

1    **Making tie-stalls more comfortable: IV. Increasing stall bed length and decreasing manger**  
2    **wall height to heal injuries and increase lying time in dairy cows housed in deep-bedded**  
3    **tie-stalls**

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**SUPPLEMENTAL MATERIALS**10 Supplemental Table S1. Summary of currently recommended tie-stall dimensions in Canada<sup>1</sup>

<b>Stall Aspect</b>	<b>Recommendation<sup>1</sup></b>
Stall width	2× width of the cow at the hook bone
Bed length	1.2× height of cow at rump
Tie-rail height	0.80× height of cow at rump
Tie-rail (forward) position	35 cm more than stall length, from the back of the stall
Manger wall height	<20 cm
Chain length	Height of tie-rail – Height of the manger wall

<sup>1</sup> From Anderson (2014)

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13 Supplemental Table S2. Bedding quality (bedding dryness) scoring method<sup>1</sup>

Towel Score	Description	Final score
0	No moisture on towel, completely dry	Dry
1	Moisture patch less than the size of a dollar coin on the 1st quarter	Wet
2	Moisture patch less than the size of a dollar coin on the 2nd quarter	
3	Moisture patch less than the size of a dollar coin on the 3rd quarter	
4A	Moisture patch less than the size of a dollar coin on the 4th quarter	Very Wet
4B	Moisture patch the size of your knee on the 4th quarter	
4C	Moisture patch larger than the size of your knee on the 4th quarter	

<sup>1</sup>Based on Vasseur et al. (2015). The full scoring method is available online on the Canadian Dairy Research Portal (<https://www.dairyresearch.ca/animal-comfort-tool.php>).

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Supplemental Table S3. Herd prevalence monitoring table, including average prevalence for all experimental cows for the following variables: body condition score, cow cleanliness, body injuries, stall cleanliness, bedding quality, bedding quantity, stall lameness scoring, milk yield, and somatic cell score.

Outcome Measure	Period 1 <sup>a</sup>				Period 2 <sup>a</sup>			
	wk 0	wk 1	wk 3	wk 6	wk 0	wk 1	wk 3	wk 6
Body Condition Score	N/A	2.61	2.64	2.58	N/A	2.63	2.68	2.75
Cow Cleanliness (% clean)								
Leg	N/A	100.0	100.0	100.0	N/A	100.0	100.0	100.0
Flank	N/A	100.0	95.8	100.0	N/A	90.8	95.0	100.0
Udder	N/A	91.7	100.0	87.5	N/A	90.0	95.8	83.3
Body injuries (% injured <sup>b</sup> )								
Lateral Calcaneus (hock)	83.3	87.5	75.0	54.2	47.6	52.4	23.8	38.1
Dorsal Calcaneus (hock)	62.5	41.7	4.2	0.0	4.8	0.0	0.0	0.0
Medial Calcaneus (hock)	29.2	16.7	4.2	0.0	0.0	9.5	4.8	4.8
Lateral Tarsal (hock)	100.0	100.0	100.0	79.2	95.2	85.7	71.4	38.1
Medial Tarsal (hock)	12.5	4.2	0.0	0.0	0.0	0.0	0.0	0.0
Carpal Joints (knees)	54.2	16.7	0.0	4.2	14.3	9.5	4.8	9.5
Distal Neck	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medial Neck	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0
Proximal Neck	12.5	8.3	0.0	0.0	0.0	0.0	0.0	0.0
Anatomical Knee	62.5	33.3	33.3	29.2	28.6	23.8	28.6	28.6
Flank	0.0	8.3	0.0	0.0	0.0	4.8	0.0	0.0
Hind Leg	16.7	20.8	20.8	12.5	4.8	4.8	4.8	4.8
Hip Bone	29.2	16.7	20.8	20.8	19.0	23.8	4.8	9.5
Shoulder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Back	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sacrum	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0
Pin Bone	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0
Stall Cleanliness (% clean)	N/A	81.3	85.4	89.6	N/A	81.0	83.3	83.3
Bedding Dryness (% dry)	N/A	58.3	64.6	60.4	N/A	47.6	50.0	54.8
Bedding Quantity (% deep)	N/A	68.8	68.8	77.1	N/A	47.6	28.6	61.9
Stall Lameness Scoring (% lame)	N/A	16.7	20.8	29.2	N/A	23.8	23.8	33.3
Milk Yield (kg/d)	45.3	44.8	43.9	42.9	39.2	39.4	39.5	36.0
Somatic Cell Score	1.36	1.87	1.58	1.59	1.65	1.93	1.92	2.40

<sup>a</sup> 24 cows on the experiment during Period 1 and 21 cows on the experiment during Period 2

<sup>b</sup> Percent of cows with an injury severity score of  $\geq 2$  at each different injury location

21 Supplemental Table S4: Inter- and intra-observer reliability scores ( $K_w^{1,2}$ ) for measured  
 22 variables: injury, body condition, and lying-down and rising events.

Measured variables	Type of media used	Weeks	Number of cows	Number of observers	Inter-observer (overall average $K_w$ )	Intra-observer (overall average $K_w$ )
Injury	live	0, 8, 14	12, 12, 10	3	0.61	0.79
Body condition	live	0, 8, 14	12, 12, 10	2	0.67	0.79
Lying-down events	video	7, 14	24, 21	2	1.00	1.00
Rising events	video	7, 14	24, 21	2	1.00	1.00

<sup>1</sup>Weighted kappa  
<sup>2</sup>A score of  $K_w \geq 0.6$  was considered an acceptable level of agreement.

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25 Supplemental Table S5. Mean ( $\bar{x}$ ), S.E.M., variance ( $\sigma$ ), and coefficient of variation (CV)<sup>1</sup> for all  
 26 measured study variables except injury scores and stall lameness scoring (as they were scores  
 27 taken from a baseline measurement).

Category	Variable	$\bar{x}$	S.E.M.	$\sigma$	CV
Resting Behaviors	Lying Time	814.22	12.54	13677.18	16.80
	Number of Lying Bouts	14.15	0.36	11.05	0.78
	Average Bout Length	62.39	2.09	381.58	6.12
	SD of Bout Length	41.97	2.46	526.46	12.54
Quality of Lying-Down Motion	Average Intention Time	21.79	0.74	68.09	3.13
	Average Lying-Down Time	6.15	0.14	2.38	0.39
	Contact with Stall	0.65	0.65	0.08	0.13
	Slipping	0.05	0.01	0.01	0.26
	Hindquarter stepping	0.07	0.02	0.04	0.51
	Abnormal lying	-	-	-	-
	Number of lying attempts	1.01	0.00	0.00	0.00
	Abnormal or Normal Lying	0.69	0.02	0.08	0.12
	Average Time to Rise	13.74	1.59	325.23	23.68
Quality of Rising Motion	Backwards movement on knees	0.08	0.02	0.03	0.40
	Contact with Tie-rail	0.08	0.01	0.02	0.27
	Delayed rising	0.07	0.02	0.05	0.73
	Horse rising	0.00	0.00	0.00	0.16
	Number of rising attempts	1.37	0.06	0.43	0.32
	Abnormal or Normal Rising	0.44	0.03	0.12	0.28
	Average Daily Fat Percentage	1.63	0.03	0.14	0.09
Milk Data	Average Daily Lactose Percentage	1.93	0.05	0.34	0.18
	Average Daily Protein Percentage	1.39	0.03	0.10	0.07
	Average Milk Yield	41.29	1.03	143.56	3.48
	Beta-hydroxybutyrate	0.05	0.00	0.00	0.01
	Fat Percentage	4.08	0.06	0.51	0.12
	Lactose Percentage	4.65	0.01	0.03	0.01
	Protein Percentage	3.42	0.03	0.09	0.03
	Somatic Cell Score	1.87	0.15	3.08	1.65
	Milk Urea Nitrogen	13.28	0.25	8.17	0.62
	Average Daily Fat Percentage	1.63	0.03	0.14	0.09
Stall Measures	Bedding Quantity	59.63	2.71	988.67	16.58
	Stall Cleanliness	84.07	2.45	807.90	9.61
	Bedding Quality (% dry)	56.30	3.34	1508.57	26.80
Health Measures	Body Condition Score	2.65	0.03	0.11	0.04
	Stall Lameness Scoring	0.03	0.02	0.07	2.52
Injury	Shoulder	0.01	0.01	0.00	0.50
	Flank	0.17	0.03	0.12	0.73

Back	-0.01	0.01	0.03	-2.51
Hip bone	-0.25	0.06	0.49	-1.94
Sacrum	0.01	0.01	0.02	1.24
Pin bone	-0.01	0.01	0.02	-1.24
Hind leg	0.03	0.04	0.19	7.39
Knee	-0.35	0.07	0.69	-1.96
Lateral Calcanei	-0.24	0.06	0.49	-2.04
Dorsal Calcanei	-0.55	0.07	0.70	-1.29
Medial Calcanei	-0.22	0.06	0.45	-2.04
Lateral Tarsal	-0.35	0.05	0.40	-1.14
Medial Tarsal	-0.08	0.03	0.10	-1.25
Carpal Joints	-0.25	0.05	0.29	-1.19
Distal Neck	-	-	-	-
Medial Neck	0.01	0.04	0.19	25.18
Proximal Neck	-0.13	0.06	0.50	-3.96

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<sup>1</sup> CV =  $\sigma / \bar{x}$

Supplemental Table S6. Random effects variances ( $\sigma^2_{\text{cow}}$ ,  $\sigma^2_{\text{e}}$ , CS), covariance parameter estimates, phenotypic variance ( $\sigma^2_{\text{p}}$ )<sup>1</sup>, the variable means ( $\bar{x}$ )<sup>2</sup>, and coefficient of variation (CV)<sup>3</sup> for all variables not taken as a measure compared to baseline. Variables without values were not normal, and thus were not analyzed further.

Category	Variable	$\sigma^2_{\text{cow}}$	AR(1)	CS	$\sigma^2_{\text{e}}$	$\sigma^2_{\text{p}}$	$\bar{x}$	CV (%)
Resting Behaviors	Lying Time	-	-	474.63	4165.34	4639.97	814.22	8.37
	Number of Lying Bouts	-	-	5.96	4.79	10.75	14.15	23.17
	Average Bout Length	-	-	158.98	62.39	221.37	62.39	23.85
	SD of Bout Length	-	-	235.87	67.52	303.39	41.97	41.50
	Average Intention Time	-	-	25.13	40.79	65.92	21.79	37.27
Quality of Lying-Down Motion	Average Lying-Down Time	-	-	-	-	-	-	-
	Contact with Stall	-	-	0.02	0.05	0.08	0.65	43.33
	Slipping	-	-	-	-	-	-	-
	Hindquarter stepping	-	-	0.01	0.02	0.03	0.07	271.80
	Abnormal lying	-	-	-	-	-	-	-
	Number of lying attempts	-	-	-	-	-	-	-
	Abnormal or Normal Lying	-	-	0.02	0.05	0.07	0.69	39.42
	Average Time to Rise	-	-	202.49	132.19	334.68	13.74	133.18
	Backwards movement on knees	-	-	0.01	0.01	0.03	0.08	216.97
	Contact with Tie-rail	-	-	0.00	0.01	0.01	0.08	150.78
Quality of Rising Motion	Delayed rising	-	-	-	-	-	-	-
	Horse rising	-	-	-	-	-	-	-
	Number of rising attempts	-	-	0.21	0.13	0.34	1.37	42.56
	Abnormal or Normal Rising	-	-	0.05	0.05	0.10	0.44	74.07
	Average Daily Fat Percentage	-	-	0.08	0.05	0.13	1.63	22.34
	Average Daily Lactose Percentage	-	-	0.22	0.02	0.25	1.93	25.77
	Average Daily Protein Percentage	-	-	0.07	0.01	0.08	1.39	20.46
	Average Milk Yield	-	-	95.76	8.32	104.09	41.29	24.71
	Beta-hydroxybutyrate	-	-	0.00	0.00	0.00	0.05	38.16
	Fat Percentage	-	-	0.35	0.17	0.52	4.08	17.68
Milk Data	Lactose Percentage	-	-	0.01	0.01	0.02	4.65	3.04
	Protein Percentage	-	-	0.07	0.01	0.07	3.42	7.85
	Somatic Cell Score	-	-	2.13	1.27	3.40	1.87	98.73



	Milk Urea Nitrogen	-	-	2.91	4.50	7.41	13.28	20.50
Stall Measures	Bedding Quantity	-	-	210.08	621.98	832.06	59.63	48.37
	Stall Cleanliness	-	-	363.93	504.79	868.72	84.07	35.06
	Bedding Quality (% dry)	-	-	315.89	1236.34	1552.23	56.30	69.98
Health Measure	Body Condition Score	-	-	0.10	0.01	0.11	2.65	12.51
	Stall Lameness Scoring	-	-	0.06	0.04	0.10	0.03	1076.25
	Shoulder	-	-	-	-	-	-	-
Injury	Flank	-	-	0.01	0.11	0.13	0.17	208.65
	Back	-	-	-	-	-	-	-
	Hip bone	-	-	0.23	0.33	0.55	-0.25	-295.70
	Sacrum	-	-	-	-	-	-	-
	Pin bone	-	-	-	-	-	-	-
	Hind leg	-	-	0.00	0.17	0.17	0.03	1589.78
	Knee	-	-	0.17	0.32	0.49	-0.35	-199.62
	Lateral Calcanei	-	-	0.20	0.27	0.47	-0.24	-286.22
	Dorsal Calcanei	-	-	0.12	0.43	0.55	-0.55	-135.42
	Medial Calcanei	-	-	0.24	0.16	0.40	-0.22	-283.32
	Lateral Tarsal	-	-	0.13	0.27	0.40	-0.35	-179.82
	Medial Tarsal	-	-	-	-	-	-	-
	Carpal Joints	-	-	0.07	0.23	0.30	-0.25	-220.52
	Distal Neck	-	-	-	-	-	-	-
	Medial Neck	-	-	0.03	0.13	0.16	0.01	5404.05
	Proximal Neck	-	-	0.14	0.25	0.39	-0.13	-493.63
	Shoulder	-	-	-	-	-	-	-
	Flank	-	-	0.01	0.11	0.13	0.17	208.65

$$^1\sigma_p^2 = \sigma_{cow}^2 + \sigma_e^2$$

$^2\bar{x}$  = the average between the two treatment LSMEANS

$$^3CV = (\text{sqrt}(\sigma_p^2) / \bar{x}) * 100$$

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Stall #		1	2	3	4	5	6	7	8	9	10	11	12
<b>Row 1</b>	Stall bed length (cm) <sup>1</sup>	188	188	188	188	188	188	188	188	188	188	188	188
	Manger wall height (cm) <sup>2</sup>	5	5	20	20	20	20	20	5	5	5	20	5

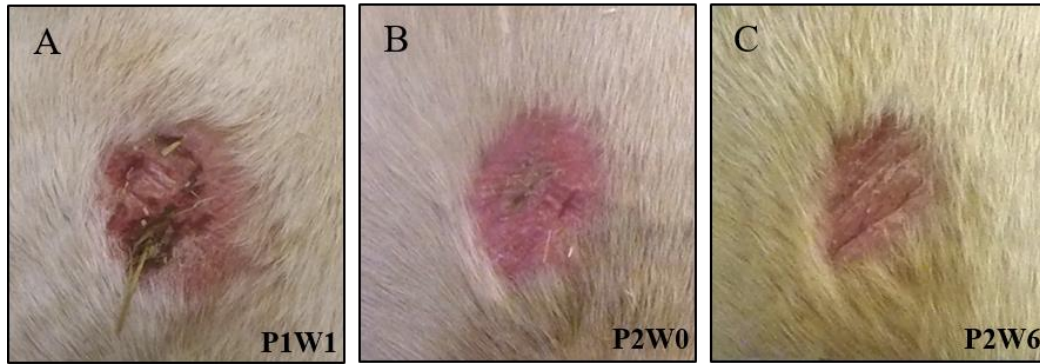
  

Stall #		1	2	3	4	5	6	7	8	9	10	11	12
<b>Row 2</b>	Stall bed length (cm)	178	178	178	178	178	178	178	178	178	178	178	178
	Manger wall height (cm)	20	20	5	20	5	20	5	5	20	5	5	20

<sup>1</sup> 188 = long stall bed length treatment; 178 = short stall bed length treatment

<sup>2</sup> 5 = low manger wall height treatment; 20 = high manger wall height treatment

Supplemental Figure S1: Diagram showing the experimental design and stall set-up for stall bed length and manger wall height. All other stall component dimensions remained the same for all stalls in both rows and were  $\pm 5$  cm of current Canadian recommendations based on average experimental cow size: stall width = 141 cm; tie-rail height = 122 cm; tie-rail forward position = 36 cm; chain length = 1.00 m. The crossover experiment lasted 14 weeks in total, with 2 periods of 6 wk plus 1 initial wk of habituation. At the start of the experiment, twenty-four cows were blocked into 6 blocks, then 2 cows from each block were randomly assigned to either row 1 or row 2 (long or short stall bed length treatment). Then for each row, the 2 cows in each block would be randomly selected to start in a stall with a high or low manger wall, so that each manger wall height treatment on each row had 1 cow from each block. During the second period, cows would be moved in the same row to a stall with a different manger wall height. All stalls were randomly assigned once each treatment was determined. Once a cow was assigned to a row, they remained on that row (the same stall bed length treatment) for the entire trial.



Supplemental Figure S2. Injury progression for one cow at the anatomical knee over a 12-wk period. A) Anatomical knee during first wk of the first period (P1W1) of the experiment. Injury severity score was 4, indicating that the most severe injury observed was an open wound or lesion. B) Anatomical knee 6 wk later (42 d) during the baseline wk of period 2 (P2W0). Injury severity score was 2, indicating that the most severe injury seen was a bald spot. C) Anatomical knee during last wk of the experiment, 42 d after Picture B, during wk 6 of period 2 (P2W6). Injury severity score was 2, indicating that the most severe injury observed was a bald spot or minor swelling.