Short communication: Use of the Clegg hammer measure as an indicator of stall-surface compressibility in tie-stall housing and its relationship with stall comfort

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ABSTRACT

Stall base and stall surface (i.e., with or without bedding) are key risk factors in cow comfort in dairy herds. In Canada, rubber mats, concrete floors, and mattresses are the most common stall bases used in tie-stall systems. Straw, wood shavings, and sand, at variable depths, are the most commonly used type of bedding. The Clegg hammer (Clegg Impact Soil Tester Hammer; Lafayette Instrument Company, Lafayette, IN) is a tool used by engineers to test the compressibility of pavement or golf course surfaces. Recently, this tool has also been used to measure the compressibility of the stall surface on freestall dairy farms. A total of 32 tie-stall dairy herds were selected in Québec to test the usefulness of the Clegg hammer as a tool to assess stall surface compressibility in tie-stall housing. This study had 2 main objectives: (1) identify the location and the number of measurements needed to obtain a stable indicator of compressibility, and (2) identify differences in the compressibility of the stall surface depending on the stall base and bedding depth. On each farm, we tested the compressibility of 10 stalls. No significant differences were found between the front and the back of the stall for the location of the Clegg hammer measures. The differences in readings of the Clegg hammer were nonsignificant after the third measure taken at the same location, meaning that 3 measures are sufficient at one location to obtain a compressibility measure. Significant differences were found among the different stall base and surface combinations tested. Rubber mats were less compressible than mattresses. When a large quantity of bedding (>7.5 cm) was added on top of rubber mats, the compressibility results were equal to those of mattresses ≥ 10 yr old without bed-

ding. To appropriately test the compressibility of stall surface in tie-stall farms, we recommend measuring the compressibility of the stall base on its own and with the usual amount of bedding used on the farm. Our study establishes that both stall base and surface affect compressibility, and that a large quantity of bedding helps increase the compressibility of the bed, especially on a harder stall base.

Key words: Clegg hammer, stall base, compressibility, bedding

Short Communication

Stall base and stall surface (i.e., with or without bedding), along with management conditions and barn design, have been identified as risk factors for cow comfort in dairy herds. Research has shown that animals housed in tie-stall systems with hard surfaces have a higher risk of swelling of the carpus joint (Rushen et al., 2007). During a cow comfort assessment conducted on 100 Canadian tie-stall dairy farms, Nash et al. (2016) found that stall base was one of the factors associated with prevalence of hock and knee lesions, with the odds of knee injury being 2 times greater on rubber mats and 3 times greater on concrete compared with mattresses. Cook (2003) concluded that dairy cows housed in tie-stalls with a sand stall base had lower prevalence of lameness; the soft bedding allowed for more cushioning and increased lying time.

A variety of methods have been used to test bed surface hardness. On commercial farms, different knee tests have been used but these are very subjective and do not provide a precise measure of the cushioning of the stall surface (Nordlund and Cook, 2003). Objective methods have also been used in research but would be impractical on commercial dairy farms (Tucker et al., 2009; Main, 2013). To test bed compressibility, Fulwider and Palmer (2004) used a Clegg hammer on different lying surfaces (foam, cork, rubber mats,

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rubber mattresses, and waterbeds) used as stall bases in freestall housing. They found a positive correlation between compressibility and the cows' preference for the stall base. They also tested the compressibility of the different stall bases at a 13-mo interval and found that the compressibility of most stall bases decreased over time, indicating a tendency to harden (Fulwider and Palmer, 2004).

In Canada, tie-stall housing is used in approximately 70% of dairy herds to house lactating cows (AAFC, 2016). Stall surface softness is particularly important for cows kept in tie-stalls because the animals are confined to their stalls for the majority of their lives. However, a limited number of tools are available to test stall surface softness, especially on commercial tie-stall dairies. In this study, we aimed to assess the possibility of using the Clegg hammer measure as an indicator of the compressibility of the stall base and stall base and bedding combination in commercial tie-stall barns.

The data used for this study were collected by the Dairy Production Centre of Expertise Québec-Atlantic (Valacta Inc., St-Anne-de-Bellevue, Canada) between May and August 2015. The protocols used followed the animal welfare guidelines of the Canadian Council on Animal Care (2009). A total of 32 tie-stall dairy herds from the central region of the province of Québec (Canada) participating in the DHIA Valacta Inc. were visited for this study. Enrollment criteria for the farms were that they had at least 40 milking cows and used

tie-stalls and one of the stall bases of interest (mattresses or rubber mats).

Rubber mats and mattresses were the 2 types of stall base found in the 32 herds included in this study and are the most commonly used stall base types on Canadian tie-stall dairy farms (51% of farms used rubber mats and 44% used mattresses; Nash et al., 2016). The producers were asked about the year of installation of the stall bases used for their milking cows to determine whether changes in compressibility of the stall bases could be associated with the time-in-use variable. The time-in-use observations were classified in 3 age categories for mattresses (≥ 10 yr old, 5–9 yr old, < 5 yr old) and 2 age categories for the rubber mats (≥ 10 yr old, < 10 yr old; Table 1). For the stall surface, the most commonly used type of bedding was straw (63%), followed by wood shavings (13%) and a mix of straw and wood shavings (25%). The depth of the bedding was measured in the stalls where Clegg hammer measures were taken. The recorded bedding depths varied from 0.5 to 15 cm and were divided into 4 categories for analysis purposes (Table 1).

To assess the compressibility of the different combinations of stall base and stall surface, 10 stalls per farm were tested using a 10-kg Clegg Impact Soil Tester Hammer (Lafayette Instrument Company, Lafayette, IN). The functioning and operating of the Clegg hammer is described in Fulwider and Palmer (2004) and Vlcek and Valaskova (2018). The Clegg hammer measures

Table 1. Bedding depth and age categories of the different stall bases used on the 32 tie-stall herds in Québec, Canada

Stall base	No. of herds ¹	Bedding depth (cm)	No. of herds
Rubber mats ≥ 10 yr old	5	≤ 2.5	0
		> 2.5 to ≤ 5	3
		> 5 to ≤ 7.5	0
		> 7.5	2
Rubber mats < 10 yr old	5	≤ 2.5	1
		> 2.5 to ≤ 5	1
		> 5 to ≤ 7.5	3
		> 7.5	0
Mattresses ≥ 10 yr old	5	≤ 2.5	2
		> 2.5 to ≤ 5	2
		> 5 to ≤ 7.5	0
		> 7.5	1
Mattresses 5 to 9 yr old	6	≤ 2.5	1
		> 2.5 to ≤ 5	0
		> 5 to ≤ 7.5	2
		> 7.5	1
Mattresses < 5 yr old	17	≤ 2.5	3
		> 2.5 to ≤ 5	3
		> 5 to ≤ 7.5	6
		> 7.5	5

¹Four herds used both types of stall base.

the force of impacts in tens of gravities (Clegg Impact Value: **CIV**); a lower value (on a scale from 0 to 100) represents a more compressible surface. To test the compressibility of the stall base and surface combination, 6 measures were taken with and without bedding at 2 different locations—front and back of stalls—for a total of 4 series and 24 measures per stall. For each series of 6 measures, taken in less than 30 s, the first 3 measures were considered part of the standard procedure to level and compact the surface, the fourth measure was the actual measurement of surface compressibility used for analysis, and the final 2 measures were used as controls, based on the Clegg hammer manual.

The statistical software SAS (version 9.4; SAS Institute Inc., Cary, NC) was used to analyze the data, and the level of significance was set at $P < 0.05$. The first analysis tested differences among the 6 measurements of the Clegg hammer taken at the same location and under the same stall base and surface combination. The statistical model included the Clegg hammer readings as the dependent variable and the repetitions (1 to 6) as the independent variables. The differences between sequential measures were adjusted with Scheffé's methodology for multiple comparisons. According to the Clegg hammer instruction manual, the manufacturer recommends using the fourth measures for analysis because the first 3 repetitions are used to level the surface tested. Therefore, the fourth measure was used as the dependent variable. Mixed model analyses (Proc Mixed, SAS 9.4) were used to test the association of the fixed effect of stall base (grouped by type of stall base and age), type of bedding, bedding depth, and location of the Clegg hammer measure (front or back), with the fourth reading being taken the back of the stall. These variables were all tested as class effects. Different interactions among these classes were also tested for significance (model [1]). Herd and stall within herd were included as random effect variables.

Model 1 was used to test the associations between different stall variables and the results of the Clegg hammer:

$$Y_{ijmno} = \text{Herd}_i + \text{Stall}_{ij} + \text{BaseAge}_m + \text{Depth}_n + \text{Location}_o + \text{BaseAge}_m \times \text{Depth}_n + e_{ijmno}, \quad [1]$$

where Y_{ijmno} is the fourth Clegg hammer measure taken at the back of the stall; Herd_i represents the random effect of the i th herd where the measures were taken; Stall_{ij} is the random effect of the j th stall nested within the i th herd, where the compressibility of the bed was measured with the Clegg hammer; BaseAge_m represents the class fixed effect of the stall base surface (mattress

or rubber mat) and the age of the stall base; Depth_n is the n th depth of the bedding used to cover the stall base; Location_o represents the location of the reading (front or back of the stall); $\text{BaseAge}_m \times \text{Depth}_n$ represents the interaction between the stall base and the depth of the bedding; and e_{ijmno} is the random error assumed distributed identically and independently normal.

A total of 24 readings with the Clegg hammer were obtained per stall, 12 at a specific position at the front of the stall, and 12 at a specific location at the back of the stall. Considering that the process is long and demanding, it is important to optimize the number of readings needed to obtain a precise estimate of stall bed compressibility. According to the instruction manual, the fourth measure should be used for analysis. In this case, the surface tested is the stall base (when no bedding is present) or the combination of stall base and stall surface (stall base with bedding). Our hypothesis was that the fourth measure should be considered the reliable indicator of compressibility. Our results did not indicate significant differences between the third and the fourth readings ($P > 0.3$), the fourth and fifth readings ($P > 0.9$), or the fifth and the sixth readings ($P > 0.6$). Figure 1 presents the results of the differences in the Clegg hammer readings at the 2 locations tested (front and back of the stall) with and without bedding. Based on these results, we considered that the third reading taken at one specific location should be considered the true reading of surface compressibility. Future studies should consider that only 3 measures are necessary at one given location, instead of 6.

We also tested differences between the fourth measures taken at the front and at the back of the stall, taken independently with and without bedding (Figure 1). We did not find significant differences between the fourth measure of the Clegg hammer taken at the front of the stall and the fourth measure taken at the back of the stall, for measures taken with or without bedding ($P > 0.9$). Finding no significant differences between the results obtained at the front and the back also simplifies the assessment process, because only one area needs to be tested to obtain a precise assessment of stall bed compressibility.

Fulwider and Palmer (2004) took 3 measures and used the results obtained at the first impact of the Clegg hammer at the back of the stall to test stall surface compressibility on freestall farms. They considered that the rear part of the freestall was the most representative area of the stall surface as a cow experiences it, and they considered that the first impact would simulate the body of a cow when she lies down for the first time. In tie-stall housing systems, our results indicated that to test the compressibility of a stall base or surface, 3

Figure 1. Average differences in compressibility between the Clegg hammer (Clegg Impact Soil Tester Hammer; Lafayette Instrument Company, Lafayette, IN) drops, compared 2 by 2, at 2 positions in stall (front and rear) and with and without bedding. CIV = Clegg impact value.

drops (i.e., Clegg hammer measurements) at one location are necessary to provide a precise measurement. These results are important because they provide a scientifically verified method to test the stall-base or surface compressibility using the Clegg hammer in tie-stall housing. Limiting measures to the back of the stall is especially important in tie-stall housing because access to the front of the stall is difficult when animals are kept in the stall during the measurements, and removing animals from the stalls for the assessment would be both labor intensive and stressful for the animals.

To maximize cow comfort in tie-stall farms, greater stall-base or surface compressibility (i.e., lower Clegg

measure) should be targeted. Figure 2 presents the least squares means and standard errors of compressibility for rubber mat and mattress (of different age groups) stall bases without bedding (0 cm). A significant difference was found between the compressibility of rubber mats and mattresses independent of their age. Even when comparing the compressibility of newer rubber mats (<10 yr old) and older mattresses (≥ 10 yr old), we detected an important difference in compressibility (9.9 ± 1.2 CIV) favorable to the mattresses. Fulwider and Palmer (2004) tested the compressibility of different rubber mats and mattresses in freestall housing and the preference of the animals based on lying time and

Figure 2. Least squares means ($\pm$ SE) compressibility (Clegg impact value, CIV) for rubber mat and mattress stall bases by age and bedding depth categories.

frequency of lying bouts. Similar to our results, they found that the Clegg hammer measure for their softest rubber mats was similar to that for their harder mattresses. They also found that the softest mattresses were preferred by the animals.

According to Fulwider and Palmer (2004), stall bases can lose compressibility over time. In our sample, the age or time in use was categorized within each stall base type but actually varied from a few months to 20 yr. When investigating compressibility without bedding, we did not find significant differences in compressibility between the age groups for rubber mats or mattresses. Among the latter, we observed a difference of 4.9 ± 1 CIV ($P = 0.35$) between mattresses ≥ 10 yr and those that had < 5 yr of use (Figure 2). Interestingly, the compressibility of rubbers mats with < 10 yr of use was half that measured on mattresses that were 10 yr old or greater (Figure 2). Fulwider and Palmer (2004) did measure a small loss of compressibility in rubber mats (0.6 CIV) over 1 yr of use.

To assess the effect of bedding depth on the compressibility of the stall surface, Clegg hammer measures were taken with and without bedding on different stall base types and ages. For each comparison carried out, the effect of the amount of bedding was compared with the stall-base compressibility measured without bedding (0 cm). Figure 2 presents the compressibility results of the different stall base types depending on the age category and bedding depth. Significant differences ($P < 0.01$) in stall-base or surface compressibility were found for all levels of bedding added in both rubber mat age categories, with an estimated difference of at least 9 CIV for any bedding depth > 2.5 cm. Even when adding between 1 and 2.5 cm of bedding, a significant increase in stall base/surface compressibility was noted (-5.62 ± 0.85 CIV; $P = 0.002$). This increase in compressibility (lower CIV) for rubber stall bases was greater when a deeper layer of bedding was present (> 7.5 cm; Figure 2). In contrast, the addition of bedding to mattresses did not have a significant effect on stall-surface compressibility in most cases (Figure 2; $P > 0.05$). A significant increase in stall-surface compressibility was found only in mattresses that were ≥ 10 yr when > 2.5 cm of bedding was added (-4.61 ± 0.55 CIV; $P < 0.001$). Unfortunately, Fulwider and Palmer (2004) did not examine the effect of bedding on stall-surface compressibility using the Clegg hammer, limiting our abilities to compare results. Overall, our results indicate that the addition of bedding has a greater positive effect on stall-base or surface compressibility when the stall base is harder. The limited variability in bedding depth and bedding type encountered on the farms enrolled in this study may have restricted our ability to detect a signifi-

cant effect of bedding on compressibility, especially on mattresses. The addition of bedding tended to increase the compressibility on both stall base types but only to a certain plateau, especially on newer mattresses. Regardless of the amount of bedding, compressibility never reached the level of compressibility measured by Fulwider and Palmer (2004) on pastureland (3.6 CIV). The associations between the compressibility level of the stall base or surface and outcome measures of cow welfare, such as the prevalence of body lesions, lameness, and lying time, still need to be determined because compressibility is only one of the attributes of a good lying surface.

The results of this study validate the use of the Clegg hammer to evaluate the compressibility of the lying surface in tie-stall housing. We show that it is not necessary to take measurements in both the front and rear of the stall, and that using the third measure taken at the rear of the stall is sufficient, which has practical implications for on-farm assessment. Our study helped established that both stall base and stall surface affect compressibility, and that a large quantity of bedding helps to increase the compressibility of the bed, especially on a harder stall base. Compressibility is only one attribute of the lying surface available to a cow in her stall, and the effect of compressibility on cow welfare outcome still needs to be determined; other factors, such as levels of friction and dryness, may also play an important role in cow comfort.

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