay and grass silage in 10 calves. *Research in Veterinary Science* 93:1407–1412.

Braun U., Krueger S. & Haessig M. (2013) Ultrasonographic examination of the reticulum, rumen, omasum and abomasum during the first 100 days of life in calves. *Research in Veterinary Science* 95:326–333.

Breukink H.J., Wensing T., van Weeren-Keverling Buisman A., van Bruinessen-Kapsenberg E. G. & de Visser N.A. (1988) Consequences of failure of the reticular groove reflex in veal calves fed milk replacer. *Veterinary Quarterly* 10:126–135.

Brink D.R., Lowry S.R., Stock R.A. & Parrott J.C. (1990) Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. *Journal of Animal Science* 68:1201–1207.

Brownlee A. (1956) The development of rumen papillae in cattle fed on different diets. *British Veterinary Journal* 112:369–375.

Brscic M., Heutinck L.F.M., Wolthuis-Fillerup M., Stockhofe N., Engel B., Visser E.K., Gottardo F., Bokkers E.A., Lensink B.J., Cozzi G. & van Reenen C.G. (2011) Prevalence of gastrointestinal disorders recorded at postmortem inspection in white veal calves and associated risk factors. *Journal of Dairy Science* 94:853–863.

Brscic M., Prevedello P., Stefani A.L., Cozzi G. & Gottardo F. (2014) Effects of the provision of solid feeds enriched with protein or nonprotein nitrogen on veal calf growth, welfare, and slaughter performance. *Journal of Dairy Science* 97:4649–4657.

Bull L.S., Bush L.J., Friend J.D., Harris Jr. B. & Jones E.W. (1965) Incidence of ruminal parakeratosis in calves fed different rations and its relation to volatile fatty acid absorption. *Journal of Dairy Science* 48:1459–1466.

Castells L., Bach A., Araujo G., Montoro C. & Terré M. (2012) Effect of different forage sources on performance and feeding behavior of holstein calves. *Journal of Dairy Science* 95:286–293.

Cheng K.J., McAllister T.A., Popp J.D., Hristov A.N., Mir Z. & Shin H.T. (1998) A review of bloat in feedlot cattle. *Journal of Animal Science* 76:299–308.

Clarke R.T.J. & Reid C.S.W. (1974) Foamy bloat of cattle. A review. *Journal of Dairy Science* 57:753–785.

Cockram M.S. & Hughes B.O. (2011) Health and disease. In: Appleby M., Hughes B., Mench J. & Olsson A. (Eds.), *Animal Welfare*. 2nd edition. Wallingford, UK, CABI, pp. 120–137.

Council of the European Union (2009) COUNCIL DIRECTIVE 2008/119/EC of 18 december 2008 laying down minimum standards for the protection of calves. *Official Journal of the European Union,* L 10, 15.1.2009:7–13.

Cozzi G., Gottardo F., Mattiello S., Canali E., Scanziani E., Verga M. & Andrighetto I. (2002a) The provision of solid feeds to veal calves: I. growth performance, forestomach development, and carcass and meat quality. *Journal of Animal Science* 80:357–366.

Cozzi G., Gottardo F., Mutinelli F., Contiero B., Fregolent G., Segato S. & Andrighetto I. (2002b) Growth performance, behaviour, forestomach development and meat quality of veal calves provided with barley grain or ground wheat straw for welfare purpose. *Italian Journal of Animal Science* 1:113–126.

Dado R.G. & Allen M.S. (1995) Intake limitations, feeding behavior, and rumen function of cows challenged with rumen fill from dietary fiber or inert bulk. *Journal of Dairy Science* 78:118–133.

Dantzer R. (1986) Behavioral, physiological and functional aspects of stereotyped behavior: A review and a re-interpretation. *Journal of Animal Science* 62:1776–1786.

Di Giancamillo A., Bosi G., Arrighi S., Savoini G. & Domeneghini C. (2003) The influence of different fibrous supplements in the diet on ruminal histology and histometry in veal calves. *Histology and Histopathology* 18:727–733.

Faleiro A.G., Gonzalez L.A., Blanch M., Cavini S., Castells L., Ruiz de la Torre J.L., Manteca X., Calsamiglia S. & Ferreta A. (2011) Performance, ruminal changes, behaviour and welfare of growing heifers fed a concentrate diet with or without barley straw. *Animal* 5:294–303.

Gonzalez L.A., Manteca X., Calsamiglia S., Schwartzkopf-Genswein K.S. & Ferret A. (2012) Ruminal acidosis in feedlot cattle: Interplay between feed ingredients, rumen function and feeding behavior (a review). *Animal Feed Science and Technology* 172:66–79.

Grant R.J. (1997) Interactions among forages and nonforage fiber sources. *Journal of Dairy Science* 80:1438–1446.

Greenwood R.H., Morrill J.L., Titgemeyer E.C. & Kennedy G.A. (1997) A new method of measuring diet abrasion and its effect on the development of the forestomach. *Journal of Dairy Science* 80:2534–2541.

Harrison H.N., Warner R.G. & Sander E.G. (1960) Changes in the tissue and volume of the stomachs of calves following the removal of dry feed or consumption of inert bulk. *Journal of Dairy Science* 43:1301–1312.

Heinrichs J. (2005) Rumen development in the dairy calf. *Advances in Dairy Technology* 17:179–187.

Heinrichs A.J. & Lesmeister K.E. (2005) Rumen development in the dairy calf. In: Garnsworth P.C. (Ed.), *Calf and heifer rearing*. Nottingham, UK, Nottingham University Press, pp. 53–65.

Heneghan H., Healy N., Martin S., Ryan R., Nolan N., Traynor O. & Waldron R. (2011) Modern management of pyogenic hepatic abscess: A case series and review of the literature. *BMC Research Notes* 4:80.

Herd R. & Cook L. (1989) Hairballs in feedlot-raised calves. *Australian Veterinary Journal* 66:372–373.

Hill S.R., Hopkins B.A., Davidson S., Bolt S.M., Diaz D.E., Brownie C., Brown T., Huntington G.B. & Whitlow L.W. (2005) Technical note: Technique for dissection and analysis of the rumen in young calves. *Journal of Dairy Science* 88:324–326.

Hinders R.G. & Owen F.G. (1965) Relation of ruminal parakeratosis development to volatile fatty acid absorption. *Journal of Dairy Science* 48:1069–1073.

Hodgson J. (1971) The development of solid food intake in calves. 1. The effect of previous experience of solid food, and the physical form of the diet, on the development of food intake after weaning. *Animal Production* 13:15–24.

Iraira S.P., Ruíz de la Torre J.L., Rodríguez-Prado M., Calsamiglia S., Manteca X. & Ferret A. (2013) Feed intake, ruminal fermentation, and animal behavior of beef heifers fed forage free diets containing nonforage fiber sources. *Journal of Animal Science* 91:3827–3835.

Jasper J. & Weary D. M. Effects of ad libitum milk intake on dairy calves. *Journal of Dairy Science* 85:3054–3058.

Jensen R., Deane H.M., Cooper L.J., Miller V.A. & Graham W.R. (1954) The rumenitis-liver abscess complex in beef cattle. *American Journal of Veterinary Research* 15:202–216.

Khan M.A., Weary D.M. & von Keyserlingk M.A.G. (2011) Hay intake improves performance and rumen development of calves fed higher quantities of milk. *Journal of Dairy Science* 94:3547–3553.

Kooijman J., Wierenga H.K. & Wiepkema P.R. (1991) Development of abnormal oral behavior in group-housed veal calves effects of roughage supply. In: Metz J.H.M. & Groenestein C.M. (Eds.) *New Trends in Veal Calf Production*. Wageningen, The Netherlands, Pudoc, pp. 54–58.

Leibholz J. & Russell C.L. (1978) Chaffed or ground straw and lucerne in the diet of the early weaned calf. *Animal Production* 27:171–180.

Leruste H., Brscic M., Cozzi G., Kemp B., Wolthuis-Fillerup M., Lensink B.J., Bokkers E.A.M. & van Reenen C.G. (2014) Prevalence and potential influencing factors of non-nutritive oral behaviors of veal calves on commercial farms. *Journal of Dairy Science* 97:7021–7030.

Mason G.J. (1991) Stereotypies a critical review. *Animal Behaviour* 41:1015–1038.

Mason G.J. (2006) Stereotypic behavior in captive animals: fundamentals and implications for welfare and beyond. In: Mason G.J. & Rushen J. (Eds.) *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*. Wallingford, UK, CABI, pp. 325–356.

Mattiello S., Canali E., Ferrante V., Caniatti M., Gottardo F., Cozzi G., Andrighetto I. & Verga M. (2002) The provision of solid feeds to veal calves: II. Behavior, physiology, and abomasal damage. *Journal of Animal Science* 80:367–375.

McGavin M.D. & Morrill J.L. (1976) Scanning electron microscopy of ruminal papillae in calves fed various amounts and forms of roughage. *American Journal of Veterinary Research* 37:497–508.

McLeod M.N. & Smith B.R. (1989) Eating and ruminating behavior in cattle given forages differing in fiber content. *Animal Production* 48:503–512.

Mertens D.R. (1997) Creating a system for meeting the fiber requirements of dairy cows. *Journal of Dairy Science* 80:1463–1481.

Mertens D.R. (2002) Measuring fiber and its effectiveness in ruminant diets. In: *Proceedings of the Plains Nutritional Council*. Texas A&M Publication AREC 02-20, pp. 40–66.

Montoro C., Miller-Cushon E., De Vries T.J. & Bach A. (2013) Effect of physical form of forage on performance, feeding behavior, and digestibility of holstein calves. *Journal of Dairy Science* 96:1117–1124.

Moon Y.H., Lee S.C. & Lee S.S. (2002) Chewing activities of selected roughages and concentrates by dairy steers. *Asian-Australasian Journal of Animal Sciences* 15:968–973.

Moon Y.H., Lee S.C. & Lee S.S. (2004) Effects of neutral detergent fiber concentration and particle size of the diet on chewing activities of dairy cows. *Asian-Australasian Journal of Animal Sciences* 17:1535–1540.

Morisse J.P., Cotte J.P., Huonnic D. & Martrenchar A. (1999) Influence of dry feed supplements on different parameters of welfare in veal calves. *Animal Welfare* 8:43–52.

Morisse J.P., Huonnic D., Cotte J.P. & Martrenchar A. (2000) The effect of four fibrous feed supplementations on different welfare traits in veal calves. *Animal Feed Science and Technology* 84:129–136.

Nagaraja T.G. & Chengappa M.M. (1998) Liver abscesses in feedlot cattle: A review. *Journal of Animal Science* 76:287–298.

Nagaraja T.G. & Lechtenberg K.F. (2007) Liver abscesses in feedlot cattle. *Veterinary Clinics of North America: Food Animal Practice; Topics in Nutritional Management of Feedlot Cattle* 23:351–369.

Nagaraja T.G., Narayanan S.K., Stewart G.C. & Chengappa M.M. (2005) Fusobacterium necrophorum infections in animals: Pathogenesis and pathogenic mechanisms. *Anaerobe* 11:239–`246.

National Research Council (2000) *Nutrient requirements of beef cattle.* 7th revised edition, 2000 update. Washington, D.C., National Academy Press.

National Research Council (2001) *Nutrient requirements of dairy cattle.* 7th revised edition. Washington, D.C., National Academy Press.

Ngapo T.M. & Gariépy C. (2006) Factors affecting the meat quality of veal. *Journal of the Science of Food and Agriculture* 86:1412–1431.

Nicol A.M. & Sharafeldin M.A. (1975) Observations on the behaviour of single-suckled calves from birth to 120 days. *Proceedings of the New Zealand Society of Animal Production* 35:221–230.

Nocek J.E., Heald C.W. & Polan C.E. (1984) Influence of ration physical form and nitrogen availability on ruminal morphology of growing bull calves. *Journal of Dairy Science* 67:334–343.

Owens F.N., Secrist D.S., Hill W.J. & Gill D.R. (1998) Acidosis in cattle: A review. *Journal of Animal Science* 76:275–286.

Porter J.C., Warner R.G. & Kertz A.F. (2007) Effect of fiber level and physical form of starter on growth and development of dairy calves fed no forage. *The Professional Animal Scientist* 23:395-400.

Pounden W.D. & Hibbs J.W. (1949) Rumen inoculations in young calves. *Journal of the American Veterinary Medical Association* 114:33–35.

Prevedello P., Brscic M., Schiavon E., Cozzi G. & Gottardo F. (2012) Effects of the provision of large amounts of solid feeds to veal calves on growth and slaughter performance and intravitam and postmortem welfare indicators. *Journal of Animal Science* 90:3538–3546.

Redbo I. & Nordblad A. (1997) Stereotypies in heifers are affected by feeding regime. *Applied Animal Behaviour Science* 53:193–202.

Reinhardt V. & Reinhardt A. (1981) Natural sucking performance and age of weaning in zebu cattle (*Bos indicus*). *The Journal of Agricultural Science* 96:309–312.

Roy J.H., Stobo I.J., Gaston H.J., Ganderton P., Shotton S.M. & Thompson S.Y. (1971) The nutrition of the veal calf: 4. The effect of offering roughage on health and performance. *British Journal of Nutrition* 26:353–362.

Sander E.G., Warner R.G., Harrison H.N. & Loosli J.K. (1959) The stimulatory effect of sodium butyrate and sodium propionate on the development of rumen mucosa in the young calf. *Journal of Dairy Science* 42:1600–1605.

Sato S., Ueno N., Seo T. & Tokumoto K. (1994) Haloperidol injections entirely suppress tongue-playing in cattle. *Journal of Ethology* 12:77–80.

Schweizer G., Flückiger M., Metzger L. & Braun U. (2005) Ruminal tympany due to a trichobezoar in a heifer. *Veterinary Radiology & Ultrasound* 46:500–501.

Steele M.A., Garcia F., Lowerison M., Gordon K., Metcalf J.A. & Hurtig M. (2014) Three-dimensional imaging of rumen tissue for morphometric analysis using micro-computed tomography. *Journal of Dairy Science* 97:7691–7696.

Stobo I.J.F., Roy J.H.B. & Gaston H.J. (1966) Rumen development in the calf: The effect of diets containing different proportions of concentrates to hay on rumen development. *British Journal of Nutrition* 20:171–188.

Suárez B.J., van Reenen C.G., Stockhofe N., Dijkstra J. & Gerrits W.J.J. (2007) Effect of roughage source and roughage to concentrate ratio on animal performance and rumen development in veal calves. *Journal of Dairy Science* 90:2390–2403.

Sudweeks E.M. (1977) Chewing time rumen fermentation and their relationship in steers as affected by diet composition. *Journal of Animal Science* 44:694–701.

Sudweeks E.M., Ely L.O., Mertens D.R. & Sisk L.R. (1981) Assessing minimum amounts and form of roughages in ruminant diets: Roughage value index system. *Journal of Animal Science* 53:1406–1411.

Sudweeks E.M., Mccullough M.E., Sisk L.R. & Law S.E. (1975) Effects of concentrate type and level and forage type on chewing time of steers. *Journal of Animal Science* 41:219–224.

Swanson E.W. & Harris Jr., J.D. (1958) Development of rumination in the young calf. *Journal of Dairy Science* 41:1768–1776.

Tadepalli S., Narayanan S.K., Stewart G.C., Chengappa M.M. & Nagaraja T.G. (2009) *Fusobacterium necrophorum*: A ruminal bacterium that invades liver to cause abscesses in cattle. *Anaerobe* 15:36–43.

Tamate H., McGilliard A.D., Jacobson N.L. & Getty R. (1962) Effect of various dietaries on the anatomical development of the stomach in the calf. *Journal of Dairy Science* 45:408–420.

Terré M., Pedrals E., Dalmau A. & Bach A. (2013) What do preweaned and weaned calves need in the diet: A high fiber content or a forage source? *Journal of Dairy Science* 96:5217–5225.

Thomas D.B. & Hinks C.E. (1982) The effect of changing the physical form of roughage on the performance of the early weaned calf. *Animal Production* 35:375–384.

van Ackeren C., Steingaß H., Hartung K., Funk R. & Drochner W. (2009) Effect of roughage level in a total mixed ration on feed intake, ruminal fermentation patterns and chewing activity of early-weaned calves with ad libitum access to grass hay. *Animal Feed Science and Technology* 153:48–59.

Veal Farmers of Ontario (2015) Available at: http://ontarioveal.on.ca Accessed: May 2015.

Veissier I., Ramirez de la Fe A.R. & Pradel P. (1998) Nonnutritive oral activities and stress responses of veal calves in relation to feeding and housing conditions. *Applied Animal Behaviour Science* 57:35–49.

Warner J.F., Fales W.H., Sutherland R.C. & Teresa G.W. (1975) Endotoxin from *Fusobacterium necrophorum* of bovine hepatic abscess origin. *American Journal of Veterinary Research* 36:1015–1020.

Warner R.G., Flatt W.P. & Loosli J.K. (1956) Dietary factors influencing the development of the ruminant stomach. *Agricultural and Food Chemistry* 4:788–792.

Webb L.E., Bokkers E.A.M., Engel B., Gerrits W.J.J., Berends H. & van Reenen C.G. (2012) Behaviour and welfare of veal calves fed different amounts of solid feed supplemented to a milk replacer ration adjusted for similar growth. *Applied Animal Behaviour Science* 136:108–116.

Webb L.E., Bokkers E.A.M., Heutinck L.F.M., Engel B., Buist W.G., Rodenburg T.B., Stockhofe-Zurwieden N. & van Reenen C.G. (2013) Effects of roughage source, amount, and particle size on behavior and gastrointestinal health of veal calves. *Journal of Dairy Science* 96:7765–7776.

Webb L.E., Engel B., Berends, H., van Reenen, C. G., Gerrits, W. J. J., de Boer, I. J. M. & Bokkers E.A.M. (2014a) What do calves choose to eat and how do preferences affect behaviour? *Applied Animal Behaviour Science* 161:7–19.

Webb L.E., Jensen M.B., Engel B., van Reenen C.G., Gerrits W.J.J., de Boer I.J.M. & Bokkers E.A.M. (2014b) Chopped or long roughage: What do calves prefer? Using cross point analysis of double demand functions. *PLoS One* 9:e88778.

Webb L.E., van Reenen C.G., Berends H., Engel B., de Boer I.J.M., Gerrits W.J.J. & Bokkers E.A.M. (2015) The role of solid feed amount and composition and of milk replacer supply in veal calf welfare. *Journal of Dairy Science* 98:5467–5481.

Webster A.J.F. (1991) Control of infectious disease in housed veal calves. In: Metz J.H.M. & Groenestein C.M. (Eds.) *New Trends in Veal Calf Production*. Wageningen, The Netherlands, Pudoc, pp. 103–112.

Webster A.J.F., Saville C., Church B.M., Gnanasakthy A. & Moss R. (1985) The effect of different rearing systems on the development of calf behaviour. *British Veterinary Journal* 141:249–264.

Welch J.G. (1986) Physical parameters of fiber affecting passage from the rumen. *Journal of Dairy Science* 69:2750–2754.

Welch J.G. & Smith A.M. (1970) Forage quality and rumination time in cattle. *Journal of Dairy Science* 53:797–800.

Woodford S.T. & Murphy M.R. (1988) Effect of forage physical form on chewing activity dry matter intake and rumen function of dairy cows in early lactation. *Journal of Dairy Science* 71:674–686.

Xu Y. & Ding Z. (2011) Physiological, biochemical and histopathological effects of fermentative acidosis in ruminant production: A minimal review. *Spanish Journal of Agricultural Research* 9:414–422.

Zebeli Q., Aschenbach J.R., Tafaj M., Boguhn J., Ametaj B.N. & Drochner W. (2012) Invited review: Role of physically effective fiber and estimation of dietary fiber adequacy in high-producing dairy cattle. *Journal of Dairy Science* 95:1041–1056.

4. Risk factors for abomasal damage

Conclusions

1. **The prevalence of abomasal lesions in milk-fed veal calves is high.**

2. **The welfare significance of abomasal damage that does not develop into a perforated ulcer is not clear. However, there is no evidence that abomasal erosions and ulcers are not associated with pain and discomfort, and some clinical reports suggest that signs of pain can be associated with abomasal ulceration.**

3. **There are multiple risk factors for abomasal damage. Further work is required to study how the various risk factors interact to cause the high prevalence of abomasal damage found in milk-fed veal calves (both in those with and without solid feed in their diet).**

4. **Although it was not possible to identify definitive evidence for the cause or causes of abomasal damage in veal calves, a critical analysis of the literature together with an examination of the underlying pathophysiology of abomasal damage enabled some conclusions to be drawn as to the most likely risk factors for abomasal damage.**

5. **Most abomasal damage in milk-fed veal calves occurs in the pylorus region of the abomasum, nearest to the small intestine, and in particular at the site of the torus pyloricus. The pathology associated with these abomasal lesions is consistent with local ischemia (reduced blood flow) followed by focal necrosis. It is likely that distension of the abomasum by large volumes of milk replacer can result in reduced blood supply to the pyloric mucosa leading to ischemia and hypoxia of the mucosa. This would result in pathological changes leading to erosion and ulceration of the abomasal mucosa.**

6. **Once the mucosal layer lining is damaged, the underlying tissues are then exposed to potentially harmful secondary factors, such as acids. There is evidence that long periods of fasting lead to long periods of hyperacidity in the abomasum in milk-fed veal calves and that increasing milk meal frequency results in increased average abomasal pH.**

7. **There is clear evidence that the addition of fibrous feed (particularly coarse feeds) to the diet of milk-fed veal calves increases the risk of abomasal damage. Whether this risk is associated with inadequate ruminal development is not clear.**

8. **There is no clear evidence that infectious agents are a major risk factor for the erosions and ulcers found in the pylorus region of the abomasum of milk-fed veal calves.**

9. **Although there is some evidence that different rearing practices can affect the risk of abomasal damage, there is little convincing evidence that stress plays a major role in the development of abomasal ulcers.**

10. **There is some evidence that offering grain to milk-fed veal calves can increase the risk of abomasal damage. However, work is required on grain-fed veal calves to identify the prevalence of abomasal damage and the risk factors for abomasal damage.**

4.1 Introduction

Abomasal damage is common in milk-fed veal calves. For example, in milk-fed veal calves examined at slaughter, the percentage of abomasa with one or more ulcers has been reported to range from 40% to 74% (Van Putten, 1982; Welchman & Baust, 1987; Brscic et al., 2011; Berends et al. 2012). The occurrence of abomasal ulceration in veal calves is greater than in beef calves (6%), dairy cows (2.6%), and beef cows (1.8%) (Marshall, 2009).

The severity of abomasal damage can progress from mild to severe in the following stages:

1. abomasitis: inflammation of the mucous membrane (*lamina propria*) lining the abomasal cavity.
2. erosion: discrete areas of superficial erosion of the mucous membrane that do not penetrate the *muscularis mucosa*.
3. ulcer: discrete areas of deeper damage that penetrate through the entire thickness of the mucosa to reach the submucosa or the deeper layers of the abomasal wall.

Ulceration involves necrosis and sloughing of necrotic tissue. An ulcer can heal to form a scar or it can progress deep into the abomasal wall to cause haemorrhage, perforation, and peritonitis (Gottardo et al., 2002; Mattiello et al., 2002; Marshall, 2009).

Marshall (2009) described the following types of ulcers:

1. "Non-perforating ulcer: The ulcer does not perforate the abomasal wall and intraluminal haemorrhage is minimal.
2. Non-perforating ulcer with severe blood loss: The ulcer does not perforate the abomasal wall, but erodes a major vessel in the submucosa, resulting in severe intraluminal haemorrhage.
3. Perforating ulcer with local peritonitis: The ulcer perforates the abomasal wall and abomasal contents leak into the peritoneal cavity or omental bursa. Peritonitis is localized by fibrin deposition and the abomasum becomes adhered to the peritoneum, omentum, or surrounding viscera.
4. Perforating ulcer with diffuse peritonitis: The ulcer perforates the abomasal wall and abomasal contents quickly leak into and spread throughout the peritoneal cavity, resulting in diffuse peritonitis."

In veal calves, most abomasal ulcers do not progress to perforation of the wall or result in severe haemorrhage. However, haemorrhage and/or peritonitis associated with abomasal ulceration are a cause of some morbidity and mortality. Bähler et al. (2012) reported finding a perforating abomasal ulcer in 22% of veal calf mortalities that were submitted for post-mortem examination. In a survey of milk-fed dairy-type veal calves in Belgium, Pardon et al. (2012) found that the mortality risk from abomasal haemorrhage was 0.0% (range 0-0.1%) and from perforation of an abomasal ulcer it was 0.35% (range 0-0.6%). The overall mortality risk from all causes was 4.9%.

In milk-fed veal calves, abomasal lesions are mainly found in the pylorus region of the abomasum (Dämmrich, 1983; Welchman & Baust, 1987; Bähler et al., 2010; Brscic et al., 2011), whereas in dairy cows they are mainly found in the fundic part of the abomasum (Breukink et al., 1991). In a slaughter plant survey by Brscic et al. (2011) of calves from 170 veal calf farms in the Netherlands, France, and Italy, 74% of abomasa had lesions only in the pylorus, 8% of abomasa had lesions only in the fundic area, and 8% of abomasa had lesions in the fundic area and the pylorus.

In one study, Jensen et al. (1992) reported finding abomasal erosions (mainly in the fundic area) in 25% of slaughtered grain-fed feedlot beef cattle. This suggests that weaned grain-fed calves might be vulnerable to abomasal damage. However, no research on the prevalence of abomasal damage in weaned grain-fed veal calves was identified. The research discussed below on risk factors for abomasal damage is relevant to milk-fed veal calves and grain-fed calves before weaning.

4.2 Implications of abomasal damage for animal welfare

Morisse et al. (2000) suggested that despite the very high frequency of abomasal lesions observed in veal calves, growth and other aspects of their health remain normal. However, no comparisons of production parameters or general health have been conducted between calves with abomasal lesions and calves without lesions. Because abomasal lesions are recorded postmortem, retrospective studies comparing calves with and without lesions do not seem to be reported and would be helpful. Abomasal ulcers are hard to diagnose antemortem because they are reported as subclinical in veal calves (there are no signs) (Marshall, 2009). Nonetheless, veterinary textbooks and manuals do mention signs of pain. The clinical signs will depend on whether the ulcer is (a) non-penetrating, (b) non-penetrating but associated with intraluminal haemorrhage, or (c) penetrating and associated with peritonitis and/or haemorrhage. In adult dairy cattle and beef calves, bleeding ulcers are reported to be associated with abdominal pain, usually localized to the right ventral quadrant (Fecteau & Whitlock, 2008). Abdominal pain is commonly characterized in cattle by pain on abdominal palpation, kicking at the belly, paddling of the feet, getting up and down, and teeth grinding (bruxism) (Naylor & Bailey, 1987). According to the Merck Veterinary Manual (2015), adult cattle with bleeding abomasal ulcers may be asymptomatic except for intermittent darkening of faeces (occult blood or melena), hence difficult to detect by the producer, or they can die acutely from massive haemorrhage. Common clinical signs include mild abdominal pain, bruxism, sudden loss of appetite, increased cardiac frequency, and melena that may be intermittent. Self-grooming and other behaviours such as looking, kicking, rubbing, or biting, which are directed to the affected part, are also indicative of pain (Karas et al., 2008). Signs of blood loss are seen with major haemorrhage and may include tachycardia, pale mucous membranes, weak pulse, cool extremities, shallow breaths, tachypnea, and melena. More severe signs include acute rumen stasis, generalized abdominal pain with a reluctance to move and an audible grunt or groan with each breath, weakness, and dehydration. In calves that deteriorate rapidly, melena (blood in faeces) may not be present because it takes at least 8 h for abomasal blood to be detected in the feces. As the condition progresses, body temperature drops, and the animal becomes recumbent and dies within 6–8 h (Merck Veterinary Manual, 2015).

Wiepkema et al. (1987) found no significant relationship between the severity of abomasal damage (identified at slaughter) and the occurrence of oral manipulation of pen substrates (e.g., walls, gates and feeding equipment) by veal calves during rearing. However, a negative correlation was found between the occurrence of tongue-playing during rearing and the severity of abomasal damage. Calves that developed tongue-playing had no ulcers (or scars), while the calves that did not develop tongue-playing all had ulcers or scars.

4.3 Risk factors for abomasal damage

Many different causes have been suggested for abomasal lesions, but there is no reliable evidence of a unique cause and effect relationship, so it is considered a multi-factorial syndrome.

The following potential risk factors have been proposed for abomasal ulceration in veal calves (Marshall, 2009; Ahmed et al., 2002; Breukink et al., 1991):

- mechanical abrasion to the mucosa from coarse roughage feeds and/or trichobezoars (hairballs)
- distension of the abomasum
- stress
- hyperacidity
- bacterial infection
- trace mineral deficiency
- vitamin E deficiency.

Table 4.1 lists some of the factors that have been considered to be potential risk factors for abomasal damage.

Table 4.1 Potential risk factors for abomasal damage

Factor	Condition	Mechanism	Note	Reference
Milk and milk replacer	Large volumes of milk replacer associated with low frequency of milk meals	Abomasal distension associated to local ischemia leading to focal necrosis	Suggested. No studies inducing/measuring ischemia	Welchman & Baust (1987); Breukink et al. (1991)
		Fasting leading to sustained periods of low pH and abomasal hyperacidity.	Suggested, but no studies on relationship between abomasal hyperacidity and ulceration.	Ahmed et al. (2002); Constable et al. (2006)
	Milk replacers with vegetable protein	Non- milk proteins can trigger allergic reaction in the gut of calves	No studies on relationship between protein type in milk replacers and ulceration.	EFSA (2006)
		Milk replacers that do not coagulate in the abomasum	No studies on relationship between non-coagulating milk replacers and ulceration.	Constable et al. (2005)
	Delivery of milk	Trough feeding increases the risk of lesions more than bucket feeding, and both increase the risk more than provision of milk replacer via an automatic milk feeder, where the calf drinks many meals through a teat	A multivariate logistic regression analysis identified that bucket feeding with a teat increased the risk of fundic abomasal lesions compared with an automatic feeding system.	Bähler et al. (2010)
Solid feed	Abrasiveness on abomasal walls	Coarse roughage particles exert a mechanically abrasive effect on an already sensitive abomasal mucosa and delay the healing of lesions already present	Clear experimental evidence that provision of fibrous feeds to the diet of milk-fed veal calves increases the risk of abomasal damage, but no direct evidence on the mechanisms whereby fibrous feeds increase abomasal damage.	Brscic et al. (2011); Cozzi et al. (2002b); Mattiello et al. (2002)
	Mechanical load on the abomasum	Solid feed is consumed within the first hour after milk delivery	Demonstrated by behavioural observations, but no pathophysiological evidence to explain how solid feeds increase the mechanical load to cause abomasal damage	Brscic et al. (2011)
Mineral deficiencies	Deficiency of copper	Copper is a co-factor in prostaglandin synthesis, which has a cytoprotective effect on gastric mucosa by increasing gastric mucus secretion and microcirculation, as well as reducing the secretion of hydrochloric acid	Demonstrated in laboratory animals and humans, but no reliable evidence in veal calves	Mills et al., (1990); Lilley et al. (1985); Fecteau & Whitlock (2008)
Water	Ad libitum vs no water available	Increased risk of abomasal lesions in the pylorus when ad libitum water is provided	Association shown by a one-way logistic regression analysis that was not present when all factors were considered within a multivariate regression model	Brscic et al. (2011)
		Increased risk of lesions in the fundic area when no water was provided	No effect of the provision of drinking water on the incidence of abomasal lesions. Non-significant association using a one-way logistic regression analysis that was not present when all factors were considered within a multivariate regression model	Gottardo et al. (2002); Bähler et al. (2010)
Poor rumen development	Poor ruminal development resulting in the entry of underdigested coarse feed into the abomasum	Provision of solid feed develops rumen musculature and papillae but increases risk and severity of abomasal lesions	Clear experimental evidence that provision of solid feeds to the diet of milk-fed veal calves results in ruminal development. Other than clear evidence that provision of fibrous feed increases the risk of abomasal damage, the mechanisms whereby fibrous feeds increase abomasal damage, e.g., by passage coarse particles from an under developed rumen into the abomasum have not been demonstrated.	Berends et al. (2012); Webb et al. (2013); Brscic et al. (2011)
Pathogens	Management factors, age (newborn), and stress lead to abnormal proliferation of pathogenic microorganisms	Toxins produced by microorganisms damage cells in the abomasal mucosa	Clostridial toxin damage demonstrated	Songer & Miskimins (2005); Hund et al. (2015); Jelinski et al. (1995)
	Intraruminal inoculation of *C. perfringens* in newborn calves	Inflammation of the abomasum (Abomasitis) in association with depression, diarrhoea, and abomasal ulcerations in 8 of 8 inoculated animals	Demonstrated by inoculation/ few animals	Roeder et al. (1988)
	Intra-abomasal and intra-jejunal inoculation of *C. perfringens* in adult cows	No signs of disease or abomasal ulcers found in inoculated animals	Dose and concomitant factors were not studied	Ewoldt & Anderson (2005)

Although it is not possible to provide definitive evidence to identify the cause or causes of abomasal damage in veal calves, a critical analysis of the literature together with an examination of the underlying pathophysiology of abomasal ulcers has enabled some conclusions to be drawn as to the most likely risk factors for abomasal damage.

4.3.1 Pathophysiology of abomasal ulcers

Gastric ulcers occur in humans (Holle, 2010) and are common in horses and pigs (Argenzio, 1999). Their pathophysiology and risk factors have been reviewed by Yeomans (2011), Murray (1999) and Robertson et al. (2002).

The mucosal layer lining the abomasum is normally protected by mucus, mucosal bicarbonate secretion, efficient blood flow, and continued renewal of the surface epithelial cells (Kawano & Tsuji, 2000; Monnig & Prittie, 2011; Yandrapu & Sarosiek, 2015). For ulceration to occur, this protective barrier has to be disturbed. Pearson et al. (1987) found reduced amounts or absence of mucus at the sites of erosion or ulceration in the pyloric region of the abomasa of veal calves. Once the mucosal layer lining is damaged, the underlying tissues are then exposed to potentially harmful secondary factors, such as acids and coarse fibrous feed.

4.3.2 Physiological disturbance

It has been suggested that low abomasal pH could increase the risk of ulceration, e.g., following decreased meal frequency and/or decreased meal volume (Constable et al., 2005). During 24 h of fasting, abomasal pH can remain below 2.0. After ingestion of milk replacer, the abomasal pH rises and is above pre-prandial pH for between 5 and 7 h depending on the type of milk replacer and frequency of consumption. Increasing the frequency of ingestion of milk replacer to more than twice a day increases mean 24 h abomasal pH compared with ingesting two meals per day (Ahmed et al., 2002; Constable et al., 2005). Research is required to investigate the role of low abomasal pH in the development of ulcers. After the mucosa is damaged and an abomasal lesion has formed, an acidic environment is likely to cause further damage and delay healing.

Although duodenal-gastric reflux has been considered a potential factor in the development of gastric ulcers in humans, duodenal-abomasal reflux is not considered to be a likely factor affecting abomasal damage in calves. There are anatomical and physiological differences in that the bile duct and the pancreatic duct enter the duodenum at a greater distance from the pylorus than in humans. Although there is some retrograde duodenal motility that passes into the abomasum, it is minimal (Ooms & Oyaert, 1978) and the torus pyloricus of the abomasum is considered to form an effective valve to prevent reflux (Marshall, 2009).

4.3.3 Stress

Although the role of stress in the development of gastric ulcers in humans currently receives less emphasis in the literature than it did previously, it is considered by some to predispose to ulceration and impair recovery (Overmier & Murison, 2013). Stress can potentially affect "gastric secretion, gut motility, mucosal permeability and barrier function, visceral sensitivity and mucosal blood flow" (Konturek et al., 2011). In addition, stress can cause changes in the composition of microorganisms, neurotransmitters, and immune function in the gastrointestinal tract (Konturek et al., 2011). These changes have the potential to increase the risk of gastric ulcers (Konturek et al., 2011) by reducing gastric mucosal protection (Monnig and Prittie, 2011). Breukink et al. (1989) found no beneficial effects of including clenbuterol (beta-adrenergic agonist) in the milk of veal calves on the percentage of 6-month-old calves with an abomasal ulcer. However, in those offered roughage pellets from about 2 months of age, it did appear to reduce the percentage of calves with an ulcer. Although Lensink et al. (2000) did not find any significant difference in stress hormones between veal calves gentled during rearing by stroking the calves and allowing them to suck the stockperson's fingers and those that received minimal contact, they did not find any abomasal ulcers in the gentled calves, but one-third of the control calves had an ulcer or a scar around the pylori. Despite early suggestions that emphasised its role, the role of stress in the development of abomasal lesions is not clear. There are some reports that some management factors that might be associated with stress can influence the prevalence of abomasal lesions in veal calves (Marshall, 2009).

4.3.4 Abomasal displacement

There are occasional clinical reports of calves with a perforated ulcer in the pyloric region together with adhesions and abomasal displacement (Hawkins et al., 1986; Mueller et al., 1999). However, abomasal displacement is not a common finding in calves with abomasal lesions.

4.3.5 Mineral deficiency

Although a nutritional deficiency of copper was proposed as a potential cause of abomasal ulceration in suckled beef calves in the Western United States (Lilley et al., 1985; Mills et al., 1990), this was largely speculation as these studies did not have an appropriate control group. Other studies could not find an association between abomasal ulceration and copper deficiency in suckling calves (Roeder et al., 1987, 1988).

4.3.6 Bacterial infection

Several bacteria, including *Salmonella* and *Clostridium perfringens* type A, can cause a widespread abomasitis (Roeder et al., 1988; Jelinski et al., 1995; Manteca et al., 2001**;** Carlson et al., 2002). However, abomasal ulcers that develop following bacterial inoculation tend to be diffusely spread throughout the abomasum. Jelinski et al. (1995) suggest that this indicates "that the bacteria did not colonize or penetrate the tissue, but rather that preformed toxins contained within the broth may have caused widespread nonspecific cellular damage." In addition, many of the bacteria (e.g., *Clostridium perfringens* and *Campylobacter jejuni*) that have been recovered from abomasal ulcers (Roeder et al., 1987; Mills et al.,1990) are likely to be post-mortem invaders from the alimentary tract or opportunistic secondary infective agents that invade after injury to the abomasal mucosa (Ahmed et al., 2002).

Although *Helicobacter pylori* can cause ulcers in humans (Yeomans, 2011), Valgaeren et al. (2013) failed to recover *Helicobacter* species from fundic ulcers in slaughtered veal calves. In addition, the percentage of abomasa with *Clostridium perfringens* was not significantly different between healthy calves and those with fundic ulceration. Jelinski et al. (1995) conducted post-mortem examinations on unweaned suckling beef calves that had a perforating or a haemorrhagic ulcer or were of a similar age but died of a disease unrelated to the abomasum. *Helicobacter pylori* was not present in any of the abomasal tissue samples. *Clostridium perfringens* type A was found in 79% of the calves with abomasal ulcers and in 75% of the controls. *Campylobacter spp.* was recovered from three of the calves with abomasal ulcers and from three of the controls.

Hund et al. (2015) studied bacteria present in abomasal ulcers of calves (and in bulls and cows) at slaughter. There were differences between the types of bacteria recovered from the mucosa of calves and those from other cattle. There were few statistically significant differences in the numbers and types of bacteria recovered from healthy and ulcerated abomasal mucosa. The authors concluded that their results "suggest that bacteria may have only limited involvement in the etiology of abomasal ulcers. However, future research will be needed to verify the contribution of bacteria to abomasal ulcer formation as presence or absence of bacteria does not necessarily correlate with etiology of disease."

4.3.7 Hairballs/trichobezoars

As both hairballs and ulcers are frequently found in the abomasum of calves, hairballs have been reported to be a potential cause of ulcers. However, post-mortem reports of hairballs could be an artifact arising from recording an interesting and potentially relevant observation when they are associated with abomasal ulcers, but when they are observed in calves with lesions in other parts of the body, their presence could be regarded as irrelevant and would not be recorded (Jelinski et al., 1996). Jelinski et al. (1996) conducted post-mortem examinations on unweaned beef calves that either died of a perforated abomasal ulcer or died of an unrelated cause. In calves < 1 month of age, an abomasal hairball was found in a greater percentage of calves that had an ulcer than in those that did not. However, when week of age was considered within the analysis, there was no significant difference between calves with and those without an ulcer. In calves between 1 and 2 months of age, there was no significant difference between calves with and those without an ulcer in the percentage of calves with a hairball in the abomasum.

4.3.8 Rearing system

Bokkers and Koene (2001) examined 18 veal farms and found no significant difference in the number of abomasal ulcers at the time of slaughter (about 6.5 months of age) between milk-fed veal calves (some with access to grain) reared in individual stalls or in groups (from about 2 months of age). Veissier et al. (1997) found no significant effects of providing veal calves kept in individual stalls with either open or solid partitions or with a tire or a chain within the stall on the prevalence of abomasal ulcers or scars. In veal calves offered milk replacer in buckets, Veissier et al. (1998) found more ulcers in those that had been reared in pens than in those that had been reared in individual stalls. However, this was a small study with only 16 calves and the differences seem to be affected by diet. In veal calves offered only milk replacer, more erosions were found in those reared in groups than in individual stalls, but in those offered solid feed in addition to milk replacer, more erosions were found in those reared in individual stalls than in those reared in groups.

Welchman and Baust (1987) reported that the rearing system affected both the prevalence of abomasal lesions and the location within the abomasum where most lesions occurred. They found more calves with abomasal ulcers after they had been housed in groups with straw (n=110) or wood shavings (n=96) bedding and ad libitum milk (98 and 96%, respectively) than after they had been reared in individual stalls with no bedding and limited milk replacer fed from a bucket (n=98) (66%). There were between 20 and 50% of abomasa with ulcers in the *torus pyloricus*, but few abomasa had ulcers in the fundus (2 to 12%). There were more abomasa with ulcers in the pyloric region of calves that had been group reared with ad libitum milk replacer on straw or wood shavings than in those that had been bucket-fed in individual stalls. However, these differences could be due to the bedding, the housing, or the feeding. The severity of the erosions was greatest in calves offered ad libitum milk replacer and kept on wood shavings. The severity of the ulcers was greatest in those offered ad libitum milk and kept on straw and least in those offered milk in buckets and kept in individual stalls without straw. Welchman (1987) found fewer abomasa with ulcers on the *torus pyloricus* of calves (4%) that had been group housed on straw bedding with restricted milk replacer via teats and access to solid feed (pellets) (n=27) than in those that had been (a) group housed on straw bedding with either ad libitum milk replacer via teats (51%) (n=37) or restricted amounts of milk replacer in buckets (44%) (n=18) or (b) those reared in individual stalls with restricted amounts of milk replacer in buckets either with (58%) (n=38) or without (36%) (n=11) solid feed (pellets).

A survey of 125 veal calves slaughtered in Switzerland showed that 74% of abomasa had lesions only in the pylorus, 8% of abomasa had lesions only in the fundus, and 8% of abomasa had lesions in the fundus and pylorus (Bähler et al., 2010). A multivariate logistic regression analysis identified that bucket feeding with a teat (twice a day) increased the risk of fundic abomasal lesions by x 12 (CI 2 to 97) compared with an automatic feeding system. The multivariate analysis was not able to identify significant management risk factors for the pyloric lesions. Although method of ventilation was a significant factor, this was likely an artificial result caused by an identified factor correlated with ventilation.

4.3.9 Drinking water

No effect of the provision of drinking water was observed on the incidence of abomasal lesions (inflammation, erosions, and ulcers) in calves offered drinking water in addition to milk replacer, milk replacer plus wheat straw, or milk replacer plus beet pulp (Gottardo et al., 2002).

4.3.10 Ischemia associated with prolonged abomasal distension after milk feeding

A high prevalence of pyloric lesions in the abomasum of milk-fed veal calves that consume high volumes of milk replacer could result from overfilling of the abomasum, causing local ischemia followed by focal necrosis as a consequence of strong contractions of the pyloric wall. Ischemia occurs when there is insufficient blood supply to an organ or part of the body. It is caused by an interruption of the flow of blood through a blood vessel. Blood flow can be restricted by an embolus (a migrating blood clot that can form a blockage), a thrombus (a stationary clot attached to the wall of a blood vessel that can prohibit blood passage), or constriction of the blood vessel.

Dämmrich (1983) described the following pathology associated with abomasal lesions that would be consistent with ischemia of the abomasum:

- Reduced number of goblet cells leading to decreased secretion of mucus
- Frequent circulatory disturbance
- Initial signs: local hyperemia and dilated capillaries
- Later stagnation of blood flow leading to hyaline thrombi (clumping of red blood cells to form a plug within a capillary)
- Oedema and haemorrhage.

In light of the pathological changes observed, Dämmrich (1983) suggested that the following pathophysiological responses could explain the formation of ulcers in the region of the pylorus (the area of the abomasum where most abomasal lesions are found in veal calves). Distension of the abomasum with large volumes of milk replacer can result in strong peristaltic contractions in the pyloric area with closure of the pyloric sphincter. The pyloric sphincter closes the pyloric channel and it remains closed until digestion is completed (up to 13–17 h). The muscle sphincter compresses the pyloric mucosa in the tortus pylori area, leading to ischemia and hypoxia of the villi. Once the digestion is complete and the pyloric sphincter relaxes, blood returns to the pyloric area, but circulatory disturbance due to hyaline microthrombi remains. The capillary walls become permeable, resulting in haemorrhage and oedema. Autodigestion develops the focal necrosis of villi to erosions and then ulcers. This theory is supported by experimental studies in animals, other than calves, that have shown that local reduction in gastric blood flow can cause gastric ulceration in specific regions of the stomach (Kawano & Tsuji, 2000).

4.3.11 Poor ruminal development

Poor rumen development might result in the passage of incompletely digested coarse feed particles from the rumen into the abomasum thereby aggravating any existing mucosal damage (Webb et al., 2013). Although Webb et al. (2013) found that the addition of fibre to the diet of calves offered milk replacer increased rumen weight and stimulated chewing and rumination (indicating rumen development; however, no direct measurements of development of ruminal papillae were made), there was no obvious beneficial effect of apparent rumen development on the prevalence of abomasal damage. The effects of early rumen development on the prevalence of abomasal damage was studied by Berends et al. (2012) in a complex experimental design with different feeding practices during two 3-month periods. The authors reported that provision of a diet that stimulated early rumen development did not affect the percentage of calves with abomasal erosions or ulcers at the time of slaughter, at about 6 months of age. However, early rumen development significantly decreased the prevalence of large abomasal scars. Therefore, it is possible that abomasal lesions were present early in the rearing period, but rumen development stimulated by provision of solid feed (maize silage, barley straw, and concentrate [25:25:50 on a DM basis]) during the first 3 months of rearing may, by the time of slaughter at about 6 months of age, have had a beneficial effect in faciltating healing of the erosions or ulcers to form a scar.

4.3.12 Provision of fibre in the diet

Provision of roughage could exert a mechanically abrasive effect on the abomasal mucosa and delay the healing of any lesions already present, or they could cause a partial blockage of the pyloric exit, delaying abomasal emptying (Mattiello et al., 2002) (thereby potentially exacerbating any ischemia due to abomasal distension). See section 3.5.6 *Abomasal damage* in Chapter 3. Table 3.8 in that chapter shows the results of studies that found that the provision of hay, straw, dried beet pulp, corn silage, and corn cob silage can cause abomasal damage. Although there is clear evidence for an effect of provision of coarse feeds on the occurrence of abomasal lesions, some studies on the influence of type of solid feed in the diet of veal calves on the risk of abomasal damage have not shown an effect of some types of solid feed (Table 3.8).

In a slaughter plant survey of batches of veal calves from 170 veal units in the Netherlands, France, and Italy, Brscic et al. (2011) found that 74% (range 32 to 100%) of the abomasa had at least one lesion (scar to ulcer) in the pyloric area and 77% (range 25 to 100%) of the abomasa had a lesion in the torus pylorus. A multivariate regression model for abomasal lesions in the pyloric area showed that the prevalent type of solid feed and the season were the most relevant factors explaining about 41% of the total variance. Pairwise comparisons among classes of solid feeds showed that the highest risk of lesions in the pyloric area were in calves offered cereal grain (barley or corn/maize) compared with those offered maize silage (x 1.6 CI 1.2 to 2.1) or rolled/flaked corn/maize (x 1.8 CI 1.2 to 2.8).

Van Putten (1982) reported that the provision of straw (or straw pellets) to veal calves had no effect on the prevalence of abomasal erosions or ulcers. Whereas, Wensing et al. (1986) found ulcers in 8% of 5.75-month-old veal calves that had been offered milk replacer only, but in calves that had also been offered pelleted feed (chopped barley, hay, or corn silage) from 1.75 months of age, a greater percentage of calves had ulcers (significantly greater in those that had been offered straw [prevalence 42%] or corn silage [prevalence 29%]).

In calves, about 7 months of age, that had been offered a diet of 50% roughage (50% corn silage and 50% chopped wheat straw) and 50% concentrates, there was no significant increase in the surface area of abomasal damage with increased DM intake of solid feed (20 to 260 kg of DM during a 17-week period), but when the diet consisted of 20% roughage and 80% concentrates there was a significant increase in the surface area of abomasal damage with increased DM intake of solid feed (Berends et al., 2014).

Cozzi et al. (2002b) found no effect of offering milk-fed veal calves ground wheat straw compared with barley grain on the number of calves with abomasal erosions, ulcers, or scars, at the time of slaughter (about 5.25 months of age). However, the severity of abomasal lesions was greater in the calves that had been offered barley grain than in those that had been offered ground wheat straw.

Mattiello et al. (2002) found a greater percentage of calves with an abomasal ulcer, at the time of slaughter (about 5.75 months of age), after they had been offered a diet of milk replacer and 250 g/d of wheat straw (NDF 86%) or dried beet pulp (NDF 47%) (Cozzi et al., 2002a) than after they had been offered a diet of only milk replacer. The percentage of calves with an abomasal erosion was greater after the wheat straw diet than after the dried beet pulp or milk replacer only diets. There was no effect of diet on the percentage of calves with an inflamed abomasal mucosa. The authors suggested the reduced effect of dried beet pulp compared with straw may have been due to the less structured fibre within the beet pulp causing less damage to the mucosa.

In milk-fed calves (twice a day bucket feeding), kept in individual stalls, no effect of dietary treatments on the prevalence of abomasal lesions at the time of slaughter (about 5 months of age) was found in two separate studies after the calves had been offered ground barley and straw pellets. In study 1, NDF 26% and particle size 1–2 mm pellets were offered at either 50 g/d at 3 weeks to 100 g/d at 17 weeks or 50 g at 3 weeks to 300 g at 17 weeks (Morisse et al., 1999). In study 2, pellets (particle size 2 to 5 mm) with different compositions were offered ranging in NDF% from 26 to 78% and with a starch content between 2 and 48% (50 g/d at 3 weeks to 300 g/d at 17 weeks of age) (Morisse et al., 2000). The absence of an effect of diet might have been due to the small particle size of the barley and straw within the pellets.

Prevedello et al. (2012) found one or more abomasal lesions in the torus pylorus area of more than 80% of the veal calves slaughtered at about 7 months of age after they had been group housed, offered milk replacer twice a day via a bucket with teat (amount increased from 350 to 3,060 g of milk replacer powder/calf/d and concentration increased from 6% to 17%) and, from week 3 after arrival, one of the following solid feed diets:

- 80% corn grain and 20% wheat straw (5 cm length) (as fed-basis) (NDF 25%)
- 72% corn grain, 20% wheat straw (5 cm length), and 8% extruded soybean (NDF 28%)
- 100% corn grain (NDF 11%).

There was no effect of diet (solid feed intake 864–883 g DM/d) on either the percentage of calves with an abomasal lesion (92, 92, and 85 %, respectively) or on the severity of abomasal lesions.

Brscic et al. (2014) found no effect on the prevalence or the severity of abomasal lesions, at the time of slaughter (about 6.75 months of age), of offering veal calves milk replacer and a solid diet (NDF 23%) of 85% corn grain and 15%, 5 cm long, chopped straw (as fed basis), and then from about 1.3 months of age, the following solid feeds (NDF 23%), in addition to milk replacer: (a) 85% corn grain and 15%, 5 cm long, chopped straw, (b) 72% corn grain, 15%, 5 cm long, chopped straw and 13% extruded pea. or (c) 83% corn grain, 16%, 5 cm long, chopped straw, and 1% urea (as fed-basis). The prevalence of abomasal lesions ranged from 92 to 97%.

Webb et al. (2013) studied the effects of fibre type, amount, and particle size (offered from week 2) on abomasal lesions at the time of slaughter (about 6 months of age) in veal calves that had been offered milk replacer (starting at 3 L/d and rising to 17 L/d) in buckets, twice a day, and reared in individual stalls for the first 6 weeks, then in groups. Although there was not a significant effect of diet on the prevalence of abomasal lesions, individual comparisons showed that (a) straw increased the prevalence of erosions, ulcers, and scars compared with milk replacer alone, (b) corn/maize silage and corn/maize cob silage increased the prevalence of ulcers compared with milk replacer alone, (c) there was no significant difference between the prevalence of erosions and ulcers in calves offered hay compared with milk replacer alone, and (d) there were no scars in the calves offered milk replacer alone (see Table 4.2).

Table 4.2 Effect of type of fibre on the prevalence of abomasal lesions†

	Probability of effect of diet	Milk replacer	Hay	Straw‡	Corn/maize silage‡	Corn/maize cob silage‡
Prevalence (%)						
Erosion	0.06	15[a]	30[ab]	39[b]	25[a]	20[a]
Ulcer	> 0.1	25[a]	40[a]	73[b]	65[b]	78[b]
Scar	> 0.1	0[a]	30[b]	23[b]	18[ab]	16[ab]

† adapted from Webb et al. (2013)
‡ offered as chopped (4 to 5 cm) or ground (1 cm), but particle size was not significant (P>0.05)
a,b different superscripts within a row differ (P < 0.05), but overall treatment effect was not significant for prevalence of abomasal lesions.

Although there was no effect of particle size, there were some interactions between fibre type and amount of fibre:

- when provided at 250 g DM/d, calves offered corn/maize cob silage had fewer erosions than calves offered straw or corn/maize silage. When provided at 500 g DM/d, calves offered corn/maize silage had fewer erosions than calves offered straw or corn/maize cob silage.
- when provided at 250 g DM/d, calves offered corn/maize silage had fewer ulcers than calves offered straw or corn/maize cob silage. Calves offered corn/maize silage had more ulcers when it was provided at 500 g DM/d than at 250 g DM/d.
- calves offered straw had larger erosions than calves offered corn/maize silage or corn/maize cob silage and had larger scars than calves offered corn/maize cob silage.
- ulcer size was smaller in calves offered straw, corn/maize silage, or corn/maize cob silage at 250 g DM/d (1.3 ± 0.2 cm^2) than in calves offered 500 g DM/d (2.0 ± 0.2 cm^2).

These results show that calves that consume large volumes of milk replacer have abomasal damage. The absence of scars at 6 months of age, but presence of erosions and ulcers, would be consistent with most of the damage occurring during the latter part of rearing, when the calves were consuming the greatest volumes of milk replacer (as the damage did not appear to have had time to start to heal into scar tissue). The effect of offering fibre in addition to milk replacer was to increase the prevalence of abomasal damage and, except for hay, this effect was greater at higher intakes than at lower intakes of fibre. There was more damage when the fibre type was likely to have been coarser, i.e., more damage was caused by straw than by hay. The effects of fibre type and amount were not reduced by chopping the fibre into very short lengths to reduce particle size from 4–5 cm to 1 cm.

Webb et al. (2013) concluded "that abomasal lesions, whether ulcers or erosions, may come about from a combination of factors, including:

1. overloading of the abomasum, resulting in local ischemia and subsequent lesions;
2. exacerbation of existing damage due to the passage of underdigested feed particles from a poorly developed rumen to a sensitized abomasum; and
3. exacerbation of existing damage with coarse feed stuffs due to their greater abrasive quality."

4.4 References

Ahmed A.F., Constable P.D. & Misk N.A. (2002) Effect of feeding and route of administration on abomasal luminal pH in dairy calves fed milk replacer. *Journal of Dairy Science* 85:1502–1508.

Argenzio R.A. (1999). Comparative pathophysiology of nonglandular ulcer disease: A review of experimental studies. *Equine Veterinary Journal* 31:19–23.

Bähler C., Regula G., Stoffel M.H., Steiner A. & von Rotz A. (2010) Effects of the two production programs 'Naturafarm' and 'conventional' on the prevalence of non-perforating abomasal lesions in Swiss veal calves at slaughter. *Research in Veterinary Science* 88:352–360.

Bähler C., Steiner A., Luginbuehl A., Ewy A., Posthaus H., Strabel D., Kaufmann T. & Regula G. (2012) Risk factors for death and unwanted early slaughter in swiss veal calves kept at a specific animal welfare standard. *Research in Veterinary Science* 92:162–168.

Berends H., van den Borne J.J.G.C., Mollenhorst H., van Reenen C.G., Bokkers E.A.M. & Gerrits W.J.J. (2014) Utilization of roughages and concentrates relative to that of milk replacer increases strongly with age in veal calves. *Journal of Dairy Science* 97:6475–6484.

Berends H, van Reenen C.G., Stockhofe-Zurwieden N. & Gerrits W.J.J. (2012) Effects of early rumen development and solid feed composition on growth performance and abomasal health in veal calves. *Journal of Dairy Science* 95:3190–3199.

Bokkers E.A.M. & Koene P. (2001) Activity, oral behaviour and slaughter data as welfare indicators in veal calves: a comparison of three housing systems. *Applied Animal Behaviour Science* 75:1–75.

Breukink H.J., Wensing T. & Mouwen J.M.V.M. (1991) Abomasal ulcers in veal calves: Pathogenesis and prevention. In: J.H.M. Metz & C.M. Groenestein (Eds) *New Trends in Veal Calf Production*. European Federation of Animal Science (EAAP), Pudoc, Wageningen, the Netherlands, pp. 118–122.

Breukink H.J., Wensing T., van Dijk S. & Mevius D. (1989) Effect of clenbuterol on the incidence of abomasal ulcers in veal calves. *The Veterinary Record* 125:109–111.

Brscic M., Heutinck L.F.M., Wolthuis-Fillerup M., Stockhofe N., Engel B., Visser E.K., Gottardo F., Bokkers E.A.M., Lensink B.J., Cozzi G. & van Reenen C.G. (2011) Prevalence of gastrointestinal disorders recorded at postmortem inspection in white veal calves and associated risk factors. *Journal of Dairy Science* 94:853–863.

Brscic M., Prevedello P., Stefani A.L., Cozzi G. & Gottardo F. (2014) Effects of the provision of solid feeds enriched with protein or nonprotein nitrogen on veal calf growth, welfare, and slaughter performance. *Journal of Dairy Science* 97:4649–4657.

Carlson S.A., Stoffregen W.C. & Bolin S.R. (2002) Abomasitis associated with multiple antibiotic resistant salmonella enterica serotype typhimurium phagetype DT104. *Veterinary Microbiology* 85:233–240.

Constable P.D., Ahmed A.F. & Misk N.A. (2005) Effect of suckling cow's milk or milk replacer on abomasal luminal pH in dairy calves. *Journal of Veterinary Internal Medicine* 19:97–102.

Constable P.D., Wittek T., Ahmed A.F., Marshall T.S., Sen I. & Nouri M. (2006) Abomasal pH and emptying rate in the calf and dairy cow and the effect of commonly administered therapeutic agents. In: Proceedings of the 24th World Buiatrics Conference. World Association for Buiatrics, Nice, France, pp. 54–68.

Cozzi G., Gottardo F., Mattiello S., Canali E., Scanziani E., Verga M. & Andrighetto I. (2002a) The provision of solid feeds to veal calves: I. growth performance, forestomach development, and carcass and meat quality. *Journal of Animal Science* 80:357–366.

Cozzi G., Gottardo F., Mutinelli F., Contiero B., Fregolent G., Segato S. & Andrighetto I. (2002b) Growth performance, behaviour, forestomach development and meat quality of veal calves provided with barley grain or ground wheat straw for welfare purpose. *Italian Journal of Animal Science* 1:113–126.

Dämmrich K. (1983) Pathological approaches to evaluate calf boxes under animal welfare aspects. In: Smidt D. (Ed.), *Indicators relevant to farm animal welfare*. Hingham, MA, USA, Martinus Nijhoff, pp. 143–153.

European Food Safety Authority (2006) The risks of poor welfare in intensive calf farming systems. An update of the Scientific Veterinary Committee Report on the Welfare of Calves. *The EFSA Journal* 366:1–36.

Ewoldt J.M. & Anderson D.E. (2005) Determination of the effect of single abomasal or jejunal inoculation of *Clostridium perfringens* Type A in dairy cows. *Canadian Veterinary Journal* 46:821–824.

Fecteau M. & Whitlock R.H. (2008) Abomasal ulcers (Chapter 10). In: Anderson D.E. & Rings M. (Eds) *Current Veterinary Therapy: food animal practice*. W.B. Saunders, Philadelphia.

Gottardo F., Mattiello S., Cozzi G., Canali E., Scanziani E., Ravarotto L., Ferrante V., Verga M. & Andrighetto I. (2002) The provision of drinking water to veal calves for welfare purpose. *Journal of Animal Science* 80:2362–2372.

Hawkins C.D., Fraser D.M., Bolton J.R., Wyburn R.S., McGill C.A. & Pearse B.H. (1986). Left abomasal displacement and ulceration in an eight-week-old calf. *Australian Veterinary Journal* 63:53-55.

Holle G.E. (2010) Pathophysiology and modern treatment of ulcer disease (review). *International Journal of Molecular Medicine* 25:483–491.

Hund A., Dzieciol M., Schmitz-Esser S. & Wittek T. (2015) Characterization of mucosa-associated bacterial communities in abomasal ulcers by pyrosequencing. *Veterinary Microbiology* 177:132–141.

Jelinski M.D., Ribble C.S., Campbell J.R. & Janzen E.D. (1996) Descriptive epidemiology of fatal abomasal ulcers in Canadian beef calves. *Preventive Veterinary Medicine* 26:9–15.

Jelinski M.D., Ribble C.S., Chirino-Trejo M., Clark E.G. & Janzen E.D. (1995) The relationship between the presence of *Helicobacter pylori*, *Clostridium perfringens* type A, *Campylobacter spp*, or fungi and fatal abomasal ulcers in unweaned beef calves. *Canadian Veterinary Journal* 36:379–382.

Jensen R., Spraker T.R., Glock R.D., Jones R.L., Collins J.K., Flack D.E., Kerschen R. & Hoff R.L. (1992) Abomasal erosions in feedlot cattle. *American Journal of Veterinary Research* 53:110–115.

Karas A.Z., Danneman P.J. & Cadillac J.M. (2008) Strategies for assessing and minimizing pain. Chapter VIII. In Fish R., Danneman P.J., Brown M. & Karas A. (eds). *Anesthesia and Analgesia in Laboratory Animals*. 2nd edition. American College of Laboratory Animal Medicine. Academic Press. Elsevier. Waltham, MA.

Kawano S. & Tsuji S. (2000) Role of mucosal blood flow: A conceptional review in gastric mucosal injury and protection. *Journal of Gastroenterology and Hepatology* 15(Suppl.):D1–D6.

Konturek P.C., Brzozowski T. & Konturek S.J. (2011) Stress and the gut: Pathophysiology, clinical consequences, diagnostic approach and treatment options. *Journal of Physiology and Pharmacology* 62:591–599.

Lensink B.J., Fernandez X., Boivin X., Pradel P., Le Neindre P. & Veissier I. (2000) The impact of gentle contacts on ease of handling, welfare, and growth of calves and on quality of veal meat. *Journal of Animal Science* 78:1219–1226.

Lilley C.W., Hamar D.W., Gerlach M. & Johnson J.L. (1985) Linking sources and manufacturers copper and bacteria with abomasal ulcers in beef calves. *Veterinary Medicine* 80:85–88.

Manteca C., Jauniaux T., Daube G., Czaplicki G. & Mainil J.G. (2001) Isolation of clostridium perfringens from three neonatal calves with haemorrhagic abomasitis. *Revue De Medecine Veterinaire* 152:637–639.

Marshall T. (2009) Abomasal ulceration and tympany of calves. *Veterinary Clinics of North America: Food Animal Practice* 25:209–220.

Mattiello S., Canali E., Ferrante V., Caniatti M., Gottardo F., Cozzi G., Andrighetto I. & Verga M. (2002) The provision of solid feeds to veal calves: II. Behavior, physiology, and abomasal damage. *Journal of Animal Science* 80:367–375.

Merck Veterinary Manual online. Abomasal ulcers. Available at: www.merckvetmanual.com/mvm/digestive_system/diseases_of_the_abomasum/abomasal_ulcers.html?qt=ulcers%20bovine&alt=sh. Accessed: July 17th 2015.

Mills K.W., Johnson J.L., Jensen R.L., Woodard L.F. & Doster A.R. (1990) Laboratory findings associated with abomasal ulcers/tympany in range calves. *Journal of Veterinary Diagnostic Investigation* 2:208–212.

Monnig A.A. & Prittie J.E. (2011) A review of stress-related mucosal disease. *Journal of Veterinary Emergency and Critical Care* 21:484–495.

Morisse J.P., Cotte J.P., Huonnic D. & Martrenchar A. (1999) Influence of dry feed supplements on different parameters of welfare in veal calves. *Animal Welfare* 8:43–52.

Morisse J.P., Huonnic D., Cotte J.P. & Martrenchar A. (2000) The effect of four fibrous feed supplementations on different welfare traits in veal calves. *Animal Feed Science and Technology* 84:129–136.

Mueller K., Merrall M. & Sargison N.D. (1999) Left abomasal displacement and ulceration with perforation of abdominal musculature in two calves. *Veterinary Journal* 157:95–97.

Murray M.J. (1999) Pathophysiology of peptic disorders in foals and horses: A review. *Equine Veterinary Journal* 31:14–18.

Naylor J.M. & Bailey J.V. (1987) A retrospective study of 51 cases of abdominal problems in the calf: etiology, diagnosis and prognosis. *Canadian Veterinary Journal* 28:657–662.

Ooms L. & Oyaert W. (1978) Electromyographic study of the abomasal antrum and proximal duodenum in cattle. *Zentralblatt Fuer Veterinaermedizin Reihe A* 25:464–473.

Overmier J.B. & Murison R. (2013) Restoring psychology's role in peptic ulcer. *Applied Psychology: Health and Well-being* 5:5–27.

Pardon B., de Bleecker K., Hostens M., Callens J., Dewulf J. & Deprez P. (2012) Longitudinal study on morbidity and mortality in white veal calves in Belgium. *BMC Veterinary Research* 8:26.

Pearson G.R., Welchman D.B. & Wells M. (1987) Mucosal changes associated with abomasal ulceration in veal calves. *Veterinary Record* 121:557–559.

Prevedello P., Brscic M., Schiavon E., Cozzi G. & Gottardo F. (2012) Effects of the provision of large amounts of solid feeds to veal calves on growth and slaughter performance and intravitam and postmortem welfare indicators. *Journal of Animal Science* 90:3538–3546.

Robertson I.D., Accioly J.M., Moore K.M., Driesen S.J., Pethick D.W. & Hampson D.J. (2002) Risk factors for gastric ulcers in australian pigs at slaughter. *Preventive Veterinary Medicine* 53:293–303.

Roeder B.L., Chengappa M.M., Nagaraja T.G., Avery T.B. & Kennedy G.A. (1988) Experimental induction of abdominal tympany, abomasitis, and abomasal ulceration by intraruminal inoculation of Clostridium perfringens type A in neonatal calves. *American Journal of Veterinary Research* 49:201–207.

Roeder B.L., Chengappa M.M., Nagaraja T.G., Avery T.B. & Kennedy G.A. (1987) Isolation of clostridium perfringens from neonatal calves with ruminal and abomasal tympany, abomasitis, and abomasal ulceration. *Journal of the American Veterinary Medical Association* 190:1550–1555.

Songer J.G. & Miskimins D.W. (2005) Clostridial abomasitis in calves: Case report and review of the literature. *Anaerobe* 11:290–294.

Valgaeren B.R., Pardon B., Flahou B., Verherstraeten S., Goossens E., Timbermont L., Haesebrouck F., Ducatelle R., Van Immerseel F. & Deprez P.R. (2013) Prevalence and bacterial colonisation of fundic ulcerations in veal calves. *Veterinary Record,* 172:269.

Van Putten, G. (1982) Welfare in veal calf units. *Veterinary Record* 111:437–440.

Veissier I., Chazal P., Pradel P. & Le Neindre P. (1997) Providing social contacts and objects for nibbling moderates reactivity and oral behaviors in veal calves. *Journal of Animal Science* 75:356–365.

Veissier I., Ramirez de la Fe A.R. & Pradel P. (1998) Nonnutritive oral activities and stress responses of veal calves in relation to feeding and housing conditions. *Applied Animal Behaviour Science* 57:35–49.

Webb L.E., Bokkers E.A.M., Heutinck L.F.M., Engel B. & Buist W.G. (2013) The effect of roughage type, amount and particle size on veal calf behavior and gastrointestinal health. *Journal of Dairy Science* 96:7765–7776.

Welchman D.D.B. (1987) Physiological aspects of welfare research in veal calves with special reference to abomasal ulcers. In: Schlichting M.C. and Smidt D. (Eds.) *Welfare Aspects of Housing Systems for Veal Calves and Fattening Bulls*. Luxembourg, Commission of the European Communities, pp. 89–970.

Welchman D.D.B. & Baust G.N. (1987) A survey of abomasal ulceration in veal calves. *Veterinary Record* 121:586–590.

Wensing T., Breukink H.J. & van Dijk S. (1986) The effect of feeding pellets of different types of roughage on the incidence of lesions in the abomasum of veal calves. *Veterinary Research Communications* 10:195–202.

Wiepkema P.R., van Hellemond K.K., Roessingh P. & Romberg H. (1987) Behaviour and abomasal damage in individual veal calves. *Applied Animal Behaviour Science,* 18:257–268.

Yandrapu H. & Sarosiek J. (2015) Protective factors of the gastric and duodenal mucosa: An overview. *Current Gastroenterology Reports* 17:24.

Yeomans N.D. (2011) The ulcer sleuths: The search for the cause of peptic ulcers. *Journal of Gastroenterology and Hepatology* 26:35–41.

5. Comparison of the welfare implications of rearing veal calves in stall, tether, and group housing systems

Conclusions

1. **Most studies report that calves are more active in group pens than in individual pens, mainly because the extra space allows for the expression of many activities. The role of the social effect on the expression of locomotion itself is less well understood.**

2. **Calves are motivated to seek social contact.**

3. **Calves kept in pairs have greater weight gains than those kept individually.**

4. **Calves in individual housing have been reported to rest less with their legs extended and to rest more with legs bent than calves in group housing. This may be due more to the greater space allowance typically found in group housing.**

5. **There is no evidence that group housing increases the risk of diarrhoea.**

6. **There is some evidence that when the prevalence of respiratory disease is high, the prevalence may be greater in group housing than in individual housing.**

7. **Calves with more space are reported to be less at risk of anaemia than those kept in more confined situations.**

8. **Studies that have compared mortality rates in group and individual housing find higher mortality in large groups (> 10 calves) compared to individual housing, but no differences have been found between small groups (< 7–10 calves) and individual housing.**

9. **There are few studies comparing tethered to non-tethered calves in similar stalls; therefore, it is difficult to report conclusions on the effects of tethers. In the two studies that compared tethered calves to group housed calves, tethered calves had lower weight gains in the latter stages of production, lower blood haemoglobin concentration and packed cell volume, and spent less time in rapid eye movement (REM) sleep. We do not know if these effects are due to the tether or to the space allowance.**

5.1 Introduction

In recent years, public concern regarding individual housing of most animal production species has grown, and veal calf production has been heavily criticized for keeping calves in stalls. A stall is an enclosure that is too narrow for the animal to turn around in, while a pen allows more space and the possibility to move and turn around. Much research has been done on developing best practices for group rearing of dairy replacement calves but less frequently for group rearing of veal calves. In this review, we will present the work done on calves reared individually, in pairs, and in groups. We will bring together the research looking at calves fed only milk as well as those fed both milk and grain, and results on animal health, behaviour, physiology, and performance are examined.

Two potential welfare advantages with group housing arise. One is that calves have the opportunity for social contact, and the other is that group pens provide more space to the calves. In fact, when the space allowance per calf is the same for a group as for individual pens, the total amount of space available to the calves is larger in group pens allowing for a greater range of behaviours such as running, jumping, and play.

Scientific evidence shows that young calves are very motivated to have social contact with conspecifics. Holm et al. (2002) examined how much work pair housed calves (8 weeks of age) were willing to do to gain access to their companion calf after they had been isolated from that companion for a maximum of 6 weeks (during the experimental period). They looked at how much the calves would work to interact with their companion calf when it was in a pen where they could only have access to the companion's head versus when they could have full-body contact with the companion. They found that calves worked more to get full-body social contact with their companion rather than access to head contact alone. These results suggest that, for calves, full social contact is of a greater value than head contact alone.

The occurrence of cross-sucking and the risk of increased disease transmission are welfare concerns regarding group housing. However, research has shown that cross-sucking is related to how and how much calves are fed and can be reduced with appropriate feeding methods (see *Chapter 1 – Management of milk feeding*). The effects of group housing on animal health are adressed below.

A number of studies have made direct comparisons between calves kept in groups and those kept individually. Table 5.1 summarises the results of these studies. They consist of large epidemiological studies of commercial herds and smaller scale experimental studies. While some have involved veal calves, the majority involve calves in dairy production.

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
VEAL								
Andrighetto et al. (1999)	34 Male Holstein Milk-fed Veal	Tether 0.6×1.4m	3 $1.5m^2$/calf	40 d	142 d	Daily gain 71 to 142 d (1387 vs 1317 g/d) Feed efficiency 71 to 142 d (1.83 vs 1.94 g DM/g gain) Haemoglobin (10.9 vs 7.7 g /100ml) PCV (32.9 vs 23.6 %) Sham ruminating (1.9 vs 5.1 %)	Tongue playing (5.1 vs 2.6 %) Self-grooming (6.5 vs 2.9 %)	Daily gain 0 to 70 d (1076 vs 1055 g/d) Daily gain 0 to 142 d (1198 vs 1223 g/d) DM intake 0 to 142 (2066 vs 2060 g/d) Feed efficiency 0 to 142 d (1.73 vs 1.69 g DM/g gain) Live weight at 142 d (238.4 vs 240.7 kg) Treatment for gastrointestinal and respiratory diseases
Bokkers & Koene (2001)	12 farms Holstein Male Veal	. $1.4m^2$	5-7 $1.8m^2$	8 wk	26 wk	Standing wk 12 Carcass weight (147.8 vs 139.4kg)	Hair balls (86 vs 33 %)	Standing wk 3, 6, 24 Oral behavior Self-grooming Hemoglobin Abomasal ulcers Tongue damage Adrenal weights
Stull & McDonough (1994)	550 Male Holstein Milk-fed Veal	0.48 – 0.55 wide	30 $1.66m^2$	1 wk	16 wks	Plasma cortisol wk 8-16	Body weight wk16 (161 vs 153 kg) Neutrophil:lymphocyte ratio wk 8	Body weight wk 8 (96 vs 94kg) Neutrophil:lymphocyte ratio wk 12 -16

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
VEAL								
Xiccato et al. (2002)	80 Male Holstein Veal	0.65× 1.8m tether	4 7.04m^2	60 d	16 wks	Body weight (254.7 vs 249.2 kg) Weight gain (1.42 vs 1.38 kg/d) Feed efficiency (0.62 vs 0.61 gain:feed) Packed cell volume (d71, d113)		Milk intake Solid feed intake
Veissier et al. 1998	32 Male Holstein and Montbeliard Milk-fed Veal	0.9 × 2.0m 1.8m^2/ calf	4 3.6 × 2.0 1.8m^2/calf	Not reported	19 wk	Time moving (1.5 % vs 0 %) Basal cortisol Cortisol after CRF Abomasal ulcers	Licking objects (2.8 % vs 1.2 %) Sniffing (6 % vs 4 %) Calves tongue rolling (15/16 vs 6/16)	Nibbling at objects Cortisol after ACTH Basal ACTH Adrenal weights Hematocrit 38 & 66 d Duration of medical treatments Weight gain
DAIRY								
Bernal-Rigoli et al. (2012)	50 Male Holstein Dairy	1.22 × 2.44 m	3 or 4 2.98m^2/calf	3 d	66 d	Fecal scores (more watery) for bucket fed calves (2.1 vs 1.3) Average daily gain d41-48 (0.81 vs 0.66 kg/d; P =0.07) BW at 66d (72.6 vs 69.9 kg) Dry matter intake overall average (1.25kg/d vs 1.15 kg/d)		Overall health score Fecal scores for bottle fed calves Overall average daily weight gain. Feed efficiency

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
DAIRY								
Chua et al. (2002)	30 Holstein Dairy	1.2 × 1.7m 2.04m^2	2 2.04m^2	2 d	8 wk	Weight gain wk 6 Standing (4.77 vs 3.33) Moves (1.43 vs 0.64)	Head out of pen (12.63 vs 9.59)	Weight gain wks 1-5 and wks 7-8 Scours duration (3.7 d vs 3.1 d Self-grooming (3.53 vs 3.07) Sucking teat (3.43 vs 3.77)
Cobb et al. (2014a)	90 Female Holstein Dairy	1.83 × 1.87m 2.5m^2 * poor ventilation and dirty building	2 or 3 2.5m^2 * poor ventilation and dirty building	(2 ± 1 d)	90 d	Grain intake wk 8, 9, 11 Incidence of respiratory disease (10 vs 23 vs 34 % p=0.09)		Grain intake wk 1-7 Overall weight gain Incidence of scours (66 vs 44 vs 57 % for 1, 2 and 3) Incidence of severely ill calves first 2 wk (30 vs 37 vs 13 %) Calf mortality (7 vs 23 vs 17 % for 1, 2 and 3) Immune measures
Cobb et al. (2014b)	49 Female Holstein Dairy	1.09 × 2.13 4.8m^2 *outdoor hutch	3 7.0 m^2 *outdoor hutch	2 ± 1 d	90 d	Postweaning starter intake Weight gain during weaning (d54 –d68) Fecal scores (after d9 P = 0.097) Improved neutrophil response	Exploration in novel environment	Preweaning starter intake Feed efficiency Incidence of scours Haptoglobulin concentrations
Costa et al. (2015)	40 Male Holstein Dairy	1.2 × 2m	2 2.4m^2/calf	6 ± 3 d (Early-Paired EP) 43 ± 3 d (Late-Paired (LP)	64 d EP 27 d LP	Calf starter intake (EP > LP and Indiv) Total DMI (EP > LP and Indiv) Overall weight gain (EP 0.89 > Indiv 0.76 and LP 0.73). Post-weaning weight gain (EP > LP and Indiv.)		Intake of TMR Pre-weaning weight gain to 6 wk

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
DAIRY								
De Paula Vieira et al. (2012)	18 Holstein Dairy Calves	1.2 × 2.0m	2 2.4m^2/calf	1 wk	10 wk	Exploration in test with unfamiliar calf (358.2 vs 262.1s)	Defecation rate in response to novelty (1.3 vs 0.6) “Backing-off “(4.7 vs 1.6). Latency to initiate a social interaction with unfamiliar calf (111.1 vs 20.4 s)	
De Paula Vieira et al. (2010)	27 Holstein Dairy Calves	1.2 × 2.0m	2 2.4m^2/calf	4 d	52 d (On d 56 individuals and pairs were moved to groups of 6 calves)	Starter intake during milk feeding period up to d 36 (93 vs 59 g/d) Visits to feeder after grouping at 56d (41.6 vs 26.4 visits/d) Time spent at the feeder after grouping (87. vs 65.3 min/d) Weight gains 2-3d after grouping (0.5 vs −2.4 kg/d; and 0.8 vs −0.9 kg/d)	Vocalizations from d 42 to d 48 (7.6 vs 2.1 calls/ 2-h) Vocalizations at weaning (194 vs 84 calls/2-h) Vocalizations from d 49 to 55 (75.7 vs 29.4 calls/calf; P < 0.001) Latency to start feeding after mixing in groups (49.5 ± 4.1 vs 9.1 ± 2.6 h/calf)	Milk intake (9.6 kg/d) Pre-weaning weight gain (61.0 ± 4.7 kg/calf)
Duve & Jensen (2012)	54 Male and Female Holstein Dairy	1.5 × 1.5m	2 2.25m^2/calf	< 60 h (Early EP) 3 wks (Late LP)	6 wks 3wks			Weight gain Time spent lying down Very little cross-sucking
Gaillard et al. (2014)	18 Holstein Dairy Calves	1.2 × 2.0m 2.25m^2	2 2.4m^2/calf	4-5 d	4 to 7 wks	Improved reversal learning (P= 0.018).		Rate of initial discrimination learning Time spent exploring a new object

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
DAIRY								
Hänninen et al. (2005)	36 Male Holstein	1.05 × 1.8m	2 1.89m^2/ca	1 wk	20 wk	Time lying on the side		Average daily weight gain Total time lying down
Hänninen et al. (2003)	32 Male Ayrshire /Friesian Dairy Calves	1.0 × 1.2m	4 3 m^2/calf	8 d	12 wk	Resting with head on ground (1.5±0.4 vs 5.7±1.2 %) Resting on the side (1.4 vs 2.46 %) Locomotion (3.5vs 5.4 %)	Diarrhoea incidence (6.3 vs 1.2 %)	Average daily weight gain (756 vs 888 g/d) Diarrhoea duration
Jensen et al. 2015	48 Male and Female Holstein	3.0 × 4.5m	2 6.75m^2	3	40 d	Concentrate intake if fed 9L/d milk (840 vs 530g/d) Weight gain if fed 9L/d milk (990 vs 850g/d)	Locomotor play	Concentrate intake if fed 5L/d milk Daily weight gain if fed 5L/d milk Total play (social + locomotor)
Losinger and Heinrichs 1997	47,057 Female Holstein Dairy	Not reported	2-6 (small) 7+ (large)	Not reported	Not reported	Risk of having high mortality Large > Individual (1.0 vs 0.61)		Risk of having high mortality Small = Individual (0.67 vs 0.48)
Miller-Cushon & De Vries 2016	20 Male Holstein Dairy	1.8 × 2.4m 4.32m^2	2 4.32m^2	birth	52 d	Feed DM intake during weaning (0.46 vs 0.20 kg/d) Weight gain during weaning (0.67 vs 0.41 kg/d) Solid feed intake wk6 (0.17 vs 0.062 kg DM/d) Solid feed meal frequency wk6 Prefer feeding next to another calf		Pre-weaning Milk replacer intake Pre-weaning feed DM intake Pre-weaning weight gain Milk replacer intake wk6 Post-weaning feed intake Post-weaning weight gain

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
DAIRY								
Pempek et al. 2016	40 Female Jersey Dairy	1.22 × 1.17 $1.43m^2$ hutch	2 $1.46m^2$	birth	9 wk	Weight gain (0.63 vs 0.59kg/d; P=0.09) Final body weight (64.9 vs 61.7 kg) Grain intake wk9 (2.36 vs 2.1 kg/d)	Non-nutritive sucking (21.5 vs 8.15 %) Self-grooming (1.94 vs 0.67 %) Object play (1.36 vs 0.21 %)	Fecal score Body temperature Grain intake Standing vs lying Locomotor play
Pereira et al. 2014	658 Female Holstein Dairy	Not stated	15 - 20	3 d	65 d	E. coli resistance to 2 antibiotics	E. coli resistance to 5 anitbiotics Salmonella occurrence (83 % vs 33 %)	Overall E. coli antibiotic resistance
Richard et al. 1988	12 Holstein Dairy Calves	1.17 × 1.96 m	3 2.05 m^2/calf	1 d	6 wk	Mean preweaning body weight (wk1-5) (62.9 vs 58.2 kg) Milk replacer intake (1.48 vs 1.20 kg/d) Plasma glucose concentration wk2-4	Packed cell volume (37.2 vs 29.6 %; P<0.10)	Body weight wk6 Average daily weight gain Calf starter intake
Svensson et al. 2003	3081 Female Holstein Red + white Dairy	Not reported	3-8 Small 6 – 30 Large	1-2 wk	5-9 wk	Respiratory disease incidence Large > Individual (7.4 vs 3.5)		Diarrhoea incidence Respiratory disease incidence (Individual = Small) (3.1 vs 3.5 %

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
DAIRY								
Tapki 2007	24 Holstein Dairy	1.0 × 1.5m 1.5m^2	3 3m^2/calf	34 d	30 d	Walking (19.14 vs 3.81 %; P<0.01) Playing (12.80 vs 2.86 %; P<0.01) Grooming (8.06 vs 4.60 %; P<0.01) Calf starter intake (37.35 vs 23.39 kg/30d; P<0.01) Alfalfa hay intake (8.76 vs 7.14 kg/30 days; P=0.045) Feed intake (46.11 vs 30.53 kg/30 days; P<0.01) Body weight 63d (69.87 vs 67.71) Gain 34 to 63 d (20.94 vs 18.58 kg); Gain 4 to 63 d (33.87 vs 30.69 kg)	Licking objects (2.94 vs 1.03 %; P<0.01) Idle standing (36.29 vs 20.73 %; P<0.01) Lying (39.53 vs 30.19; P<0.01) Restlessness (3.47 vs 1.69; P<0.01)	Tongue rolling (6.50 vs 6.36 %; P<0.01)
Valníčková et al. 2015	40 Female Holstein and Czech Dairy	2.9m^2 *outside hutch 50 % kept with mother but no inter-action	4 2.9m^2 *outside hutch 50 % kept with mother but no inter-action	11 d	8 wk	Locomotor play in home pen wk 2 and 5 Body weight wk4 - 9	Locomotor play in large test pen	
Waltner-Toews et al. 1986	682 Female Holstein Dairy	Not reported	Not reported	Not reported	Not reported	Risks of summer mortality (X 3.91) (P > 0.15)		

Table 5.1 Summary of results from studies examining differences between group and individual housing of calves (continued…)

Reference	Type of animal	Indiv. housing	Size of group and area/calf	Age into group	Duration in Group	Group>Indiv	Indiv>Group	Indiv=Group
DAIRY								
Warnick et al. 1977	36 male and female Holstein Dairy	1.2 × 2.4m (outdoor hutch)	6 10.16 m^2	? (at birth)	124 d	Weight gain d74-124 (45.6 vs 40.9 kg)		Weight gain d0-d74 Solid feed intake
BEEF								
Hanekamp et al. 1994	1040 Red and white Beef	0.65 × 1.65m	5 1.2 m^2	1-2 wks	3 mo	Respiratory disorders (60 vs 38.5 %)	Weight gain (677 vs 650g/d) Feed intake (750 vs 730)	Mortality (2.1 vs 3.5 %) Feed conversion

5.2 Behaviour

5.2.1 Activity

Exercise is important to maintain the health and welfare of growing animals. Of most interest for the veal industry are the findings from research on humans and other animals showing that exercise can increase blood haemoglobin concentration and the proportion of red cells (packed cell volume or PCV), which enhances oxygen-carrying capacity and reduces the risk of anaemia (e.g., Hu & Lin, 2012). This effect has been demonstrated when calves are housed in groups of 3 with the possibility to exercise compared to tethered calves (Andrighetto et al., 1999). Exercise can also increase bone and muscle growth (Iwamoto et al., 2004). In young calves, exercise related behaviours include walking, running, jumping, and bucking (often called "locomotor play").

Locomotor play has been suggested as a sign of good welfare of growing animals (Held & Spinka, 2011). In calves, it is well documented that many threats to welfare, such as hunger from a low feed allowance, weaning off milk (Krachun et al., 2010), or lack of pain control during dehorning, reduce the amount of locomotor play shown (Mintline et al. 2012a; Rushen & de Passillé, 2012). Calves showing higher amounts of locomotor play have higher growth rates both before and after weaning off milk (Miguel-Pacheco et al., 2015).

Most studies report that calves are more active in group pens than in individual pens (not stalls), but this may reflect the extra space available in group pens rather than the social effect itself. Six studies measured the time calves spent standing up rather than lying down (Table 5.1). Three studies found more time standing in group pens: two of these were of calves in large group pens (Bokkers & Koene, 2001: 9 m^2 ; Tapki, 2007: 9 m^2), and the effect has also been reported in one study involving smaller pens (does not include stalls) (Chua et al., 2002: 4.08 m^2). In 3 studies, involving smaller group pens, no differences were found (Pempek et al., 2016: 2.92 m^2; Hanninen et al., 2005: 3.5 m^2; and Duve & Jensen, 2012: 4.5 m^2). Four studies report measures of "locomotion," "moving," or "walking," and all find more activity in group pens (Veissier et al., 1998; Tapki, 2007; Hanninen et al., 2003; and Chua et al., 2002). Four studies measured high energy activity, such as running, jumping, and bucking (commonly called "locomotor play"): two found an advantage to group housing (Tapki, 2007; Valníčková et al., 2015), one found an advantage to individual housing (Jensen et al., 2015; both had large pens), while one reports no difference (Pempek et al., 2016). However, these advantages of group housing are most probably related to the total space available. For example, LeNeindre (1993) showed that calves in groups were more active than calves in individual housing with a smaller spatial allowance, while there was no difference if the individual housing provided a similar space allowance as the group housing.

The two studies that found more locomotor play in group pens used pens with a much larger total area than the individual pens (Tapki et al., 2007: 9m^2 vs 1.5m^2; Valníčková et al., 2015: 11.6m^2 vs 2.9 m^2). The one study that found no difference used smaller pens (Pempek et al., 2016: 2.92 m^2 vs 1.43 m^2). Jensen et al. (2015) found more locomotor play in individual pens, but these were as large as the group pens, with more space available per animal (13.5 m^2 vs 6.75 m^2). This is supported by other studies showing that more locomotor play occurs in large areas (Mintline et al., 2012b).

Calves kept tethered showed more activity when released into an open area than calves kept in group housing (Dantzer et al., 1983). Greater activity when released into an open area has also been found for calves housed individually in a small area compared to a large area (most recently by Rushen and de Passillé, 2014), which has been interpreted as a compensatory "rebound" in motivation for activity due to the reduced amount of activity shown in the smaller home pen (Dellmeier et al., 1985). Jensen et al. (1997) found increased immobility in individually housed calves compared to group housed calves when they were placed in an unfamiliar open area (an "open field" test), which they interpreted as signs of fearfulness.

The effect of social contact per se (independently of space allowance) on locomotor play is not well understood. When housed together, calves engage in social play, which involves mainly play fighting (Jensen & Kyhn, 2000). Jensen et al. (2015) found that the time spent by group-housed calves in social play and locomotor play together was the same as the amount of time spent by individually-housed calves in locomotor play, suggesting that the extra locomotor play substituted for the absence of social play.

5.2.2 Resting positions

Some studies report that calves in group housing are more able to adopt relaxed resting positions, including legs outstretched (Andrighetto et al., 1999) or lying fully on their side or with the head resting on the ground (Hänninen et al., 2005). These postures, either lying fully on their side or with the head resting on the ground, are important because they are most associated with the REM (rapid eye movement) sleep of calves (Hänninen et al., 2008). The effect of group housing is most likely due to the greater space availability in the larger group pens. LeNeindre (1993), in a review of veal calf welfare, shows data (from a non-peer reviewed report) suggesting that calves in larger individual crates adopted more postures with the legs outstretched and less postures with the legs bent than calves in smaller individual crates as well as in group housing. Furthermore, epidemiological study results indicate that a space allowance of less than 1.8 m^2/calf is associated with a higher prevalence of bursitis; the authors suggested that higher space allowance allows calves to stretch out their legs thereby perhaps reducing swelling of the carpal bursae (Brscic et al., 2011).

Jensen (1995) compared 12-week-old heifers tethered or housed in groups of 3 animals (and then tethered at 23 wks). At 20 wks old, tethered heifers spent more time lying down (62% vs 56%), laying with their head raised (52.2% vs 45.6%) than group housed heifers. Calves tethered at a late age have more initial problems changing position in the tie-stall and suffer a reduction in lying time for longer than calves tethered at an early age. In another study (Andrighetto et al., 1999), tethered calves spent more time lying with all four legs bent than group housed animals (41.8 vs 26.6 %). Tethered animals never outstretched all four legs during the observation period, probably due to the reduced dimensions of the stall.

Tethering reduced the calves' frequency of lying with the head turned backwards (REM sleep phase) compared to non-tethered calves housed in pens (de Wilt, 1985). In stalls provided with gliding chains, the occurrence of this posture was lower than in calves housed in stalls of identical width but equipped with fixed chains.

5.2.3 Abnormal behaviour

Five studies report a higher frequency of some abnormal behaviours in individually housed calves compared to grouped calves such as tongue playing (LeNeindre, 1993; Andrighetto et al., 1999), non-nutritive sucking (Pempek et al., 2016), or licking objects (Veissier et al., 1998; Tapki et al., 2007). In contrast, for example, in a review of non-peer reviewed research, LeNeindre (1993) reported more object licking (combined with scratching) in group housed calves. However, there is some evidence that the greater space allowance in group housing may be responsible for the differences: LeNeindre (1993) showed that calves in groups showed less tongue rolling than calves in individual housing with a smaller spatial allowance, while there was no difference if the individual housing provided a similar space allowance as the group housing. Supporting this, in an epidemiological study Leruste et al. (2014) found that increasing space allowance for group housed calves beyond the legal minimum required in the EU of 1.8m^2/calf reduced the incidence of tongue rolling.

Furthermore, calves in group pens sometimes perform cross-sucking directed at another calf, which cannot occur in most individual housing. Bokkers and Koene (2001) measured the time spent in all oral behaviours and found no difference between group and individually housed calves. As explained in Chapter 1 of this report, the occurrence of such behaviours may reflect feeding practices more than housing methods per se.

5.3 Weight gain

Twenty-two studies (5 veal production, 16 dairy production, and 1 beef production) have compared group and individual housing for weight gains. Of these, 15 (3 veal, 12 dairy) found some advantage to group housing at some time point, 2 (1 veal and 1 beef) showed an advantage to individual housing, while 5 (1 veal and 4 dairy) found no difference in any measure at any time. The reasons for different findings between these studies does not appear to be due to the age of calves when introduced into groups: the age of introduction for studies that found an advantage to group housing ranged from soon after birth to 60 d, while the two studies that found an advantage of individual housing introduced calves into groups at 1–2 weeks of age (Hanekamp et al., 1994) or at an average of 7d (Stull & McDonough, 1994). Indeed, Costa et al. (2015) found improved weight gain for calves placed in groups at 6 d of age but not for calves placed in groups at 43 d of age, suggesting that placing calves into groups at an early age does not negatively affect their growth rates.

Nor is the space allowance per calf in individual housing an obvious cause for the difference in weight gain. The space allowance for the individually-housed calves in the studies that reported an advantage to group housing were often the same as the space allowance of the group housed calves (Chua et al., 2002, groups of 2; Costa et al., 2015, groups of 2; De Paula Vieira et al., 2010, groups of 2; Bernal-Rigoli et al., 2012, groups of 3 or 4; Miller-Cushon & De Vries, 2016, groups of 2) or in one case larger than that of the group housed calves (Jensen et al., 2015, groups of 2).

Tethered calves showed lower average daily gain (1317 vs 1387 g/d) than group-housed calves during the last 72 d of the trial (Andrighetto et al., 1999).

The number of calves in the group may be important: the majority of those studies that found an advantage with group housing studied groups of 2–4 animals. In two studies where groups of 5–7 animals were compared to individually housed calves, one study reports higher carcass weights from group housed calves (Bokkers & Koene, 2001) and the other similar weight gains (Warnick et al., 1977). However, in both of these studies methodological issues, such as differences in diet between individually penned calves and group penned calves (Bokkers & Koene, 2001) and keeping the individually penned calves outside and the group reared calves inside (Warnick et al., 1977), do not permit unambiguous conclusions on the effect of group housing on weight gain. The studies finding an advantage of individual housing were comparing calves kept in groups of 30 animals (Stull & McDonough, 1994) or 5 (Hanekamp et al., 1994). This body of research suggests that it is possible to achieve equal or better weight gains in group housing compared to individual systems.

5.4 Feed intake and feed conversion efficiency

The higher weight gains that were found in group housing can be explained by a higher solid feed intake. Four studies compared group and individual housing for intakes of milk or milk replacer: one study found an advantage to group housing (Richard et al., 1998, groups of 3) while 3 reported no difference (Xiccato et al., 2002, groups of 4; De Paula Vieira et al., 2010, groups of 2; and Miller-Cushon & De Vries, 2016, groups of 2). Twelve studies examined intake of solid feed: 9 found an advantage of group housing (Tapki, 2007; Costa et al., 2015; De Paula Vieira, et al., 2010; Bernal-Rigoli et al., 2012; Jensen et al., 2015; Pempek et al., 2016; Cobb et al., 2014a and b; Miller-Cushon & De Vries, 2016), 3 found no difference (Xiccato et al., 2002; Richard et al., 1988; Warnick et al., 1977), while 1 found an advantage to individual housing (Hanekamp et al., 1994). Five studies examined feed conversion efficiency: 2 found an advantage to group housing when comparing to tethered calves (Andrighetto et al., 1999, groups of 3; Xiccato et al., 2002, groups of 4), while 3 reported no difference between group and individually housed calves (Bernal-Rigoli et al., 2012, groups of 3 or 4; Cobb et al., 2014b, groups of 3; Hanekamp et al., 1994, groups of 5). In general, housing in groups of 2–5 calves appeared to improve intakes of solid feed, and sometimes improved feed conversion efficiency, and no deleterious effects were reported on milk intake.

5.5 Health

Transmission of gastrointestinal pathogens occurs directly via the faecal oral route from the faeces of infected calves to the mouths of susceptible calves. It can also occur from nose-to-nose contact or inhalation of aerosols produced by coughing, urination, or defecation. Individual housing prevents suckling and licking behaviours and faecal cross-contamination more effectively than group housing (Barrington et al., 2002). Transmission of respiratory pathogens occurs by nose-to-nose contact, environmental or fomite exposure, and airborne exposure. The common viral respiratory pathogens can be transmitted for more than 4 metres. Therefore, keeping calves singularly in adjacent pens in a common air space may not significantly reduce the risk of transmission between calves by aerosol. Increased contact between calves shedding respiratory pathogens and susceptible calves will increase the spread of disease. The larger the group size, the greater the risk of the group containing at least one calf that is shedding respiratory pathogens. This one calf can expose the rest of the group to disease by close contact, airborne transmission, or environmental transmission via common feeding equipment etc. In addition, increasing group size might increase the risk of respiratory disease by reducing the floor space per calf, cubic air space per calf, and air quality (by increasing aerial contamination) (Callan & Garry, 2002).

Seventeen studies report a comparison between group and individual housing for some health measure; one shows an advantage to group housing, 11 show an advantage to individual housing, while 5 report no differences (Table 5.2). However, the reasons for the differences are not obvious and the health measures are often inconsistent.

Bernal-Rigoli et al. (2012) found higher faecal scores (more liquid feces) in group housed calves but only if the calves were fed from a bucket (not if fed from a bottle). Cobb et al. (2014b) similarly found higher faecal scours in group housed calves, but the actual incidence of diarrhoea did not differ. In contrast, Hanninen et al. (2003) reported a lower incidence of diarrhoea in group housed calves, while Svensson et al. (2003), Andrighetto et al. (1999), Chua et al. (2002), Pempek et al. (2016), and Cobb et al., (2014a) report no differences in the incidence of diarrhoea or duration of diarrhoea. Pereira et al. (2014) were able to isolate *Salmonella* (one potential cause of diarrhoea) from more individually housed calves than from group housed calves, while the incidence of antibiotic resistance of *E. coli* was equal in the two housing systems.

Table 5.2 Mortality rates, culling rates, morbidity, and timing and causes of mortality in dairy and veal calves.

Reference	Overall annual mortality [group[e] range; farm range]	Overall annual culling [group range; farm range]	Peak death losses [cause as determined by necropsy as a % of all mortalities]	Week at peak losses (death and cull)	Single leading cause of mortality [% of all mortality]	Morbidity
Sargeant et al.(1994a) - 4863 white veal calves - 6 Ontario farms (300-6000 calves per farm) - housed in stalls (40-107 stalls/room) - all treated w/ antibiotics in week 1	3.7 % [0-17.5 %; 1.4-7.9 %]	5.1 % [ŧ] [0-20.6 %; 2.6-10.6 %] [ŧ]	Weeks 2 & 3 and 7 & 8	5 & 8	Pneumonia (especially in weeks 4-10)*	Overall 59 % received at least 1 individual treatment w/ majority of these being first treated in wks 3-6
Sargeant et al. (1994b) - 2251 pink veal calves - 7 Ontario farms raising 46-1135 calves/year - group housed with groups ranging from 5-55	5.4 % [1.0-21.7 %]	0.8 % [a] [0-2.9 %]		5 & 17-20 [b]		17.5-84.9 % received at least 1 individual treatment
Windeyer et al. (2014) - 2874 dairy replacement heifer calves on 19 dairy farms in Minnesota and Ontario - followed for 3 months	3.5 %; median 3.2 % [c] [--; 0-10 %] [c]		11 days [c]	--		23 % of calves treated for diarrhoea farm level range in treatment of diarrhoea (0-44 %) 22 % of calves treated for BRD (farm range 0-56 %)
Pardon et al. (2012) - dairy, beef, and cross breeds included in Belgian study on white veal - Diet and other factors differ by breed but overall few significant differences in mortality and morbidity between different systems - 5853 calves in study - individual stall for 6 weeks followed by group housing on slats - slaughtered at 6-8 months	5.3 % (and in dairy breeds was 4.9 %) [d,f] [--, 1.8-10.9 %]	0.3 %	First peak at week 2 [pneumonia 27.3 %; enteritis 22.7 %] Second peak at week 9 [mainly peritonitis esp for dairy breeds range 0.4-2 %] Third peak in final stage [almost exclusively due to ruminal disorders] Mortality due to pneumonia peaked week 2-6 but continued at a lower level throughout	--	Digestive system [41.9%]** *Other details:* Respiratory system [27.7 %] Idiopathic peritonitis [14.6 %] Musculoskeletal [3.6 % - mainly an issue in beef breeds] *More specifically:* Pneumonia [27 %] Ruminal disord. [18.6 %] Enteritis [9.6 %]	Overall cohort level morbidity risk 25 % [BRD 56.1 %; diarrhoea 18.5 %; otitis 5.7 % and arthritis 5.5 % of calves with morbidity] Morbidity peaked in first 3 weeks and gradually declined with very few treatments at end of production. Diarrhoea especially freq in first 3 wks BRD freq immed following arrival and peak at wk 3

Table 5.2 Mortality rates, culling rates, morbidity, and timing and causes of mortality in dairy and veal calves (continued…)

Reference	Overall annual mortality [group[e] range; farm range]	Overall annual culling [group range; farm range]	Peak death losses [cause as determined by necropsy as a % of all mortalities]	Week at peak losses (death and cull)	Single leading cause of mortality [% of all mortality]	Morbidity
Pardon et al. (2013) - 3519 white veal calves on 10 commercial farms in Belgium - individual stall for 6 weeks followed by group housing on slats - mean age at arrival 18 days - all-liquid diet supplemented with solid feed	5.7 %				Pneumonia [27.1 %] Ac ruminal dis [11 %] Enteritis [7.5 %] Enterotox. [10 %] Idiop. peritonitis [7 %] DOA [5 %] Arthritis [3.5 %]	In addition to metaphylactic treatm, 22.7 % of calves were individually treated for 1 or more diseases Of these, 14.8 % for BRD, 5.3 % for diarrhoea, 1.5 % for arthritis Overall BRD incidence at cohort level 7.2 % (8.2-33.9 %)

[ǂ] Culled due to illness or poor performance.

*Together the misc and undiagnosed categories for cause of death accounted for more than one third of mortalities; no condition in misc category accounted for more than 4 deaths.

[a] The authors proposed the lower cull rate was due to the lack of market for cull calves from the red meat sector.

[b] Average time in production was 16.7 weeks in this study. The increase in losses seemed to mainly occur in weeks 17-20.

[c] The study followed calves for only 3 months.

[d] Mortality was higher in beef breeds perhaps due to longer production cycle of 28 weeks

[e] A group consisted of calves reared together within one room

[f] Mortality calculated for a production cycle of 6-8 months

**Includes abdominal disorders, enteritis, torsion related, abomasal “disorders” etc.

There is some evidence (Cobb et al., 2014a) that when respiratory disease does occur, the incidence may be higher in group housing, although few studies have examined this. Cobb et al. (2014a) reported a higher (but not statistically significant) incidence of respiratory disease (with a likely increase in mortality) of group housed dairy calves kept in a poorly ventilated barn. That this situation may not be typical of dairy or veal production is shown by the fact that mortality in this study was unusually high (17–23%), compared to the veal industry average of less than 5% (Stull & McDonough, 1994).

Hanekamp et al. (1994) also reported a higher incidence of respiratory disease in group housed calves, with a higher mortality in group pens. Again, the incidence of respiratory disease was high (60%). In contrast, Andrighetto et al. (1999) reported no treatment for respiratory disease in either group or individual housing.

A large epidemiological study found a higher incidence of respiratory disease in large groups (> 6–8) compared to small groups, suggesting that the size of the group appears to be an important factor. Svensson et al. (2003) and Brscic et al. (2012) found an increased risk of respiratory problems when there were > 15 veal calves per pen than when there were ≤ 6 per pen. The safest conclusion is that group housing does not necessarily increase the incidence of respiratory disease, but where environmental conditions result in a high incidence of respiratory disease, this may be exacerbated by group housing.

Two studies examined abomasal ulcers: one (Bokkers & Koene, 2001) found no difference, while another (Veissier et al., 1998) found more abomasal ulcers in grouped calves.

Two large epidemiological studies report higher mortality rates or risks to mortality with group housing compared to individual. However, Waltner-Toews et al. (1986) reported that the difference was lost once other management factors were taken into consideration, suggesting that the effects were not due to group housing per se. One of the management practices that can be more difficult in group housing, as discussed by some producers and authors, is the difficulty of identifying sick calves in a goup (Svensson et al., 2003; Brscic et al., 2012). A number of promising automated tools are being developed to help monitor calf health in large groups (Rushen et al., 2012). However, in small groups, producers don't seem to have a problem identifying sick calves as evidenced by the fact that health and mortality data is similar for calves housed in small groups and individual housing.

Losinger and Heinrichs (1997) reported higher mortality in groups larger than 7, while mortality rates in groups of 7 or smaller were the same as rates in individual housing.

While large group sizes appear to be a risk factor for increased health problems, there is no evidence that an early introduction into groups is responsible for the health effects of group housing. The four studies that reported health issues in group housing involved groups of 2–5 calves placed in the groups between 2 d and 1–2 weeks, which were within the ranges of the studies that found no difference or an advantage of group housing.

While the differences between group and individual housing in the occurrence of infectious diseases are often interpreted as due to differences in the probability of transmission, there is a possibility that the type of housing can affect the ability of the animal to resist infection due to improved immune responses.

van Reenen et al. (2000) reported that socially isolated calves showed a diminished clinical and fever response, and delayed viral excretion after primary infection with bovine herpes virus. However, there is too little information available to conclude much about the effects of housing on immune responsiveness.

5.6 Physiological measures

Four studies took measures of blood haemoglobin concentrations, PCV, or haematocrit to examine iron metabolism. Two studies reported higher blood haemoglobin concentrations or PCV in group housed calves vs individually housed (haemoglobin and PCV: Andrighetto et al. 1999; PCV: Xiccato et al., 2002), and two reported no differences (haematocrit: Veissier et al. 1998; PCV: Richard et al. 1988) (Table 5.1).

Three studies took physiological measures related to stress. Dantzer et al. (1983) found no differences in basal cortisol concentrations between individual and group housing, but found a higher cortisol response to ACTH injections in individually housed calves, which could be a sign of increased stress response. In contrast, Stull and McDonough (1994) found higher plasma cortisol concentrations in group housed animals, and that the neutrophil to lymphocyte ratio (a possible sign of stress) was higher in group housed calves at one test age, but they found they were lower at another test age. The authors admitted that differences in stress responses may have been due to the greater difficulties of catching group housed animals for blood sampling which in itself can cause stress.

Tethered calves also showed lower concentrations of blood haemoglobin and PCV when compared to group housed calves (4.8 vs 6.8mmol/l Hb and 23.6 vs 32.9 % PCV). Veissier et al. (1998) found higher basal cortisol and higher cortisol response to CRF in grouped calves, but no differences in basal ACTH, cortisol response to ACTH, or adrenal weights.

The conflicting findings from this limited research do not allow us to draw any firm conclusions about the effect of individual or group housing on physiological signs of stress.

5.7 References

Andrighetto I., Gottardo F., Andreoli D. & Cozzi G. (1999) Effect of type of housing on veal calf growth performance, behaviour and meat quality. *Livestock Production Science* 57:137–145.

Barrington G.M., Gay J.M. & Evermann J.F. (2002) Biosecurity for neonatal gastrointestinal diseases. *Veterinary Clinics of North America: Food Animal Practice* 18:7–34.

Bernal-Rigoli J.C., Allen J.D., Marchello J.A., Cuneo S.P., Garcia S.R., Xie G., Hall L.W., Burrows C.D. & Duff G.C. (2012) Effects of housing and feeding systems on performance of neonatal Holstein bull calves. *Journal of Animal Science* 90:2818–2825.

Bokkers E.A.M. & Koene P. (2001) Activity, oral behaviour and slaughter data as welfare indicators in veal calves: A comparison of three housing systems. *Applied Animal Behaviour Science* 75:1-15.

Brscic M., Gottardo F., Leruste H., Lensink J., van Reenen K.C.G. & Cozzi G. (2011) Prevalence of locomotory system disorders in veal calves and risk factors for occurrence of Bursitis. *Agriculturae Conspectus Scientificus* 76:291–295.

Brscic M., Leruste H., Heutinck L.F.M., Bokkers E.A.M., Wolthuis-Fillerup M., Stockhofe N., Gottardo F., Lensink B.J., Cozzi G. & van Reenen C.G. (2012) Prevalence of respiratory disorders in veal calves and potential risk factors. *Journal of Dairy Science* 95:2753–2764.

Callan R.J. & Garry F.B. (2002) Biosecurity and bovine respiratory disease. *Veterinary Clinics of North America: Food Animal Practice* 18:57–77.

Chua B., Coenen E., van Denle J. & Weary D.M. (2002) Effects of pair versus individual housing on the behavior and performance of dairy calves. *Journal of Dairy Science* 85:360–364.

Cobb C.J., Obeidat B.S., Sellers M.D., Pepper-Yowell A.R. & Ballou M.A. (2014a) Group housing of Holstein calves in a poor indoor environment increases respiratory disease but does not influence performance or leukocyte responses. *Journal of Dairy Science* 97:3099–3109.

Cobb C.J., Obeidat B.S., Sellers M.D., Pepper-Yowell A.R., Hanson D.L. & Ballou M.A. (2014b) Improved performance and heightened neutrophil responses during the neonatal and weaning periods among outdoor group-housed Holstein calves. *Journal of Dairy Science* 97:930–939.

Costa J.H.C., Meagher R.K., von Keyserlingk M.A.G. & Weary D.M. (2015) Early pair housing increases solid feed intake and weight gains in dairy calves. *Journal of Dairy Science* 98:6381–6386.

Dantzer R., Mormede P. & Bluthe R.M. (1983) The effect of different housing conditions on behavioural and adrenocortical reactions in veal calves. *Reproduction Nutrition Development* 23:501–508.

Dellmeier G.R., Friend T.H. & Gbur E.E. (1985) Comparison of four methods of calf confinement. II. Behavior. *Journal of Animal Science* 60:1102–1109.

De Paula Vieira A., de Passillé A.M. & Weary D.M. (2012) Effects of the early social environment on behavioral responses of dairy calves to novel events. *Journal of Dairy Science* 95:5149–5155.

De Paula Vieira A., von Keyserlingk M.A.G. & Weary D.M. (2010) Effects of pair versus single housing on performance and behavior of dairy calves before and after weaning from milk. *Journal of Dairy Science* 93:3079–3085.

de Wilt J.G. (1985) Behaviour and welfare of veal calves in relation to husbandry systems. Thesis. The Institute of Agricultural Engineering. Wageningen, The Netherlands, p. 138.

Duve L.R. & Jensen M.B. (2012) Social behavior of young dairy calves housed with limited or full social contact with a peer. *Journal of Dairy Science* 95:1–10.

Gaillard C., Meagher R.K., von Keyserlingk M.A.G. & Weary D.M. (2014) Social Housing Improves Dairy Calves' Performance in Two Cognitive Tests. *PLoS ONE* 9(2):e90205

Hanekamp W.J.A., Smits A.C. & Wierenga H.K. (1994) Open versus closed barn and individual versus group housing for bull calves destined for beef production. *Livestock Production Science* 37:261–270.

Hänninen L., de Passillé A.M. & Rushen J. (2005) The effect of flooring type and social grouping on the rest and growth of dairy calves. *Applied Animal Behaviour Science* 91:193–204.

Hänninen L., Hepola H., Rushen J., de Passillé A.M., Pursiainen P., Tuure V.-m., Syrjälä-qvist L., Pyykkönen M. & H. Saloniemi (2003) Resting behaviour, growth and diarrhoea incidence rate of young dairy calves housed individually or in groups in warm or cold buildings. *Acta Agriculturae Scandinavica, Section A — Animal Science* 53:21–28.

Hänninen L., Mäkelä J.P., Rushen J., de Passillé A.M. & Saloniemi H. (2008) Assessing sleep state in calves through electrophysiological and behavioural recordings: A preliminary study. *Applied Animal Behaviour Science* 111:235–250.

Held S.D.E. & Špinka M. (2011) Animal play and animal welfare. *Animal Behaviour* 81:891–899.

Holm L., Jensen M.B. & Jeppesen L.L. (2002) Calves' motivation for access to two different types of social contact measured by operant conditioning. *Applied Animal Behaviour Science* 79:175–194.

Hu M. & Lin W. (2012) Exercise training, red blood cell production and anemia. *Acta Haematologica* 127:156–164.

Iwamoto J., Shimamura C., Takeda T., Abe H., Ichimura S., Sato Y. & Toyama Y. (2004) Effects of treadmill exercise on bone mass, bone metabolism, and calciotropic hormones in young growing rats. *Journal of Bone and Mineral Metabolism* 22:26–31.

Jensen M.B., Duve L.R. & Weary D.M. (2015) Pair housing and enhanced milk allowance increase play behavior and improve performance in dairy calves. *Journal of Dairy Science* 98:2568–2575.

Jensen M.B. (1995) The effect of age at tethering on behaviour of heifer calves. *Applied Animal Behaviour Science* 43:227–238.

Jensen M.B. & Kyhn R. (2000) Play behaviour in group-housed dairy calves, the effect of space allowance. *Applied Animal Behaviour Science* 67:35–46.

Jensen M.B., Vestergaard K.S., Krohn C.C. & Munksgaard L. (1997) Effect of single versus group housing and space allowance on responses of calves during open-field tests. *Applied Animal Behaviour Science* 54:109–121.

Krachun C., Rushen J. & de Passillé A.M. (2010) Play behaviour in dairy calves is reduced by weaning and by a low energy intake. *Applied Animal Behaviour Science* 122:71–76.

Le Neindre P. (1993) Evaluating housing systems for veal calves. *Journal of Animal Science* 71:1345–1354.

Leruste H., Brscic M., Cozzi G., Kemp B., Wolthuis-Fillerup M., Lensink B.J., Bokkers E.A.M. & van Reenen C.G. (2014) Prevalence and potential influencing factors of non-nutritive oral behaviors of veal calves on commercial farms. *Journal of Dairy Science* 97:7021–7030.

Losinger W.C. & Heinrichs A.J. (1997) Management practices associated with high mortality among preweaned dairy heifers. *Journal of Dairy Research* 64:1–11.

Miguel-Pacheco G.G., Vaughan A., de Passillé A.M. & Rushen J. (2015) Relationship between locomotor play of dairy calves and their weight gains and energy intakes around weaning. *Animal* 9:1038–1044.

Miller-Cushon E.K. & De Vries T.J. (2016) Effect of social housing on the development of feeding behavior and social feeding preferences of dairy calves *Journal of Dairy Science* 99:1406–1417.

Mintline E.M., Stewart M., Rogers A.R., Cox N.R., Verkerk G.A., Stookey J.M., Webster J.R. & Tucker C.B. (2012a) Play behavior as an indicator of animal welfare: Disbudding in dairy calves. *Applied Animal Behaviour Science* 144:22–30.

Mintline E.M., Wood S.L., de Passillé A.M.B., Rushen J.P. & Tucker C.B. (2012b). Assessing calf play behavior in an arena test. *Applied Animal Behaviour Science* 141:101–107.

Pardon B., de Bleecker K., Hostens M., Callens J., Dewulf J. & Deprez P. (2012) Longitudinal study on morbidity and mortality in white veal calves in Belgium. *BMC Veterinary Research* 8:26.

Pardon B., Hostens M., Duchateau L., Dewulf J., De Bleecker K. & Deprez P. (2013) Impact of respiratory disease, diarrhea, otitis and arthritis on mortality and carcass traits in white veal calves. *BMC Veterinary Research* 9:79.

Pempek J.A., Eastridge M.L., Swartzwelder S.S., Daniels K.M. & Yohe T.T. (2016) Housing system may affect behavior and growth performance of Jersey heifer calves. *Journal of Dairy Science* 99:569–578.

Pereira R.V., Siler J.D., Ng J.C., Davis M.A. & Warnick L.D. (2014) Effect of preweaned dairy calf housing system on antimicrobial resistance in commensal *Escherichia coli*. *Journal of Dairy Science* 97:7633–7643.

Richard A.L., Heinrichs A.J. & Muller L.D. (1988) Feeding acidified milk replacer ad libitum to calves housed in group versus individual pens. *Journal of Dairy Science* 71:2203–2209.

Rushen J., Chapinal N. & de Passillé A.M. (2012) Automated monitoring of behavioural-based animal welfare indicators. *Animal Welfare* 21: 339–350.

Rushen J. & de Passillé A.M. (2012) Automated measurement of acceleration can detect effects of age, dehorning and weaning on locomotor play of calves. *Applied Animal Behaviour Science* 139:169–174.

Rushen J. & de Passillé A.M.B. (2014) Locomotor play of veal calves in an arena: Are effects of feed level and spatial restriction mediated by responses to novelty? *Applied Animal Behaviour Science* 155:34–41.

Sargeant J.M., Blackwell T.E., Martin S.W. & Tremblay R.R.M. (1994a) Production practices, calf health and mortality on six white veal farms in Ontario. *Canadian Journal of Veterinary Research* 58:189–195.

Sargeant J.M., Blackwell T.E., Martin S.W. & Tremblay R.R.M. (1994b) Production indices, calf health and mortality on seven red veal farms in Ontario. *Canadian Journal of Veterinary Research* 58:196–201.

Stull C.L. & McDonough S.P. (1994) Multidisciplinary approach to evaluating welfare of veal calves in commercial facilities. *Journal of Animal Science* 72:2518–2524.

Svensson C., Lundborg K., Emanuelson U. & Olsson S.O. (2003) Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. *Preventive Veterinary Medicine* 58:179–197.

Tapki I. (2007) Effects of individual or combined housing systems on behavioural and growth responses of dairy calves. *Acta Agriculturae Scandinavica, Section A — Animal Science* 57:55–60.

Valníčková B., Stěhulová I., Šárová R. & Špinka M. (2015) The effect of age at separation from the dam and presence of social companions on play behavior and weight gain in dairy calves. *Journal of Dairy Science* 98:5545–5556.

van Reenen C.G., Mars M.H., Leushuis I.E., Rijsewijk F.A.M., van Oirschot J.T. & Blokhuis H.J. (2000) Social isolation may influence responsiveness to infection with bovine herpesvirus 1 in veal calves. *Veterinary Microbiology* 75:135–143.

Veissier I., Ramirez de la Fe A.R. & Pradel P. (1998) Nonnutritive oral activities and stress responses of veal calves in relation to feeding and housing conditions. *Applied Animal Behaviour Science* 57:35–49.

Waltner-Toews D., Martin S.W. & Meek A.H. (1986) Dairy calf management, morbidity and mortality in Ontario Holstein herds. IV. Association of management with mortality. *Preventive Veterinary Medicine* 4:159–171.

Warnick V.D., Arave C.W. & Mickelsen C.H. (1977) Effects of group, individual, and isolated rearing of calves on weight gain and behavior. *Journal of Dairy Science* 60:947–953.

Windeyer M.C., Leslie K.E., Godden S.M., Hodgins D.C., Lissemore K.D. & LeBlanc S.J. (2014) Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. *Preventive Veterinary Medicine* 113:231–240.

Xiccato G., Trocino A., Queaque P.I., Sartoria A. & Carazzolo A. (2002) Rearing veal calves with respect to animal welfare: effects of group housing and solid feed supplementation on growth performance and meat quality. *Livestock Production Science* 75:269–280.

6. Flooring and bedding

Conclusions

1. **Most peer-reviewed studies published on the effects of flooring and bedding on cattle have been done on fattening bulls (in Europe) and mature dairy cattle (work done internationally). These studies demonstrate that softness of the flooring and bedding are essential to ensure animal comfort. There are a limited number of studies comparing different types of flooring for veal calves specifically. Because veal calves are much lighter in weight, their responses to living on different flooring surfaces may differ from the responses of bulls and cows, which are much heavier.**

2. **Contrary to what has been reported for dairy cattle, type of flooring does not seem to have a significant effect on total lying time of young calves, but lying bout frequency is reduced and atypical movements during the transition to lying and standing are increased on hard floors, especially for heavy animals. This suggests that hard floors (concrete solid floor, concrete slats, and hardwood slats) cause discomfort compared with softer floors (concrete slats covered with rubber strips, vinyl coated metal floor, sawdust, and straw).**

3. **There is a need for further research on the effects of specific characteristics of flooring materials (traction, friction, hardness, wetness, slat and gap widths, etc.) on young calves. Such studies would benefit from the use of a common standard positive reference material for comfort (e.g. deep straw bedding), and the examination of factors such as the weight of the animal, time spent on the material, ambient temperature, etc.**

4. **Generally, studies report that calves have more bursitis and carpal joint swelling on hard flooring (concrete slats, perforated concrete) than on soft flooring (rubber slots, slats with rubber cover, or perforated rubber mats). In the one epidemiological study on veal calves, a higher risk for bursitis was reported for calves on wooden slats (1.5× higher) and on concrete (4× higher) compared to straw or rubber at 2 weeks before slaughter.**

5. **Cattle, including young calves, consistently avoid wet bedding. When soiled bedding is removed from pens on a regular basis, adding extra clean bedding resulted in a significant increase in lying time. Deep dry bedding permits calves to *nest,* creating a micro environment that ensures thermoregulation.**

6. **Bedding that is soiled and wet increases ammonia emissions, fly infestations, and pathogenic bacterial growth leading to an increased risk of diarrhoea.**

7. **While some studies report that young and older calves have similar weight gains, dry matter intake, feed efficiency, and carcass weight and quality on hard flooring (concrete, hardwood slats) as on soft flooring (rubber mats, vinyl coated expanded metal, and deep bedding), others report better performance, certain carcass characteristics, and meat quality among calves reared on softer flooring (perforated rubber mat, rubber slats, and rubber mats).**

8. **In studies on cleanliness, cattle kept on slatted flooring are often the least dirty. Solid flooring and deep bedding are associated with dirtier animals, although it is difficult to isolate the effects of the flooring material from the potential effects of bedding management.**

6.1 Introduction

The surfaces that animals spend their lives standing, walking, and lying on have important effects on their well-being because they influence animal comfort, movement, thermoregulation, and even health. Soft compressible flooring surfaces or solid flooring surfaces with special design features can offer animals good traction for locomotion and for transitioning between lying and standing. Additionally, they can, either by design or through the addition of the right quantity and/or quality of bedding, provide support for animals' boney protrusions, especially their leg joints, while lying. Finding efficient ways of managing flooring surfaces and bedding to keep animals dry is essential when the comfort and thermoregulation of animals is to be assured.

There is strong evidence and general consensus in the dairy cow comfort literature that for adult dairy cattle softer surfaces afford better lying comfort. This is evidenced by longer daily lying times, shorter lying bouts and more frequent lying bouts, ease of standing and lying movements, and a lower prevalence of leg injuries and lameness. Shorter and more frequent bouts of lying are regularly regarded as reflecting superior comfort—an indication that the cows are able to transition from lying to standing, and vice versa, easily. The best walking surfaces are those that absorb pressure on the hooves during steps and afford better traction than concrete flooring.

Research findings about flooring surfaces and bedding is of special interest to veal producers because milk-fed and grain-fed veal calves are typically reared indoors rather than being on natural surfaces (e.g., soil/ground or grasslands). As caretakers are crucial in determining calves' level of comfort, in part by what flooring surfaces we put them on, knowledge of how different flooring types and materials affect veal calves during the growing period is essential.

While in countries like Switzerland most veal calves are reared on straw bedding (in groups; Bähler et al., 2012), in Canada industry records indicate that milk-fed calves, whether housed in groups or individual stalls, are most commonly kept on wooden slatted flooring (e.g., commonly Oak or Azobe wood), while there would be more variation in the types of flooring systems used for rearing grain-fed veal calves and in whether or not bedding is provided (Kendra Keels, Veal Farmers of Ontario, Guelph, ON, personal communication).

Fully slatted (Figure 6.1) or partially slatted (sometimes termed "slotted") flooring (Figure 6.2) similar to those commonly used for beef finished in indoor feedlots can be used during the finishing phase of grain-fed veal production in Canada (Kendra Keels, Veal Farmers of Ontario, Guelph, ON, personal communication). Attempts have been made to ease the hardness of both solid, slatted, and perforated "slotted" concrete flooring by covering them with rubber mats (e.g., Figure 6.3). Still other unique flooring options exist that have been tested such as synthetic rubber slats on aluminum profiles (Graunke et al., 2011) and vinyl-coated metal flooring (Wilson et al., 1998; Figure 6.4).

Limitations to the present review of literature include the fact that no two studies compare the same flooring treatments. While several compare harder and softer flooring options, these are relative terms with no common benchmark for comparison. There is also an absence of any common reference flooring material across studies, which makes interpreting the overall findings a complicated task. In a number of cases, papers lack sufficient detail for the reader to know important information about the precise flooring surfaces studied (e.g., inconsistency in reporting the widths of slats and gaps for slatted flooring). Also, surfaces such as "rubber mat" are far from being universally uniform, and authors have not made any consistent effort to report relevant characteristics of flooring surfaces that would simplify a meta-analysis (traction, friction, hardness/compressibility [e.g., Shore units], wetness). There are only a small number of papers that have isolated and compared the effects of different types of flooring surfaces on cattle. In most cases different flooring surfaces are examined within the context of comparisons of different housing systems, and so results in these cases are confounded, and we do not know for certain whether differences observed are due to the flooring, per se, or to other differences between the housing systems. For example, the effect of flooring can be confounded with housing method such as individual vs group.

Figure 6.1 A photo showing fully slatted concrete flooring.

Figure 6.2 A photo showing partially slatted concrete flooring (sometimes referred to as "slotted" flooring).

Figure 6.3 A photo showing rubber covering applied to "slatted" concrete flooring surfaces.

Figure 6.4 A photo showing an example of vinyl-coated metal flooring surface used in a study by Wilson et al. (1998).

There are few studies comparing the effects of slatted wooden flooring to other types of flooring on calf comfort and injury. This is unfortunate because the slatted wooden flooring system is commonly used for milk-fed veal production in Canada (Kendra Keels, Veal Farmers of Ontario, Guelph, ON, personal communication). Moreover there is a lack of research investigating the effects of flooring surfaces and bedding on veal calves. There is a lack of research systematically investigating the frictional characteristics of flooring surfaces for livestock and how their properties vary when wet due to contamination by feed or water, urine, or faeces. Existing studies on flooring often have methodological weaknesses; in this case robust conclusions cannot be drawn. More research has been conducted on beef cattle and dairy cows than on young calves. Because there are differences in target finishing weights of, for example, beef and veal cattle, there are also anatomical or morphological differences (e.g., muscularity, stature, weight) between purpose-bred beef cattle and veal animals, which are commonly dairy-type animals (Albertí et al., 2008). Thus, extrapolation to veal calves must consider these differences.

6.2 Behaviour – Lying

Table 6.1 lists and summarises the studies examining the effects of different flooring types on lying behaviour and general activity of cattle.

Of the 15 papers investigating calf lying behaviour responses to different flooring, 4 include younger calves, while the others looked at calves above 220 kg (Table 6.1).

Two papers report that young calves lie down longer on harder (concrete) than softer surfaces (rubber), while one reports no difference, and the other reports that calves lie down longer on softer surfaces (vinyl coated metal). Two papers report that calves have more frequent lying bouts on hard (concrete and hardwood) than on soft surfaces (vinyl coated metal and rubber).

In the studies investigating heavier calves and bulls (i.e., over 220 kg), 5 find no differences in total lying times between hard (concrete slats) and soft surfaces (deep bedding and rubber), while 4 find longer lying on soft (rubber sawdust or straw) than on hard (concrete) surfaces, and one finds the opposite (concrete vs rubber). One study reports more lying bouts on soft (deep bedding) than hard surfaces (concrete), and one reports no differences (concrete vs rubber). Lying bouts were found to be longer in 2 studies, and one reports more standing bouts on soft (rubber) than hard surfaces (concrete). The 4 studies looking at getting up and lying down movements all report more problems on hard (concrete) than on softer flooring (rubber or deep bedding).

Yanar et al. (2010) compared the effects of housing Holstein Friesian calves (25 to 43 kg initial liveweight) for 4 months on wooden slats, rubber mats, and concrete pens with all 3 floorings bedded daily with 2 kg of long wheat straw. Across the 3 treatments they studied a total of 25 calves that were housed individually; however, they did not report the dimensions of their enclosures. Calves were weaned off milk at 7 weeks of age. Calves on the slatted flooring spent significantly more time lying, and less time standing compared to calves on both the rubber and concrete floors, possibly because the calves were dryer on the slatted floors. In fact a number of studies have demonstrated that cattle avoid lying on wet bedding (Camiloti et al., 2012; Fregonesi et al., 2007; Reich et al., 2010).

Dairy heifers (17 months of age, 400–500 kg BW) are motivated to lie down for approximately 12 h/d (Jensen et al., 2004), while younger dairy calves have been observed to lie down for up to 18h/d (Wilson et al., 1999, 9 to 18 wks old; Chua et al., 2002, 1 to 8 wks old; Panivivat et al., 2004, 1 to 6 wks old). Alterations to the normal baseline lying behaviour values such as an increase in the duration or a reduction in the frequency of lying bouts and difficulties while lying down or standing up are used as indicators of reduced comfort (Elmore et al., 2015).

Lying behaviour can be influenced by several factors such as the age (Hänninen et al., 2003) and weight of the animal (Graunke et al., 2011), but aspects of lying area design (Tucker et al., 2004; Fregonesi et al., 2009a,b) such as the type of lying surface (Tucker et al., 2003; Wagner-Storch et al., 2003) and the quantity and quality of bedding provided are especially important in adult cattle.

Some data suggest that lower than average lying times are associated with reduced growth rates in young animals. Hänninen et al. (2005) reported that calves with a higher daily duration of lying were the ones with the higher average daily gain (ADG) calculated over the whole 20 weeks of their experiment ($r = 0.32$, $P = 0.05$). Mogensen et al. (1997) reported that the calves with a higher number of lying bouts tended to have greater ADG ($r = 0.60$, $P = 0.06$) in their study of 42 dairy heifers housed on fully slatted flooring.

Hänninen et al. (2005) studied the effects of two different solid flooring surfaces on the lying behaviour of male Holstein calves housed individually (1.05 × 1.80 m pens), from 1 to 21 weeks of age. Their hypothesis was that a solid rubber mat with finger-like projections on the underside for cushioning (Figure 6.5) would improve calf comfort such that their lying behaviour would be better when compared to calves kept on solid concrete. However, they found no differences in the total daily duration of lying, lying bout frequency, and the duration of time calves spent in lateral recumbency (flat on their side). The authors concluded that at this age, calves were so light that cushioning their lying surface during warm weather was not making them more comfortable.

Kartal and Yanar (2011) compared lying and standing behaviour of Brown Swiss calves on concrete floors, rubber mats, and wooden slats. Calves on rubber mats spent less time lying and more time standing than calves on concrete floor. Calves on wooden slats did not differ in the time spent lying or standing from the other treatments.

Wilson et al. (1998) found that Holstein calves on wooden slats spent more time standing and less time lying than calves housed on vinyl-coated metal flooring.

Figure 6.5 A photo showing a variety of the "rubber mat" with finger-like projections on the underside, to provide cushioning under weight.

Gygax et al. (2007) studied the lying behaviour of 18 different groups of cross-bred beef bulls (Simmental, Brown Swiss, Limousin, Angus) on 12 different farms in Switzerland at about 450 kg live weight. They found that calves housed on floor types including concrete slats, concrete slats covered over by a perforated solid rubber mat (similar to Figure 6.3), and straw bedding did not differ in their total lying duration. However, the number of lying bouts and the number of short standing bouts were lower with increasing hardness of the flooring (straw bedding < concrete slats covered by rubber mats < concrete). In addition, bulls showed more interrupted lying-down and standing-up movements on concrete and rubber-covered slats than on the straw bedding. However atypical lying-down and standing-up movements, slipping, and falling were all reduced on rubber-covered slats and on straw bedding compared to concrete slats. These results indicate the calves are more comfortable lying on softer surfaces and have difficulty moving on concrete where they do not have good footing.

Similar results were reported by Absmanner et al. (2009) examining finishing beef bulls on 7 farms in Austria making observations of the bulls when they were 450 kg and again at 600 kg. They found the total time spent lying was similar for concrete slatted floor pens, concrete slatted floor pens covered with rubber, straw bedded pens, or a combination of concrete slats and a straw yard. They report significantly lower frequency of lying bouts for bulls on the concrete slats than on straw bedding and concrete slats covered with rubber mats. Similarly, Tessitore et al. (2009) found no difference between fully slatted or deep litter flooring in terms of the total lying time, but lying bouts were longer on slatted floors, which again aligns with softer flooring being more comfortable for cattle 450–600 kg.

Ladewig (1987), summarising studies carried out in Germany, reports increased latency to lie down, increased frequency of interruption of lying down sequence, atypical sequence of movements for lying down (dog sitting), and reduced frequency of periods lying down in fattening bulls kept on slatted floors when compared to those kept on straw bedding. They concluded that softness of the lying surface increases calf comfort.

Graunke et al. (2011) compared the effect of concrete slats (CS), synthetic rubber slats on aluminium profiles (RS), and slotted rubber mats on concrete slats (RM) on behaviour and growth of dairy bulls (average liveweight

= 225–650 kg). At 250 kg, lying bouts were less frequent (CS ~ 5 vs RS ~ 6.5 vs RM ~ 7.5 bouts per 12 h) and longer (CS ~ 78 vs RS ~ 58 vs RM ~ 50 min/bout) on CS than on RS and RM, respectively. There was no significant difference in lying bout frequency or duration when animals were tested at 450 and 650 kg. Also at 250 kg, interrupted attempts at lying down (animals pausing or aborting lying attempts rather than lying in a single, continuous, fluid movement) occurred twice as often on CS as it did on the rubber floors. In total, the bulls on CS had 2.4 interrupted attempts at lying down for every completed lying-down movement, whereas they had 1.0 on RS and 0.7 on RM. Abnormal lying-down and standing-up behaviour occurred in total on 29 occasions during observations, in 21 of which the bulls sat in dog-like positions during the movements. Of these 21 occasions, all but one occurred on CS. Likewise, 14 animals (or 17.5% of the bulls in the experiment) were seen to tongue-roll. Nine of the tongue-rolling bulls were in pens with CS, 3 in pens with RS, and 2 in pens with RM.
Elmore et al. (2015) report that steers in a pen with 60% rubber mat and 40% slatted concrete flooring preferred to rest on the rubber mat area (48.83% ± 2.10%) than on the concrete area (18.06% ± 2.10%; P = 0.001). These authors also report that steers on total rubber slat flooring changed their posture more frequently than those on total rubber mat or total concrete slatted floorings. No differences in posture changing frequency were found between the latter. Platz et al. (2007) also found no differences in total lying time between bulls kept either in a fully slatted concrete-floored pen, in a slatted concrete-floored pen equipped with interlocking slatted rubber mats, or in a pen with the option to choose between these two types of flooring. However, as in the studies previously described, the lying time per bout was longer in the concrete-floored pen than in the rubber mats or the choice pens.

When animals are given the choice of hard vs soft flooring (e.g., concrete vs rubber or straw) they show a marked preference for standing and lying on soft floors (Lowe et al., 2001a; Platz et al., 2007). Schütz and Cox (2014) found that cows spending 6h/d on pasture and kept indoors the rest of the day (18h), spent more time lying on wood chips (10.8 h) and rubber mats with different thickness (7.3 h on 24 mm rubber mat and 6.0 h on 12 mm rubber mat) than on concrete (2.8 h). They also found that cows on concrete had higher gait score and shorter stride length after a 4-d 18h/d test period compared with cows on the other surface types, suggesting a deterioration in gait pattern caused by discomfort.

Thus, studies on fattening bulls provide evidence that a rubber top covering the slatted floor increases traction when animals change position from lying to standing (and vice versa), and that straw bedding provided the best traction. There is not enough information in these studies to conclude whether this benefit is gained from friction (slip-resistant surface) or by the rubber covering providing some leverage via compressibility; if the latter were the case special consideration would need to be given to the weight at which cattle gain that benefit.

Adult dairy cows spend more time lying down when stalls contain more bedding (Tucker & Weary, 2004; Tucker et al., 2009). An exception to this finding by Norring et al. (2010) found cows preferred stalls with rubber mats to stalls with a concrete floor, but did not find any preference for sand stalls compared with stalls with a concrete floor or with rubber mats. Worth et al. (2015) measured the preference (lying time) of dairy calves to different types of substrate and found that the order of preference of the rearing surfaces was sawdust > rubber > sand > small river stones. Young calves (Camiloti et al., 2012) and adult cattle (Haley et al., 2001; Wagner-Storch et al., 2003) show aversion to lying down on bare concrete, even when some straw bedding is provided. Lying times are also lower when sand-bedded stalls are not leveled: for every 1 cm decrease in bedding, cows spent 11 min less time lying per 24-h period (Drissler et al, 2005). Providing 6 cm of sand resulted in an average increase in lying time of 69 min/24 h compared to not having sand bedding (Drissler et al., 2005). Panivivat et al. (2004) did not find an effect of the type of bedding (among 5 different materials on concrete floors) on lying behaviour of dairy calves aged less than 7 wk.

Fregonesi et al. (2007) found that lying times of dairy cows decrease when sawdust bedding becomes wet when compared to dry bedding (8.8 ± 0.8 vs 13.8 ± 0.8 h/d). When cows were able to choose between stalls with wet or dry bedding, cows spent more time lying down in the dry stalls (12.5 ± 0.3 h/d) than in stalls with wet bedding

(0.9 ± 0.3 h/d). Reich et al. (2010) found similar results, with bedding dry matter content directly relating to lying time of dairy cows. Camiloti et al. (2012) showed that lying time for dairy calves decreased on increasingly wet bedding from 5.3 ± 1.1 h/d at 74% DM to almost zero at 29% DM. Lying times on the side of the pen with dry bedding varied from 12.2 ± 1.2 h/d (when the wet bedding was 74% DM) to 16.8 ± 1.2 h/d (at 29% DM). Stefanowska et al. (2002) compared the use of hardwood or recycled plastic slatted flooring by dairy calves. Although plastic slats were softer, calves spent more time lying on hardwood slats. The fact that hardwood slats absorbed humidity and plastic slats did not might have contributed to this effect.

Fisher et al. (1997) found that older heifers (468 kg initial weight) had lower lying times at a space allowance of 1.5 m^2/animal than 2.0, 2.5, and 3.0 m^2 (lying time = 10.3, 11.8, 12.0, and 11.7 h/d, respectively).

Veal calves slip frequently on wooden slats, with younger calves (38 days of age) slipping more frequently than older calves (70 days of age). The frequency of slipping was greater on rubber coated plastic slats than on wooden slats (Stefanowska et al., 2002).

Table 6.1 Studies examining the effects of flooring and bedding on the lying behaviour and general activity of cattle

Effect studied	Reference	Animals & Methods	Treatments	Behaviour	Results
TYPE OF FLOORING (15 papers)	Wilson et al., 1998	1. N = 48 2. Type: Holstein bull calves (tethered) 3. Age: 3 to 7 d old 4. Initial BW: 48.6 kg 5. Study period: 19 to 21 wks	1. Vinyl diamond expanded metal flooring 2. Vinyl rectangular 3. Slatted oak wood	Time standing Time lying Excitability inside stall Excitability from stall to loading area	Wooden slats > Vinyl coated (both) Wooden slats < Vinyl coated (both) = =
	Hänninen et al., 2005	1. N = 48 2. Type: male Holstein calves 3. Age: 1 wk old 4. Initial BW:48 ± 1.0 kg 5. Study period:140 d	1. Concrete solid floor pairs (n=16) 2. Concrete solid floor individual (n=16) 3. Rubber mat individual (n=16)	Total resting time Time resting on the sternum Duration and frequency of bouts of resting on the side	= = Concrete pairs > Concrete individual
	Kartal & Yanar, 2011	1. N = 30 2. Type: Brown Swiss 3. Age: Not given 4. Initial BW: 37.3±1.0 kg 5. Study period: 6 months	1. Concrete 2. Rubber mats 3. Wooden slats	Time lying Time standing	Rubber mats < Concrete Wooden slats = both Rubber mats > Concrete Wooden slats = both
	Stefanowska et al., 2012	1. N = 8 2. Type: Holstein–Friesian calves 3. Age: 69.59 ± 9.1 d (older); 37.59 ± 10.9 d (younger) 4. Initial BW: 88.79 ± 12.3 kg (older); 63.79 ± 5.3 kg (younger) 5. Study period: 60 d	1. Hardwood slats 2. Synthetic slats	Total time spent on type of flooring Total lying time Frequency of lying bouts	Hardwood > Synthetic Hardwood > Synthetic Hardwood > Synthetic
	Graunke et al., 2011	1. N = 80 2. Type: Holstein bull calves 3. Age: 14 wks after weaning 4. Initial BW: 225 ± 33 kg 5. Study period: ~150d	1: Concrete slats (n=30) 2: Rubber slats (n=25) 3: Slotted rubber mats (n=25).	Lying bouts and duration at 250 kg BW Lying bouts and duration at 450 and 650 kg BW Interrupted attempts at lying down at 250 kg BW Abnormal lying down and standing up behaviour Tongue-rolling	Concrete slats > Rubber slats = Slotted rubber mats = Concrete slats > Rubber slats = Slotted rubber mats Concrete slats > Rubber slats = Slotted rubber mats Concrete slats > Rubber slats = Slotted rubber mats

Table 6.1. Studies examining the effects of flooring and bedding on the lying behaviour and general activity of cattle (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Behaviour	Results
TYPE OF FLOORING (continued)	Gottardo et al., 2003	1. N = 48 2. Type: Simmental 3. Age: Not given (young bulls) 4. Initial BW = 321.2 ± 34.1 kg 5. Study period:250 d	1. Concrete slats (n=24) 2. Straw bedded (n=24)	Frequency of lying (d 240) Frequency of eating (d 240) Frequency of 3 or 5-6 animals standing at manger at the same time Frequency of sniffing-licking Frequency of grooming Frequency of aggression Frequency of mounting	Straw bedded > Concrete slats Straw bedded > Concrete slats Straw bedded > Concrete slats = = = =
	Mogensen et al., 1997	1. N = 80 (Experiment A); 70 (Experiment B) 2. Type: Friesian heifers 3. Age: >10 months 4. Initial BW:311 to 335 kg (Experiment A); 309 to 313 kg (Experiment B) 5. Study period: 150 d	Exp. A 1.5 vs 3.0 m2/animal on slatted floor (n=24 & n=18 respectively); Exp. B Deep bedding area: 1.8; 2.7 and 3.6 m2 per heifer (n=30, n=20 & n=20 respectively)	Lying bouts frequency Lying bouts duration	Deep bedding > Slatted Deep bedding < Slatted
	Tessitore et al., 2009	1. N = 20 farms 2. Type: Beef cattle 3. Age: Not given 4. Initial BW: <350 kg (Class 1) and >350 kg (Class 2) 5. Study period: 2 h/farm	1. Slats (material not described) 2. Deep litter (material not described)	Percentage of animals lying Percentage of animals standing Percentage of animals feeding Percentage of animals drinking Duration of lying sequence Displacement Chasing Horning Avoidance distance	= = = = Slats > Deep litter = = = =
	Elmore et al., 2015	1. N = 48 2. Type: crossbred Angus steers 3. Age: 9 mo old 4. Initial BW= 374.1 ± 27.5 kg 5. Study period:84 d	1= Concrete slats (n=16) 2= Fully slatted rubber mat (n=16) 3= Solid rubber mat (n=16)	Percentage of time lying Percentage of grooming Percentage of standing Frequency of postural changes	Solid rubber mat > Concrete slats Solid rubber mat > Concrete slats = Slatted rubber > Solid rubber mat = Concrete slats

Table 6.1. Studies examining the effects of flooring and bedding on the lying behaviour and general activity of cattle (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Behaviour	Results
TYPE OF FLOORING (continued)	Platz et al., 2007	1. N = 18 2. Type: crossbred beef cattle (Holstein Frisian × Fleckvieh) 3. Age: 267 to 339 d 4. Initial BW: Not given 5. Study period: 1 year	1. Concrete slats 2. Rubber slats 3. Choice between rubber and concrete slats	Total time spent on type of flooring Time to stand up from lying Total lying time per day (age < 15 months) Total lying time per day (age >15 months) Frequency of standing up	Rubber slats > Concrete slats Concrete slats > Rubber slats = Concrete slats > Rubber slats = Choice Rubber slats > Concrete slats
	Brscic et al., 2015a	1. N = Variable 2. Type: beef - Charolais and cross-bred bulls 3. Age: Not given 4. Initial BW: ~400 kg 5. Study period:120 d	1. Concrete slats 2. Straw-sawdust deep bedding	Percentage of standing animals Percentage of ruminating animals	= =
	Brscic et al., 2015b	1. N = 326 2. Type: Charolais & Limousine finishing beef bulls 3. Age: Not given 4. Initial BW: 414.6 ± 52.0 kg 5. Study period: 7 to 9 months	1. Concrete slatted floors 2. Concrete slatted floors covered with 30-mm synthetic rubber slats	Percentage of animals Standing Percentage of animals Lying Percentage of animals Lying in lateral recumbency Social interactions (mounting, chasing, head butt/displacement Slipping events Abnormal lying down Unsuccesful attempts to lie down Time required to lie down	= = = = = Concrete > Rubber Concrete > Rubber Concrete > Rubber
	Cozzi et al., 2013	1. N = 48 2. Type: Male beef crosses (Charolais × Aubrac) 3. Age: ~ 12 months 4. Initial BW: 425.9 ± 48.8 5. Study period: 4 months	1. Concrete slatted floor 2. Perforated concrete panels (70 holes of 6.5 cm of diameter/m2) 3. Perforated concrete coated with perforated rubber mattress	Time standing Time eating Time lying sternal Lying down attempts Number of transitions Time to lie down Rising sequence duration Ruminating time Slipping Mounting Fighting Allogrooming	Perforated rubber > Concrete slats = Perforated concrete Perforated rubber > Concrete slats = Perforated concrete = Concrete slats > Perforated rubber Perforated rubber > Concrete slats = Perforated concrete Concrete slats > Perforated rubber = both to Perforated concrete = = Concrete slats > Perforated rubber and concrete Perforated rubber > Concrete = =

Table 6.1. Studies examining the effects of flooring and bedding on the lying behaviour and general activity of cattle (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Behaviour	Results
TYPE OF FLOORING (continued)	Earley et al., 2015	1. N =144 2. Type: Continental cross and Holstein–Friesian steers 3. Age: Not given 4. Initial BW : 503 ± 51.8 kg 5- Study period:148 d	1. Concrete slats (n=36) 2. Rubber mat 1 (n=36) 3. Rubber mat 2 (n=36) 4. Deep bedding (n=36)	Percentage of animals lying Percentage of animals eating Drinking bouts and duration Percentage of animals head butting Percentage of animals mounting Percentage of grooming	Rubber mat 1 and 2 > Concrete = Deep bedding Deep bedding > Concrete = Rubber mat 1 and 2 = Rubber mat 1 = Deep bedding > Concrete Rubber mat 2 = to all Rubber mat 2 > Deep bedding = Rubber mat 1 Concrete > Rubber mat 1 Rubber mat 2 > Rubber mat 1 = Deep bedding
	Lowe et al., 2001b	1. N = 112 2. Type: crossbred Continental steers 3. Age: 22 ± 0.34 months 4. Initial BW:536 ± 5.1 kg 5. Study period:3 wks	Choice between: 1. concrete slats vs rubber mats 2. concrete slats vs straw 3. concrete slats vs sawdust 4. rubber mats vs straw 5. straw vs sawdust 6. rubber mats vs sawdust	Total time spent on type of flooring Time lying Time standing eating Time standing performing other behaviours Time nosing the ground	Straw > Sawdust > Rubber mats > Concrete slats Straw > Sawdust =Rubber mats > Concrete slats Rubber mats = Straw > Concrete slats Rubber mats = Straw > Concrete slats Rubber mats = Straw = Sawdust > Concrete slats
SPACE ALLOWANCE (1 paper)	Mogensen et al., 1997	1. N = 80 (Experiment A); 70 (Experiment B) 2. Type: Friesian heifers 3. Age: $\geq$10 months 4. Initial BW:311 to 335 kg (Experiment A); 309 to 313 kg (Experiment B) 5. Study period: 150 d	Exp. A 1. 1.5 m^2/animal 2. 3.0 m^2/animal Exp. B Deep bedding area: 1. 1.8 m^2/animal 2. 2.7 m^2/animal 3. 3.6 m^2/animal	Lying time Frequency of lying bouts Lying time Frequency of lying bouts Duration of lying bouts	3.0 m^2 > 1.5 m^2 3.0 m^2 > 1.5 m^2 = = =
BEDDING DRY MATTER (1 paper)	Camiloti et al., 2012	1. N = 5 2. Type: Holstein calves 3. Age: 13.4 ± 1.8 d 4. Initial BW: 51.2 ± 4.3 kg 5. Study period: 2 d	Double pen with random dry half (90 ± 0.2% DM sawdust) and other half with 1. 74 ± 0.3 % DM sawdust 2. 59 ± 0.4 % DM sawdust 3. 41 ± 0.25 % DM sawdust 4. 29 ± 0.5 % DM sawdust 5. Bare concrete	Lying time Standing time	Dry > wet > bare concrete Dry > wet

6.3 Locomotor problems

Table 6.2 summarises the studies investigating flooring effects on leg injuries and locomotion. Of the 6 studies investigating occurrences of bursitis and carpal joint swelling in calves on different flooring material, only one was done on young calves, and the other 5 looked at older and heavier calves. Heavier calves had more injuries on hard than on soft flooring in all 5 studies, while there was no flooring effect on the younger calves.

In the 4 studies examining gait score on different flooring, the one study on young calves reports no differences between soft and hard flooring, while the 3 studies on older calves report more lameness on hard than soft flooring with the highest risk found with concrete slatted floors.

In the 3 studies looking at hoof lesions in heavier calves, 2 report more lesions on soft than hard flooring, while one finds the opposite. These injuries are most likely related to the wetness of the flooring, with rubber slats and deep bedding being wetter than concrete slats.

In the 5 studies reporting leg lesions, 3 find no effect of flooring, 2 report more injury on the hard flooring, and one found more on the soft flooring.

Several studies on health indicators comparing flooring type have been done on dairy and beef cattle. The majority of these studies focus in beef cattle attaining higher live weights than finishing veal calves. Some types of flooring have been associated with abnormal locomotion that has been linked to poor performance of the veal calf. Murphy et al. (1987) found that 2-year-old Friesian and Hereford cattle had a higher incidence of diseases when kept on slatted floor (9.73%) than on straw yards (5.42%), with lameness showing the highest incidence (in the same order 4.75 and 2.43%) among other affections. However, compared to bulls kept on slatted floors, animals on straw yards showed higher incidence of necrotic lesions (45.3 vs 9.8%) and diffuse aseptic pododermatitis (13.3 vs 5.5%). When both breeds were compared, Friesians showed an overall higher incidence of disease (13.73%) than Herefords (8.36%), as well as increased wear of the hoof when kept on slatted floors.

Hard flooring surfaces are considered a predisposing factor for bursitis, resulting in irritation during sternal recumbency (Fathy & Radad, 2006). Brscic et al. (2011) report that veal calves raised on concrete and on fully-slatted wooden floors had a higher risk (4x and 1.5x, respectively) of developing bursitis compared to veal calves raised on rubber or straw. The increased risk for calves on concrete was noted already after 13 weeks of fattening.

The risk of occurrence of bursitis also increased when calves were housed on new floors compared to floors aged more than 8 years. Hardness and slipperiness were greater for new floors (used for < 8 years) when compared to older floors (used for > 8 years), which are more likely to be worn out by a prolonged use and absorb more water as well (Brscic et al., 2011).

Cerchiaro et al. (2005) found in a large survey of beef cattle in Italy that the use of bedding reduced the risk of culling by 33% compared to slatted floors. Tessitore et al. (2009) found that fully slatted floors increased the incidence of hairless patches and lameness compared to deep litter floors. Sundrum and Rubelowski (2001) compared claw health of fattening bulls in a survey carried out on 50 farms in Germany with housing systems where flooring was completely slatted, deep litter, or two area straw yard. The percentage of neglected claws and double soles was higher on litter (respectively, 74.3 and 64.9%) compared to slatted floor (14.0 and 10.5%). On the other hand, inclusions were found more often on slatted floor (75.4%) than in deep litter (62.8%). The lowest percentage of inclusions was found in the system with littered concrete floor (22.8% for two area straw yard). Nevertheless, calves kept on concrete flooring had the highest percentage of sole haemorrhages (17.1%) compared to slatted floor (14.0%) and deep litter (8.9%). However, correlations between the incidence of early losses and either space allowance or floor quality were low (respectively, -0.31 and -0.27). The fact that these results do not belong to an experiment comparing the types of flooring within the same farm and the relatively low number of farms with straw yards (n = 6) compared to deep litter (n = 14) and slatted flooring (n = 30) means that other aspects linked to each housing system may have also had important effects, beyond the flooring.

Graunke et al. (2011) found that severe sole lesions and white line haemorrhages (20 and 24% prevalence, respectively) only appeared in animals kept on concrete slats, and that milder lesions of these disorders were also most prevalent for animals on concrete slats than for animals on slotted rubber mats. Swelling on legs had the highest scores on concrete slats, as 100% of animals on this floor developed swelling, with 68% exhibiting severe swelling (clearly visible). The severity score for heel horn erosion was lowest on concrete slats due to increased wear of hoof compared to slotted rubber mats or rubber covered aluminum slats. Floor type had no effect on dermatitis, leg hairlessness, or skin damage. Both claw horn growth and wear were greater on concrete slats than on rubber covered aluminum slats and slotted rubber mats. Wilson et al. (1998) also found more hoof wear in calves on wood slats compared to calves on vinyl-coated flooring types. Platz et al. (2007) found that net claw growth, measured by dorsal wall and diagonal length, was greater in calves housed on slatted rubber mats than in calves housed on concrete slats or on a pen where half of the pen had concrete slats and the other half had slatted rubber mats.

Elmore et al. (2015) found that steers on rubber mats showed a higher prevalence of lesions (0.80 ± 0.08) compared to steers on rubber slats (0.38 ± 0.08) and concrete slats (0.37 ± 0.08), which were similar. Steers on rubber slats showed a reduced (more normal) gait score (1.69 ± 0.04; scale range from 1 to 5, where a score of 1 represents no lameness and a score of 5 represents a severely lame and hindered animal) compared to rubber mats (1.95 ± 0.04) and concrete slats (1.98 ± 0.04), which did not differ. Steers on rubber-slatted flooring had less joint swelling (both knees and hocks) compared to rubber mats and concrete slats, which did not differ. Wilson et al. (1998) found only a slight increase in knee swelling when comparing wooden slats to vinyl-coated metal floors, but no differences in ambulation score were found between floorings. Schulze Westerath et al. (2007) found that bulls kept on straw developed the smallest lesion scores at the joints when compared to bulls on rubber coated concrete slats, soft mats, and concrete slats. Animals on concrete slats had the highest lesion scores at the carpal and tarsal joints, as well as the highest swelling scores.

Earley et al. (2105) found that the total number of lesions on hooves and the level of hoof erosion was greater on two types of mats and wood-chips compared with concrete slats. The level of erosion was also greater in animals on mats compared with those on slats and woodchips. As well, the quantity of overgrowth and white line dominance was greater on mats and wood-chips compared with slats.

Hinterhofer et al. (2006) measured the mechanical stress of bovine claw on solid and slatted floors, finding that stress distribution in a model claw on solid flooring was more even, and maximum stress values (100%) were smaller than on slatted floors, which could explain to some degree the increased lesions other studies have observed in animals kept on slatted floors. A recent survey in Canadian dairy farms (Zaffino Heyerhoff et al., 2014) found that the odds of hock injury was lower on sand (OR = 0.07) and concrete (OR = 0.44) stall bases in comparison to mattresses, but the odds of knee injury was greater on concrete (OR = 3.19) stall bases compared with mattresses.

Madsen and Nielsen (1985) found in a survey that only producers who kept bulls on slatted flooring report tail tip inflammation, while producers that kept bulls on straw bedding did not report any cases. Schrader et al. (2001) also found a higher frequency of tail tip lesions in farms with slatted floors compared to farms with straw bedding. In addition, the frequency of tail tip lesions increased with the weight of bulls on farms with slatted floors, but not on farms with straw bedding.

Deep bedding and sand bedding have also been reported to be factors associated to fewer clinical and severe lameness cases on dairy farms (Chapinal et al., 2013). Results from a recent survey in Canada indicate that the odds of lameness were higher among cows housed in stalls with ≤ 2 cm of bedding, compared with those with stalls with >2 cm of bedding (Solano et al., 2015). In contrast to the results for dairy cows, no hoof or joint lesions in veal calves were reported by Brscic et al. (2011), while lameness was observed in ≤1% of the observed animals. Gottardo et al. (2003) reported satisfactory health status and similar values for several blood indicators of chronic stress between bulls housed on fully slatted floors and animals on straw bedded floors with the same space allowance (3 m^2/head).

Table 6.2 Studies examining the effects of flooring and bedding on cattle locomotion and injuries

Effect studied	Reference	Animals & Methods	Treatments	Locomotion & Injuries	Results
TYPE OF FLOORING (13 papers)	Brscic et al., 2011	Cross-sectional field study 1. N = 174 farms 2. Type: veal calves 3. Age: 3wks after arrival; 13 wks of rearing; 2 weeks before slaughter 4. Initial BW: Not given 5. Study period: 3 visits per farm	1. Wooden slatted floor (80% of farms) 2. Concrete floor (slat, partial, full; 14% of farms) 3. Rubber or straw (6% of farms)	Risk of bursitis	Concrete = Wooden slat > Rubber or straw New floor > old floor
	Wilson et al., 1998	1. N = 48 2. Type: Holstein bull calves (tethered) 3. Age: 3 to 7 d old 4. Initial BW: 48.6 kg 5. Study period: 19 to 21 wks	1. Vinyl diamond metal flooring 2. Vinyl rectangular metal flooring 3. Slatted oak wood g	Health indicators (navel score, appearance of nose and eyes, body condition score, fecal score, and state of dehydration) Ambulation score Hoof wear Knee swelling Number and size of hairballs	= = Wood slats > Vinyl coated (both) = =
	Stefanowska et al., 2002	Eight Holstein–Friesian calves were divided into two groups of four animals according to age. The ‘‘older’’ calves selected for group 1 were 69.59 ± 9.1 days old (mean ± SD) (two females and two males). The ‘‘younger’’ calves in group 2 were 37.59 ± 10.9 d old (one female and three males).	Half of the floor was made of 1. Slats of synthetic ‘‘ekogrip’’ (plastic waste) with a 3 mm thick rubber coating (hardness 90.9 ± 0.7 shores in pen 1 and 91.8 ± 0.4 shores in pen 2) and the other half of 2. Hardwood slats (hardness 97.1 ± 1.6 shores in pen 1 and 98.0 ± 0.6 shores in pen 2) [Concrete floor hardness: 100 shores]	Slip incidents	=

Table 6.2 Studies examining the effects of flooring and bedding on cattle locomotion and injuries (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Locomotion & Injuries	Results
TYPE OF FLOORING (continued …)	Graunke et al., 2011	1. N = 80 2. Type: Holstein bull calves 3. Age: 14 wks after weaning 4. Initial BW: 225 ± 33 kg 5. Study period: ~150d	n=5 per pen Fully slatted floor pens with three types of flooring on the feeding alley 1: Concrete slats (CS) (six pens) 2: Rubber slats (RS) (five pens) 3: Slotted rubber mats (RM) (five pens).	Severe and moderate sole lesions and white line haemorrhages Joint swelling Severe heel horn erosion Prevalence of dermatitis, leg hairlessness and skin damage. Claw horn growth and wear	Concrete slats > Rubber slats = Rubber mats Concrete slats > Rubber slats = Rubber mats Concrete slats < Rubber slats = Rubber mats = Concrete slats > Rubber slats = Rubber mats
	Gottardo et al., 2003	1. N = 48 2. Type: Simmental 3. Age: Not given (young bulls) 4. Initial BW = 321.2 ± 34.1 kg 5. Study period:250 d	n=6 (8 groups of 6 animals; 4 groups per treatment) 1. Slatted floor 2. Straw bedded	Blood chronic stress indicators (WBC, Neutrophils, Lymphocytes, N:L ratio, Hematocrit, and Total protein).	=
	Tessitore et al., 2009	1. N = 20 farms 2. Type: Beef cattle 3. Age: Not given 4. Initial BW: <350 kg (Class 1) and >350 kg (Class 2) 5. Study period: 2 h/farm	Twenty intensive beef cattle farms were selected according to weight of the animals (<350 kg vs >350 kg) and the type of flooring (fully slatted vs deep litter).	Coughing and nose discharge Risk of hair and skin damages and lameness	= Slatted > Deep litter
	Elmore et al., 2015	1. N = 48 2. Type: crossbred Angus steers 3. Age: 9 mo old 4. Initial BW= 374.1 ± 27.5 kg 5. Study period:84 d	n = 4 (12 groups of 4 animals; 4 groups per treatment) 1= Concrete slats (CON) 2=Fully slatted rubber mat (SLAT) 3= solid rubber mat covering 60% of the pen floor (SOLID)	Leg lesions Gait score Joint swelling (knees and hocks)	Solid rubber mat > Rubber slat = Concrete slat Solid rubber mat = Concrete slat > Rubber slat Solid rubber mat = Concrete slat > Rubber slat

Table 6.2 Studies examining the effects of flooring and bedding on cattle locomotion and injuries (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Locomotion & Injuries	Results
TYPE OF FLOORING (continued…)	Platz et al., 2007	1. N = 18 2. Type: crossbred beef cattle (Holstein Frisian × Fleckvieh) 3. Age: 267 to 339 d. 4. Initial BW: Not given 5. Study period: 1 year	n=6 per treatment 1. Fully slatted concrete-floored pen (CONCRETE PEN) 2. Slatted concrete-floored pen equipped with interlocking slatted rubber mats (RUBBER PEN) 3. Option to choose between these two types of flooring (CHOICE PEN)	Skin lesion score Net claw growth	Concrete > Rubber = Choice Rubber > Choice = Concrete
	Brscic et al., 2015a	1. N = Variable 2. Type: beef - Charolais and cross-bred bulls 3. Age: Not given 4. Initial BW ~400 kg 5. Study period:120 d	1. Concrete slats 2. Straw-sawdust deep bedding	Risk of hairless patches Risk of bursitis and integument alterations Risk of nasal discharge (1 month after arrival) Mortality rate Early culling	Concrete slats > Straw Concrete slats > Straw Straw > Concrete slats = Concrete slats > Straw
	Brscic et al., 2015b	1. N = 326 2. Type: Charolais & Limousine finishing beef bulls 3. Age: Not given 4. Initial BW: 414.6 ± 52.0 kg 5. Study period: 7 to 9 months	1. Concrete slatted floors 2. Concrete slatted floors covered with 30-mm synthetic rubber slats	Percentage of animals treated locomotor Percentage of animals treated respiratory Percentage of early culling Occurrence of bursitis Prevalence of lesions/wounds Hoof overgrowth	Concrete > Rubber = Concrete > Rubber (P = 0.08) Concrete > Rubber = Rubber > Concrete
	Cozzi et al., 2013	1. N = 48 2. Type: Male beef crosses (Charolais × Aubrac) 3. Age: ~ 12 months 4. Initial BW: 425.9 ± 48.8 5. Study period: 4 months	n=16 per treatment 1. Concrete slatted floor 2. Perforated concrete panels (70 holes of 6.5 cm of diameter/m2) 3. Perforated concrete coated with perforated rubber mattress	Signs of lameness Prevalence of hoof overgrowth Risk of hoof overgrowth Skin lesions	Concrete slat > Perforated concrete or rubber Perforated rubber > Concrete slats = Perforated concrete Perforated rubber > Concrete slats =

Table 6.2 Studies examining the effects of flooring and bedding on cattle locomotion and injuries (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Locomotion & Injuries	Results
TYPE OF FLOORING (continued)	Keane et al., 2015	1. N = 72 2. Type: Charolais and Limousin crossbred beef bulls 3. Age: Not given 4. Initial BW: 441 ± 45.1 kg 5. Study period: 6 months	n=18 per treatment 1. Old Concrete slats 2. New Concrete slats 3. Old Concrete slats with 22 mm rubber mats attached 4. New Concrete slats with 22 mm rubber mats attached	Hoof lesions Blood parameters (Total leukocyte, neutrophil, lymphocyte, eosinophil and monocyte percentage, red blood cell number, haemoglobin, mean cell haemoglobin concentration, mean corpulscar volume, haematocrit and platelet number)	Rubber mats > Concrete slats =
	Earley et al., 2015	1. N =144 2. Type: Continental cross and Holstein–Friesian steers 3. Age: Not given 4. Initial BW : 503 ± 51.8 kg 5- Study period:148 d	1. Concrete slats 2. Rubber mat 1 3. Rubber mat 2 4. Deep bedding	Blood parameters on d 23, 45, 86, 107, 128 and 148 (for plasma albumin, globulin, protein, creatine kinase, glucose, β-hydroxy butyrate, fibrinogen, and haptoglobin concentrations, white blood cell number and IFN-γ production) Total number of lesions on hooves Hoof erosion Hoof overgrowth White line disease	= Rubber mat 1 = Rubber mat 2 = Woodchips > concrete slats Rubber mat 1 and 2 > concrete slats and woodchips Rubber mat 1 = Rubber mat 2 = woodchips > Concrete slats Rubber mat 1 = Rubber mat 2 > woodchips > Concrete slats
BEDDING (1 paper)	Panivivat et al., 2004	1. N = 60 2. Type: female dairy calves 3. Age: Newborn 4. Initial BW: 32 to 35 kg 5. Study period:90 d	n=12 per treatment Bedding types: 1:river sand 2:granite fines 3:rice hulls 4:long wheat straw 5: soft wood shavings	Days in scours (1st week) Days in scours (2nd week) Blood indicators (serum cortisol, N:L ratio, α1-acid glycoprotein)	Granite fines > straw Granite fines = sand > rice hulls = wood shavings = straw =

Table 6.2 Studies examining the effects of flooring and bedding on cattle locomotion and injuries (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Locomotion & Injuries	Results
SPACE ALLOWANCE (2 papers)	Andersen et al., 1997	1. N = 120 2. Type:Danish Friesian bull calves 3. Age:70 d 4. Initial BW: ~100kg 5. Study period: ~140d	Period I 100 kg to 300 kg BW Floor space/animal 1. LOW=1.4m2 2. MODERATE=1.7m2 3. HIGH=2.5m2 Period II 300 kg to 460 kg BW Floor space/animal 1. LOW=1.8m2 2. MODERATE=2.2m2 3. HIGH=3.1m2	Severe and moderate tail tip lesions	Low > High
	Brscic et al., 2011	Cross-sectional field study 1. N = 174 farms 2. Type: veal calves 3. Age: 3wks after arrival; 13 wks of rearing; 2 weeks before slaughter 4. Initial BW: Not given 5. Study period: 3 visits per farm	1. Wooden slatted floor (80% of farms) 2. Concrete floor (slat, partial, full; 14% of farms) 3. Rubber or straw (6% of farms)	Risk of bursitis	Less than 1.8 m^2/calf > Larger space

6.4 Bedding management

Bedding materials include straw, sawdust, rice hulls, sand, gravel, etc. Bedding is used to keep calves dry and provide warmth and comfort for lying and for locomotion (Ninomiya & Sato, 2009), but bedding management, which is labour intensive, also has a big impact on how well bedding provides both comfort and warmth. To improve bedding dryness on concrete flooring, the slope of the floor must permit proper drainage, the waterer should be positioned to avoid wetting the bedding, and bedding needs to be changed regularly. Soiled bedding from urine and feces is not typically changed or removed in veal calf production; rather, new bedding may be added through fattening. Bähler et al. (2012), in a study of Swiss farms with mainly straw bedding, found that calf losses increase on farms where barns are cleaned and bedding is replaced only once per production cycle (odds ratio [OR] = 2.2) in comparison with farms where this is done twice per production cycle.

Poor management of bedding leads to high concentrations of ammonia (NH_3) in calf pens or hutches, creating an environment rich in nutrients for microorganism growth and for the breeding of flies (Calvo et al., 2010). Differences in the emissions of ammonia are positively correlated to the absorbance capacity and negatively correlated to the density of the bedding types (Misselbrook & Powell, 2005).

Panivivat et al. (2004) reported that, after 42 days of dairy calf rearing, there were significant differences in ammonia concentration 10 cm above the different bedding types. The lowest ammonia concentration was found with long wheat straw, followed by sand, rice hulls, wood shavings, and granite fines.

Godden et al. (2008) compared bacterial growth of bacterial inoculates on bedding materials (clean sand, recycled sand, digested manure solids, and wood shavings) sampled from dairy farms. Digested manure solids promoted the greatest amounts of growth of *K. pneumoniae*, followed by recycled sand and then wood shavings, whereas clean sand promoted the least.

Calves kept on bedding 11 to 15 cm deep had a lower risk of *Cryptosporidium* infection than those bedded to a depth of between 0 and 5 cm (Brook et al., 2008).

Panivivat et al. (2004) found that among 5 types of bedding (granite fines, sand, rice hulls, wheat straw, and wood shavings) used with dairy calves (1 to 42 days of age) no differences were found on serum immunoglobulin (IgG) concentration, stress indices (cortisol and neutrophil to lymphocyte ratio), and α1-acid glycoprotein (AGP), an acute phase protein. However, the number of days calves were treated with antibiotics due to scours was affected ($P < 0.05$) by bedding materials during the first 2 weeks of life, with calves on sand and granite fines having the higher number of treatment days. This may relate mainly to thermoregulation issues, since wet sand and granite fines would be colder than the other bedding types.

Flies can be a problem in calf pens when bedding is mixed with urine, faeces, spilled milk, spilled grain, and water. It has been found that for calves in hutches there are lower larvae densities when calves are kept on sand, and on gravel, compared to straw (Schmidtmann, 1991). There were fewer stable fly maggots when sawdust was used compared to when straw was used (Schmidtmann, 1991), and acidification of bedding with sodium bisulphate lead to lower house fly larvae density (Calvo et al., 2010).

6.5 Thermoregulation

A relatively high ratio of body surface to body mass, thin skin, small quantity of subcutaneous fat, and poor cutaneous vascular control are factors that contribute to a deficient thermoregulation of calves in comparison to older cattle (Olson et al., 1980; Carstens, 1994). Sufficient dry bedding provides the calf with an insulation barrier that helps conserve body heat. Dry bedding is important to keep calves dry; wet hair will increase heat loss.

Dry bedding reduces heat loss from conduction by helping animals cope with cold environments; the lower critical temperature for young calves is 18°C when they lie down on concrete vs 6°C when they lie down on deep dry straw (Wathes et al., 1983; Webster, 1984). Lago et al. (2006) surveyed naturally ventilated calf barns during winter months in Wisconsin and observed that wet bedding material reduced the ability of calves to nestle into the bedding (measured as nestling score where 1 = most of the calves appeared to lie on top of the bedding with legs exposed; 2 = calves would nestle slightly into the bedding, but part of the legs were visible above the bedding; and 3 = calf appeared to nestle deeply into the bedding material and legs were not visible). Ninomiya and Sato (2009) found that calves 21 and 51 days of age spent more than double the amount of time resting, lying in postures associated with slow-wave sleep, when they were given double the amount of bedding.

Calves may benefit from deep bedding, as this allows them to nestle into the bedding, perhaps reducing heat loss via radiation and convective cooling. Deep, dry bedding may be a more effective method of managing for drafts and cold stress than providing solid sides to the pen (Lago et al., 2006). The time that unweaned calves spent resting on their side, in lateral recumbency, was shorter in outdoor unheated shelters than in outdoor or indoor heated shelters (Hänninen et al., 2003).

Panivivat et al. (2004) found a significant effect of bedding type on the surface temperature of the bedding recorded daily during 42 days of use by dairy calves. The warmest temperature was provided by wheat straw and this was significantly warmer than wood shavings or rice hulls, with sand and granite fines having the lowest temperatures.

In an epidemiological study in dairy calves, damp bedding has been found to be a risk factor for diarrhoea in young calves (Curtis et al., 1993; Hill et al., 2007). When sand was compared to straw it was wetter and calf faeces were looser (Hill et al., 2007).

Several studies have shown that calves kept on deep litter have an increased risk of diarrhoea (Svensson et al., 2003) and infections with enteropathogens (Mohammed et al., 1999; Jäger et al., 2005). This contrasts with the results of Gulliksen et al. (2009) who, in an epidemiological study of 135 dairy herds in Norway, found that one of the factors associated with an increase in the risk of *Cryptosporidium* shedding and diarrhoea (prevalence = 4.7%) was the use of slatted concrete floor in group pens (n = 69) vs deep litter in the resting area in group pens (n = 10) and the use of straw in single pens (n = 64) [hazard ratio (HR) = 8.9 concrete vs deep litter group and straw individual].

Jäger et al. (2005) found increased prevalences of *Giardia*, *Cryptosporidium*, *Eimeria*, and strongylid nematodes in deep-bedded pens compared to pens with slatted flooring.

Mohammed et al. (1999) found that disposal of bedding daily, bi-weekly, or weekly was significantly associated with a decreased risk of infection with *Cryptosporidium parvum* in comparison to situations where bedding was not changed (OR = 0.40, 0.02, respectively). Daily cleaning by removing only soiled bedding or removing all bedding was associated with a significantly reduced risk of infection with *C. parvum* in comparison to situations where housing was not cleaned while calves were present during the rearing period.

Anderson et al. (2006) found that dry matter intake was lower ($P < 0.06$) for calves with bedding compared to steers without bedding during winter. The fact that gains were also lower for the steers without bedding reflects that these steers had higher maintenance requirements than their bedded counterparts. Birkelo and Lounsbery (1992) found that daily gain was higher (1.41 kg/d vs 1.30 kg/d) and feed conversion was better when steers were kept on bedding (5.93 kg feed/kg BW gain for straw and 5.88 kg feed/kg BW gain for shredded newspaper) compared to no bedding (6.33 kg feed/kg BW gain) in two different housing systems during winter.

Hill et al. (2007) found that dairy calves bedded with wheat straw gained 5 to 12% faster from 0 to 56 d than calves bedded with hardwood shavings during cold temperatures. Inclusion of bedding in the pens was more successful than increasing the rate of milk replacer fed to enhance performance of the calves.

6.6 Dirtiness

Dry bedding improves cattle cleanliness. Because bedding management is labour intensive, slatted floors were proposed to reduce the maintenance of bedding while still keeping animals dry and clean. Table 6.3 summarises the studies reviewed that have investigated flooring effects on dirtiness. Eleven studies report measures of dirtiness of animals. Two on young calves and 9 in heavier animals. Tessitore et al. (2009), in a study that included 20 intensive beef cattle farms, found that bulls' cleanliness was more likely (OR = 4.39) to be impaired on bedded floor compared to slatted floor. Brscic et al. (2015a) found that deep litter had a detrimental effect on bulls' cleanliness both 1 month after arrival and 1 week before the slaughter day. Prevalence data for bulls classified as dirty were, respectively, 95.3 and 94.4% for deep litter and, in the same order, 45.0 and 5.7% for slatted flooring. Gottardo et al. (2003) found that bulls housed on straw bedding were always dirtier than those on slatted floor.

Graunke et al. (2011) measured dirtiness of animals (sum of 4 body parts on a 5-graded ordinal scale from 0=clean to 4=whole or almost whole surface covered with manure) on different types of floors and found that bulls housed on concrete and rubber slats were cleaner than bulls on rubber mats. Schütz et al. (2015) also found that cows on rubber mats were almost 3 times dirtier than cows on concrete or wood chips. Elmore et al. (2015) found as well that steers on rubber mat flooring were dirtier than those on either rubber slats or concrete slats. Kartal and Yanar (2011) found no differences between concrete, rubber mats, and wooden slats in the cleanness score of the bedding material (on a scale of 1 to 5 as follows: 1=dry and clean, 2=20% to 40% surface dirty or wet, 3=40% to 60% of surface dirty or wet, 4=60% or 80% surface dirty or wet) during the pre-weaning period (1 to 7 wks of age), but from 4 to 6 months bedding of calves on wooden slats was cleaner (3.1 ± 0.1/5 points) than bedding of calves on rubber mats (3.7 ± 0.1/5 points).

However, Earley et al. (2015) found that animals housed on wood-chip deep bedding had greater dirtiness scores than those on slats, and two types of mats. Animals housed on wood-chips had greater ($P < 0.05$) dirt scores on day 45, 65, 86, 107, 128, and 148 compared with the other treatments, while animals housed on mat 2 were cleaner ($P < 0.05$) than bulls in the other treatments. Schulze Westerath et al. (2007) found no difference in dirtiness when fattening bulls were kept on straw, rubber coated concrete slats, soft mats, or concrete slats. Cattle kept on slats and mats were significantly dirtier than those kept on straw-bedded solid floors (Lowe et al., 2001a), but a second one-year experiment found that cattle kept on the fully slatted pens were no cleaner than cattle on any of the other floor types (slats with rubber strips, slats with perforated mats, or solid floor with straw).

Comparing 5 different types of bedding (river sand, granite fines, rice hulls, long wheat straw, and soft wood shavings) Panivivat et al. (2004) found that calves on granite fines were dirtier than calves on any other bedding material. Coliform and gram-negative bacteria count of granite fines was only surpassed by long wheat straw after calves occupied the pen.

Table 6.3 Studies examining the effects of flooring and bedding on the dirtiness of cattle

Effect studied	Reference	Animals & Methods	Treatments	Dirtiness	Results
TYPE OF FLOORING (11 papers)	Wilson et al., 1998	1. N = 48 2. Type: Holstein bull calves (tethered) 3. Age: 3 to 7 d old 4. Initial BW: 48.6 kg 5. Study period: 19 to 21 wks	1. Vinyl-coated, diamond-shaped expanded metal flooring; 2. Vinyl-coated, rectangular-shaped, expanded metal flooring 3. Slatted oak wood flooring	Cleanliness score of hindquarters Cleanliness score of all categories	Rectangular shaped dirtier than Diamond shaped Wooden slats dirtier than Vinyl coated (both)
	Kartal & Yanar, 2011	1. N = 30 2. Type: Brown Swiss 3. Age: Not given 4. Initial BW: 37.3±1.0 kg 5. Study period: 6 months	1. Concrete 2. Rubber mats 3. Wooden slats	Score of bedding material (pre-weaning 1 to 7 wks) Score of bedding material (4 to 6 months)	= Rubber mats dirtier than Wooden slats
	Graunke et al., 2011	1. N = 80 2. Type: Holstein bull calves 3. Age: 14 wks after weaning 4. Initial BW: 225 ± 33 kg 5. Study period: ~150d	1: Concrete slats (n=30) 2: Rubber slats (n=25) 3: Slotted rubber mats (n=25).	Dirtiness score	Rubber mats dirtier than Rubber slats = Concrete slats
	Gottardo et al., 2003	1. N = 48 2. Type: Simmental 3. Age: Not given (young bulls) 4. Initial BW = 321.2 ± 34.1 kg 5. Study period: 250 d	1. Concrete slats (n=24) 2. Straw bedded (n=24)	Dirtiness score	Straw dirtier than Concrete slats
	Tessitore et al., 2009	1. N = 20 farms 2. Type: Beef cattle 3. Age: Not given 4. Initial BW: <350 kg (Class 1) and >350 kg (Class 2) 5. Study period: 2 h/farm	1. Slats (material not described) 2. Deep litter (material not described)	Dirtiness score	Deep litter dirtier than Slats
	Elmore et al., 2015	1. N = 48 2. Type: crossbred Angus steers 3. Age: 9 mo old 4. Initial BW= 374.1 ± 27.5 kg 5. Study period: 84 d	1= Concrete slats (n=16) 2= Fully slatted rubber mat (n=16) 3= Solid rubber mat (n=16)	Dirtiness score Pen cleanliness	Solid rubber mat dirtier than Slatted rubber mat = Concrete slats Solid rubber mat t dirtier than Slatted rubber mat and both dirtier than Concrete slats
	Brscic et al., 2015a	1. N = Variable 2. Type: beef - Charolais and cross-bred 3. Age: Not given (bulls) 4. Initial BW ~400 kg 5. Study period: 120 d	1. Concrete slats 2. Straw-sawdust deep bedding	Prevalence of bulls classified as dirty	Deep bedding dirtier than Concrete slats

Table 6.3 Studies examining the effects of flooring and bedding on the dirtiness of cattle (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Dirtiness	Results
TYPE OF FLOORING (continued)	Brscic et al., 2015b	1. N = 326 2. Type: Charolais & Limousine finishing beef bulls 3. Age: Not given 4. Initial BW: 414.6 ± 52.0 kg 5. Study period: 7 to 9 months	1. Concrete slatted floors 2. Concrete slatted floors covered with 30mm synthetic rubber slats	Percentage of bulls scored as dirty	Rubber slats > Concrete slats
	Keane et al., 2015	1. N = 72 2. Type: Charolais and Limousin crossbred beef bulls 3. Age: Not given 4. Initial BW: 441 ± 45.1 kg 5. Study period: 6 months	1. Old Concrete slats 2. New Concrete slats 3. Old Concrete slats with 22 mm rubber mats attached 4. New Concrete slats with 22 mm rubber mats attached	Dirtiness score 42 to 105 d Dirtiness score 105 to 126 d Dirtiness score 126 to 148 d Dirtiness score 148 to 180 d	Concrete slats dirtier than Rubber mats = Concrete slats dirtier than Rubber mats =
	Lowe et al., 2001a	1. N = 60 (Year 1); 80 (Year 2) 2. Type: Continental-cross steers 3. Age: Not given 4. Initial BW: 450 ± 2.5 kg (Year 1); 423 ± 2.8 kg (Year 2). 5. Study period: 140 d (Year 1); 142 d (Year 2)	1: Concrete slats (n=20) 2: Concrete slats with perforated rubber mats (n=20) 3: Solid floors bedded with straw (n=20) On 2nd year added 4:rubber strips secured directly onto slats (n=20)	Dirtiness score (Year 1) Dirtiness score (Year 2)	Concrete slats = Rubber mats dirtier than Straw Rubber mats dirtier than Concrete slats = Rubber strips = Straw
	Earley et al., 2015	1. N =144 2. Type: Continental cross and Holstein–Friesian steers 3. Age: Not given 4. Initial BW : 503 ± 51.8 kg 5- Study period: 148 d	1. Concrete slats (n=36) 2. Rubber mat 1 (n=36) 3. Rubber mat 2 (n=36) 4. Deep bedding (n=36)	Dirtiness score	Deep bedding dirtier than Concrete = Rubber mat 1 dirtier than Rubber mat 2
BEDDING (1 paper)	Panivivat et al., 2004	1. N = 60 2. Type: female dairy calves 3. Age: Newborn 4. Initial BW: 32 to 35 kg 5. Study period: 90 d	n=12 per treatment Bedding types: 1:river sand 2:granite fines 3:rice hulls 4:long wheat straw 5: soft wood shavings	Cleanliness score Coliform count on d 42 (end)	Granite fines dirtier than all others Long wheat straw < all others

6.7 Slipperiness

Dairy cattle exposed to very slippery floors had 2 times the odds of being lame compared with cows exposed to non-slippery floors (Solano et al., 2015). Cows walk more slowly and have more acute leg angles when a floor is covered with a slurry of excreta, compared with a dry floor (Phillips & Morris, 2000). Slippery floors lead to an increased step frequency (Phillips & Morris, 2001) and greater risk for leg injuries in cows (Webb & Nilsson, 1983). Wierenga (1987) quotes a study where slips were recorded in bulls during self-grooming (licking or scratching) on slatted floor, perforated floor, or deep bedding. Slips were observed in 22.7 % of the occasions on slatted floor, 8.1% on perforated floor, and near zero percent in deep straw bedding. Similar results were found when slips were recorded during sexual and social interactions.

6.8 Measures of animal production

In Table 6.4, studies on the effect of flooring and bedding on measures of animal production are summarised. Fifteen studies have investigated production outcomes for calves housed on different floorings. Of these, 4 have looked at younger lighter calves and 11 at calves over 225 kg. Younger calves do as well on hard as on softer flooring according to 3 studies, and in another they do better on hard than on soft.

Older calves had similar performances on hard as on soft flooring according to the results of 7 studies, while they did better on softer flooring in 4 and worst on soft than hard flooring in one study.

An early study compared rearing bull calves in Israel (in groups) on slatted concrete flooring to rearing them with bedding on the ground. From this study, Levy et al. (1970) reported that on slatted floors, the animals required less feed per unit of live weight, were fatter, had a higher percentage of saleable meat, and were more efficient at feed conversion.

Wilson et al. (1998) compared productive traits of tethered calves kept on wooden slats or vinyl-coated metal flooring with two designs (rectangular or diamond shaped). During the 20 wks fattening period no differences were found between floorings for final weight, ADG, carcass weight, carcass dressing percent, organ (liver, spleen, and lung) conditions, or carcass muscle (flank and brisket) colour.

Hänninen et al. (2005) found similar ADG between young dairy calves kept on solid concrete floors (individually or in pairs) or covered by a rubber mat.

Kartal and Yanar (2011) compared Brown Swiss calves kept on concrete, rubber mats, and wooden slats. No differences were found between treatments for feed efficiency and total weight gain until 4 months of age. However, calves on rubber mats gained less weight from 4 to 6 months of age than calves on concrete or wooden slats.

Lowe et al. (2001a) compared three floor types on Year 1 (fully slatted floors, fully slatted floors covered with perforated rubber mats, or solid floors bedded with straw) and added a fourth type (concrete slats covered with secured rubber strips) on Year 2. Type of floor had no significant effect on intake, growth rate, carcass composition, and meat quality of finishing beef cattle in either of the Years. However, in both years the animals on slatted floors were allowed a space allowance of approximately 3.0 m^2 per animal (4.35 × 3.45 m pen for 5 animals) and animals on solid floors were allowed 5.3 m^2 per animal (7.45 × 3.55 m pen for 5 animals). According to Lowe et al. (2001a), these design differences were justified as the comparison in the study is of floor type systems rather than of the floor types per se, in order that the findings are directly applicable to the beef industry. Consequently, these results must be interpreted cautiously in the context of the veal industry.

In another study, Lowe et al. (2001b) did not find differences in DM intake for steers kept in pens where they could choose between two types of flooring (combinations of concrete slats, rubber mats, straw, or sawdust). Graunke et al. (2011) found no differences in daily DM and ME intake between calves housed on different floor types (concrete slats, slotted rubber mats, or aluminium slats covered with rubber). However, animals on concrete slats had lower ADG than animals on slats covered with rubber ([Mean ± SEM] 1.43 ± 0.03 vs 1.56 ± 0.03 kg/d). Animals on slotted rubber mats showed no difference in ADG (1.51 ± 0.03 kg/d) from those on concrete or rubber slats. No effect of floor type on carcass characteristics was observed. Slaughter age also tended to be higher and carcass conformation score tended to be lower on concrete slats than on rubber floors.

Elmore et al. (2015) did not find differences in total weight gained or ADG in beef cattle (36 to 48 wks old) on fully slatted concrete, fully slatted rubber mat, or solid rubber mat flooring.

Brscic et al. (2015a) found no difference between deep bedded and fully slatted floors on bulls' final live weight, average daily gain, and days of finishing.

Earley et al. (2015) did not find differences in several performance characteristics (total DM intake, live weight gain, carcass weight, dressing percent, carcass conformation score, carcass fat score, and kidney channel fat) of finishing steers kept on concrete slats, two types of rubber mats, and deep-bedding pens.

Gottardo et al. (2003) found no differences in daily gain, average final live weight, dry matter intake, and feed efficiency between bulls on slatted concrete floor and bulls on straw bedded concrete floor. Carcass characteristics (carcass weight, dressing percentage, carcass conformation, fatness score, meat chemical composition, and quality traits measured on longissimus thoracis muscle) were also similar between flooring types.

Anderson et al. (2006) found greater final weights for finishing steer calves that have moderate or generous quantities of straw bedding (respectively, 532 kg and 536 kg bodyweight) compared to animals with no bedding (508 kg body weight) under winter conditions in North Dakota. Generously-bedded steers gained 1.6 kg/d, modestly-bedded steers gained 1.67 kg/d, and steers without bedding gained 1.28 kg/d. Carcass weight and dressing percent improved with bedding. Marbling scores also improved with bedding as did the percent of carcasses grading choice (23% of carcasses of steers without bedding graded choice, vs 45% and 63% for bedded steers). Yield grade, fat thickness over the 12th rib, and internal fat (kidney, pelvic, and heart fat) were not affected by bedding. Similar results are reported by Stanton and Schutz (1996).

Panivivat et al. (2004) compared 5 types of bedding (granite fines, sand, rice hulls, wheat straw, and wood shavings) for dairy calves from 1 to 42 days of age. Growth rate and feed efficiency were not different between bedding materials.

Andersen et al. (1997) found that on fully slatted floors low space allowance (1.4 m^2/animal) for bull calves from 100 to 300 kg negatively affected growth rate, feed conversion, and cleanliness when compared to higher space allowances (1.7 & 2.5 m^2/animal).

Fisher et al. (1997) found that older heifers (468 kg initial weight) kept at a space allowance of 1.5 m^2/animal had lower ADG than heifers at 2.0, 2.5, and 3.0 m^2 (ADG = 0.52, 0.65, 0.70, and 0.69 kg/d, respectively).

Table 6.4 Studies examining the effects of flooring and bedding on measures of animal production

Effect studied	Reference	Animals & Methods	Treatments	Animal Production Measures	Result
TYPE OF FLOORING (13 papers)	Wilson et al., 1998	1. N = 48 2. Type: Holstein bull calves (tethered) 3. Age: 3 to 7 d old 4. Initial BW: 48.6 kg 5. Study period: 19 to 21 wks	n=16 animals per treatment 1. Vinyl-coated, diamond-shaped expanded metal flooring; 2. Vinyl-coated, rectangular-shaped, expanded metal flooring 3. Slatted oak wood flooring	Average Daily Gain Final weight Carcass weight Dressing percentage Organ conditions Carcass muscle color	= = = = = =
	Hänninen et al., 2005	1. N = 48 2. Type: male Holstein calves 3. Age: 1 wk old 4. Initial BW: 48 ± 1.0 kg 5. Study period: 140 d	1. Concrete solid floor pairs (n=16) 2. Concrete solid floor individual (n=16) 3. Rubber mat individual (n=16)	Average Daily Gain Resting behaviour and weight change	= + Correlation (r = 0.32)
	Kartal & Yanar, 2011	1. N = 30 2. Type: Brown Swiss 3. Age: Not given 4. Initial BW: 37.3±1.0 kg 5. Study period: 6 months	1. Concrete 2. Rubber mats 3. Wooden slats	Average Daily Gain (0 to 4 months) Average Daily Gain (4 to 6 months) Feed efficiency Body length	= Concrete floor = Wooden slats > Rubber mats = Wooden slats > Concrete = Rubber mats
	Graunke et al., 2011	1. N = 80 2. Type: Holstein bull calves 3. Age: 14 wks after weaning 4. Initial BW: 225 ± 33 kg 5. Study period: ~150d	1: Concrete slats (n=30) 2: Rubber slats (n=25) 3: Slotted rubber mats (n=25).	Dry-matter intake Average Daily Gain (225 to 440 kg BW) Average Daily Gain (overall) Feed conversion Carcass weight Dressing percent Carcass conformation Fatness score Slaughter age	= ↓Concrete ↑Rubber Slats = both to Rubber mats = = = = ↓Concrete (Trend, P = 0.07) = Concrete >Rubber slats > Rubber Mats (Trend, P = 0.06)
	Gottardo et al., 2003	1. N = 48 2. Type: Simmental 3. Age: Not given (young bulls) 4. Initial BW: 321.2 ± 34.1 kg 5. Study period: 250 d	1. Concrete slats (n=24) 2. Straw bedded (n=24)	Dry-matter intake Average Daily gain Feed conversion Final live weight Carcass weight Dressing percentage Carcass conformation Fatness score Meat chemical composition Quality traits of *longissimus thoracis*	= = = = = = = = = =

Table 6.4 Studies examining the effects of flooring and bedding on measures of animal production (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Animal Production Measures	Result
TYPE OF FLOORING (continued)	Elmore et al., 2015	1. N = 48 2. Type: crossbred Angus steers 3. Age: 9 mo old 4. Initial BW= 374.1 ± 27.5 kg 5. Study period: 84 d	1. Concrete slats (n=16) 2. Fully slatted rubber mat (n=16) 3. Solid rubber mat (n=16)	Average Daily Gain Total weight gain	= =
	Brscic et al., 2015a	5. N = Variable 6. Type: beef - Charolais and cross-bred bulls 7. Age: Not given 8. Initial BW: ~400 kg 9. Study period: 120 d	1. Concrete slats 2. Straw-sawdust deep bedding	Average Daily Gain Final live weight Slaughter age	= = =
	Brscic et al., 2015b	1. N = 326 2. Type: Charolais & Limousine finishing beef bulls 3. Age: Not given 4. Initial BW: 414.6 ± 52.0 kg 5. Study period: 7 to 9 months	5 commercial beef cattle farms n= 153 on Concrete and 173 on Rubber 1. Concrete slatted floors 2. Concrete slatted floors covered with 30-mm synthetic rubber slats	Final live weight Average Daily Gain	Rubber slatted > Concrete Rubber slatted > Concrete
	Cozzi et al., 2013	1. N = 48 2. Type: Male beef crosses (Charolais × Aubrac) 3. Age: ~12 months 4. Initial BW: 425.9 ± 48.8 5. Study period: 4 months	n= 16 animals per treatment (8 animals × 2 pens) 1. Concrete slatted floor 2. Perforated concrete panels (70 holes of 6.5 cm of diameter/m2) 3. Perforated concrete coated with perforated rubber mattress	Average Daily Gain Dry Matter Intake	Rubber mattress > Concrete = both to Perforated concrete =
	Keane et al., 2015	1. N = 72 2. Type: Charolais and Limousin crossbred beef bulls 3. Age: Not given 4. Initial BW: 441 ± 45.1 kg 5. Study period: 6 months	1. Old Concrete slats 2. New Concrete slats 3. Old Concrete slats with 22 mm rubber mats attached 4. New Concrete slats with 22 mm rubber mats attached No effect of age of floor, comparison is between Concrete slats and Rubber mats	Average Daily Gain Dry Matter Intake Carcass gain Kidney and channel fat Feed efficiency Slaughter weight Carcass weight Fat score Conformation score	Rubber > Concrete = Rubber > Concrete Rubber > Concrete Rubber > Concrete = = = =

Table 6.4 Studies examining the effects of flooring and bedding on measures of animal production (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Animal Production Measures	Result
TYPE OF FLOORING (continued)	Lowe et al., 2001a	1. N = 60 (Year 1); 80 (Year 2) 2. Type: Continental-cross steers 3. Age: Not given 4. Initial BW: 450 ± 2.5 kg (Year 1); 423 ± 2.8 kg (Year 2). 5. Study period: 140 d (Year 1); 142 d (Year 2)	1. Concrete slats (n=20) 2. Concrete slats with perforated rubber mats (n=20) 3. Solid floors bedded with straw (n=20) On 2nd year added 4. Rubber strips secured directly onto slats (n=20)	Dry-matter intake Average Daily Gain Carcass conformation Fatness score Carcass composition Quality traits of *longissimus dorsi*	= = = = = =
	Earley et al., 2015	1. N = 144 2. Type: Continental cross and Holstein–Friesian steers 3. Age: Not given 4. Initial BW: 503 ± 51.8 kg 5. Study period: 148 d	1. Concrete slats (n=36) 2. Rubber mat 1 (n=36) 3. Rubber mat 2 (n=36) 4. Deep bedding (n=36)	Dry-matter intake Average Daily Gain Carcass weight Dressing percent Carcass conformation score Carcass fat score Kidney channel fat	= = = = = = =
	Lowe et al., 2001b	1. N = 112 2. Type: crossbred Continental steers 3. Age: 22 ± 0.34 months 4. Initial BW: 536 ± 5.1 kg 5. Study period: 3 wks	Choice between: 1. concrete slats vs rubber mats 2. concrete slats vs straw 3. concrete slats vs sawdust 4. rubber mats vs straw 5. straw vs sawdust 6. rubber mats vs sawdust	Dry matter intake Intake of straw in front of each pen	= =
BEDDING (2 papers)	Panivivat et al., 2004	1. N = 60 2. Type: female dairy calves 3. Age: Newborn 4. Initial BW: 32 to 35 kg 5. Study period: 90 d	1. River sand (n=12) 2. Granite fines (n=12) 3. Rice hulls (n=12) 4. Long wheat straw (n=12) 5. Soft wood shavings (n=12)	Average Daily Gain Starter intake (wk 2)	= Rice hulls = Granite fines > wood shavings
	Birkelo & Lounsbery, 1992	1. N = 273 2. Type: crossbred steer calves 3. Age: Not given 4. Initial BW: 579 to 588 kg 5. Study period: 189 d	1. Straw (n=91) 2. Shredded newspaper (n=91) 3. No bedding (n=91)	Dry-matter intake Average Daily Gain Feed conversion	= Straw = Shredded newspaper > No bedding Straw = Shredded newspaper > No bedding

Table 6.4 Studies examining the effects of flooring and bedding on measures of animal production (…continued)

Effect studied	Reference	Animals & Methods	Treatments	Animal Production Measures	Result
SPACE ALLOWANCE (2 papers)	Andersen et al., 1997	1. N = 120 2. Type: Danish Friesian bull calves 3. Age: 70 d 4. Initial BW: ~100kg 5. Study period: ~140d	1. Low (n=40) 2. Moderate (n=40) 3. High (n=40) Period I From 100 kg to about 300 kg live weight Period II From 300 kg live weight until slaughter at 460 kg live weight	**Period I (100 to 300 kg BW)** Dry matter intake Average Daily Gain Feed conversion **Period II (300 to 460 kg BW)** Dry matter intake Average Daily Gain Feed conversion **Overall experiment** Dry matter intake Average Daily Gain Feed conversion Dressing percentage EUROP classification Commercial cutting Lean, fat and bone in loin % Rib-eye area	**=** High > Low = both to Moderate High = Moderate < Low = = = = High > Low = both to Moderate High = Moderate < Low = = = = Low > High = both to Moderate
	Mogensen et al., 1997	1. N = 80 (Experiment A); 70 (Experiment B) 2. Type: Friesian heifers 3. Age: ≥10 months 4. Initial BW: 311 to 335 kg (Experiment A); 309 to 313 kg (Experiment B) 5. Study period: 150 d	Exp. A 1. 1.5 m^2/animal (n=24) 2. 3.0 m^2/animal (n=56) Exp. B 1. 1.8 m^2/animal (n=30) 2. 2.7 m^2/animal (n=20) 3. 3.6 m^2/animal (n=20)	Average Daily Gain Average Daily Gain Daily Gain and Number of lying periods	1.5 m^2 < 3.0 m^2 1.8 m^2 = 2.7 m^2 = 3.6 m^2 + Correlation ($r = 0.6$; $P = 0.06$)
COMPETITION (1 paper)	Andersen et al., 1997	1. N = 120 2. Type: Danish Friesian bull calves 3. Age: 70 d 4. Initial BW: ~100kg 5. Study period: ~140d	1. Trough feeder (5 places) (n=12 pens of 5 animals) 2. Self- feeder (1 place) (n=12 pens of 5 animals)	Dry-matter intake Average Daily Gain Feed Conversion	= = =

6.9 References

Absmanner E., Rouha-Mulleder C., Scharl T., Leisch F. & Troxler J. (2009) Effects of different housing systems on the behaviour of beef bulls - An on-farm assessment on Austrian farms. *Applied Animal Behaviour Science* 118:12–19.

Albertí P., Panea B., Sañudo C., Olleta J.L., Ripoll G., Ertbjerg P., Christensen M., Gigli S., Failla S., Concetti S., Hocquette J.F., Jailler R., Rudel S., Renand G., Nute G.R., Richardson R.I. & Williams J.L. (2008) Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. *Livestock Science* 114:19–30.

Andersen H.R., Jensen L.R., Munksgaard L. & Ingvartsen K.L. (1997) Influence of floor space allowance and access sites to feed trough on the production of calves and young bulls and on the carcass and meat quality of young bulls. *Acta Agriculturae Scandinavica, Section A — Animal Science* 47:48–56.

Anderson V.L., Wiederholt R.J. & Schoonmaker J.P. (2006) Effects of bedding feedlot cattle during the winter on performance, carcass quality and nutrients in manure. *North Dakota State University Beef Feedlot Research Report* 29:28–36.

Bähler C., Steiner A., Luginbühl A., Ewy A., Posthaus H., Strabel D., Kaufmann T. & Regula G. (2012) Risk factors for death and unwanted early slaughter in Swiss veal calves kept at a specific animal welfare standard. *Research in Veterinary Science* 92:162–168.

Birkelo C.P. & Lounsbery J. (1992) Effect of straw and newspaper bedding on cold season feedlot performance in two housing systems. In *South Dakota Beef Report*. South Dakota State University, Brookings. p. 42.

Brook E., Hart A., French N. & Christley R. (2008) Prevalence and risk factors for *Cryptosporidium spp.* infection in young calves. *Veterinary Parasitology* 152:46–52.

Brscic M., Gottardo F., Leruste H., Lensink J., van Reenen K C.G. & Cozzi G. (2011) Prevalence of locomotory disorders in veal calves and risk factors for occurrence of bursitis. *Agriculturae Conspectus Scientificus* 76:291–295.

Brscic M., Gottardo F., Tessitore E., Guzzo L., Ricci R. & Cozzi G. (2015a) Assessment of welfare of finishing beef cattle kept on different types of floor after short- or long-term housing. *Animal* 9:1053–1058.

Brscic M., Ricci R., Prevedello P., Lonardi C., De Nardi R., Contiero B., Gottardo F. & Cozzi G. (2015b) Synthetic rubber surface as an alternative to concrete to improve welfare and performance of finishing beef cattle reared on fully slatted flooring. *Animal* 9:1386–1392.

Calvo M.S., Gerry A.C., McGarvey J. A., Armitage T.L. & Mitloehner F.M. (2010) Acidification of calf bedding reduces fly development and bacterial abundance. *Journal of Dairy Science* 93:1059–1064.

Camiloti T.V., Fregonesi J.A., von Keyserlingk M.A.G. & Weary D.M. (2012) Short communication: Effects of bedding quality on the lying behavior of dairy calves. *Journal of Dairy Science* 95:3380–3383.

Carstens G.E. (1994) Cold thermoregulation in the newborn calf. *Veterinary Clinics of North America: Food Animal Practice* 10:69–106.

Cerchiaro I., Contiero B. & Mantovani R. (2005) Analysis of factors affecting health status of animals under intensive beef production systems. *Italian Journal of Animal Science* 4(S3):122–124.

Chapinal N., Barrientos A.K., von Keyserlingk M.A.G., Galo E. & Weary D.M. (2013) Herd-level risk factors for lameness in freestall farms in the northeastern United States and California. *Journal of Dairy Science* 96:318–328.

Chua B., Coenen E., van Delen J. & Weary D.M. (2002) Effects of pair vs individual housing on the behavior and performance of dairy calves. *Journal of Dairy Science* 85:360–364.

Cozzi G., Tessitore E., Contiero B., Ricci R., Gottardo F. & Brscic M. (2013) Alternative solutions to the concrete fully-slatted floor for the housing of finishing beef cattle: Effects on growth performance, health of the locomotor system and behaviour. *The Veterinary Journal* 197:211–215.

Curtis C.R., Erb H.N., Scarlett J.M. & White M.E. (1993) Path model of herd-level risk factors for calfhood morbidity and mortality in New York Holstein herds. *Preventive Veterinary Medicine* 16:223–237.

Drissler M., Gaworski M., Tucker C.B. & Weary D.M. (2005) Freestall maintenance: Effects on lying behavior of dairy cattle. *Journal of Dairy Science* 88:2381–2387.

Earley B., McDonnell B. & O'Riordan E.G., (2015) Effect of floor type on the performance, physiological and behavioural responses of finishing beef steers. *Acta Veterinaria Scandinavica* 57:73–83.

Elmore M.R.P., Elischer M.F., Claeys M.C. & Pajor E.A. (2015) The effects of different flooring types on the behavior, health, and welfare of finishing beef steers. *Journal of Animal Science* 93:1258–1266.

Fathy A. & Radad K. (2006) Surgical treatment and histopathology of different forms of olecranon and presternal bursitis in cattle and buffalo. *Journal of Veterinary Science* 7:287–291.

Fisher A.D., Crowe M.A., Prendiville D.J. & Enright W.J. (1997) Indoor space allowance: effects on growth, behaviour, adrenal and immune responses of finishing beef heifers. *Animal Science* 64:53–62.

Fregonesi J.A., Veira D.M., von Keyserlingk M.A.G. & Weary D.M. (2007) Effects of bedding quality on lying behavior of dairy cows. *Journal of Dairy Science* 90:5468–5472.

Fregonesi J.A., von Keyserlingk M.A.G., Tucker C.B., Veira D.M. & Weary D.M. (2009a) Neck-rail position in the free stall affects standing behavior and udder and stall cleanliness. *Journal of Dairy Science* 92:1979-1985.

Fregonesi J.A., von Keyserlingk M.A.G. & Weary D.M. (2009b) Cow preference and usage of free stalls compared with an open pack area. *Journal of Dairy Science* 92:5497–5502.

Godden S., Bey R., Lorch K., Farnsworth R. & Rapnicki P. (2008) Ability of organic and inorganic bedding materials to promote growth of environmental bacteria. *Journal of Dairy Science* 91:151–159.

Gottardo F., Ricci R., Fregolent G., Ravarotto L. & Cozzi G. (2003) Welfare and meat quality of beef cattle housed on two types of floor with the same space allowance. *Italian Journal of Animal Science* 2:243–253.

Graunke K.L., Telezhenko E., Hessle A., Bergsten C. & Loberg J.M. (2011) Does rubber flooring improve welfare and production in growing bulls in fully slatted floor pens? *Animal Welfare* 20:173–183.

Gulliksen S.M., Jor E., Lie K.I., Hamnes I.S., Løken T., Åkerstedt J. & Østerås O. (2009) Enteropathogens and risk factors for diarrhea in Norwegian dairy calves. *Journal of Dairy Science* 92:5057–5066.

Gygax L., Mayer C., Westerath H.S., Friedli K. & Wechsler B. (2007) On-farm assessment of the lying behaviour of finishing bulls kept in housing systems with different floor qualities. *Animal Welfare* 16:205–208.

Haley D.B., de Passillé A.M. & Rushen J. (2001) Assessing cow comfort: Effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. *Applied Animal Behaviour Science* 71:105–117.

Hänninen L., de Passillé A.M. & Rushen J. (2005) The effect of flooring type and social grouping on the rest and growth of dairy calves. *Applied Animal Behaviour Science* 91:193–204.

Hänninen L., Hepola H., Rushen J., de Passillé A.M., Pursiainen P., Tuure V.-m., Syrjälä-Qvist L., Pyykkönen M. & Saloniemi H. (2003) Resting behaviour, growth and diarrhoea i ncidence rate of young dairy calves housed individually or in groups in warm or cold buildings. *Acta Agriculturae Scandinavica, Section A — Animal Science* 53:21–28.

Hill T.M., Bateman H.G. II, Aldrich J.M. & Schlotterbeck R.L. (2007) Effects of feeding rate of milk replacers and bedding material for calves in a cold, naturally ventilated nursery. *The Professional Animal Scientist* 23:656–664.

Hinterhofer C., Ferguson J.C., Apprich V., Haider H. & Stanek C. (2006) Slatted floors and solid floors: Stress and strain on the bovine hoof capsule analyzed in finite element analysis. *Journal of Dairy Science* 89:155–162.

Jäger M., Gauly M., Bauer C., Failing K., Erhardt G. & Zahner H. (2005) Endoparasites in calves of beef cattle herds: Management systems dependent and genetic influences. *Veterinary Parasitology* 131:173–191.

Jensen M.B., Munksgaard L., Pedersen L.J., Ladewig J. & Matthews L.R. (2004) Prior deprivation and reward duration affect the demand function for rest in dairy heifers. *Applied Animal Behaviour Science* 88:1–11.

Kartal T.Z. & Yanar M. (2011) Effect of floor types on the growth performance and some behavioural traits of Brown Swiss calves. *Veterinarija ir Zootechnika* 55:20–24.

Keane M., McGee M., O'Riordan E.G., Kelly A.K. & Earley B. (2015) Effect of floor type on Hoof lesions, dirtiness, immune response and production of beef bulls. *Livestock Science* 180:220–225.

Ladewig J. (1987) Physiological results of welfare research in fattening bulls. In: Schlicting M.C & Smidt D. (Eds.) *Welfare aspects of housing systems for veal calves and fattening bulls*. Commission of the European Communities, Brussels, Belgium, pp. 123–129.

Lago A., McGuirk S.M., Bennett T.B., Cook N.B. & Nordlund K.V. (2006) Calf respiratory disease and pen microenvironments in naturally ventilated calf barns in winter. *Journal of Dairy Science* 89:4014–4025.

Levy D., Holzer Z. & Volcani R. (1970) Concrete slatted floors vs bedding for fattening Israeli-Friesian bull calves. *Journal of Animal Science* 31:816–820.

Lowe D.E., Steen R.W.J., Beattie V.E. & Moss B.W. (2001a) The effects of floor type systems on performance, cleanliness, carcass composition and meat quality of housed finishing beef cattle. *Livestock Production Science* 69:33–42.

Lowe D.E., Steen R.W.J. & Beattie V.E. (2001b) Preferences of housed finishing beef cattle for different floor types. *Animal Welfare* 10:395–404.

Madsen E.B. & Nielsen K. (1985) A study of tail tip necrosis in young fattening bulls on slatted floors. *Nordisk Veterinaer Medicin* 37:349–357.

Misselbrook T.H. & Powell J.M. (2005) Influence of bedding material on ammonia emissions from cattle excreta. *Journal of Dairy Science* 88:4304–4312.

Mogensen L., Krohn C.C., Sørensen J. T., Hindhede J. & Nielsen L.H. (1997) Association between resting behaviour and live weight gain in dairy heifers housed in pens with different space allowance and floor type. *Applied Animal Behaviour Science* 55:11–19.

Mohammed H.O., Wade S.E. & Schaaf S. (1999) Risk factors associated with *Cryptosporidium parvum* infection in dairy cattle in southeastern New York State. *Veterinary Parasitology* 83:1–13.

Murphy P.A., Hannan J. & Monaghan M. (1987) A survey of lameness in beef cattle housed on slats and on straw. In: Wierenga and Peterse (Eds) *Cattle Housing Systems, Lameness and Behaviour.* Proceedings of a seminar on the influence of the design of housing systems for cattle on lameness and on behaviour, Brussels CEE, pp. 67–72.

Ninomiya S. & Sato S. (2009) Effects of 'Five freedoms' environmental enrichment on the welfare of calves reared indoors. *Animal Science Journal* 80:347–351.

Norring M., Manninen E., de Passillé A.M., Rushen J. & Saloniemi H. (2010) Preferences of dairy cows for three stall surface materials with small amounts of bedding. *Journal of Dairy Science* 93:70–74.

Olson D.P., Papasian C.J. & Ritter R.C. (1980) The effects of cold stress on neonatal calves 1. Clinical condition and pathological lesions. *Canadian Journal of Comparative Medicine* 44:11–18.

Panivivat R., Kegley E.B., Pennington J.A., Kellogg D.W. & Krumpelman S.L. (2004) Growth performance and health of dairy calves bedded with different types of materials. *Journal of Dairy Science* 87:3736–3745.

Phillips C.J.C. & Morris I.D. (2000) The locomotion of dairy cows on concrete floors that are dry, wet or covered with a slurry of excreta. *Journal of Dairy Science* 83:1767–1772.

Phillips C.J.C. & Morris I.D. (2001) The locomotion of dairy cows on floor surfaces with different frictional properties. *Journal of Dairy Science* 84:623–628.

Platz S., Ahrens F., Bahrs E., Nuske S. & Erhard M.H. (2007) Association between floor type and behaviour, skin lesions, and claw dimensions in group-housed fattening bulls. *Preventive Veterinary Medicine* 80:209–221.

Reich L.J., Weary D.M., Veira D.M. & von Keyserlingk M.A.G. (2010) Effects of sawdust bedding dry matter on lying behavior of dairy cows: A dose-dependent response. *Journal of Dairy Science* 93:1561–1565.

Schmidtmann E.T. 1991. Suppressing immature house and stable flies in outdoor calf hutches with sand, gravel, and sawdust bedding. *Journal of Dairy Science* 74:3956–3960.

Schrader L, Roth H.R., Winterling C., Brodmann N., Langhans W., Geyer H. & Graf B. (2001) The occurrence of tail tip alterations in fattening bulls kept under different husbandry conditions. *Animal Welfare* 10:119–130.

Schulze Westerath H., Gygax L., Mayer C. & Wechsler B. (2007) Leg lesions and cleanliness of finishing bulls kept in housing systems with different lying area surfaces. *The Veterinary Journal* 174:77–85.

Schütz K.E., Huddart F.J., Sutherland M.A., Stewart M. & Cox N.R. (2015) Effects of space allowance on the behavior and physiology of cattle temporarily managed on rubber mats. *Journal of Dairy Science* 98:6226–6235.

Schütz K.E. & Cox N.R. (2014) Effects of short-term repeated exposure to different flooring surfaces on the behavior and physiology of dairy cattle. *Journal of Dairy Science* 97:2753–2762.

Solano L., Barkema H.W., Pajor E.A., Mason S., LeBlanc S.J., Zaffino Heyerhoff J.C., Nash C.G.R., Haley D.B., Vasseur E., Pellerin D., Rushen J., de Passillé A.M. & Orsel K. (2015) Prevalence of lameness and associated risk factors in Canadian Holstein-Friesian cows housed in freestall barns. *Journal of Dairy Science* 98:6978–6991.

Stanton T.L. & Schutz D.N. (1996) Effect of bedding on finishing cattle performance and carcass characteristics. *Colorado State University Beef Program Report,* pp. 37–41.

Stefanowska J., Swierstra D., Smits A.C., van den Berg J.V. & Metz J.H.M. (2002) Reaction of calves to two flooring materials offered simultaneously in one pen. *Acta Agriculturae Scandinavica, Section A — Animal Science* (2):57–64.

Sundrum A. & Rubelowski I. (2001) The meaningfulness of design criteria in relation to the mortality of fattening bulls. *Acta Agriculturae Scandinavica, Section A — Animal Science* 51(S30):48–52.

Svensson C., Lundborg K., Emanuelson U. & Olsson S.O. (2003) Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. *Preventive Veterinary Medicine* 58:179–197.

Tessitore E., Brscic M., Boukha A., Prevedello P. & Cozzi G. (2009) Effects of pen floor and class of live weight on behavioural and clinical parameters of beef cattle. *Italian Journal of Animal Science* 8(S2):658–660.

Tucker C.B., Weary D.M. & Fraser D. (2003) Effects of three types of free stall surfaces on preferences and stall usage by dairy cows. *Journal of Dairy Science* 86:521-529.

Tucker C.B., Weary D.M. & Fraser D. (2004) Free-stall dimensions: Effects on preference and stall usage. *Journal of Dairy Science* 87:1208–1216.

Tucker C.B., Weary D.M., von Keyserlingk M.A.G. & Beauchemin K.A. (2009) Cow comfort in tie-stalls: Increased depth of shavings or straw bedding increases lying time. *Journal of Dairy Science* 92:2684–2690.

Wagner-Storch A.M., Palmer R.W. & Kammel D.W. (2003) Factors affecting stall use for different freestall bases. *Journal of Dairy Science* 86:2253–2266.

Wathes C.M., Jones C.D.R. & Webster A.J.F. (1983) Ventilation, air hygiene and animal health. *Veterinary Record* 113:554–559.

Webb N.G. & Nilsson C. (1983) Flooring and injury – an overview. In: Baxter S.H., Baxter M.R. & MacCormack J.A.C. (Eds.) *Farm Animal Housing and Welfare.* Nijhoff, The Hague, pp. 226–259.

Webster J. (1984) *Calf Husbandry, Health and Welfare*. Collins, London, UK.

Wierenga, H K. (1987) Behavioural problems in fattening bulls. In: Schlicting M.C & Smidt D. (Eds.) *Welfare aspects of housing systems for veal calves and fattening bulls*. Commission of the European Communities, Brussels, Belgium, pp. 105–122.

Wilson L.L., Terosky T.L., Stull C.L. & Stricklin W.R. (1999) Effects of individual housing design and size on behavior and stress indicators of special-fed Holstein veal calves. *Journal of Animal Science* 77:1341–1347.

Wilson L.L., Smith J.L., Terosky T.L. & Wheeler E.F. (1998) Comparison of three flooring types for special-fed Holstein veal calves. *Applied Engineering in Agriculture* 14:537–541.

Wilson L.L., Terosky T.L., Stull C.L. & Stricklin W.R. (1999) Effects of individual housing design and size on behavior and stress indicators of special-fed Holstein veal calves. *Journal of Animal Science* 77:1341–1347.

Worth G.M., Schütz K.E., Stewart M., Cave V.M., Foster M. & Sutherland M.A. (2015) Dairy calves' preference for rearing substrate. *Applied Animal Behaviour Science* 168:1–9.

Yanar M., Kartal T.Z., Aydin R., Kocyigit R. & Diler A. (2010) Effect of differential floor types on the growth performance and some behavioural traits of Holstein Friesian calves. *Journal of Animal and Plant Science* 20:175–179.

Zaffino Heyerhoff J.C., LeBlanc S.J., De Vries T.J., Nash C.G.R., Gibbons J., Orsel K., Barkema H.W., Solano L., Rushen J., de Passillé A.M. & Haley D.B. (2014) Prevalence of and factors associated with hock, knee, and neck injuries on dairy cows in freestall housing in Canada. *Journal of Dairy Science* 97:173–184.