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An Update on Dairy Cow Free Stall Design

Nigel B. Cook, *BVSc, Cert CHP, DBR, MRCVS;* **Ken Nordlund,** *DVM, Diplomate ABVP-Dairy*
Department of Medical Sciences, School of Veterinary Medicine, University of Wisconsin-Madison, WI 53706

Abstract

This paper summarizes recent advances in our knowledge of free stall design for dairy cows. New information related to free stall surface cushion and traction, resting space, head lunge and bob movement and neck rail location is reviewed and summarized. Diagonal lying of cows in stalls has several potential adverse effects, and can result from mechanical and social obstructions related to overall stall size. Recent research has shown that lame cows behave differently on mattress than on sand surfaces. It is likely that lameness is a risk factor for other stall injuries and entrapments. Currently, sand remains an optimal stall surface for the dairy cow as its cushion and traction allows lame cows to maintain normal patterns of daily stall activity.

Résumé

Cet article présente les derniers développements en ce qui concerne nos connaissances sur le design des étables à stabulation libre chez les vaches laitières. L'article fait le point et résume l'information disponible sur le recouvrement et l'adhérence des surfaces, l'espace de repos, l'élan et les mouvements de tête de même que la position de la barre de blocage. La position couchée en diagonal de la vache a plusieurs conséquences néfastes pouvant découler d'obstructions mécaniques et sociales reliées à la taille de la logette. Des travaux récents ont montré que des vaches avec boiterie se comportent différemment sur des matelas que sur des surfaces avec du sable. Il est bien possible que la boiterie soit un facteur de risque pour l'entrave ou d'autres blessures associées à la logette. En fait, le sable demeure la surface optimale pour les vaches laitières car le support et l'adhérence offerts par celui-ci permettent aux vaches qui boitent de maintenir une activité journalière normale.

Introduction

In the last few years, there has been unprecedented interest in free stall design and its impact on dairy cow health and performance. New facilities are being built in North America using radically updated stall designs and dimensions that appear to benefit the herd owner and dairy cow alike.[2] Additionally, a significant amount of research published in the past year further improves our understanding of the effect of free stall design on cow behavior and health.

This article serves to update our original publication entitled "Flowchart for evaluating dairy cow free stalls"[9] which approached free stall design on the basis of surface cushion, adequate body resting space, room to lunge and bob the head, and room to rise below the neck rail. This article will retain that structure and update each step with new knowledge gained through research or clinical experience.

Surface Cushion and Traction

Recent studies continue to demonstrate that dairy cows prefer stall surfaces that provide more cushion. Cows appear to prefer to lie in stalls with rubber crumb-filled mattresses rather than on sparsely bedded hard rubber mats, water beds or concrete.[14] More recently, a cow preference for thick foam-filled mattresses over other less cushioned products has been demonstrated.[7]

A study at the University of British Columbia showed that lying times could be altered by the amount of sawdust bedding used on top of a rubber crumb-filled mattress. The addition of 2.2 lb (1 kg) of bedding to the stall made little difference in lying behavior compared to no bedding at all. However 16.5 lb (7.5 kg) of bedding increased lying time by over 1.3 hours per day (h/d).[11] It is difficult to retain this amount of bedding on a sloped stall surface in conventional mattress stalls, but new designs have the mattress embedded into the stall platform so that the rear curb protrudes and acts as a bedding retainer. With these designs, it is important that wet bedding be removed from the rear of the stall frequently so that it does not incubate high numbers of potential udder pathogens.[4]

Techniques of assessing surface cushion in the field remain rather subjective, but the Clegg Impact Soil Tester (model 95051, Lafayette Instruments, Lafayette,

IN) has been used to measure surface softness in a research study. The device measures the peak deceleration of a 44 lb (20 kg) hammer as it makes impact with a surface from a height of 11.8 inches (30 cm). The study also reported that many mattress products hardened and lost cushion over a one year period, and that the readings correlate well with stall preference.[7] While the instrument provides a more repeatable measurement than the 'knee test' for the determination of surface softness, we no longer view cushion *per se* as the critical issue determining the success of any given stall surface. Instead, we are focused upon the ability of the surface to meld around the weight bearing hoof, providing a greater surface area of contact, traction and support as the cow gets up and down.

Interactions of stall surface, standing time, and lameness

We recently reported that normal cows behave similarly on mattress and sand surfaced stalls, but lame cows behave very differently.[6] Other authors have previously noted that cows spend more time standing in mattress stalls than on other surfaces such as sand and deep bedded sawdust, and have suggested that this was a reflection of the cow's preference to stand on a mattress surface rather than on concrete.[12,14] However, several research findings make this an unlikely interpretation. First, lame cows in mattress barns spend more time standing during a stall-use session (consisting of bouts of standing and lying while in the stall) compared to non-lame cows,[6] but there is no increase in stall standing of lame cows in sand stalls. Slightly lame cows on mattresses compensate for increased stall standing by decreasing time spent in the alley so that a lying time of around 12 h/d is maintained. The finding that non-lame cows on mattresses, and lame and non-lame cows on sand spend the least amount of time standing in stalls suggests that increased time standing on mattresses is an interaction of lameness and mattress surfaces, not an expression of preference for standing on mattress stalls. Second, cows rarely stand in a stall that they do not subsequently use for lying,[11] which suggests that stall standing activity is closely linked with lying behavior. Third, moderately lame cows in mattress stalls spend so long standing in the stall that other behaviors are compromised.[6] Like the slightly lame cows, moderately lame cows spend less time in the alley. However, they increase the time spent standing in the mattress stalls so much that they are unable to maintain daily lying time, which falls to around 10 h/d. There is also a trend for them to spend less time eating. These changes would not be seen if this were a simple preference in standing surface.[6]

We believe that this change in behavior of lame cows in mattress stalls relates to fear and pain associated with the movements made as they lie down and rise in the stall. For lame cows, pain after rising and the fear and discomfort associated with lying again keeps them standing for long periods in the stall. The fact that lame cows in sand stalls maintain normal patterns of stall use behavior suggests that some property of sand makes rising and lying easier. We propose that the traction and security of a loose bedded deep sand stall allows lame cows to distribute weight over a larger area of the hoof during rising and lying movements, allowing them to maintain normal daily patterns of stall use behavior. Video of cows rising in a sand stall shows that the rear foot is driven deep into the sand, with the entire hoof and inter-digital space making contact with the stall surface. In contrast, it is the tip of the toe of the weight bearing rear foot that makes contact during the initial rising movement on a mattress surface, and much of the weight of the cow is born by the dorsal hoof wall. We speculate that this may be very painful to the cow if that foot is also suffering a sole ulcer or other claw horn lesion. We would expect all loose bedded stalls to allow better distribution of weight bearing and provide more traction than a sparsely bedded mat or mattress stall, but as yet, we have only subjective assessments of this surface property.

Hygiene

In our opinion, sand remains the gold standard bedding material, largely due to the finding that lame cows maintain normal daily activity patterns when compared to similar cows on mattress stalls. In addition, hygiene scores are on average better on sand than in mattress stall herds.[4] In particular, the proportion of dirty udders on sand stalls is 50% of the proportion on mattresses (Table 1).

We propose that the improved hygiene is due to one or a combination of the following factors:

- Sand appears to act as a cleaning agent, removing manure from the legs, udder and flanks.

Table 1. Least squares mean (SE) hygiene scores (proportion scoring 3 and 4 for each zone using a 4-point scale to assess degree of cleanliness where 1=clean, 2=slightly dirty, 3=moderately dirty and 4=extremely dirty) in the high group pen on 12 free stall herds (six sand and six mattress).

	Sand herds (n=6)	Mattress herds (n=6)	SE	P
Udder	16.7	33.3	4.2	0.02
Lower leg	39.2	74.2	8.6	0.02
Upper leg and flank	1.7	11.7	2.1	0.01

- Manure deposited on the stall platform will become mixed into the sand rather than lie on the surface, as it would in a mattress stall, decreasing the risk of transfer to the udder.
- Cows perch (stand with the front two feet on the stall platform and the rear feet in the alley) more in sand stalls because of their reluctance to stand on a raised rear curb, whereas cows tend to stand with all four feet in mattress stalls. The increased likelihood of perching in sand stalls makes it less likely that manure is deposited on the stall platform.
- It is possible that lame cows become dirtier because their abnormal gait may splash more manure up their legs during movement through the alleys. There are fewer lame cows in sand stall herds.[5]

Traction

Assessments of stall surfaces should include not only cushion, but also consider traction and the potential to distribute weight across the entirety of the hoof during rising and lying down movements. Therefore, we do not recommend the use of smooth covered, firm mattresses and rubber mats without a deep bedding cover, which would necessitate the use of some kind of bedding retainer.

Adequate and Defined Resting Space for the Size of the Animal

In our previous article, we proposed larger stall surface areas for larger cows than the default 46 inches (117 cm) wide and 66 inches (168 cm) long beds that are widely placed in new barns in the United States.[9] Measurements of stall width have typically been taken on center – measuring the mean mounting separation of around six dividers to allow for variation from stall to stall. Recent research has shown that increasing stall surface area has an impact on resting and standing behavior. A Canadian study found that cows lay down for 1.2 h/d longer in wider stalls (52 inches; 132 cm) compared with 44 inches (112 cm) wide and spent less time standing in the stall[13] (Figure 1). The median weight of cows in this study was 1625 lb (738 kg). This finding supports the guideline of a 51 inch (130 cm) stall width for a 1600 lb cow suggested in our earlier article.[9] We would reiterate the view that stalls should be sized for the largest quartile of cows in any given pen, and our guidelines serve as a useful starting point for sizing them. However, stall dimensions will be modified according to the owner's tolerance and ability to prevent the stalls from becoming excessively dirty, and the need on some farms to manage mixed groups of first-lactation and mature cows together, where small heifers may get dirty in stalls designed for large mature cows. We are currently seeing apparent improvements in stall use in new barns where cows are grouped by age and size and dividers are mounted 50 inches (127 cm) on center for mature Holstein cows (typical weight 1600 lb, 727 kg), and 54 inches (137 cm) on center for large pre-fresh cows (typical weight 1800 lb, 818 kg). Widths of 46 (117 cm) to 48 inches (122 cm) appear satisfactory for first-lactation Holstein heifers (typical weight 1400 lb, 636 kg). Apprehensions about cows lying backwards in wide stalls do not appear to have been realized. However, these wider stalls have been redesigned to eliminate obstructions to the rising movements of the cow, which suggests that forward obstructions were the main reason for heifers turning around in the stalls.

Figure 1. Remodeled sand stalls in a mature cow free stall pen. The stalls were widened from 45 inches to 50 inches (114 cm to 127 cm) wide on center.

We have a greater appreciation for keeping the brisket locator no higher than four inches (10 cm) above the stall surface so that the cow can lie with one forelimb extended if she chooses to, and be able to thrust the forelimb forward during the rising motion.[9] This forward thrust over the top of the brisket locator is an important motion that allows the cow to support her weight more easily during rising, before bringing the leg back into a vertical position. Failure to provide for this movement is one of the major factors influencing how the cow positions herself in the stall. In stalls with high brisket locators, or where concrete has been filled above the level of the stall beyond the brisket locator, cows will tend to lie diagonally to create more space for front leg movement when rising (Figure 2). In some cases, heifers may lie backwards. Maintaining the correct brisket locator height is difficult in a loose bedded stall because of variation in fill between deliveries of fresh

Figure 2. Brisket locators higher than four inches (10 cm) above the stall surface impede the forward thrust of the front limb when rising. Cows will tend to lie diagonally across the stall to give themselves more room. Note that the long lower divider rail is rubbed shiny from cows lying against it.

bedding. However, the following steps are suggested to minimize this problem:

1. When mounting the brisket locator in the stall, the upper edge should be no higher than four inches (10 cm) above the upper edge of the rear curb.

2. Fresh sand or other loose bedding should be added no less frequently than every seven days. When full, the stall surface should slope from the top of the brisket locator to the top of the rear curb. At its lowest fill, the bedding should remain within four inches (10 cm) of the upper edge of the brisket locator.

3. At each milking, the stall bed should be leveled off, redistributing the bedding from the sides of the stall and keeping the fill level to within four inches (10 cm) of the top of the brisket locator, and level with the rear curb.

In order to provide sufficient length for the cow to lie comfortably, the brisket locator should be mounted 68 to 72 inches (173 to 183 cm) from the rear lip of the curb for cows ranging from 1400 to 1800 lb (636 to 818 kg). The measurement is taken from the bottom of the brisket locator where the cow's knee would be positioned, not from the top edge, as this may be several inches forward of the suggested location.

Room to lunge and bob the head

New barns continue to be built with obstructions to the lunge and bob movements of the head. The most common obstructions are the continued use of the transverse pipe for mounting the dividers, head-to-head platforms of inadequate length, and inadequate front lunge space in stalls along a side wall.

We appreciate that the transverse mounting pipe makes installation of dividers easier. However, when the pipe is located in the area at the end of the head lunge (referred to as the 'bob zone'), it will impede the movement of the head when lying down and rising and encourage more side-lunging. We have updated our earlier guidelines that suggested no barriers between six inches and 32 inches (15-81 cm) above the stall surface, and now suggest that there should be nothing in the lunge area higher than the stall surface, and that it remain clear to a height of about 40 inches (102 cm). Preferred stall dividers are mounted on vertical posts or have mounting attachments that can be secured to the stall platform. Another recent and successful innovation retains the transverse mounting pipe dropped below the sand bedding level, and uses a right-angle mounting attachment to hold the divider (Figure 3).

In open front head-to-head stalls with high neck rails, some farmers have complained of cows walking through the front of the stall. Injury can result, and the behavior is a frustration to those who wish to breed or treat a cow in the stall. To prevent this behavior, it has been suggested that a deterrent strap or wire be hung across the front of the stall. This should avoid the head lunge and bob zone and be mounted approximately 40 inches (102 cm) above the stall surface. A single wire covered in polypropylene or plastic tubing provides enough deterrent without being solid enough to cause injury to the cow should she venture beneath it (Figure 4).

Figure 3. A transverse mounting pipe is retained in this stall, but mounted below the bedded surface in a sand free stall. The bedding has been moved to show the bar and the right-angle mounting bracket.

Figure 4. A deterrent wire is fitted in this stall, located 40 inches (102 cm) above the stall surface and covered with plastic tubing.

Based upon recent suggestions out of Canada,[2] and upon our calculations of total stall length for 1,800 lb (818 kg) cows and larger, free stalls should have a total length of 9.5 to 10 feet (2.90 to 3.05 m) of length against a side wall, measured from the rear lip of the curb to the furthest point forward where the cow's muzzle could reach when lunging.[2] Shorter stall lengths for this size of animal will force the cow to side lunge and lie diagonally across the stall. Stall dividers are not readily available for this length of stall. However, traditional stall dividers may be mounted on posts separated from the side wall, keeping the cow's head away from the curtain wall (Figure 5). We would recommend that stalls be made no shorter than nine feet (2.74 m) long in new installations for large, mature Holstein cows.

Figure 5. An open front stall against a side wall, with dividers mounted to provide space for front lunging.

We do not think that stalls should continue to be built which require a cow to side lunge, but in most situations the cow should be provided the option to do so if she chooses. The recommendation that the height of the upper edge of the lower divider rail is no higher than 11 inches (28 cm) above the stall surface at the position of the brisket locator remains a useful rule of thumb. However, many "wide" loop divider designs cannot achieve this dimension without the neck rail being mounted too low. The divider opening between the upper and lower rails should therefore be approximately 35 inches (89 cm), and loops with narrower openings should not be used for mature cows. It is also important to leave a five inch (13 cm) space between the lower edge of the lower divider rail and the top of the brisket locator as it allows the cow to work her leg free if it should get stuck between the two barriers.

Correct Neck Rail Location

No other part of stall design has been as problematic as correct location of the neck rail – both vertically above the stall surface and horizontally from the rear curb. Current recommendations put the vertical height above the stall surface at 48 to 50 inches (122 – 127 cm) in mattress stalls, measured from the lower edge of the rail to the stall surface.[1] Because of variation in level of fill in loose bedded sand stalls, the neck rail height should range between 44 and 50 inches (112 – 127 cm) above the bedded surface.[4] In barns with old, narrow-loop dividers, some dairy managers have lifted neck rails using elevator brackets in an attempt to improve stall use. It is debatable how effective this practice might be in stalls where cows must still side lunge, because the upper rail of the divider becomes the default neck rail during the rising motion. In a compromised stall design, however, higher neck rails reduce the risk of cows becoming entrapped and breaking their backs, and for that reason alone, the modification may be worthwhile.

In controlled studies, neck rail location had little influence on lying time or standing time. However, the vertical and horizontal location relative to the rear curb did influence the type of standing behavior. Higher neck rails appear to increase the amount of standing with all four feet on the stall platform.[10] With the neck rail located at a horizontal location of 67 inches (170 cm), measured from a point directly above the rear edge of the curb to the rear edge of the rail, cows spent more time standing with all four hooves on the stall platform and less time perching with only the front two hooves in the stall, compared to a 60 inch (152 cm) location.[10]

On commercial farms today, it is common to find the neck rail located at 57 to 68 inches (145 to 173 cm)

from the rear curb in both sand and mattress stalls. This huge variation suggests that we are not providing farmers with advice that works in practice. It is our opinion that the appropriate horizontal location of the neck rail is determined by cow size, but is modified depending upon the construction and materials used for the stall bed. Essentially, we are now recommending neck rail positions that allow cows on mattresses to stand with all four feet in the stall, but we are suggesting locations in sand stalls that force cows to perch when standing in them.

If we are to encourage cows to lie down straight rather than diagonally across the stall, we should design stalls that encourage them to stand parallel to the dividers. In a mattress stall, the neck rail should be located vertically above the brisket locator, or around 68 to 72 inches (173 – 183 cm) from the rear curb for commonly sized cows (1400 – 1800 lb; 636 – 818 kg). This location allows the cow to stand square in the stall with all four feet on the platform, while still ensuring that most of the manure falls into the alley when the cow defecates.

This same location creates problems in sand stalls. In deep-loose bedded stalls, rear curbs are rounded or sloped and cows prefer not to stand on them. With the horizontal neck rail locations that are appropriate for mattress stalls, we observe cows stepping into sand stalls on the diagonal to avoid standing on the rear curb. When these cows urinate and defecate, the rear of the stall becomes excessively soiled. Therefore, our recommendation in loose-bedded stalls is to move the neck rail from above the brisket locator toward the rear curb a distance equivalent to the width of the rear curb (Figure 6). We therefore prefer curbs that are not too wide. For example, in a mature cow sand stall with 72 inches (183 cm) from the rear lip of a six inch (15 cm) wide curb to the brisket locator, the neck rail should be located 72 – 6 = 66 inches (183 – 15 = 168 cm) horizontally from the rear lip of the curb. For first lactation heifers with 68 inches (173 cm) from the rear curb to the brisket locator, the neck rail should be located 68 – 6 = 62 inches (173 - 15 = 158 cm) from the rear lip of the curb. These guidelines will force cows to perch when standing in the stalls, and will prevent cows from soiling the stall excessively. In stalls with neck rails lower than the recommended height, these guidelines must be modified by moving the neck rails forward in order to avoid cows hitting them when rising.

The recommendation to force cows to perch when standing in sand stalls is not made casually. Two studies have associated perching with lameness.[3,8] However, we found that cows in sand stall barns perch more and also have about half the prevalence of lameness than cows in mattress barns.[6] Our research also shows that lame cows in sand stalls maintain normal daily lying

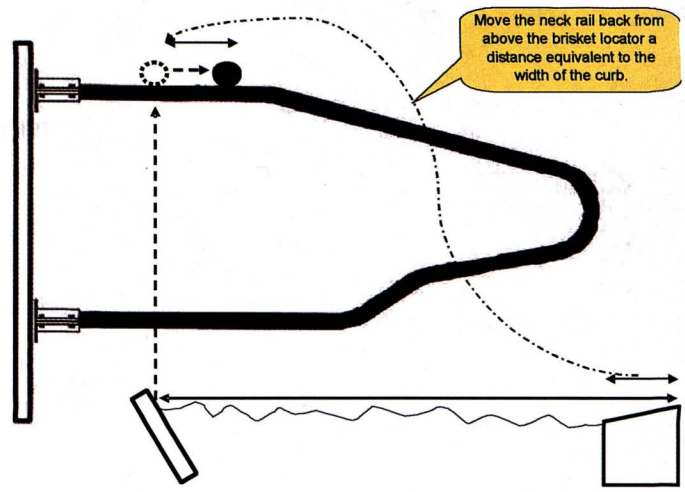

Figure 6. Correct location of the neck rail in a loose-bedded stall with a raised rear curb by moving the rail back from above a correctly positioned brisket locator a distance equivalent to the width of the rear curb.

times and do not stand for long periods in their stalls, unlike similar cows in mattress barns.[6] We are therefore prepared to tolerate perching in sand stall barns, and additionally, we believe that potential stresses related to perching would also be less in sand stalls because the front feet sink into the loose bedding, reducing the elevation compared to mattress stalls with an equivalent curb height.

Multiple Causes of Diagonal Lying in Stalls

Cows that lie diagonally across the stall deposit manure in the rear corner of the stall and contaminate the bedding material with fecal matter. Manure is transferred directly to the flank and udder. Once the cow lies diagonally across the stall, the tail is more likely to hang in the alley and potentially lead to transfer of manure to the tail, to the flank and to the rear udder.[4] In addition, diagonal lying is a major cause of medial hock injury in the dug out, loose bedded stall, or any stall with an unprotected curb with a sharp interior edge.[9]

Diagonal lying is a complex issue caused by a variety of stall design problems that include lunge space intrusions, neck rail locations that encourage diagonal standing positions, short brisket locator installations, barriers that prevent cows from extending their front legs into the lunge area, and "social" obstructions caused by dominant cows in head-to-head stalls (Figure 7). From an engineer's perspective, head-to-head stalls with an open front should not curtail forward lunging and should not cause diagonal lying. However, we are now aware of social obstructions if a dominant cow occupies a stall on a head-to-head platform that is only 15 feet (4.57 m)

Figure 7. Cows lying diagonally across stalls that are head-to-head layout on a 15 foot (4.57 m) platform, with a transverse mounting bar creating a head bob zone obstruction.

long. This cow becomes a social obstruction to front lunging that encourages diagonal lying of a cow in the adjacent stall in front of her.[1] For the stalls to truly function with an 'open front', the head-to-head platform must be made longer so that the opposite cow is not perceived as a barrier. Anderson described the first head-to-head stalls on an 18 foot (5.49m) stall platform.[2] By separating the cows' heads, he claimed improvements in cow lying position and in air quality and heat stress abatement. In existing barn constructions, a compromise on alley width may have to be made to achieve this platform length. We would not recommend building new head-to-head stalls on a platform less than 17 feet (5.18 m). We have included a flow diagram to help the investigator consider the possible causes and solutions of diagonal lying (Figure 8).

We are not in favor of rotating "wide loop" dividers 180 degrees so that the longer divider rail is located at the bottom, or divider designs that make the lower divider rail extend more than 24 inches (61 cm) beyond the brisket locator, which force cows to lie straighter in the stall. This limits lateral movement of the hips when lying down and is sometimes associated with bruising and injuries over the pelvis. Instead, we recommend fixing obstructions that make the cow lie down diagonally in the first place.

Lameness and Other Stall Injuries

We believe that many cows that become entrapped in poorly designed stalls do so because they are lame. Weak, tentative movements result in failed rising efforts in lame cows and sometimes result in entrapment in the front of the stall. In addition, difficulties encountered when rising and lying mean that the lower rear limb is dragged across the stall surface, increasing hock damage. It is noticeable that many of the cows with the worst hock swellings are those that are also foot lame.

The fact that our studies have associated increased lameness prevalence with mattress-based stalls, along with changes of behavior of lame cows on them, calls into question the use of mattresses in dairy barns in their current form. In the short term, we recommend that severe and moderately lame cows be removed from mattress stalls once they are recognized and taken to an area such as a well-managed straw or sand bedded pack for a recovery period. Long-term, developers of manufactured stall surface materials and dividers must show that cows with sore feet maintain normal daily activity patterns on their products before they are recommended to the dairy industry.

Conclusions

Recent research has increased our understanding of the effects of each of the components of the stall on the behavior of the cow. The stall surface materials, space around the brisket locator, lunge and bob room and neck rail location are each components of an integrated unit. Improving one design fault and leaving several other problems unchanged will have poor results in improving cow comfort. It must be realized that a new freestall barn may look adequate when used by a group of non-lame cows, but may be completely unsatisfactory for lame cows. The challenge for the future of free stall construction is, therefore, to create stalls in which lame cows can maintain normal patterns of daily behavior. At present, a well designed and managed sand free stall provides the optimal resting space for our dairy cows.

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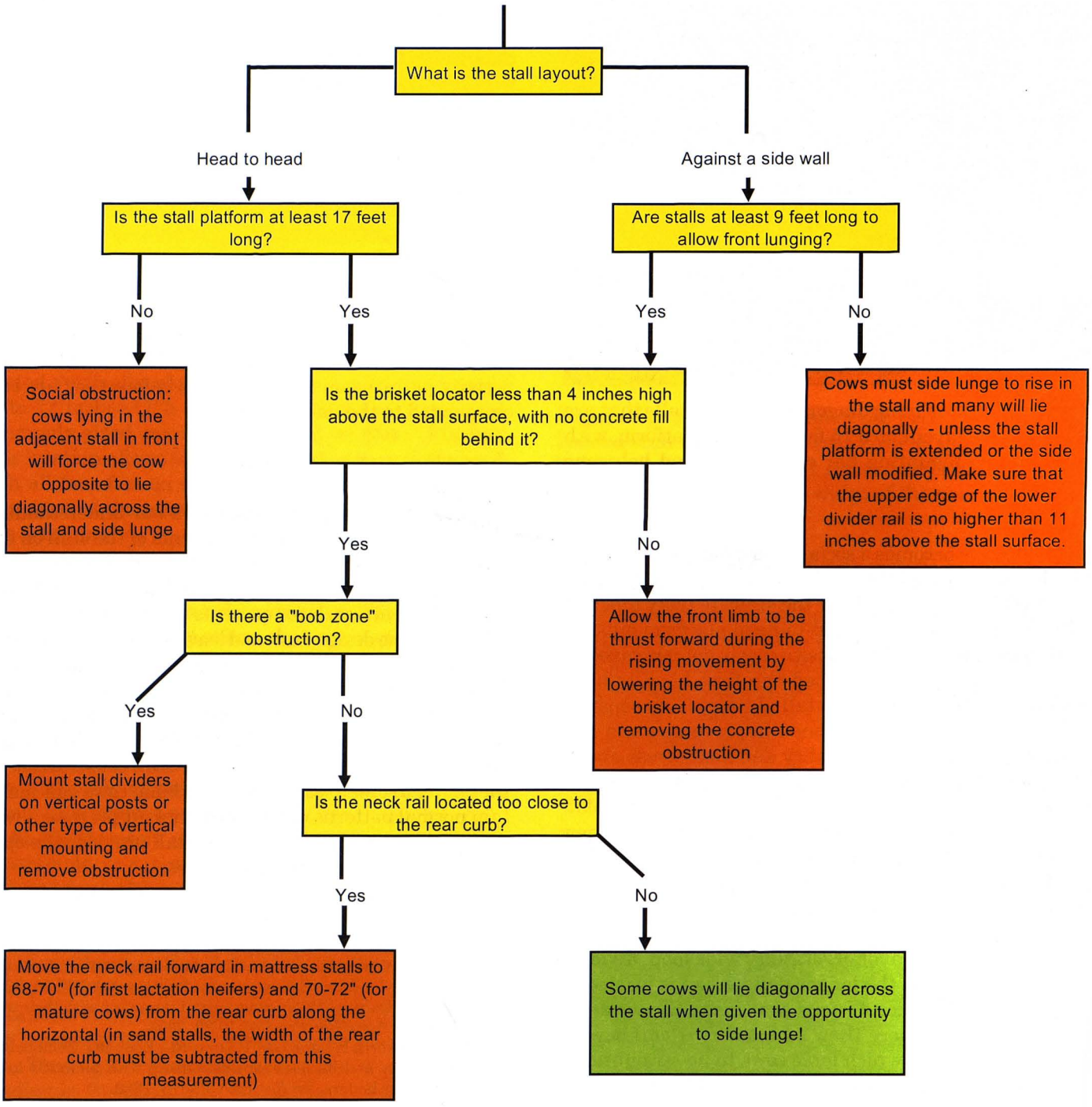

Figure 8. A flow chart for trouble-shooting reasons for diagonal lying in free stall barns.

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