What are the Options to Improve the Comfort and Welfare of Dairy Cows?

Elsa Vasseur[1*], Marianne Villettaz Robichaud[1], Doris Pellerin[2], Jeff Rushen[3], Steve Adam[4], and Anne Marie de Passillé[3]

[1]McGill University, Ste-Anne-de-Bellevue, QC; [2]Université Laval; Québec, QC; [3]University of British Columbia; Agassiz, BC; [4]Valacta; Ste-Anne-de-Bellevue, QC
*Email: elsa.vasseur@mcgill.ca

Take Home Messages

- Ten years of research projects were targeted at viable options to improve cow comfort and welfare and help dairy producers ready themselves for the welfare component of the proAction® initiative.
- We identified housing conditions that affect the welfare status of cows.
- We found that modifying the cow's stall to meet the current recommendations may improve animal-based welfare measures but may slightly decrease cow cleanliness.
- Producers often worry that meeting animal welfare standards will be costly but there are good indicators that improving welfare may also improve profitability.
- Cows are more comfortable in wider stalls. With construction costs averaging \$55–65 per ft^2, is building wider stall (and therefore larger buildings) cost-effective? The answer is that no compromise should be made regarding stall width: the current recommendation is the strict minimum to respect.
- Housing dry cows in dry-off pens allows them the opportunity to regain their condition for their next lactation. This practice is already used by Canadian dairy producers and our study provides references to expand the use of this practice.

Introduction

While restriction of movement is a reality for all domestic animals, freedom of movement is viewed by the general public as one of the most important aspects of the living conditions that should be provided to farm animals

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(Schuppli et al., 2014). Through the proAction® certification initiative, Dairy Farmers of Canada (DFC) is in the process of assuring minimum standards for animal welfare on Canadian dairy farms and will promote constant improvement of these standards. The Canadian Dairy Code of Practice is to be updated in 2019. In this context, what are the research findings supporting relevant and practical options for dairy farmers to improve the quality of life and welfare of their animals?

Despite the popularity of freestall systems when producers are renovating their barns, tie-stall systems still make up a significant proportion of the dairy systems in the U.S. (49%; United, 2017), Canada (75%), particularly in Quebec (93%; CDIC, 2016), and Europe (35-88% across European nations; Sogstad et al., 2005). However, the scientific literature is sparse in terms of studies aimed at improving current tie-stall systems and most of the research on cow welfare worldwide has been carried out on freestall cows. Over the last ten years, research aiming to document the animals' welfare status and understand risk factors for cow welfare in freestall and tie-stall systems has been conducted on Canadian dairies. We also wanted to verify if producers were complying with the Canadian Code of Practice and if complying related to better cow welfare outcomes and business profitability. The first part of this article will present the main results of the cow welfare projects funded under Dairy Research Clusters 1 and 2, initiatives of Agriculture and Agri-Food Canada (AAFC) and DFC, and how those findings supply the rationale for the recommendations for welfare improvement for cows kept in freestalls and tie-stalls.

One of the major findings was the identification of housing conditions that affect cow welfare status in both freestall and tie-stall systems. The effects of housing conditions have the potential to be exacerbated in tie-stall housing where most of the cows are restricted to their stall for their entire lactation. A major weakness of our current animal behaviour and welfare knowledge is that little is known about the impacts of this restriction of movement on the animal herself. In order to provide recommendations for welfare improvement of cows kept in tie-stalls, the dairy industry partnered with NSERC and McGill University to finance and design a research program to determine how restriction of movement impacts dairy cattle welfare, measured by the cow's ease of movement in her housing. Additionally, we also examined if increasing movement opportunity in the stall by improving stall configuration, both in freestall and tie-stall systems, would improve cow condition and ease of movement in her stall. This presentation will provide data on current knowledge resulting from the first 2.5 years of our NSERC-Novalait-DFC-Valacta Industrial Research Chair in Sustainable Life of Dairy Cattle.

▪ Large-scale On-farm Cow Comfort Study: what did we find, where did it lead us?

There are two main types of indicators used to assess animal welfare. The first type concerns the risk factors of poor welfare in terms of housing conditions (e.g., animal density, stall dimensions) and herd management (e.g., hoof trimming, pasture access). The second type of indicator concerns outcome measures of animal welfare, which are often considered as the “real” welfare measures because they are a direct assessment of impacts of housing and management on the animal itself.

Risk Factors Associated with Stall Design

Housing conditions affecting cow welfare status; stall configuration has a major impact. Welfare issues were identified in our most recent large-scale study assessing cow comfort on 230 Canadian dairies, including 110 freestall barns with milking parlours, 20 freestall barns with robotic milking systems, and 100 tie-stall barns (Vasseur et al., 2015). In freestall farms, prevalence of hock, knee, and neck injuries was 47, 24 and 9%, respectively (Zaffino Heyerhoff et al., 2014). In tie-stall barns, prevalence of hock and knee injuries was 56 and 43% (Nash et al., 2016) and lameness was 24% (Charlton et al., 2016). The prevalence of dirty cows was low (Bouffard et al., 2017; Figure 1). For tie-stall dairies, these results generally agreed with the only two other epidemiological studies conducted previously on Canadian tie-stall dairies (Zubbrigg et al., 2005a; Lapointe et al., 2010). In freestall dairies, these results were also similar to previously published Canadian and American data (von Keyserlingk et al., 2012).

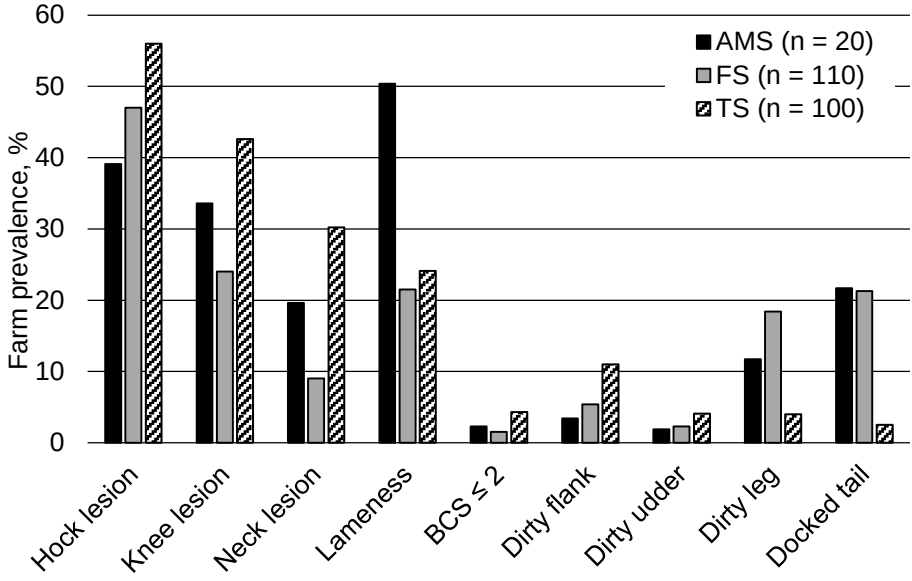

Figure 1. On-farm prevalence of different animal-based measures on 20 automatic milking system (AMS), 110 freestall (FS) and 100 tie-stall (TS) Canadian dairy farms.

Stall configuration has a significant impact on the cows' welfare status, which has the potential to be exacerbated in tie-stall farms since cows spend their entire lactation in their stalls. Our study showed that, on average, stalls met the current recommendations set by the Canadian Code of Practice (NFACC-DFC, 2009) for body dimensions for less than half of the cows on tie-stall farms (Bouffard et al., 2017, Table 1), supporting the results from previous studies (Zubbrigg et al., 2005b; Lapointe et al., 2010). We also confirmed risk factors for cow comfort associated with tie-stall configuration (Nash et al., 2016; Bouffard et al., 2017) including tie-rail positioning and chain length, which were also previously identified in the few epidemiological studies conducted in tie-stall dairies. Higher tie-rails may decrease risk of neck injuries and increase hygiene (Zurbrigg et al. 2005a,b) and longer chains may decrease risk for swollen hocks and increase hygiene (Zurbrigg et al. 2005a,b). Conversely, longer stalls but may impair hygiene (Zurbrigg et al., 2005a,b) but decrease the risk of hock lesions (Keil et al. 2006) and joint swelling (Busato et al., 2000).. Our study also highlighted risk factors for leg injuries and lameness in freestall farms where both the stall and pen configuration are important. We found that concrete stall bases increase the risk of knee injuries compared with mattresses (Zaffino Heyerhoff et al., 2014) and increase the risk of lameness compared with deep-bedded sand or a dirt

stall base (Solano et al., 2016). Farms with slippery alleys also had greater prevalence of both lameness and knee injuries.

Table 1. Mean (± SD) of the tie-stall dimensions in Québec and Ontario expressed in the same measure as the recommendations, and the percentage of stalls meeting each recommendation.

Dimension	Recommendation[1]	Measures[2]		% of stalls	
		Québec	Ontario	Québec	Ontario
Stall width	2x width of the cow at the hook bone	1.93 ± 0.18	1.86 ± 0.17	35	22
Bed length	1.2x height of cow at rump	1.19 ± 0.06	1.18 ± 0.06	46	43
Tie-rail height	0.80x height of cow at rump	0.74 ± 0.08	0.70 ± 0.09	23	16
Tie-rail position	35 cm more than stall length, from the back of the stall	5.2 ± 11.2	32.1 ± 8.9	2	54
Chain length	Height of tie rail minus 20 cm	-45.9 ± 18.1	-25.1 ± 15.4	7	39
Manger wall height	< 20 cm	21.3 ± 9.2	19.2 ± 6.6	44	62

[1]From Anderson (2014); [2]Measures expressed in the same ratio as the recommendations.

Modifications to the cow's environment and the stall configuration have the potential to improve cow welfare. In tie-stall systems, we reported (Bouffard et al. 2017) that moving the tie-rail forward (+10 cm) reduces injuries up to 42% and lameness by 24% and increases resting time by 0.07 hours/day, but also reduces hygiene by 20%. The results of a follow-up study by Palacio et al. (2015) on a sub-sample of those 100 tie-stall farms showed that improvements made by producers to their tie-stalls reduced risks of injury by 24, 27, and 33% to hocks, knees and necks, respectively. Furthermore, this study established that the four most reported modifications made to tie-stalls included both stall configuration and bed softness modifications; they were: 1) adding rubber mats; 2) adjusting the manger wall; 3) adjusting the tie-rail; and4) increasing the chain length. In a similar study conducted on free-stall farms in Alberta, the most reported changes were: 1) changing the stall base to geomattress; 2) modifying the amount of bedding used; and3) grooving the crossover alleys (Morabito et al., 2017). These results lead us to two questions which we answered with the same data we collected on our Canadian farms: 1) What is the impact of following current recommendations for stall configuration on outcome measures of welfare? 2) Is compliance with animal welfare standards associated with improved profitability on Canadian dairy farms?

What is the Impact of Following the Current Recommendations on the Animal-based Measures?

Making changes to meet current recommendations for stall configuration can lead to improvements in cow comfort and welfare, although this may result in a small reduction in hygiene. To evaluate how well Canadian dairy farms complied with recommendations for stall dimensions and the effect of compliance on cow comfort and hygiene, we assessed lactating Holstein cows (n = 3485) on 100 tie-stall dairy farms for neck and leg lesions, lameness, and hygiene, and measured time spent lying down (Bouffard et al., 2017). Data on stall dimensions (width and length of the stall, position and height of the tie rail, length of the chain and height of the manger curb) were recorded for each cow. Chains shorter than recommended increased the risk of neck, knee, and hock lesions. A tie-rail further back in the stall than recommended increased the risk of neck, knee, and hock lesions and reduced the risk of dirty udders, but reduced the frequency of lying bouts. A tie-rail lower down than recommended decreased the risk of neck lesions and lameness and increased lying time and lying bout frequency. Stalls narrower than recommended increased the risk of neck injuries and lameness and reduced the daily duration of lying time, but reduced the risk of a dirty flank and legs. Stalls shorter than recommended increased the risk of knee lesions and reduced lying bout frequency, but also reduced the risk of a dirty udder. The majority of farms do not follow recommendations for stall dimensions (with the exception of tie-rail height) and this lack of compliance was associated with increased risk of lesions and lameness, which can affect lying time. Larger than recommended stall dimensions tend to reduce hygiene, but the prevalence of dirty cows remains very low. Investigating the direct effect of stall dimensions on the animals on commercial freestall farms presented greater challenges because stall dimensions within a freestall environment may be variable and the cows can choose the stall in which they feel most comfortable. However, we believe that even though this research was conducted on tie-stall cows, some of the results, such as stall width and neck rail placement, can be applicable to freestall animals

Does Greater Comfort Mean Greater Profitability?

Farmers are often concerned that meeting animal welfare standards may be costly, but there are good reasons to assume that improved welfare may increase profitability. We examined whether meeting the Canadian animal welfare standards was associated with changes in cow productivity (Villettaz-Robichaud et al., 2018). We evaluated if freestall farms (n = 130) met the dairy industry highest animal welfare standards based on the previously recorded prevalence of leg and neck lesions, lameness, hygiene, body condition score (BCS), and stocking density. For each farm, data was also obtained on farm productivity and profitability measures: average milk

production, somatic cell count (SSC), calving interval, % culling, and % of cows in third lactation or higher. Our results show that none of the 130 farms met the nine criteria evaluated based on the highest current benchmarks of the proAction® Animal Care assessment (Criteria: prevalence of hock, knee and neck injuries; lameness; low BCS; dirty udder, leg and flank; high stocking density). The hock lesions and lameness criteria were met the least and the hygiene, BCS, and stocking density criteria were met the most. Meeting some of the individual components of the proAction® assessment scheme for animal welfare was associated with some economic measures of farm productivity and farm profitability. For example, farms that met the criterion for lameness prevalence (low prevalence) had greater improvement in milk production with increasing days in milk at first breeding compared with farms that did not met the criterion. Overall, 65% of the farms studied met five or six of the nine criteria included, and 90% of the farms met at least four of the nine criteria

In a second study, we investigated the associations between comfort and welfare indicators measured on a continuous scale and the freestall farms' productivity and profitability (instead of meeting a specific benchmark). An increase of 1% in cows with dirty flanks was associated with lower milk production (-27 kg/cow/year) and farms with lower lameness prevalence had higher average milk production (+12 kg/cow/year per 1% decrease). In terms of milk quality, farms with a higher proportion of stalls not soiled with manure had a lower average SCC (-460 cells per 1% increase in stalls not soiled). When examining the associations with the economic margins calculated for each farm over their replacement costs, we found that farms with greater variation in their cows' average daily lying time had lower margins per cow (-$431 per hour) and farms with a greater proportion of stalls with dry bedding had greater margins per cow (+$6 per 1%). Overall, our results suggest that improving cow comfort and welfare is unlikely to impose an economic burden on the Canadian dairy industry as a whole and could have the potential to financially benefit individual farms, depending on the costs associated with the improvements or changes needed to meet a specific recommendation or requirement.

Why did we need to conduct supplemental research on stall configuration in a research facility? Conducting research on commercial farms has limits when the aim is to build recommendations applicable to all farms. Under those conditions, it is impossible to isolate the risk factors from the outcome measures (e.g., is it because stalls are too short that cows have skin lesions or because they are too narrow?). It is also impossible to differentiate the individual effects of the stall configuration from other environmental and managerial factors (e.g., if we put more bedding on a stall that is too short, will it compensate for lack of length and reduce the level of injuries?). Furthermore, while there are some variables that can be measured under field conditions (e.g., neck lesions), there are many that are unmeasurable.

Behavioral data is an example of a category of variables that is difficult to measure in non-experimental settings (e.g., does tie-rail position impact neck injuries because of recurrent contacts between the cow's neck and tie-rail during rising and lying events?). Therefore, experiments conducted in a controlled environment aim to isolate the effects of individual changes to stall configuration or management on aspects of cow condition and performance. Understanding the ease with which the cow moves within her stall and uses her environment would further validate the recommendations provided to dairy producers. This is why we conducted a series of experiments at the McGill Macdonald Campus Dairy Cattle Complex.

▪ Improving Cow Comfort at the Stall is Possible: How much could we improve cow welfare at the stall and on which animal outcomes?

The primary objective of our Industrial Research Chair is to improve current tie-stall systems in terms of stall configuration, stall base/bedding, and ease of movement, through on-farm experiments carried out at the McGill Macdonald Campus Dairy Cattle Complex. A series of experiments have been designed to study the impacts of these elements on the level of cow welfare in the medium and long term (e.g. body injuries, level of production). Results reported here can be more directly applied to freestall and tie-stall systems.

Would Cow Benefit from "King-size" Beds?

Tie-stall dairy cows spend the majority of their lives in the same space, which needs to be adapted for all the activities they conduct. In freestall barns, the stall is the individual space designed for cow rest. Lying is a very important activity for dairy cows; therefore, housing designs should help ensure that the cows' needs for resting space are met, as it may impact their lying behaviours. The objective of this study was to verify if increasing stall width improves the cow's resting capacity. Two treatments were compared: the current recommendation (2x cow width + 6 inches) and double the current recommendation for stall width.

Sixteen cows of varied parities and lactation stages were randomly assigned to one of two treatments for six weeks. Live scoring was performed weekly to evaluate injuries, cow and stall hygiene, bedding quantity, and body condition (Gibbons et al., 2012; Vasseur et al., 2013; Vasseur et al., 2015). Lameness scoring was performed weekly through video observation (Gibbons et al., 2014; Palacio et al., 2017). The protocols used are available on the Dairy Research Portal of DFC (section: Producer Resources; Animal Comfort Tool https://www.dairyresearch.ca/animal-comfort-tool.php). Milk yield was recorded at each milking and milk samples were collected weekly to evaluate milk components. Feeding/rumination time was recorded continuously using

ear-mounted activity data loggers. Resting behaviour such as daily lying time, lying bout frequency, and duration of lying bouts were continuously recorded using leg mounted accelerometers. Cows were recorded one day/week by overhead cameras and six lying and rising events were evaluated per recording. A trained observer assessed the position and the location of the cows' body, head, and limbs when the cow was lying down (Figure 2).

Figure 2. A cow in a double-width stall lying in a deep rest posture, on her side with all limbs in extended posture.

What we learned: 1) Stall widths tested did not have a significant impact on cow and stall hygiene, body condition, lameness, body injury, feeding/rumination time, production of milk, or milk components. The amount of bedding in the double stalls was greater than in the stalls of recommended width (+ 23% stalls with deep bedding per week). 2) Regarding resting behaviours and ease of movement when transitioning between standing and lying, the total time spent lying did not differ between treatments, but cows in the double stalls rested differently with a lower total number of lying bouts (-1 bouts/day) and a higher duration of time/bout (+10 min/bout). There was no effect of treatment on the quality of the rising movements, but the contact with the stall was almost 2-fold less frequent during the lying down motion for the cows in the double stalls (43% in double stalls, compared to 77% with the current recommendation). 3) Cows in double stalls could assume more lying postures and use more space within their stall, extending their hind limbs more often than control cows (21.7% vs. 7.6%). They also entered the neighbouring stalls with their hind limbs less often than did the control cows (2.4% vs. 16.3% of the resting time for the left side, and 0.14% vs. 13.1% for the right side), instead using the full width of the double stall to position their hind limbs, using it in 38.3% and 29.2% of their resting time for the left and right sides, respectively. Cows in double stalls had their head in the stall more often (+25 % time during rest) and less often in the manger (-29% rest time), and they used the space of the double stall with the different parts of their body (Figure 3).

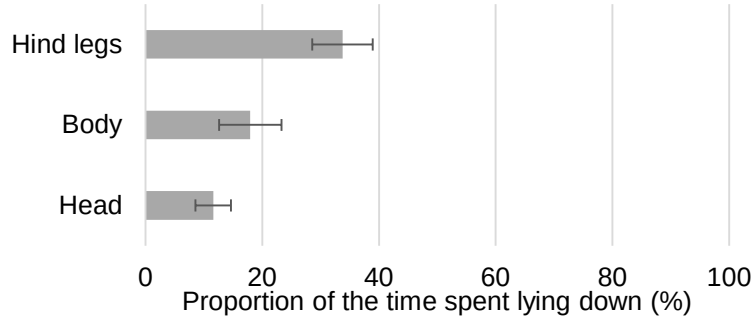

Figure 3. Use of the full stall width by cows in double stalls during lying down hours.

In conclusion, the stall is designed to position the cow parallel to the dividers and perpendicular to the neck rail. Our results show that cows adopt a variety of resting postures and maximize the use of the double width if given the opportunity. Cows are more comfortable with more width: these results are applicable in freestall and tie-stall-housing systems. Regarding economics, at $55–65 per sq. ft. in construction costs, is it profitable? The real answer is that there is no compromise possible for stall width: it is essential to follow the current recommendations as a minimum.

Drying off in Deep-bedded Loose Pens

In addition to our series of experiments on stall configuration and movement of the cow in her stall, we also tackled a related question: what movement opportunities can be offered to the cow outside the stall and how do we implement this practice (i.e., getting the cow outside her stall) in herd management? A cow's housing environment can significantly impact her overall welfare, particularly during the dry period as she undergoes a number of managerial and physiological changes. These characteristics make the dry period an ideal time to investigate the impact of taking the cow out of the stall, for example, by providing alternative housing, and to see how this housing alternative meets the needs of the cow during calving preparation.

Lying behaviours of dairy cows can be a useful measurement to evaluate the level of comfort and opportunity of movement provided in alternative housing environments. The first objective of the this experiment was to determine if lying time and lying postures differ between dairy cows housed in a tie-stall versus a loose-pen during the eight-week dry period. The second objective was to evaluate if the loose-pen provided increased locomotor opportunity, measured by step activity, and how locomotion of cows improved over the same period of time.

Twenty cows were blocked based on parity and calving date and assigned at dry-off to either a deep-bedded straw loose-pen (LP) or a tie-stall (TS) with a rubber mat base and 2 cm of wood shavings. Lying time and step activities were measured by leg-mounted pedometers (Shepley et al., 2017c). Twenty-four-hour video recordings were taken weekly for each cow by overhead-mounted cameras and the cows' lying postures were recorded by a trained observer using 1-min scan sampling of the video images for videos taken on the first, middle, and last week of the dry period. Locomotion was evaluated each week using NRS scoring of overall gait and associated behaviours of gait (Figure 4).

Figure 4. Cow walking in test corridor to evaluate quality of gait

What we learned: 1) Daily lying time was numerically, but not significantly, higher for LP cows compared with TS cows (850 ± 32.4 and 754 ± 19.1 min/day, respectively). The LP cows rested their head on their back more often than did TS cows (8.6 vs. 5.7% of the observed time). Similarly, LP cows exhibited greater variability in positioning of their hind legs, keeping legs tucked in less often (73.2 vs. 92.9%). Cows in LP also changed head position (22.0 vs. 14.7 changes/24-hour recording for LP and TS, respectively), front leg position (22.2 vs. 7.6), and hind leg position (88.8 vs. 23.6) more often than did TS cows. Similarities in daily lying time between the two housing options suggest that neither environment impeded the cows' lying abilities. The increased variety of postures and frequency of posture changes displayed by LP cows when lying may suggest that the cow is able to move with greater ease when provided with a combination of more space and a different lying surface, potentially increasing overall comfort for the cow. 2) There was no statistical difference between step activity for TS cows and LP cows (mean ± SE for steps/day: 867 ± 70.6 vs. 714 ± 77.8). However, the variation in the number of steps during the dry period was greater in the cows in pens than in those housed in stalls. 3) Dairy cows in LP housing showed significant improvement in joint flexion over time (score difference from start of -0.70), contrasting the worsening of joint flexion found in the TS (score difference from start of +0.06). In conclusion, housing dairy cows in loose pens during the eight-week dry period was beneficial for rest and locomotor recovery. These benefits can be attributed to a combination of factors: fewer obstacles in the environment (by eliminating the stall itself), a larger rest area,

and a more comfortable lying area. We don't know if similar results would be observed in freestall housing systems. Overall, housing cows in loose pens during the dry period gives the cow the chance to rebuild her condition for the next lactation. This practice is already used by dairy farmers in Canada. This study establishes references to broaden the implementation of dry-off pens.

■ Conclusion: Next steps?

Known problems with stall dimensions in both freestall and tie-stall systems, and that tie-stall animals are tethered for their entire lactation, may explain some of the poor welfare outcome measures that have been recorded in previous studies. This also raises the question of exercise as not only an aid to some of these management deficiencies, but also as a complementary management practice. Cows are motivated to access the outdoors when provided the opportunity in both winter (Shepley et al., 2017b) and summer (Shepley et al., 2017a) conditions when the alternative is a movement-restrictive (i.e., typical freestall barn) or a less movement-restrictive (i.e. deep bedding composted pack) indoor housing environment. We also identified the impact of providing outdoor access to tie-stall cows on mid- and long-term welfare outcome measures in commercial settings. Palacio et al. (2017) evaluated cows over one year and showed that farms providing cows with outdoor access had 20% fewer lame cows and 16% fewer cows with hock injuries at the end of winter (the period during which cows are most restricted to the indoors) than farms providing no outdoor access. Desrochers and Daigle (2017) showed that if access to an outdoor yard is provided, tie-stall cows have fewer hoof lesions (10% less).

Based on the results of these recent research projects, there is evidence that dairy cows can benefit from being released from the confinement of their stalls. The next step is to provide viable options for Canadian freestall and tie-stall dairy producers (without having to rebuild their barns), to improve the opportunities for movement provided to their animals, for example, by developing recommendations for cows to access to an exercise yard.

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References

Anderson, N. 2014. Dairy cow comfort tie-stall dimensions. OMAFRA, Ontario Ministry of Agriculture, Food and Rural Affairs. Visited on Sep 15 2018. http://www.omafra.gov.on.ca/english/livestock/dairy/facts/tiestalldim.htm.

Bouffard V., A.M. de Passillé, J. Rushen, E. Vasseur, C. Nash, D. Haley, and D. Pellerin. 2017. Effect of following recommendations for tiestall configuration on neck and leg lesions, lameness, cleanliness, and lying time in dairy cows. J. Dairy Sci. 100:2935-2943.

Busato, A., P. Trachsel, and J.W. Blum. 2000. Frequency of traumatic cow injuries in relation to housing systems in Swiss organic dairy herds. J. Vet. Med. A 47:221-229.

Charlton, G.L., V. Bouffard, J. Gibbons, E. Vasseur, D.B. Haley, D. Pellerin, J. Rushen, and A.M. de Passillé. 2016. Invited paper: Can automated measures of lying time help assess lameness and leg lesions on tiestall dairy farms? Applied Animal Behaviour Science. 175:14-22.

Canadian Dairy Information Centre (CDIC). 2017. The farm: Dairy barns by type in Canada. Visited on Sep 152018. http://www.dairyinfo.gc.ca/index_e.php?s1=dff-fcil&s2=farm-ferme&s3=db-el.

NFACC-DFC Dairy Farmers of Canada - National Farm Animal Care Council. 2009. Code of practice for the care and handling of dairy cattle. Visited on Sep 15 2018. https://www.dairyfarmers.ca/what-we-do/animal-health-and-welfare/code-of-practice-for-the-care-and-handling-of-dairy-cattle.

Desrochers, M. and A. Daigle. 2017. Une stratégie collective pour améliorer la santé des onglons dans les troupeaux laitiers du Québec. Conférence présentée au Symposium sur les bovins laitiers du CRAAQ. Drummondville, Québec, Canada October 2017. p104-114.

Gibbons, J., E. Vasseur, J. Rushen, and A.M. de Passillé. 2012. A training program to ensure high repeatability of injury of dairy cows. Animal Welfare 21:379-388.

Gibbons, J., D.B. Haley, J. Higginson Cutler, C. Nash, J. Zaffino Heyerhoff, D. Pellerin, S. Adam, A. Fournier, A.M. de Passillé, J. Rushen, and E. Vasseur. 2014. Technical Note: Reliability and Validity of a Method to Measure Lameness Prevalence of Cows in Tie-stalls. J. Dairy Sc. 97:350-353.

Keil, N.M., T.U. Wiederkehr, K. Friedli, and B. Wechsler. 2006. Effects of frequency and duration of outdoor exercise on the prevalence of hock lesions in tied Swiss dairy cows. Preventive Vet. Med. 74:142-153.

Lapointe, G., A. Fournier, and S. Lizotte. 2010. Vos vaches sont-elles confortables. Conférence présentée au 34e Symposium sur les bovins

laitiers du CRAAQ. Drummondville, Québec, Canada October 2010. p119-142.

Morabito, E., H.W. Barkema, E.A. Pajor, L. Solano, D. Pellerin, and K. Orsel. 2017. Effects of changing freestall area on lameness, lying time, and leg injuries on dairy farms in Alberta, Canada. J. Dairy Sce. 100:6516-6526.

Nash, C., D. Kelton, T. DeVries, E. Vasseur, J. Coe, J.C. Heyerhoff Zaffino, V. Bouffard, D. Pellerin, J. Rushen, A.M. de Passillé, and D. Haley. 2016. Prevalence of and risk factors for hock and knee injuries on dairy cows in tiestall housing in Canada. J. Dairy Sci. 99:6494-6506.

Palacio, S., M. Roulleaux, R. Bergeron, J. Rushen, A.M. de Passillé, D. Pellerin, D. Haley, T. DeVries, and E. Vasseur. 2015. Do improvements in housing and management voluntarily applied by producers following a cow comfort assessment reduce cow injuries in tie-stall dairies? ADSA-ASAS Joint Annual Meeting. Orlando, FL July 2015. Abstract #501.

Palacio, S., L. Peignier, C. Pachoud, C. Nash, S. Adam, R. Bergeron, D. Pellerin, A.M. de Passillé, J. Rushen, D. Haley, T. DeVries, and E. Vasseur. 2017. Technical Note: Assessing lameness in tie-stalls using live stall lameness scoring. J. Dairy Sci. 100:6577-6588.

Schuppli, C.A., M.A.G. von Keyserlingk, and D.M. Weary. 2014. Access to pasture for dairy cows: Responses from an online engagement. J. Anim. Sci. 92:5185-5192.

Shepley, E., R. Bergeron, and E. Vasseur. 2017a. Invited Paper: Daytime access to pasture vs. free-stall barn in dairy cows with year-long outdoor experience: A case study. Applied Animal Behaviour Science. 192:10-14.

Shepley, E., R. Bergeron, F. Bécotte, and E. Vasseur. 2017b. Short Communication: Dairy cow preference for outdoor exercise during winter under Eastern Canada climatic conditions. Can. J. Anim. Sci. 97:1-5.

Shepley, E., M. Berthelot, E. Vasseur. 2017c. Validation of the ability of a 3D pedometer to accurately determine the number of steps taken by dairy cows when housed in tie-stalls. Agriculture. 7(7):53.

Sogstad, Å.M., T. Fjeldaas, O. Østerås, and K.P. Forshell. 2005. Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. Preventive Veterinary Medicine 70:191-209.

Solano, L., H.W. Barkema, E.A. Pajor, S. Mason, S.J. LeBlanc, C.G.R. Nash, D.B. Haley, D. Pellerin, J. Rushen, A.M. de Passillé, E. Vasseur, and K. Orsel. 2016. Associations between lying behaviour and lameness in Canadian Holstein-Friesian cows housed in freestall barns. J. Dairy Sci. 99:2086-2101.

Vasseur, E., J. Gibbons, J. Rushen, and A.M. de Passillé. 2013. Development and implementation of a training program to ensure high repeatability of body condition score of dairy cows. J. Dairy Sci. 96:4725-4737.

Vasseur, E., J. Gibbons, J. Rushen, D. Pellerin, E. Pajor, D. Lefebvre, and A.M. de Passillé. 2015. An assessment tool to help producers improve cow comfort on their farms. J. Dairy Sci. 98:1-11.

Villettaz-Robichaud, M., J. Rushen, A.M. de Passillé, E. Vasseur, D.B. Haley, K. Orsel, and D. Pellerin. 2018. Is the profitability of Canadian freestall

farms associated with their performance on an animal welfare assessment? J. Dairy Sci. 2350–2358.

Von Keyselingk, M.A.G., A. Barrientos, K. Ito, E. Galo, and D.M. Weary. 2012. Benchmarking cow comfort on North American freestall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. J. Dairy Sci. 95:7399-7408.

Zaffino-Heyerhoff, J.C., S.J. LeBlanc, T.J. DeVries, C.G.R. Nash, J. Gibbons, K. Orsel, H.W. Barkema, L. Solano, J. Rushen, A.M. de Passillé, and D.B. Haley. 2014. Prevalence of and factors associated with hock, knee, and neck injuries on dairy cows in freestall housing in Canada. J. Dairy Sci. 97:173-184.

Zurbrigg, K., D. Kelton, N. Anderson, and S. Millman. 2005a. Tie-stall design and its relationship to lameness, injury, and cleanliness on 317 Ontario dairy farms. J. of Dairy Science 88:3201-3210.

Zurbrigg, K., D. Kelton, N. Anderson, and S. Millman. 2005b. Stall dimensions and the prevalence of lameness, injury, and cleanliness on 317 tie-stall dairy farms in Ontario. Canadian Vet. J. 46:902-909.