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Association of lameness with per cent body weight distribution and shifting to individual limbs of static Karan Fries crossbred cows

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ABSTRACT

Lameness in crossbred cows causes considerable economic loss hence efforts were made to develop effective automated technique to diagnose it at an earlier stage. Lactating Karan Fries crossbred cows (148) were assigned the appropriate lameness score (VLS). Total body weight and body weight distributed to individual limbs were recorded. Data were analyzed to access the effect of pregnancy, stage of lactation and parity on body weight distribution. Stage of pregnancy had significant effect on total body weight as well body weight distributed to right hind and left hind limbs. Total body weight and body weight distributed to all the 4 limbs was the highest during third trimester of pregnancy. Stage of lactation significantly affected total body weight which was highest during late lactation. Total body weight and weight distributed to right front and right hind legs were significantly higher for cows in fourth or above parity. Per cent distribution of body weight to individual limbs of cows suffering from various categories of lameness was significantly different from one another. Percentage distribution of total body weight on front and rear half of no lame cows was observed in a ratio of 26:21 while for right and left half it was 53:43. The pattern of front to rear and right to left distribution of per cent body weight of cows under various categories of lameness was similar. Shifting of per cent body weight to right and left hind limbs was significant. Lame cows reflected both contra lateral as well as diagonal weight shifting; moreover cows lame with hind limbs shifted their weight to their front limbs also.

Key words: Lameness, Load cell, Weight distribution, Weight shifting

Lameness is the third most expensive health problem of dairy animals after mastitis and infertility (Esslemont *et al*. 1997). Affected animals show poor production and reproduction performance (O'Callaghan 2002, Booth *et al*. 2004, Garbarino *et al*. 2004, Singh *et al*. 2011), and added costs of treatment, culling (Whitaker *et al*. 2000) and replacement result in losses to farmers (Enting *et al*. 1997). Farmers are able to identify only 25–50% cases of lameness (Whay *et al*. 2003). Early detection of lameness is must to minimize the loss (Nordlund *et al*. 2004) as its subclinical form reduces milk yield also (Singh *et al.* 2011). Subjective visual gait scoring system is used as a cost-effective lameness detection method (Colborne2004, Flower and Weary 2006); but is not much reliable due to its subjective nature (Hood *et al.* 2001, Winckler and Willen 2001). Discrepancies between hoof health and gait scores of dairy cows (Winckler and Willen, 2001, O'Callaghan *et al.* 2003) raise doubt about its authenticity. Parallel force-plates (Rajkondawar *et al.*2006), machine-vision based gait analysis (Flower *et al.* 2005) and Markov models (Magee and Boyle 2002) were found less specific and sensitive. Weight shifting behavior of static cows is used as an index for identification of lameness (Keegan *et al.*1998, Hood *et al.*2001, Rietmann *et al.*2004, Pastell *et al.*2006, Rushen *et al.* 2007). Measurements of how a static cow distribute its weight (leg weight ratio i.e. LWR, Pastell *et al.* 2010) and weight shifting between legs on different flooring (Chapinal *et al.* 2011) may help in automated detection of lameness (Rajkondawar *et al.* 2002, Pastell and Kujala 2007). Neveux *et al.* (2003) observed greater variability in weight distribution among the 4 limbs of cows with comfortable and uncomfortable flooring but without any direct relationship between the visible injuries on a hoof and weight placed on that limb. The overall objective of the present investigation was to evaluate distribution of per cent body weight on individual limbs of static Karan Fries (lame and no lame) crossbred cows along with determination of per cent weight shifting response (from afflicted limbs to the remaining limbs) of lame cows as compared to that of no lame cows.

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MATERIALS AND METHODS

Animals and housing

The lactating cows under present investigation were maintained under loose housing and group management system (not more than 50 cows in a single group). The paddock was large, open and brick paved with herringbone system. The paddock was adjacent to milking byre. The three sides of the paddock were surrounded by the metal pipes, and the rest one side was fenced by feeding manger and standing space. Water trough prided in one corner of the paddock. In the day, shadow of tree within the paddock provided additional shady shelter for lounging animals. The housing space for the animals was specified as per "BIS" standards. The system of housing facilitated free movement and sufficient exercise to the animals. The housing pattern though exposed the animals to climatic effects, provided impels air circulation and assisted in evaporative cooling. Mist cooling was effective in protecting these from extreme hot weather in summer.

The present experiment was conducted on lactating Karan Fries (Holstein Friesian crossbred) cows maintained at the institute. Lactating KF cows (148) were screened during April 2011 for lameness or hoof disorders out of which 97 were visually diagnosed for lameness by an experienced veterinarian. These animals were from different parity (1 to 9), stage of lactation (early, mid and late) and stage of pregnancy (first, second and third trimesters).

Gait scoring was done by making cows to walk through a 15 m long and 1.25 m wide non-grooved-concrete passageway, in a consistent manner. Before the gait scoring session the cows were made familiar with the passage for their non-hesitated walking through. An experienced veterinarian standing on left side of the moving cows assigned the appropriate gait score to each and every cow using the 5-point scale developed by Sprecher *et al.* (1997).

Load cells and platform

The weight distribution of cows in static condition was obtained by using load cell based cow weighing system (electronic static weigh-pad)-with real time logging. The dairy platform consisted of 4 independent recording units (each 68 cm × 31 cm) fitted in a 2.75 m × 1.25 m enclosure with a total capacity of 1 tonne and graduation 2 kg. The electronic static weigh-pad was made up of a framework of girders adequately reinforced with transverse beams and suitable non-slip top deck with pit less. The entire steel framework was mounted on strain gauge based compression type load cells (4, load cells), depending on length of the platform. The scale consisted of a weigh bridge supported by 2 load bars placed in the return alley of a milking parlour. Within each load cell, the internal strain gauges measured the shear stress (deformation from the tension and compression proportional to the vertical load applied) and displayed on a display unit. Horizontal forces were not measured. A program written in 'C' recorded the cow's weight and identification number. Another program processed the recorded raw data and computed the true weight of each cow detected. Data were recorded @ 1 reading /sec. The load cells were validated periodically during the study using dead weight calibration with standard weights. The weight recorded was always the same regardless of position on the unit.

The platform stood 15 cm above the floor and had a 1.5m entrance and exit ramp (sloped approximately 5° from the floor) at the front and back of the enclosure. The side barriers of the platform were 2.1 m high and were made of numerous vertical steel bars. An adjustable rear barrier discouraged cows from reversing and allowed handlers to safely correct the position of the cows. Two removable steel bars (one at 0.5 m and other at 1.0 m above the ground level) were fixed in front of cattle to prevent the forward movement. Observations of cows during preliminary trials showed that head movement influenced the weight distribution. Therefore, to limit the cow's peripheral view and ability to move their head, the sides were equipped with lateral blinders. The cows were gently manipulated to encourage repositioning for correct observation if required. Average data of static condition of cows were only taken in account for analysis purpose.

Data collection and statistical analysis

Data on total body weight (kg), its distribution (kg) to each limb i.e. right front (RF), right hind (RH), left front (LF) and left hind (LH) were recorded from the display unit of electronic weigh-pad system equipped with strain-gauged load cells. General information on the animals, for identification as well as for the classification of the data, was also recorded. Information on parity, date of conception (date of successful AI), and date of calving records of the institute were used. The data were grouped into different classes based on stage of pregnancy (first, second and third trimester), stage of lactation (0–90, 91–180 and 181–270 days) and parity (first to fourth or above) to examine the effect of these factors on weight distribution. Data were collected only for lactating cows.

Data on total body weight and its distribution to each individual limb of lactating KF cows in relation to different stages of pregnancy, stage of lactation and parity were subjected to least squares technique (Harvey 1987) and the significance of differences among various subclasses was examined by using Duncan's multiple range test (Kramer 1957).

For the adjustment of the effect of non-genetic factors on total body weight and its distribution to each individual limb, the following model was used:

$$Y_{ijkl} = \mu + P_i + Sp_j + Sl_k + e_{ijkl}$$

where, Y_{ijkl}, total body weight/body weight distributed on each limb of l^{th} cow of i^{th} parity, j^{th} stage of pregnancy and

k^{th} stage of lactation; μ, overall mean; P_i, effect of i^{th} parity; Sp_j, effect of j^{th} stage of pregnancy; Sl_k, effect of k^{th} stage of lactation; and e_{ijkl}, residual error ~(μ, σ^2).

After adjustment of data for the effect of non-genetic factors, body weight distributed to each individual limb for each cow was converted into per cent body weight distributed to individual limb (i.e.%WRF, %WRH, %WLF and%WLH) to eliminate the effect of total body weight variation of individual cows. In other words per cent distribution of body weight on each limb was calculated to avoid the effect of individuality of the particular cow. Adjusted data on the per cent body weight distributed to each limb of lactating cows were subjected to an arcsine transformation. The pattern of significant difference between the per cent body weights distributed to 4 limbs of lactating cows afflicted with various categories of lameness (5-point scale) was observed by using GLM with specified contrast.

Per cent body weight shifting (from lame limb to remaining limbs) from its normal distribution was calculated by subtracting the average per cent body weight distributed to each limb of no lame cow from the per cent body weight distributed to the corresponding limbs of cows afflicted with various categories of lameness. GLM with specified contrasts was used to test the differences for significance between the per cent body-weight shifting from lame limbs to remaining limbs of cows afflicted with various categories of lameness (5-point scale).

RESULTS AND DISCUSSION

The incidence of lameness in KF crossbred cows maintained at cattle yard NDRI, Karnal during the experimental period was observed to be 65.54%. The higher incidence in present investigation might be due to the fact that only lactating cows were considered and spreading of mild FMD a few months before the experimental period might have also added to the incidence of lameness. In present investigation about 22.97% cows were afflicted with mild, 14.19% with moderate, 21.62% with lame and 6.75% were afflicted with severe lameness.

Non-genetic factors on body weight: The mean body weight of KF crossbred cows under present investigation was 420.46±7.82 kg while the mean body weight distribution to right front, left front, right hind and left hind legs are given in Table 1. Analysis of variance revealed that stage of pregnancy significantly ($P<0.05$) affected total body weight as well as body weight distributed to right hind and left hind limbs.

Stage of lactation had significant ($P<0.01$) effect on total body weight of the lactating crossbred KF cows but it did not affect the body weight distribution of cows to their individual limbs but difference in total body weight of non pregnant cows and cows in late lactation was significant.The parity of cows significantly affected the mean of total body weight and its distribution to right front and right hind limbs ($P<0.01$).

Per cent body weight distribution: The per cent body weight distributed to individual limb of cows afflicted with various categories of lameness differed significantly (Tables 3, 4) from one another ($P<0.01$). The ratio of per cent body weight distributed to both front and both hind limbs and the per cent body weight distributed to right and left flank are given in Table 2. As the analysis for per cent body weight distribution was performed on adjusted data hence the sum of the per cent body weight distributed to all the 4 limbs of the cows was less than 100. Moreover, analysis of variance reflected significant differences for per cent body weight distributed to left front ($P<0.01$) and right hind ($P<0.05$) limbs of cows afflicted with various categories of lameness. The

Table 1. LSM±SE values of total body weight, weight distributed on right front, left front, right hind and left hind limb of KF cows under different stages of pregnancy, stages of lactation and parity

Effect	Total body weight (kg)	WRF (kg)	WLF (kg)	WRH (kg)	WLH (kg)
Overall	420.46±7.82	137.11±4.39	93.11±5.22	99.85±4.78	89.15±4.05
Stage of pregnency					
Non pregnant (100)	399.18 ^{a}±6.04	126.85±3.40	96.00±4.03	86.47 ^{a}±3.70	89.49 ^{b}±3.13
1st trimester (12)	403.66 ^{a}±17.59	129.03±9.89	84.39±11.74	98.02 ^{c}±10.77	90.96 ^{b}±9.12
2nd trimester (28)	434.15 ^{b}±12.88	141.46±7.24	95.71±8.60	92.86 ^{b}±7.88	105.22 ^{c}±6.67
3rd trimester (8)	444.86 ^{b}±20.87	151.08±11.73	96.36±13.93	122.05 ^{d}±12.77	70.94 ^{a}±10.82
Stage of lactation					
Early lactation (44)	406.55 ^{a}±11.37	134.07±6.39	88.32±7.59	97.21±6.96	85.68±5.89
Mid lactation (30)	413.70 ^{a}±12.30	136.07±7.02	87.59±8.34	99.78±7.65	89.98±6.48
Late lactation (74)	441.15 ^{b}±8.37	141.17±4.70	103.43±5.58	102.56±5.12	91.81±4.33
Parity					
1st (51)	370.27 ^{a}±10.79	122.68 ^{a}±6.06	79.08±7.20	84.43 ^{a}±6.60	83.04±5.59
2nd (39)	418.62 ^{b}±11.33	139.93 ^{ab}±6.37	94.00±7.57	100.11 ^{ab}±6.94	82.97±5.87
3rd (24)	441.31 ^{bc}±13.21	137.38 ^{ab}±7.42	99.79±8.82	101.31 ^{ab}±8.08	101.69±6.84
4th and above (34)	451.65 ^{c}±11.54	148.44 ^{b}±6.48	99.58±7.71	113.55 ^{b}±7.06	88.91±5.98

Values with different superscript (a, b and c) in the same column differ significantly from one another.

Table 2. Mean±SE values of per cent of total body weight distributed on right front, left front, right hind and left hind limb of KF cows under different categories of lameness (locomotion score)

Effect	Locomotion score									
	1		2		3		4		5	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
Overall	23.87	0.01	22.67	0.04	23.99	0.05	23.61	0.34	23.99	0.07
Per cent body weight distribution										
RF	30.70^{b}	0.01	31.24^{b}	0.03	29.85^{b}	0.03	32.46^{c}	1.24	33.71^{c}	0.03
LF	21.46^{a}	0.01	18.06^{a}	0.05	25.50^{a}	0.07	24.74^{b}	0.03	23.73^{b}	0.07
RH	21.64^{a}	0.01	22.58^{a}	0.03	19.95^{a}	0.05	17.50^{a}	0.05	15.91^{a}	0.14
LH	21.68^{a}	0.01	18.79^{a}	0.03	20.67^{a}	0.04	19.76^{a}	0.03	22.62^{ab}	0.05

Values with different superscript (a, b and c) in the same column differ significantly from one another
RF, Right front limb; LF, left front limb; RH, right hind limb; LH, left hind limb.

Table 3. Mean±SE values of per cent of total body weight distributed on right front, left front, right hind and left hind limb of KF cows under different categories of lameness Figure 3 Per cent distribution of body weight among four limbs of no lame cows

Effect	% WRF		% WLF		% WRH		% WLH	
	Mean	(±) SE	Mean	(±) SE	Mean	(±) SE	Mean	(±) SE
Overall	31.59	0.01	22.64	0.01	19.47	0.01	20.70	0.01
Locomotion score								
1	30.70	0.01	21.46^{b}	0.02	21.65^{c}	0.02	21.68	0.01
2	31.24	0.02	18.06^{a}	0.03	22.59^{c}	0.03	18.79	0.02
3	29.85	0.03	25.50^{c}	0.05	19.95^{bc}	0.05	20.67	0.03
4	32.46	0.02	24.74^{c}	0.03	17.51^{ab}	0.03	19.76	0.02
5	33.71	0.06	23.73^{c}	0.11	15.93^{a}	0.10	22.62	0.07

Values with different superscript (a, b and c) in the same column differ significantly from one another

per cent body weight distributed to left front limb did not differ significantly in moderate, lame and severe lame cows but the values differed significantly for it from no lame and mild lame cows. The per cent body weight distributed to right hind limbs of no lame, mild and moderate lame cows; lame and severely lame cows; lame and moderate lame cows as well did not differ significantly (Table 3).

Per cent body weight shifting: The results for shifting of per cent body weight distributed to individual limbs of cows afflicted with various categories of lameness from those of no lame cows reflected that the differences in shifting of per cent body weight across different limbs were significant for cows afflicted with lame ($P<0.01$) and severe lame ($P<0.5$) category of lameness. In almost all the cases of lameness there was observed positive shifting in per cent body weight distribution to both front limbs (except in mild lame cows where negative shifting was observed in left front leg) on the other hand negative shifting was observed in both limbs of cows afflicted with various categories of lameness except right hind of mild lame cows and left hind of severe lame cows (Table 4). Negative shifting of body weight in particular limb reflected that the same limb was afflicted with lameness.

Differences in per cent body weight shifted to left front limb of cows were statistically significant ($P<0.05$) for different categories of lameness (lameness score). The mean per cent body weight shifted to left front of cows under various categories of lameness (Table 5).

The result for absolute body weight distribution to individual limbs of no lame cows reflected that 54.76% of total body weight was distributed to the both front limbs and 44.95% to the both hind limbs whereas the per cent distribution to both right and left limbs was 53.44:46.47%. The higher per cent distribution of body weight to front and right half of the body of dairy cows were in agreement with the findings reported by Phillip (2002) and Neveux (2004). The significantly higher mean body weight of pregnant cows in second and third trimester of pregnancy as compared to non pregnant cows and cows in first trimester of pregnancy might be due to the increased body weight of the fetus during mid and advance stages of pregnancy. The present results were in conformity with the findings of Chapinal *et al.* (2009a), who reported higher weight shifting between contralateral legs of cows during prepartum period as compared to postpartum period; and the weight variability decreased by 30% after calving which reflected that body weight distribution in dairy cows was primarily affected by late pregnancy. However, Scott (1988) found that late pregnancy had nothing to do with the load distribution

Table 4. Mean±SE values of per cent of total body weight shifted on right front, left front, right hind and left hind limb of KF cows under different categories of lameness

Effect	Locomotion score									
	1		2		3		4		5	
Overall	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
	0.0127	0.82	–0.811	1.55	0.368	1.78	0.084	1.43	0.263	2.09
Per cent body weight shifting										
RF	0.0013	0.87	0.784	1.56	–0.775	1.61	1.761^{ade}	1.24	2.925^{b}	1.75
LF	0.0486	0.89	–2.751	1.84	4.425	2.14	3.436^{ce}	1.45	2.279^{b}	2.14
RH	–0.0003	0.79	1.309	1.48	–1.344	1.81	–3.397^{bd}	1.63	–5.126^{a}	2.59
LH	–0.0013	0.73	–2.586	1.31	–0.836	1.56	–1.465^{ade}	1.40	0.975^{b}	1.89

(-) values reflected to the limbs afflicted with lameness; values with different superscript (a, b, c, d and e) in the same column differ significantly from one another.

Table 5. Mean±SE values of per cent body weight shifting between right front, left front, right hind and left hind limbs of KF cows showing the effect of various categories of lameness

Effect	% WSRF		%WSLF		%WSRH		%WSLH	
	Mean	(±) SE	Mean	(±) SE	Mean	(±) SE	Mean	(±) SE
Overall	0.67	0.74	1.49	0.81	–1.87	–0.8	–0.83	–0.25
Locomotion score								
1	0.001	1.08	0.04^{ab}	1.19	–0.8	1.15	–0.25	0.98
2	0.78	1.32	–2.75^{a}	1.46	1.31	1.4	–2.58	1.2
3	–0.77	1.68	4.42^{c}	1.85	–1.34	1.79	–0.84	1.52
4	1.76	1.36	3.44^{bc}	1.5	–3.4	1.45	–1.46	1.24
5	2.92	2.44	2.28^{bc}	2.69	–5.12	2.6	0.97	2.21

(-) values reflected to the limbs afflicted with lameness; values with different superscript (a, b, c, d and e) in the same column differ significantly from one another.

between feet. The nonsignificant differences in the body weight of cows in first trimester of pregnancy as compared to non pregnant cows reflected the slow growth rate of fetus during first trimester while significant difference in body weight of second and third trimester pregnancy as compared to first trimester indicated higher but almost equal growth rate during second and third trimesters. The distribution of significantly higher body weight towards the right hind quarter of the body as compared to left hind quarter during the third trimester of pregnancy might have been because of rapidly growing fetus in right flank which must have shifted the center of gravity of hind half of cow body towards the right hind quarter. The distribution of higher body weight to left hind quarter than that of right hind quarter in non pregnant cows might be because of the presence of heavier rumen and reticulum on the left and lighter omasum, abomasum, intestine and reproductive organs on the right side of the body but the alternate shifting of distribution of mean body weight from right hind to left hind and then again to right hind during the course of pregnancy (it was higher on right hind during first trimester and on left hind in second trimester and again on right hind in third trimester) (Fig. 1) which might be because of the off-centered position of rumen, presence of intestine in right flank and developing fetus in right flank of pelvic cavity during first trimester while second trimester is supposed to be a transition phase during when fetus may descend (yet not completely descendent) into abdominal cavity replacing rumen towards the left from its off-centered position but during the third trimester it has fully descended into the abdominal cavity and it is heavier enough.

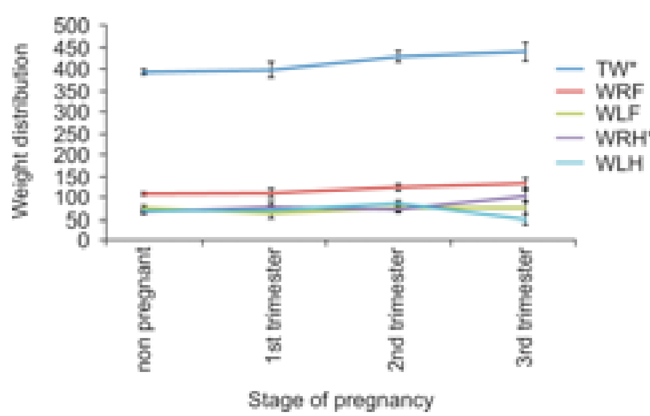

Fig. 1. Effect of stage of pregnancy on body weight and its distribution to individual limbs.

Higher mean body weight of cows during late lactation (i.e. 180 days postpartum) might be because of rapid growth rate of fetus during this period as well as its complete descendent into abdominal cavity. Chapinal *et al.* (2009a) supported the present finding that milking/stage of lactation did not affect the distribution of body weight between the 4 legs of dairy cows. Total body weight as well as its distribution to right front and right hind limbs from first to fourth and above parity increased significantly (Fig. 2) which might be due to increase in shape and size of the body of the cows with the advancement of their age.

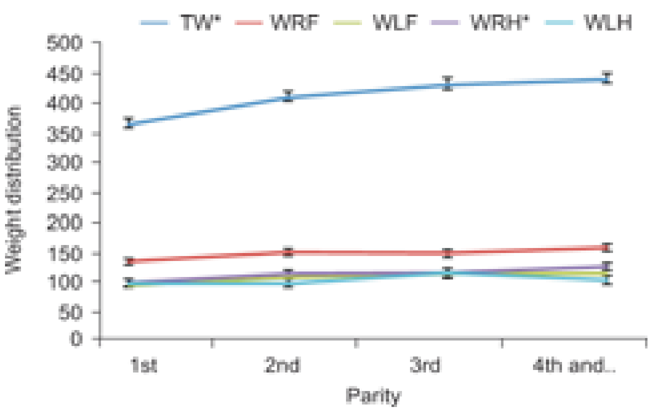

Fig. 2. Effect of parity on body weight and its distribution to individual limbs.

Similar to the findings of Phillips (2002) in cattle (55–60% front: 45–40% back), Budsberg *et al.* (1987) in other quadrupedal mammals (60:40%) and Hood *et al.* (2001) in horses (58:42%), the per cent body weight distribution ratio on front to hind half of the body of no lame cows as well as cows afflicted with various categories of lameness under present investigation was higher (Fig.3). It might have been due to the fact that front legs had to take care of the balance of neck and head region of animal body and anterior position of head and neck might have shifted the center of gravity of the body towards the front limbs instead of the center position of the four limbs.

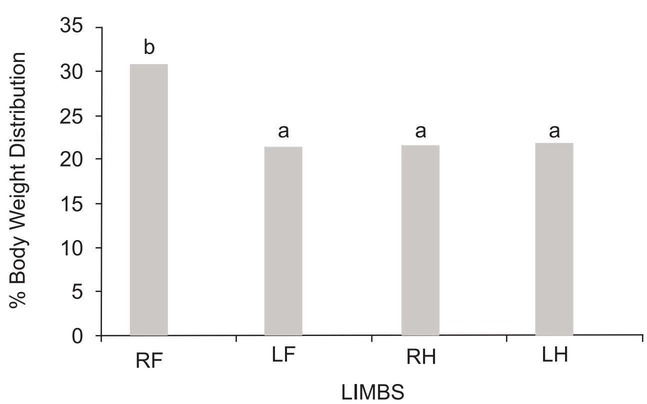

Fig. 3. Per cent distribution of body weight among four limbs of no lame cows.

Interestingly in present study the ratio of per cent body weight distributed to front and hind limbs for lame cows of all categories (except mild lame cows) was higher as compared to no lame cows which indirectly indicated the shifting of body weight from hind to front limbs, contrary to Neveux *et al.* (2004) but in accordance to that of Pastel *et al.* (2006) who reported mild shifting from hind to front legs. The increased front to hind ratio in lame cows might be due to the fact that these cows were found lame either with one or both hind limbs especially right hind limb which bears more weight out of both hind limbs in general. While mild lame cows were observed to be lame mostly with left hind limb that is why the front: hind ratio of per cent body weight distribution for these cows was to be lower than no lame cows as they could contralaterally shift their weight to right hind limbs (Fig. 4).

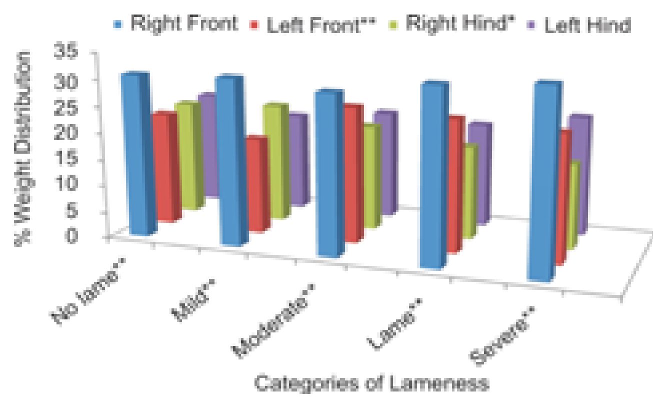

Fig. 4. Per cent distribution of body weight to four limbs of cows afflicted with various categories of lameness.

The mean per cent body weight distributed to both right legs (front and hind) or right half of body was higher as compared to that of body weight distributed to left legs or left half of the body of no lame as well as lame cows (different categories of lameness), which might be because of off-centered position of rumen and presence of intestine in the right side of the abdomen. These observations were quite similar to the findings of Neveux *et al.* (2003), who reported that cows with hoof lesions showed a greater variability in weight distribution among the four limbs when standing, compared to healthy cows.

Distribution of mean per cent body weight to left front limb of mild lame cows was significantly lower than that of no lame cows while for other cows which were afflicted with moderate, lame and severe lame conditions it was higher than that of no lame cows. At the same time this distribution to right hind limb of mild lame cows was higher than no lame cows and lower for cows afflicted with moderate, lame and severe lame conditions. It might be due to diagonal shifting of body weight from left front to right hind limb in mild lame cows, as these cows were observed to be lame with left front limb (Fig. 4).Similarly cows afflicted with moderate, lame and severe lame conditions diagonally shifted their body weight from right hind to left front limb (in forward direction) as these cows were observed to be lame with their right hind limb. From above findings it is obvious that the cows may shift their body weight from lame limbs to the remaining other limbs regardless of direction (forward/ backward and diagonal/non-diagonal) to an extent up till the center of gravity of their body falls within the boundary of their four legs.

As the differences in per cent body weight distributed to individual limbs of no lame cows did not differ significantly with the corresponding limbs of mild lame cows hence these cows might be considered under no lame cows group for their better classification based on per cent body weight distribution criteria. Similarly cows with lame and severe lame cases might be classified under one group, viz. lame cows. The per cent body weight distributed to individual limbs of moderate lame cows was not significantly different from that of mild lame cows (except for left front limb) as well as lame cows, which might be because of the least differences in visual criteria based on which cows were assigned particular locomotion score. Hence, categorization of these cows (with lameness score 3) into either lame or no lame group is very tedious; it seemed to be the probable reason why Pastell *et al.* (2010) classified the cows with lameness score >3 and ≥3.5 as lame cow and found better results for classification of cows with lameness score ≥3.5 as lame with better sensitivity and specificity (AUC = 0.88) by using leg weight ratio for ROC curve analysis.

Negative shifting of body weight to a limb revealed that the particular limb was afflicted with lameness and shifted its weight to remaining limbs. In no lame cows negative weight shifting on both hind legs indicated that cows in general used to shift their body weight from back (hind part) to front to some extent but not from front to back (Fig. 5). It might be due to the fact that back shifting of body weight might have disturbed the normal center of gravity of body of cow which was essential for their balanced static standing condition. Moreover little positive per cent weight shifting on front legs of no lame cows reflected the anterior position of center of gravity in cows. Similar findings were also reported by Gray (1944), Merkens *et al.* (1993) and van der Tol *et al.* (2002) that cows may shift up to 10–20% of their body weight from back to front limbs in order to maintain the anterior position of center of gravity for their static condition.

In cows afflicted with lameness (locomotion score 4) it was right hind and left hind limb which was diagnosed to be afflicted with lameness but the body weight shifting in these cows was observed from right hind limb to left front limb (Figs 5, 6). The results of present finding appeared to be contradictory to the findings of Neveux *et al.* (2004) who found strong negative correlations between the amounts of weight applied to contralateral hooves and observed no

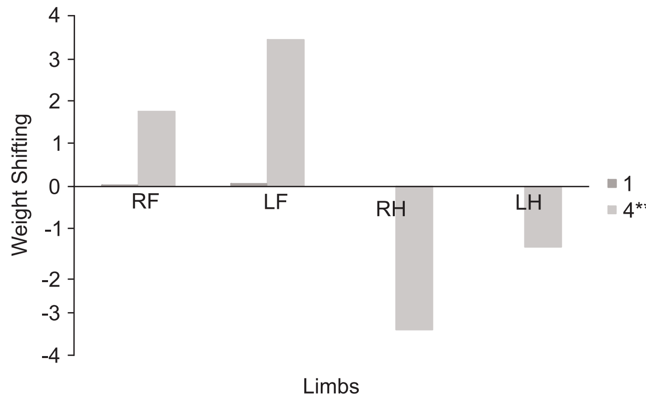

Fig. 5. Comparison of per cent body weight shifting (1 = No lame cows; 4 = cows with lameness score 4 i.e. 'lame cow')

(N.B.: Negative weight shifting reflects the limbs afflicted with lameness.)

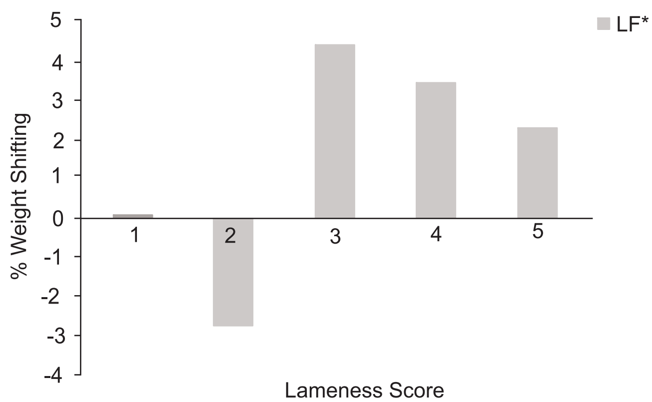

Fig. 6. Per cent weight shifting to left front limb of cows suffering from various categories of lameness

weight shifting to the front hooves on exposure of either one or both back hooves to an uncomfortable surface. It might be due to the fact that in present study both of the hind limbs of mild lame cows were afflicted with lameness but weight shifting due to left hind limb was not observed to be significant. However, contradictory to Neveux *et al.* (2006) cows afflicted with severe lameness in present study also revealed weight shift from back to front limbs but this shifting was found nonsignificant. A nonsignificant contralateral and diagonal weight shifting in present study was also observed in mild and moderate lame cows which were having lameness in their one front and one hind leg. In general all the 3 types of weight shifting i.e. diagonal, ipsilateral as well as contralateral was observed in cows afflicted with moderate, lame and severe lame conditions but interestingly with the increase in the severity of lameness the weight shifting pattern was changed from diagonal to ipsilateral limbs (Fig. 7) to provide better balance by maintaining center of gravity of the lame cows within the boundary of their fourlimbs. In most of the cases (except right hind for mild lame and left hind for moderate lame cows) both the hind limbs were afflicted with lameness indicating that hind limbs were more prone to lameness as compared to front limbs of cows, supporting previous studies by Pastell and Kujala (2007) Rushen *et al.* (2007) and Chapinal *et al.* (2009b), in which they reported higher incidence in hind digits and greater SD of weight applied to the rear legs in the lame cows.

Although the maximum positive weight shifting occurred on both front limbs (except right front of moderate lame cows and left front of mild lame cows which might be due to the fact that in these cows the left front limb itself was afflicted with lameness) but it was left front limb in all cases which received maximum shifting. It might be due to the fact that in maximum cases both the hind limbs were afflicted with lameness which shifted the center of gravity of the cow body towards the left front limb by shifting the off-centered position of rumen towards the left front limb. The mean values for per cent body weight shifted to left front limbs of cows decreased nonsignificantly with the severity of lameness in these cows which might be due to the fact that the weight shifting in more severe cases might have occurred more evenly on other non afflicted limbs (Fig. 7).

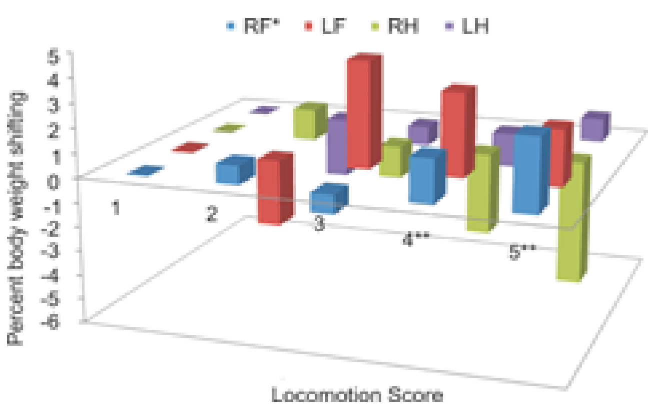

Fig. 7. Weight shifting (from afflicted limb to remaining limbs) patterns of KF cows afflicted with various categories of lameness.

In static dairy cows total body weight and its distribution is affected by various factors viz. stage of pregnancy, stage of lactation and parity. Static cows are exposed to discomfort and stress as well when their one or more limbs are afflicted with various categories of lameness hence the cows try to shift their body weight from afflicted to remaining limbs, regardless of the position of lame limb. The shifting of body weight takes place to maintain the center of gravity of dairy cows within the periphery of their all the four limbs. The weight shifting from front to back and vice-versa may take place in diagonal, collateral or ipsilateral patterns provided the center of gravity of the body of the animal does not fall outside the boundary of all the 4 legs of the cow. Thus, shifting in body weight may prove to be an important measure for early detection of lameness by using an improved automated technique.

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REFERENCES

Booth C J, Warnick L D, Grohn Y T, Maizon D O, Guard C L and Janssen D. 2004. Effect of lameness on culling in dairy cows. *Journal of Dairy Science* **87**: 4115–22.

Budsberg S C, Verstraete M C and Soutas-Little R W. 1987. Force plate analysis of the walking gait in healthy dogs. *American Journal of Veterinary Research* **48**: 915–18.

Chapinal N, de Passille A M and Rushen J. 2009a. Weight distribution and gait in dairy cattle are affected by milking and late pregnancy. *Journal of Dairy Science* **92**(2): 581–88.

Chapinal N, de Passille A M, Weary D M, von Keyserlingk M A G and Rushen J. 2009b. Using gait score, walking speed and lying behaviour to detect hoof lesions in dairy cows. *Journal of Dairy Science* **92**: 4365–74.

Chapinal N, de Passille A M, Rushen J and Tucke C B 2011. Measures of weight distribution and frequency of steps as indicators of restless behavior. *Journal of Dairy Science* **94**(2): 800–03.

Clarkson M J, Downham D Y, Faull W B, Hughes J W, Manson F J, Merritt J B, Murray R D, Russell W B, Sutherst J E, Ward W R. 1996. Incidence and prevalence of lameness in dairy cattle. *Veterinary Record* **138**: 563–67.

Colborne G R. 2004. Gait analysis: technology looking for a place to happen? *Veterinary Journal* **168**: 112–13.

Coulmance M, Gahery Y, Massion J and Swett J E. 1979. The placing reaction in the standing cat: a model for the study of posture and movement. *Experimental Brain Research* **37**: 265–81.

Enting H, Kooij D, Dijkhuizen A A, Huirne R B M and Hoordhuizen – Stassen E N. 1997. Economic losses due to clinical lameness in dairy cattle. *Livestock Production Science* **49**: 259–67.

Esselmont R J, Kossaibati M A. 1997. Culling in 50 dairy herds in England. *Veterinary Record* **140**: 36–39.

Flower F C and Weary D M. 2006. Effect of hoof pathogenesis on subjective assessments of dairy cow gait. *Journal of Dairy Science* **89**: 139–46.

Flower F C, Sanderson D J and Weary D M. 2005. Hoof pathologies influence kinematic measures of dairy cow gait. *Journal of Dairy Science* **88**: 3166–73.

Gahery Y and Nieoullon A. 1978. Postural and kinetic coordination following cortical stimuli which induce flexion movements in the cat's limbs. *Brain Research* **149**: 25–37.

Garbarino E J, Hernandez J A, Shearer J K, Risco C A and Thatcher W W 2004. Effect of lameness on ovarian activity in postpartum Holstein cows. *Journal of Dairy Science* **87**: 4123–31.

Gray J 1944. Studies in the mechanics of the tetrapod skeleton. *Journal of Experimental Biology* **20**: 88–116.

Green L E, Hedges V J, Schukken Y H, Blowey R W, Packington

A J. 2002. The impact of clinical lameness on the milk yield of dairy cows. *Journal of Dairy Science* **85**: 2250–56.

Harvey W B. 1987. User's Guide for LSMLMW, mixed model least squares and maximum likelihood computer programme. PC-I Version, Mimeograph, Ohiostate University, Ohio, USA.

Hernandez J, Shearer J K and Webb D W. 2002. Effect of lameness on milk yield in dairy cows. *Journal of American Veterinary Medical Association* **220**: 640–644.

Hood D M, Wagner P, Taylor D D, Brumbaugh G W and Chaffin M K. 2001. Voluntary limb- load distribution in horse with acute and chronic laminitis. *American Journal of Veterinary Research* **62**: 1393–1398.

Keegan K G, Wilson D A, Wilson D J, Smith B, Gaughan E M, Pleasant R S, Lillich J D, Kramer J, Howard R D, Bacon-Miller C, Davis E G, May K A, Cheramie H S, Valentino W L and Van Harreveld P D. 1998. Evaluation of mild lameness in horses trotting on a treadmill by clinicians and interns or residents and correlation of their assessments with kinematic gait analysis. *American Journal of Veterinary Research* **59**: 1370–77.

Kramer C Y. 1957. Extension of multiple range tests to group correlated adjusted means. *Biometrics* **13**: 13–18.

Magee D R and Boyle R D 2002. Detecting lameness using 'Re-sampling Condensation' and 'multi-stream cyclic hidden Markov models'. *Image and Vision Computing* **20**: 581–94.

Main D C J, Clegg J, Spatz A and Green L E. 2000. Repeatability of lameness scoring system for finishing pigs. *Veterinary Record* **147**: 574–76.

Manson F J and Leaver J D. 1988. The influence of concentrate amount on locomotion and clinical lameness in dairy cattle. *Animal Production* **47**: 185–90.

Merkens H W, Schamhardt H C, Van Osch G J V M and Van der Bogeert A J. 1993. Ground reaction force patterns of Dutch Warm-blood horses at normal trot. *Equine Veterinary Journal* **25**: 134–37.

Neveux S, Oostra J, de Passille A M and Rushen J. 2003. Validating on- farm tools for their ability to detect lameness in dairy cows. in *Proceedings of 37th International Congress of the International Society for Applied Ethology*. pp. 129, Abano Terme, Italy.

Neveux S, de Passillé A M, Rushen J and Weary D. 2004. Changes in weight distribution to detect hoof pain in dairy cows. *Proceedings of 38th International Congress of the International Society for Applied Ethology*. pp. 138, Helsinki, Finland.

Neveux S, Weary D M, Rushen J, Von Keyserlingk M A G and de Passillé A M. 2006. Hoof discomfort changes how dairy cattle distribute their body weight. *Journal of Dairy Science* **89**: 2503–09.

Nordlund K V, Cook N B and Oetzel G R. 2004. Investigation strategies for laminitis problem herds. *Journal of Dairy Science* **87(E)**: E27- E35.

O'Callaghan K A. 2002. Lameness and associated pain in cattle – challenging traditional perceptions. *In Practice* **24**: 212–19.

O'Callaghan K A, Cripps P J, Downham D Y and Murray R D 2003. Subjective and objective assessment of pain and discomfort due to lameness in dairy cattle. *Animal Welfare* **12**: 605–10.

Pastell M, Takko H, Grohn H, Hautala M, Poikalinen V, Praks J, Veermae I, Kujala M and Ahokas J 2006. Assessing cows' welfare: Weighing the cows in a milking robot. *Biosystem Engineering* **93**: 81–87.

Pastell M E and Kujala M. 2007. A probabilistic neural network model for lameness detection. *Journal of Dairy Science* **90**: 2283–92.

Pastell M, Hanninon L, de Passille A M and Rushen J. 2010. Measures of weight distribution of dairy cows to detect lameness and presence of hoof lesions. *Journal of Dairy Science* **93**: 954–60.

Phillips C. 2002. Locomotion and movement. *Cattle Behaviour and Welfare*. 2nd edn, pp. 180–297. Blackwell, University, Cambridge, United Kingdom.

Rajkondawar P G, Tasch U, Lefcourt A M, Erez B, Dyer R M and Varner M A 2002. A system for identifying lameness in dairy cattle. *Applied Engineering in Agriculture* **18**: 87–96.

Rajkondawar P G, Liu M, Dyer R M, Neerchal N K, Tasch U, Lefcourt A M, Erez B and Varner M A 2006. Comparison of models to identify lame cows based on gait and lesion scores and limb movement variables. *Journal of Dairy Science* **89**: 4267–4275.

Rietmann T R, Stauffacher M, Bernasconi P, Auer J A and Weishaupt M A 2004. The association between heart rate, heart rate variability, endocrine and behavioural pain measures in horses suffering from laminitis. *Journal of Veterinary Medicine* **51**: 218–25.

Rushen J, Pombourcq E and Ripley B D. 2007. Validation of two measures of lameness in dairy cows. *Applied Animal Behaviour Science* **106**: 173–77.

Scott G B. 1988. Lameness and pregnancy in Friesian dairy cows. *British Veterinary Journal* **144(3)**: 273–81.

Scott G B. 1989. Changes in limb loading with lameness for a number of Friesian cattle. *British Veterinary Journal* **145**:28–38.

Singh Y, Lathwal S S, Chakrabarty A K, Gupta A K, Mohanty T K, Raja T V, Dangi R L and Roy B K. 2011. Effect of lameness (hoof disorders) on productivity of Karan Fries crossbred cows. *Animal Science Journal* **82**: 169–74.

Sprecher D J, Hostetler D E and Kaneene J B. 1997. A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. *Theriogenology* **47**: 1179–87.

Van der Tol P P J, Metz J H M, Noordhuizen-Stassen E N, Back W, Braam C R and Wijs W A. 2002. The pressure distribution under the bovine claw during square standing on a flat surface. *Journal of Dairy Science* **85**: 1476–81.

Webster A J F. 2002. Effect of housing practices on the development of foot lesions in dairy heifers in early lactation. *Veterinary Record* **151**: 9–12.

Wells S J, Trent A M, Marsh W E and Robinson R A. 1993. Prevalence and severity of lameness in lactating dairy cows in a sample of Minnesota and Wisconsin herds. *Journal of American Veterinary Medical Association* **202**: 78–82.

Whay H R, Main D C J, Green L E and Webster A J F. 2003. Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records. *Veterinary Record* **153**: 197–202.

Whitaker D A, Kelly J M and Smith S. 2000. Disposal and disease rates in 340 British dairy herds. *Veterinary Record* **146**: 363–67.

Winckler C and Willen S. 2001. The reliability and repeatability of a lameness scoring system for use as an indicator of welfare in dairy cattle. *Acta agriculturæ Scandinavica Section A, Animal science* 30(Suppl.): 103–07.