ABSTRACT

Given increased societal concern for the welfare of dairy cattle and the heightened concern of consumers about the ability of cows to fulfill their needs for rest and for movement, an understanding of the effect of stall-based housing systems on such needs becomes of prime scientific importance. In tie-stall systems, the ability of the cow to express her need for movement is largely affected by tethering; increasing chain length increased the cow’s ease of movement in the space allowed to her. Regarding the ability of the cow to rest, the size of the stall bed (including its width) has been linked with measures of lying time. For the most part, current industry recommendations are not being followed on commercial farms, although improvements in terms of compliance seem to have been made in the last decade. Following the recommendations for chain length appears to aid in reducing the prevalence of injuries and may even aid in maintaining the cleanliness of the cows, although the few studies available are inconsistent. Wider stalls were associated with increased lying time and reduced prevalence of injuries, although in the latter case, data from different studies show inconsistent results. The link between stall width and common welfare outcome measures appears more clearly in tiestall systems, although improving the lateral space allowance for cows reduces collisions with equipment in freestall systems as well. Overall, the width of the stall and the length of the chain play roles in modulating the cows’ ability to rest and to move comfortably in the confines of the stall, and should be carefully considered when designing stall-based housing systems that enhance the welfare of dairy cows.

Key words: dairy cow, comfort, welfare, stall design

INTRODUCTION

The intensification of dairy production around the world has brought considerable changes to the management of dairy cows. The advent of significant increases in dairy productivity resulting from improvements in the genetics, nutrition, and management of dairy cattle has been accompanied by marked modifications to the housing systems, including total confinement or year-long indoor housing of cows. In such contexts, stall-based systems have become the dominant type of housing systems, particularly in North America (USDA, 2016; CDIC, 2019) and the European Union (Eurostat, 2010).

The stall typically refers to an ensemble of structural elements defining an individual lying space for a cow, although stalls are used for both standing and lying (Tucker et al., 2004). In tiestall or freestall systems, the stall plays an important role in determining the cow’s level of comfort, because it is a structure in which she will spend most of her time. In freestalls, the cow enters a stall to rest and leaves it to access resources such as water and feed, and to be milked. In tiestall systems, the cow is tied at the front of the stall and cannot enter or leave at will. Her feed is delivered at the front of the stall and cannot enter or leave at will. Her feed is delivered at the front of the stall, and a water-providing structure is included to allow water access at all times. In both systems, the different stall-defining elements determine the amount of longitudinal and lateral space available to the cow, and improperly positioned structural elements can hinder the natural movements of dairy cows when they transition between standing and lying (Dairyland Initiative, 2020a,b). Housing cows in poorly dimensioned stalls can also increase the likelihood of body injuries (Regula et al., 2004; Zurbrigg et al., 2005a; Bouffard et al., 2017) and lameness (Espejo and Endres, 2007; Solano et al., 2015).
The condition of the cow is likely to affect its ability to move and to rest as well. Lame cows have altered resting patterns compared with sound cows (Ito et al., 2010), likely due to their reduced movement capacity. Conversely, the provision of exercise or greater freedom of movement has been linked to improvements in indicators of dairy cow ease of movement, such as the duration of intention movements before lying down (Krohn and Munksgaard, 1993; Gustafson and Lund-Magnussen, 1995) or the duration of lying-down movements (Krohn and Munksgaard, 1993; Gustafson and Lund-Magnussen, 1995; Popescu et al., 2013) and rising movements (Palacio, 2016). The presence of stalls themselves has been linked with changes in some of these markers of ease of movement (Krohn and Munksgaard, 1993), indicating that some aspects of stall design may restrict cows’ ability to use the space available to them with ease, or that the space allowed does not fully respond to their requirements.

The size and accessibility of the dynamic space—the space made available for the cow to move—and of the resting space in the stall can be directly linked to different aspects of stall design. We hypothesized that among the different stall-design aspects, the length of the chain (specific to tiestalls) can restrict the ability of the cow to move freely in the space granted to her, directly affecting her ability to fulfill her need for movement. We also hypothesized that stall width, as a factor defining the size of the stall bed, modulates the ability of the cow to rest in the space provided to her. Both chain length and stall width could impose limits on the cow in her ability to fulfill her needs for movement and rest.

Failure to provide cows with space that fully meets their needs for rest and movement will decrease welfare and may result in various outcomes, including injuries, lameness, and poor hygiene. Therefore, such indicators can serve to evaluate the effects of different aspects of stall design on dairy cow welfare (Main et al., 2003; von Keyserlingk et al., 2012; Vasseur et al., 2015), and to identify which changes should be proposed to producers, depending on the outcome measures that require improvement on their farm.

The purpose of this review was to provide a systematic report of the effect of 2 specific stall-design factors—chain length and stall width—on common outcome measures of welfare in lactating dairy cows, as documented in published epidemiological and experimental studies. Other components of the stall bed that play a role in the cow’s resting comfort—namely stall bed length and bedding—are covered in another review paper from McPherson and Vasseur (2020).

**CHAIN LENGTH, A TIE-STALL-SPECIFIC DESIGN FACTOR**

**Introduction to Chain Length in Stall-Based Dairy Housing Systems**

Chain length is a feature unique to tiestall housing systems, being the element responsible for keeping the cow from leaving her stall at will (Anderson, 2014) and ensuring that each animal remains in her assigned space. As such, its length is likely to affect the cow’s level of movement: short chains have the potential to reduce the cow’s ability to move by limiting the amount of space made available to them (Nash et al., 2016). Chain length in itself has received very little attention in terms of scientific research and is only scarcely mentioned in the scientific literature, either because of a lack of significant results or because it was not an object of investigation in the first place. Therefore, recommendations for chain length have been extrapolated based on field experience from advisors, who also provide the principal reasoning behind the numbers they bring forward. The main principles guiding the formulation of the recommendation for chain length can be found in Anderson (2014), who states that a chain of proper length will enable a cow to rest with her head turned back against her body, to groom herself, and to extend her head forward, all while maintaining her safety by limiting her risk of getting a leg caught in the chain. The chain should not interfere with the cow when she lies down or when she rises (Graves et al., 2007). The resulting recommendation for chain length thus stipulates that the snap or tie should touch the top of the manger wall (Anderson, 2014; Valacta, 2014). Dairyland Initiative (2020a), making its recommended length theoretically dependent upon 2 other stall parameters: manger wall height and tie-rail position. These recommendations are also dependent on cow size (Anderson, 2014; Valacta, 2014; Dairyland Initiative, 2020a; Supplemental Table S1, https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en). Respecting all recommendations for the the body dimensions of an average Holstein cow, this results in a chain length of approximately 1 m (Lapointe, 2010; Anderson, 2014; Valacta, 2014; Supplemental Table S1). One experimental trial conducted in Canada concluded that the recommended length appeared suitable, although when cows are provided with longer chains, they use the additional dynamic space made available to them (Boyer, 2019).

Although other countries such as the United States, Slovakia, Poland, and Austria report a significant pro-
portion of tiestall farms (Eurostat, 2010; USDA, 2016),
the on-farm situation for chain length has not been
investigated outside of Canada. Records show that on
farms, chain length fell short of the recommendation,
with averages of 57.7 cm (22.7 in.) in a sample of 118
Quebec farms (Lapointe, 2010; Supplemental Table
S2, https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en) and 69.4 cm (range 25–130 cm)
in a sample of 100 farms from Quebec and Ontario
(Nash et al., 2016). From the same sample of farms,
only 7% of the stalls assessed in Quebec and 39% in
Ontario were fitted with a chain that met the current
recommendation (Bouffard et al., 2017). In the Marit-
time provinces, 15% of farms had chains of less than 50
cm, 64% had chains of 50 to 79 cm, and 21% had chains
of 80 cm or longer (Jewell et al., 2019a). Although in-
teresting, the number of stall-design changes to imple-
mant in her stall (Zurbrigg et al., 2005a), hindering her
ability to rise and lie down without struggle. This limi-
tation was in turn hypothesized to cause restlessness
in cows, increasing the movements of their hind legs
during resting bouts, and the more numerous move-
ments increasing friction between the lying surface
and the skin of the hock, leading to greater levels of in-
juries (Zurbrigg et al., 2005a). This assumption appears
plausible, because cows have been found to increase
their use of the dynamic space made available to them
with increased chain length (Boyer et al., 2018a), show-
ing that the tie chain does play a role in modulating
ews that comply with this recommendation remains low
in a sample of 100 farms from Quebec and Ontario
(Nash et al., 2016). From the same sample of farms,
only 7% of the stalls assessed in Quebec and 39% in
Ontario were fitted with a chain that met the current
recommendation (Bouffard et al., 2017). In the Marit-
time provinces, 15% of farms had chains of less than 50
cm, 64% had chains of 50 to 79 cm, and 21% had chains
of 80 cm or longer (Jewell et al., 2019a). Although in-
teresting, the number of stall-design changes to imple-
mantine in methods. However, Jewell et al. (2019a) did not
provide details on the type of tiestall installations they
surveyed, unlike Nash et al. (2016). Types of tiestalls
other than tie-rail and chain—such as “V” stalls and 2-
or 6-bar stalls—are usually fitted with shorter chains,
albeit closer to the ground, and are therefore not fully
comparable in terms of restriction of movement for a
given length of chain. Another potential explanatory
factor is compensatory management (e.g., addition of
more bedding) by producers who are aware of the
weaknesses of their stalls; this element was mentioned
by Jewell et al. (2019a) when discussing the link be-
tween stall base and risk of injuries, but not for chain
length. Overall, low compliance with recommendations
reported on farms for chain length and other factors of
stall design makes it more difficult to isolate the effects
of individual stall-design factors from other factors that
affect outcome measures.

How Does Chain Length Affect Hock Injuries?

The link between chain length and hock injuries has
been investigated in only a few studies over the years,
and the reports contain several contradictions: different
authors have reported that chains shorter than 50 cm
reduced the odds of hock lesions by 44% (Jewell et
al., 2019a; Supplemental Table S3, https://escholarship
.mcgill.ca/concern/articles/2f75rd62n?locale=en), increas-
ing them by 1% (Nash et al., 2016), or had no
significant effect (Lapointe, 2010). Longer chains have
also been associated with a 1.36% reduction in the
prevalence of hock swelling (Zurbrigg et al., 2005a).
Experimental data from cows exposed for 10 wk to
chains longer than the current recommendation showed
no effect on levels of injuries (Boyer, 2019). Differences
between scoring methods employed in the studies (e.g.,
severity of swelling not detailed in the scoring sheet
vs. different levels of swelling resulting in more or less
severe injury scores) could partially account for the
inconsistent results and conclusions related to the ef-
fect of longer chains on risk for hock injuries. Authors
hypothesized that shorter chains could be linked with
increased injuries, because they limit the cow’s move-
ment in her stall (Zurbrigg et al., 2005a), hindering her
ability to rise and lie down without struggle. This limi-
tation was in turn hypothesized to cause restlessness
in cows, increasing the movements of their hind legs
during resting bouts, and the more numerous move-
ments increasing friction between the lying surface
and the skin of the hock, leading to greater levels of inju-
ries (Zurbrigg et al., 2005a). This assumption appears
serious injury scores) could partially account for the
effects of individual stall-design factors from other factors that
affect outcome measures.

How Does Chain Length Affect Knee Injuries?

Few studies so far have reported data pertaining to
the effect of chain length on knee (or carpal joint)
injuries, but 2 reported data from the same data set
(Nash et al., 2016; Bouffard et al., 2017), collected on
100 tiestall farms from Quebec and Ontario. Shorter
chains put cows at a higher risk of knee injuries: each
1 cm decrease in chain length was associated with a
7% increase in the prevalence of knee injuries (Nash
et al., 2016; Supplemental Table S3). A third study,
conducted in the Maritime provinces of Canada, re-
ported a 40% decrease in prevalence of knee lesions
with chains shorter than 50 cm, and an increase of 45%
for chains of 80 cm or longer (Jewell et al., 2019a). As
it was for hock injuries, this result appears difficult to
explain, and other elements pertaining to stall design
or to management may again provide the reasons for
the discrepancy between the published studies. Only 1
experimental study found that exposing cows to a chain longer than the recommended length for 10 wk did not affect levels of injuries (Boyer, 2019).

How Does Chain Length Affect Neck Injuries?

Similar to what was found for hock injuries, the few studies evaluating the link between chain length and neck injuries put forward different results: 1 reported increased risk with longer chains (Lapointe, 2010), and another an 8.3% decrease in risk [odds ratios (OR) = 0.917; Bouffard et al., 2017]; 2 more found no association between chain length and neck injuries (Zurbrigg et al., 2005b; Jewell et al., 2019a; Supplemental Table S3). The discrepancy between the results from Lapointe (2010) and Bouffard et al. (2017) could lie in the range of measured lengths; although they did not report chain lengths, Lapointe (2010) commented on the fact that in most cases, lengths did not comply with the recommendations by a considerable margin, a factor that could have contributed to their results. On the other hand, the farm sample of Bouffard et al. (2017) contained a known proportion of records in which the recommendation for chain length was met, even reporting an increase in the level of compliance in Ontario compared with a report from more than 10 yr earlier by Zurbrigg et al. (2005a). The 1 experimental study that compiled data on the link between chain length and neck injuries found no effect from exposing cows to chains longer than recommended for a 10-wk period (Boyer, 2019).

How Does Chain Length Affect Lameness?

Three studies collected and analyzed data to evaluate the association between lameness and chain length, and none reported any significant link between chain length and lameness (Bouffard et al., 2017; Boyer, 2019; Jewell et al., 2019b).

How Does Chain Length Affect Cow Cleanliness?

Literature available from epidemiological studies showed no significant association between udder cleanliness and chain length in tiestall-housed dairy cows (Zurbrigg et al., 2005b; Lapointe, 2010; Bouffard et al., 2017; Supplemental Table S4, https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en). On the other hand, although most of the data pointed to an absence of a link between chain length and the risk or prevalence of dirty legs (Lapointe, 2010; Bouffard et al., 2017), 1 study identified a significant association, with each 2.54-cm increase in chain length resulting in a 1.4% decrease in the proportion of moderately dirty hind legs (Zurbrigg et al., 2005a). The reported prevalence of clean cows on Canadian farms is very high: only 4.0% dirty udders, 4.1% dirty legs, and 10.6% dirty flanks (Bouffard et al., 2017). In an experimental setup comparing the current recommendation to longer chains, no differences were found in levels of cow cleanliness, even without trainers (Boyer et al., 2018a); a tight cleanliness maintenance routine on the research farm and a low number of statistical units could both have been explanatory factors in this case.

How Does Chain Length Affect Resting Behavior?

Only Bouffard et al. (2017) and Boyer (2019) collected and analyzed data pertaining to the link between chain length and daily lying time, and they found no significant association. To our knowledge, only 1 experimental study examined the link between chain length and other aspects of lying time; namely, the number and duration of lying bouts, and found no significant effect of a longer chain on such measures (Boyer, 2019). One indicator of ease of movement in the stall; namely, the duration of intention movements before lying down, was improved in cows with chains longer than recommended (Boyer, 2019). No study compared the effect on cow ease of movement of chains shorter or longer than the current recommendation.

Summary

Chain length has been linked in epidemiological studies with outcome measures of welfare such as injuries and cleanliness. For hock and knee injuries, as well as for cleanliness, some of the data point toward a positive effect of longer chains on the prevalence of injuries, although results are contradictory in the case of hock and knee injuries. The literature shows conflicting results for the effect of chain length on neck injuries, reporting that both longer and shorter chains reduce the risks of injuries. Lameness and lying time were not linked with chain length, and in most cases, epidemiological studies did not address the link between chain length and any other behavioral indicator of ease of movement or resting ability. Overall, the amount of data available relating to chain length and its effect on dairy cow welfare is scarce: almost all data were collected in the context of epidemiological studies on commercial farms, and only on Canadian farms. The main weakness in most of these epidemiological studies can be found in the low compliance with the recommendation for most if not all aspects of tiestall design. This hindered our capacity to draw conclusions about whether the current
Housing Systems

**STALL WIDTH**

*Introduction to Stall Width in Cubicle-Based Housing Systems*

Stall width is a feature of cubicle housing systems that can be defined as the distance between the centers of the 2 dividers that define the lateral borders of each individual stall. The width of the stall defines the lateral space available to the cow for standing, lying, and for her lying-down and rising movements; the structures defining the stall and its width are meant to work as limits guiding the cow’s position in the stall and imposing a single possible orientation on her (van Erp-van der Kooij et al., 2019). This is meant to limit neighbor intrusions, as well as diagonal standing and lying, with the aim of reducing the soiling of cubicles (Aland et al., 2009; Abade et al., 2015). However, the amount of lateral space truly available to cows is also affected by the design of the dividers that define such space. Improperly designed or positioned dividers may reduce the cow’s ability to rest comfortably by impairing lying-down movements (Plesch, 2011), and they represent an injury and entrapment hazard for cows (Anderson, 2016); careful consideration of these factors is required when formulating recommendations.

The recommendation for stall width is generally based on the minimal amount of space a cow requires when lying down. This need was quantified as equivalent to 1.81 times the hip-bone width of a cow through the use of 3-dimensional kinematic analysis of lying-down and rising movements (Ceballos et al., 2004). When the cow is lying in the narrow position (i.e., with all legs held close to her body), the amount of lateral space she occupies (also referred to as her imprint width) is equivalent to twice her hip-bone (or hook-bone) width (Anderson, 2014). This measure of imprint appears to be at the base of the recommendation for minimum stall width in both tiestall and freestall systems: in the majority of the cases, the recommendation is expressed as a ratio of twice the hook-bone width (Anderson, 2014; Valacta, 2014; Supplemental Table S5, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)) for a mature lactating cow. This width may be increased by 5.08 cm (2 in.) to account for the diameter of the dividers employed and ensure that the net amount of space available is at least twice the hook-bone width (Anderson, 2014; Valacta, 2014). Valacta (2014) recommends a further addition (up to 15.24 cm, or 6 in.) when hip clearance is lacking because of divider design. Other references present recommendations for cubicle width based on an estimate of the average cow’s weight, with a resulting range of 104.14 to 132.08 cm for animals of 408 to 771 kg (McFarland et al., 2016), and 107 to 145 cm for animals of 450 to 910 kg (Dairyland Initiative, 2020b) in freestalls. In tiestalls, the range spans from 137 to 152 cm for cows of 635 to 816 kg (Dairyland Initiative, 2020a). Remarkably, although some acknowledgment is made of the fact that dry cows (i.e., in late gestation) and cows with special needs may need wider stalls (Anderson, 2014), no specific numbers have been put forward as to how much more width these cows actually require compared with lactating animals. As critical as it is given the current prevalence of lameness on farms, no experiment has yet investigated the suitability of this recommendation for impaired cows (such as lame cows) that have reduced ability to move; the measure of Ceballos et al. (2004) was collected only on sound animals.

Data pertaining to stall width are available for both tiestall and freestall systems, from North America as well as from other areas around the world. In general, tiestalls are larger than freestall cubicles. This corresponds to some of the differences between recommendations for width in tiestall versus freestall systems, for example from sources such as Valacta, which provides advisory services for cow comfort in Quebec and the Maritime provinces of Canada. Anderson (2014) also commented on the fact that some producers were building larger stalls in newer tiestall barns, a situation that is reflected throughout the industry (Supplemental Tables S6 and S7, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)). Although not mentioned in publications from extension services, one reason behind this difference in width (both recommended and on-farm) could be the need to accommodate access for the milker in tiestalls. Data from tiestall dairies in Eastern Canada have shown that compliance with stall width recommendation could be improved: mean stall width corresponded to less than the recommended ratio in most cases (Supplementary Tables S6 and S7; Nash et al., 2016; Bouffard et al., 2017; Jewell et al., 2019a), although it was higher than the 1.8× hip-bone width identified by Ceballos et al. (2004) as necessary for lying-down and rising movements. Compliance had nonetheless improved compared with a report from about a decade earlier (Zurbrigg et al., 2005b).

In freestalls, 1 study conducted on German farms reported a mean stall width of 111.7 cm, or 88.37% of the required width for the 25% largest cows in the herds (Plesch, 2011). Other studies have presented data on the stall dimensions commonly found on commercial farms (Supplemental Table S7). The average recorded stall width was 112 cm in British Columbia and 121 cm
in California (von Keyserlingk et al., 2012). Data from Alberta, Ontario, and Quebec showed that freestall width in those provinces was slightly higher than in British Columbia, at 117 cm (Solano et al., 2015). On Dutch farms consisting mostly of Holstein herds, about 40% of herds had stalls narrower than 110.2 cm, and 32% had stalls wider than 111.5 cm (de Vries et al., 2015), but the authors made no reference to the body size of the cows in the herds visited. In comparison, the most recent data available, originating from herds in the Maritime provinces of Canada, showed that 80% of the 40 herds sampled had stalls wider than 120 cm, and 40% were 125 cm or larger (Jewell et al., 2019a).

Still, few studies have compiled data on the age of the installatations, which may explain some of the differences seen between regions, even among farms that consist mostly of Holstein herds. As well, few studies describe within-farm variations in stall width or discuss the use of different cubicle widths to account for the size differences between first-parity cows and older animals, or between different breeds in some herds. This factor could also contribute to explaining the statistics on stall width on farms: producers seek to balance providing sufficient width for mature Holstein cows with keeping younger cows (or cows of smaller breeds) from engaging in unwanted behaviors such as turning in the freestalls.

**How Does Stall Width Affect Rest and Ease of Movement?**

Four studies reported results for the effect of wider stalls on daily lying time in dairy cows. In freestalls, Tucker et al. (2004) reported a 1.2 h/d increase with a stall width of 132 cm compared with 112 cm, but Solano et al. (2016) reported 0.33 h/d longer lying times in stalls that were 114 cm or wider ($P = 0.016$). In tiestalls, 1 study identified a 0.107 h/d increase in daily lying time for each 10 cm increase in stall width (Boudard et al., 2017), but no effect on the frequency of lying bouts; however, another study by Boyer et al. (2018b) found no significant difference between recommended-width and double-width stalls for daily lying time, but identified a significant decrease of 1.4 bout/day in wider stalls ($P = 0.05$), and a concurrent increase of about 0.1 h/bout ($P = 0.05$).

A few other indicators of ease of movement were investigated in some studies that evaluated the effect of stall width on dairy cow welfare. In a study collecting data from 23 German farms, Plesch (2011) recorded a tendency for a 2% decrease in the occurrence of impaired lying-down movements for each 1% improvement in stall width compliance ($P = 0.09$; compliance defined as the division of the measured stall dimension by the recommended dimension). The percentage of collisions with stall equipment (another measure of ease of movement) decreased by 34% in an experimental study comparing stalls of recommended width to double-width stalls (Boyer et al., 2018b), but Plesch (2011) found no link with increasing stall width compliance. The use of measures of ease of movement during lying-down and rising motions allowed researchers to observe improvements in cow ease of movement in freestall systems (Krohn and Munksgaard, 1993) and with regular access to exercise (Gustafson and Lund-Magnussen, 1995; Loberg et al., 2004; Palacio, 2016). However, these measures have been employed in few of the studies relating to stall design. Although the recording of such measures may add to the duration of assessments conducted on farms, they can be of use when trying to explain the results obtained for some of the more traditional measures of welfare, such as daily lying time. Future studies should consider including indicators of ease of movement, similar to Plesch (2011) and Boyer (2019), because this could further enhance our understanding of how cows perceive changes in the width of their stalls.

**How Does Stall Width Affect Hock Injuries?**

Several epidemiological studies have examined the link between stall width and hock injuries, in both tiestall and in freestall systems. In all 8 studies conducted in freestall systems, the association between the risk of hock injuries and stall width was never significant (Supplemental Table S8, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)). All results from freestalls pointed to an absence of association between these injuries and the width of the stalls, perhaps because other stall-design factors (such as stall base, bedding type, and bedding quantity) played a greater role in the development and healing of injuries than stall width. Because all data were collected in the context of epidemiological studies, other effects such as levels of compliance with multiple factors of stall design or factors relating to the management of the stalls and the herd make it difficult to isolate the individual effect of factors such as stall width in this context.

Data from tiestalls have for the most part painted the same picture as for freestalls (Supplemental Table S8), with the exception of Nash et al. (2016), who identified a significant link between the odds of hock injuries and the width of stalls. Their data showed that for very wide cows (hip width of 80 cm), the odds of hock injuries increased with increasing stall width; however, for the 3 other categories of cow width, the odds of hock injuries decreased with increasing stall width ($P = 0.006$; Nash et al., 2016). An explanatory factor brought forward by the authors was that wide cows were likely more at risk...
of being injured because they were bigger and heavier, so they may have been purposely placed in wider stalls by well-intentioned farmers trying to aid their recovery. Again, the influence of other factors linked to stall design and management on commercial farms may make it more difficult to isolate the effect of stall width alone. Overall, with respect to most data collected so far in epidemiological studies from 2 housing systems, the data seem to point to an absence of a link between stall width and hock injuries, although further research (this time in a more controlled context) could provide a more definitive answer to that question.

**How Does Stall Width Affect Knee Injuries?**

Injuries to the carpal joints were examined in fewer studies than hock injuries, but data are available from both tiestall and freestall epidemiological studies. In freestalls, no link was found between stall width and the prevalence of knee injuries in the 2 studies that reported on this question (Haskell et al., 2006; Jewell et al., 2019a). In tiestalls, the picture is slightly different: authors reported that the odds of knee injuries increased in narrower stalls ($P = 0.01$, Nash et al., 2016; $P = 0.014$, Jewell et al., 2019a; Supplemental Table S9, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)), or that knee injuries were not significantly associated with this stall-design factor (Bouffard et al., 2017). The link that appeared between stall width and knee injuries in tiestalls has not been observed in freestall systems, a difference that could be because of the lack of movement and inability of the cow to choose her stall in tiestall systems. Narrower stalls may increase the risk of cows hitting stall elements (e.g., dividers) during lying-down and rising movements (Jewell et al., 2019a), or they may force cows to reposition themselves during these same movements to avoid hitting the stall hardware. Repositioning efforts during lying-down movements may take the form of shifting the hindquarters, putting additional pressure on the carpal joints by increasing the amount of time spent in a kneeling position (Zambelis et al., 2019). For rising movements, crawling on the knees before or after the initial lunging movement could also be linked to increased risk of knee injuries, by causing friction between the surface of the stall and the carpal joint.

**How Does Stall Width Affect Neck Injuries?**

The association between neck injuries and stall width has been examined mostly in tiestall systems; only 1 study reported data from freestall farms. Most of the studies found no significant association between stall width and risk of neck injuries (Supplemental Table S10, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)). Only 1 group reported a significant link, with a 11.6% decrease in risk of neck injuries for each 10-cm increase in stall width (Bouffard et al., 2017). Overall, discrepancies between the studies make it difficult to determine a conclusive link between stall width and neck injuries, although most of the data compiled so far point to an absence of an association.

**How Does Stall Width Affect Lameness?**

In tiestalls, a discrepancy exists between the results from Bouffard et al. (2017), who found a decrease in risk of lameness with increasing stall width ($OR = 0.854; P < 0.001$; Supplemental Table S11, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)), and those from Jewell et al. (2019b), who found no significant association (Supplemental Table S11). In freestalls, none of the epidemiological studies consulted found any association between cubicle width and measures of lameness, except for Westin et al. (2016), who found that odds ratios for lameness were increased when cows did not fit the cubicule width ($OR = 1.79; P < 0.001$). Lameness may be influenced by stall components that affect the cow’s ease of movement and lying behaviors (i.e., lying time and distribution of lying time), the latter of which are also altered in lame cows (Solano et al., 2016). The relationship between stall width and lameness needs further confirmation because of contradicting results from studies with identical assessment methods (in the case of tiestall epidemiological studies), but it is likely complex and subject to multiple confounding factors related to management and other aspects of stall design.

**How Does Stall Width Affect Cow and Stall Cleanliness?**

Literature from freestall systems showed no association between increasing stall width and cleanliness of the cows (Supplemental Table S12, [https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en](https://escholarship.mcgill.ca/concern/articles/2f75rd62n?locale=en)). No significant link was observed between the cleanliness of the flanks (Rud et al., 2010; de Vries et al., 2015), hind legs (Rud et al., 2010), udder (Rud et al., 2010), or teats (Plesch, 2011) and increasing or decreasing the lateral dimensions of the stalls on commercial farms. In tiestall systems, on the other hand, increasing stall width resulted in higher risk of dirty flanks (Bouffard et al., 2017; Supplemental Table S12). For the hind legs, Zurbrigge et al. (2005a) and Bouffard et al. (2017) presented contradictory results, the former finding no association and the latter identifying an
increase of 16.6% in risk for dirty hind legs with each 10-cm increase in stall width. This difference could be attributed to progress made in the years when the 2 studies were conducted: Bouffard et al. (2017) reported a higher proportion of farms that complied with recommendations for stall width (22% of Ontario farms) than Zurbriggen et al. (2005a; 10% of farms). Results from Lapointe (2010) identified a 5% decrease in risk of dirty udders with stalls of recommended width, but Bouffard et al. (2017) found no association between stall width and udder cleanliness.

Few studies have presented data on stall cleanliness, but 1 epidemiological study conducted on 3,459 stalls (224 farms) used by Norwegian Red cows identified a 33% increase in risk of soiling the stall by direct deposition of feces when freestall width was 113 cm or narrower (Ruud et al., 2011). The same study found that the risk of stalls being soiled by feces transported in by the cows’ feet was decreased by 22% in stalls that were 113 cm wide or narrower, compared with wider stalls (Ruud et al., 2011). The effect of stall width on cubicle cleanliness is very likely linked to differences in the use of stalls by cows: more width allows the cows to stand more easily with all 4 feet in the cubicle, giving them a greater chance of bringing fecal material from the alleys than with only 2 feet in the stall (Ruud et al., 2011). The link between wider stalls and lower risk of fecal contamination appears more difficult to explain, because wider stalls theoretically give cows a greater opportunity to stand and lie diagonally, something that had been previously associated with defecation in the stalls (Ruud et al., 2011). However, some extension services have emphasized that in the field, stall-design issues such as significant obstacles in the stall front can be causes for cows’ diagonal lying behaviors, stall width more often playing a minor role in such instances (Dairyland Initiative, 2020b). This could represent an explanatory factor, because poorly designed or old cubicles often fail to meet multiple recommendations (and the cows’ needs) at once. We found no such data from research conducted on tiestall farms, so the link with increased dirtiness of hind legs and flanks observed in wider stalls by Bouffard et al. (2017) remains relatively unexplained. The addition of data related to the cleanliness of stalls could give us a better understanding of causes underlying this association.

Summary

The data available from tiestall and freestall epidemiological studies have shown that lying time increases in wider stalls compared with narrower ones. Measures of ease of movement when lying down have also pointed to overall improved ease of movement in cows with access to stalls that better meet their space requirements. Although some data have shown a decrease in the risk of lameness and of hock, knee, and neck injuries in cows given wider stalls in tiestall housing systems, contradicting results exist between studies. In freestalls, data tend toward the absence of a link between cubicle width and the risk for hock, knee, and neck injuries. The picture is the same for a link between lameness and freestall width. Results relating to cow cleanliness also come from a few studies that contradict each other as to the effect of wider or narrower stalls on risk for dirty hind legs, flanks, udders, and teats. In most cases, the contradicting results from different studies show the limitations of epidemiological studies, where potential confounders reduce the ability to properly isolate the individual role of stall width in determining the risk for body lesions, lameness, and cleanliness. Such studies also often lack the data to provide explanatory factors for the results of the risk analyses they present. Studying the effect of stall width on cow comfort in the context of controlled-design studies could yield results without interactions between different aspects of stall design, which may come as a “bundle” on commercial farms (e.g., stalls that are too narrow are often too short as well; Nash et al., 2016; Bouffard et al., 2017). Given the role that stall width appears to play in improving daily lying time, further study of cows’ capacity to rest appears to be an important step toward further improving dairy cow comfort and well-being. As such, the addition of data related to ease of movement during rising and lying down, and to the number of lying bouts and the postures employed during those bouts could provide greater insight into not only the causes behind the improvements observed in lying times, but also the different behaviors that contribute to the risks of injuries, which may be improved by providing wider stalls.

CONCLUSIONS

In stall-based housing systems, stall configuration affects the cow’s ease of movement and general comfort in both the dynamic and resting space she is given. We reviewed the effect of 2 stall-design factors (chain length and stall width) on common outcome measures of welfare: lying time, injury prevalence, lameness, and cow and stall cleanliness. The length of the chain in tiestalls does affect the cow’s ability to use the space in her stall, although the link with ease of movement does not clearly translate into differences in other outcome measures of welfare, potentially because other factors of stall design play a greater role in the risk of injuries and lameness and have a greater effect on lying behaviors. Despite contradicting findings between studies, wider tiestalls appear to have a protective effect against hock,
knee, and neck injuries, as well as on lameness. Wider stalls have been linked with indicators of greater ability to rest comfortably, both in tiestalls and freestalls. This positive effect of wider stalls on lying time and lying postures shows that the lateral space available plays a role in determining the level of comfort of the resting space granted to the cow; greater consideration should be given this factor when developing new recommendations and implementing them in renovated or new dairy cattle housing facilities.

ACKNOWLEDGMENTS

The authors acknowledge the Natural Sciences and Engineering Research Council (NSERC; Ottawa, ON, Canada) and the Fonds de recherche du Québec—Nature et technologies (FRQNT; Québec, QC, Canada) for graduate student funding, as well as the funding support of Novalait (Québec, QC, Canada), the Dairy Farmers of Canada (Ottawa, ON, Canada), and Lac-tanet (Sainte-Anne-de-Bellevue, QC, Canada) as part of the NSERC Industrial Research Chair on the Sustainable Life of Dairy Cattle. The authors declare no conflict of interest.

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