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Short communication

The development of equations to predict live-weight from linear body measurements of pasture-based Holstein-Friesian and Jersey dairy heifers

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HIGHLIGHTS

- In the absence of a weighing scales live-weight of Holstein-Friesian and Jersey heifers can be successfully predicted using body length, heart girth and withers height and their combinations.
- Regression equations of live-weight on heart girth, body volume and a polynomial of length, girth, and height equations, respectively, were accurate predictors of live-weight for pasture-based dairy heifers ($R^2 > 0.92$ and RMSE < 19.1 kg).
- Body volume of the heifer is recommended as the most suitable predictor of live-weight.

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ABSTRACT

Monitoring the live-weight of dairy heifers and thus meeting weight-for-age targets is regarded as one of the most important aspects of a heifer rearing enterprise as it optimizes future production. This is particularly important in pasture-based heifer rearing systems where growth is non-linear due to seasonal variation in grass growth and quality. Data were collected throughout the rearing period to estimate the live-weight of pasture-based Holstein-Friesian (n = 130) and Jersey (n = 57) dairy heifers using linear body measurements. Live-weight was regressed on heart girth, body volume and a polynomial of body length, heart girth, and withers height; all equations were validated within-herd. All three equations were accurate predictors of live-weight for pasture-based dairy heifers ($R^2 > 0.92$ and RMSE < 19.1 kg), therefore, in the absence of weighing scales, live-weight can be successfully predicted using linear body measurements. The equation which utilizes body volume of the heifer is proposed as the most suitable predictor of live-weight.

1. Introduction

Live-weight has a greater effect on the attainment of puberty in pasture-based dairy heifers than that of age (Archbold et al., 2012). Therefore, achieving weight-for-age targets (Troccon, 1993) will ensure heifers have achieved puberty prior to breeding at 15 months, which is essential to maintain a compact calving pattern. Electronic scales are widely used for monitoring the growth of animal's worldwide (Lukuyu et al., 2016). However, the uptake of technology among Irish and New Zealand farmers is particularly low (Teagasc, 2016; McNaughton and Lopdell, 2012). In New Zealand, less than 5% of heifers had a live-weight recorded prior to calving (McNaughton and Lopdell, 2012); while in Ireland, there were no figures available. It is evident; therefore, that the weighing of heifers is infrequent, and as such, farmers may be reluctant to invest in an electronic weighing scale.

In the absence of an electronic weighing scale, linear body measurements (LBM) such as heart girth (HG), withers height (WH), and body length (BL; Lukuyu et al., 2016) may be relatively accurate in their prediction of live-weight (Heinrichs et al., 1992) and are inexpensive to undertake. Previous research on the use of LBM to predict live-weight has been undertaken in confinement heifer rearing systems where the growth trajectory is linear (Heinrich et al., 1992). However, in pasture-based systems, such as Ireland, grass growth and quality are highly variable (Hennessy et al., 2020) and consequently, heifer growth is non-linear (Handcock et al., 2019). The relationship between LBM and live-weight varies with breed (Reis et al., 2008). Therefore, different

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prediction equations may be required for pasture-based heifers of contrasting breed groups, such as Holstein-Friesian (HF) and Jersey (JE; Handcock et al., 2019). The objective of the present study therefore was to devise a series of equations to predict live-weight from LBM of different breed groups of pasture-based dairy heifers from birth to 15 months. This will be beneficial for pasture-based dairy farmers as it allows them to monitor the growth of heifers, in the absence of a weighing scale.

2. Materials and methods

The present data were collected from heifers reared on the Dairygold Research Farm at Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Kilworth, Co. Cork, Ireland (52°09′N 8°16′W) between February 2018 and September 2020. In brief, a 2 (weaning ages; eight or 12 weeks) x 2 (post-weaning planes of nutrition; high (H) or low (L)) factorial design was in place. There were 187 heifer calves born in 2018 (n = 62 HF heifers and n = 26 JE with mean birth live-weights of 34.4 ± 4.67 kg and 23.0 ± 2.38 kg, respectively) and 2019 (n = 68 HF and n = 31 JE heifers with mean birth live-weights of 35.2 ± 4.23 kg and 24.5 ± 2.88 kg, respectively) assigned to the study.

All calves received 3 L colostrum within two hours of birth, followed by five feeds of transition milk. Calves were then grouped by age until they reached their respective weaning ages. When grouped, they were offered 6 L/day 26% crude protein milk replacer, *ad-libitum* fresh clean drinking water, concentrates and straw.

Following weaning, calves were regrouped according to their post-weaning treatment (H or L) and rotationally grazed perennial ryegrass dominated swards until housing the following winter. During the first grazing season, the H heifers were offered 1.5 kg of concentrate/heifer/day; however, if grass quality and availability were poor, the quantity of concentrate offered increased to 2.5 kg concentrate/heifer/day. Similarly, the L heifers were offered 0.5 kg of concentrate/heifer/day; however, if grass quality and availability were poor, the concentrates offered were increased to 1.5 kg concentrate/heifer/day. A difference in concentrate offered was maintained between the H and L heifers at all times. Over-winter management was similar for treatments; from week one to three, and again during weeks nine to 15, heifers grazed a forage crop (Redstart) *in-situ*, in addition to *ad-libitum* hay and 1 kg concentrates/heifer/day. During weeks four to eight of the over-winter period, heifers were housed and offered grass silage and 1.5-2 kg concentrate/heifer/day, depending on silage quality. At turnout to grass for their second grazing season, heifers were re-grouped by post-weaning treatment (H or L) and offered an all-grass diet. Contrasting pasture allowances were offered to create differences between the treatments; post-grazing heights of 4.5 and 3.5 cm were targeted for H and L heifers, respectively. The live-weights, average daily gain (ADG) between weigh dates, and LBM throughout the experimental period are outlined in Table 1.

Live-weight (kg; TruTest XR 3000, Tru-test Limited, Auckland, New Zealand) and LBM (cm) data were recorded twice a month from birth until nine months and every three months thereafter until breeding at 15 months. A soft measuring tape was used to measure the BL (horizontal distance from the top of the withers to the ischium) and HG (circumference of the animal's body measured directly behind the front legs). A specialised measuring stick (Nasco, Fort Atkinson, WI) was used to measure the WH (vertical distance from the ground to the top of the withers).

2.1. Statistical analysis

Statistical analyses were conducted using SAS (version 9.4; SAS Institute Inc., Cary, NC). Regressions of live-weight on LBM were tested (PROC REG) across the entire dataset, and then for HF and JE separately. Stratifying the dataset by breed group was found to increase the accuracy of prediction, therefore verifying that separate comprehensive equations were required for pasture-based HF and JE heifers as growth was non-linear (Table 1 and Fig. 1). Regressions of live-weight on HG, WH, BL and their combinations were tested (PROC REG) prior to cross-validation, which aimed to validate a series of the best parameters. Three equations were selected for cross-validation such that equations that utilized one, two and three LBM, respectively, were created. Within-herd validation involved stratifying the HF and JE datasets by birth year, pre- and post-weaning treatment. Numerical differences between the HF and JE datasets resulted in an average of 25% and 33%, respectively, of records from each stratum being removed for validation. The remaining records from each stratum were used to create the equations: heifers were not present in the calibration and validation data sets simultaneously. This process was repeated four and three times for HF and JE datasets, respectively, until all records had been tested using within-herd validation once. Regressions of live-weight on HG, WH, BL and their polynomial combinations were then performed. Body volume (BV) of the heifer was also regressed on live-weight whereby BV was calculated using the formula to calculate cylinder volume:

$$Body\ volume = \pi r^2 h$$

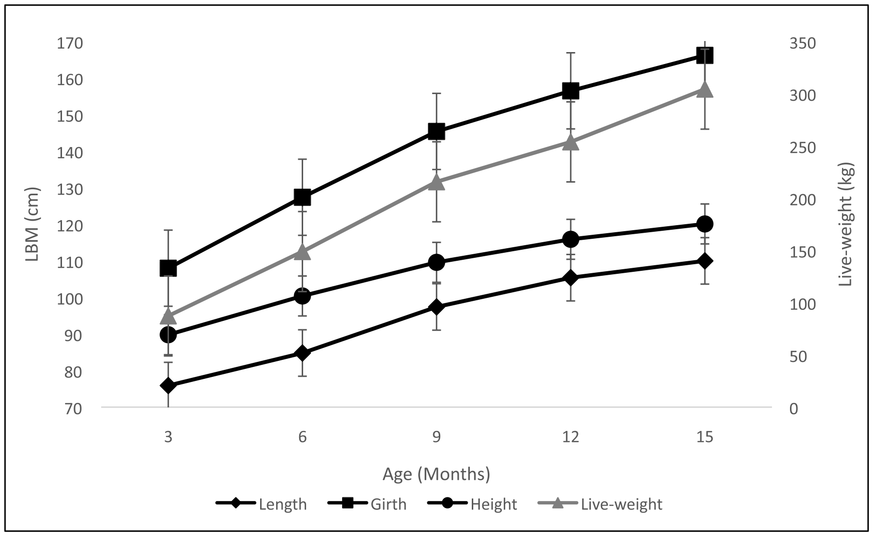
where $\pi = 3.14$, $r = (HG/2\ \pi)$ and $h = BL$. Both linear and non-linear relationships were tested. All regression equations then underwent within-herd validation. The association between predicted and actual live-weight was assessed using regression analysis.

The statistical methodology used to evaluate the accuracy of live-weight predicted by the model compared with actual live-weight on 25% and 33% of the data for the HF and JE heifers, respectively, was similar to that of Ruelle et al. (2019). In brief, the R^2, root mean square error (RMSE), slope of the line, mean square prediction error (MSPE), relative prediction error (RPE), and concordance correlation coefficient (CCC) were used to determine if the model accurately predicted live-weight. The MSPE is the sum of three components: mean bias $(M_m - P_m)^2$, line variation $S^2_p\,(1 - b)^2$, and random variation about the line, $S^2_m\,(1 - R^2)$, whereby each is expressed as a proportion of the total MSPE:

Table 1
Data available for regression analysis of HF and JE dairy heifers.

	HF (n = 130)		JE (n = 57)	
	μ	**SD**	**μ**	**SD**
3 months				
Weight	87.3	11.47	68.1	10.60
ADG birth to 3 months	0.63	0.133	0.53	0.124
Length	75.9	4.78	71.1	6.199
Girth	108.0	5.94	99.0	7.892
Height	89.8	3.39	83.7	4.37
6 months				
Weight	148.9	18.57	113.5	13.25
ADG 3 to 6 months	0.73	0.165	0.55	0.145
Length	84.8	3.48	80.8	4.50
Girth	127.4	7.99	118.5	8.08
Height	100.4	4.22	93.3	3.08
9 months				
Weight	215.7	25.29	168.1	18.83
ADG 6 to 9 months	0.80	0.182	0.65	0.194
Length	97.4	3.44	92.9	3.39
Girth	145.4	6.76	136.2	5.89
Height	109.6	4.05	105.0	3.00
12 months				
Weight	253.9	28.50	200.0	18.63
ADG 9 to 12 months	0.45	0.135	0.38	0.150
Length	105.4	3.59	102.5	3.08
Girth	156.5	7.47	148.2	6.73
Height	115.9	4.43	109.9	3.31
15 months				
Weight	304.4	28.76	238.8	20.71
ADG 12 to 15 months	0.60	0.130	0.46	0.127
Length	110.0	3.45	107.5	3.19
Girth	166.2	6.41	157.0	5.76
Height	120.1	4.33	114.5	3.09

[1]ADG = average daily gain.



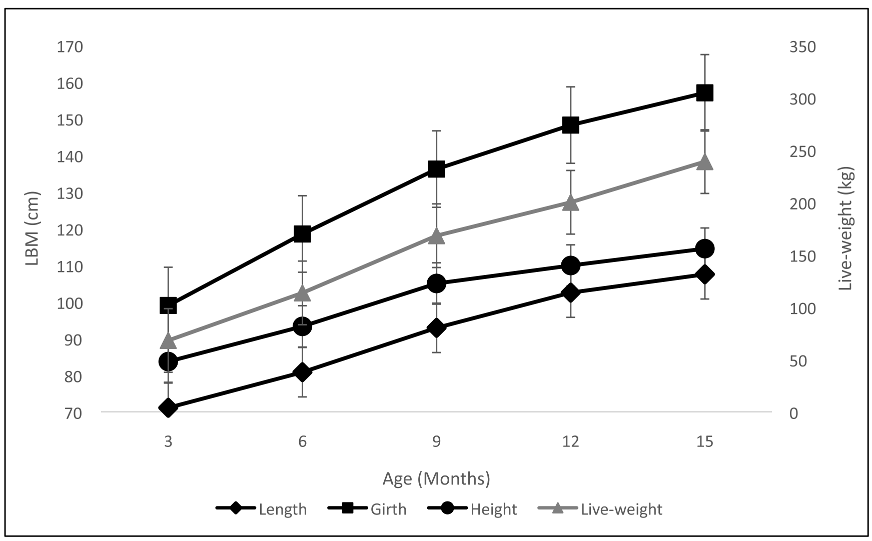


Fig. 1. Live-weights, lengths, girths and heights of Holstein-Friesian (HF) and Jersey (JE) heifers.

$$MSPE = \frac{\sum (M-P)^2}{n} = (M_m - P_m)^2 + S_p^2(1-b)^2 + S_m^2(1-R^2)$$

where *n* is number of records, *M* and *P* are measured and predicted live-weights, respectively, *Mm* and *Pm* are mean values of *M* and *P*, respectively, S_m^2 and S_P^2 are variances of M and P, respectively, b is the slope of the line of P regressed on M; and R^2 is the coefficient of determination of the line. The root mean square prediction error (RMSPE) is the root of the MSPE. The RPE is calculated as:

$$\text{RPE} = \left(\frac{RMSPE}{M_m}\right) \times 100$$

The CCC is comprised of two components:

$$\text{CCC} = p \times Cb$$

where *p* is the Pearson correlation coefficient and *Cb* is the bias correction factor:

$$Cb = \frac{2 \times \sigma_m \times \sigma_p}{\sigma_m^2 + \sigma^2{}_p + (\mu_m - \mu_p)^2}$$

and σ_m, σ_p, μ_m and μ_P are the standard deviation and average of the measured and predicted data, respectively. The CCC evaluates the correlation between the actual and predicted live-weights but also the deviation from the 45° line.

3. Results

The fitting statistics for the equations are outlined in Table 2 whereby values reported are the average of the four and three iterations for the HF and JE within-herd validations, respectively.

All three equations accurately predicted live-weight (Fig. 2) with RPE values of between 8.1 and 12.5%. In all equations, a high proportion of MSPE (>97.4%) was attributable to random variation. The equations to predict live-weight had average R^2 and RMSE values of 0.95 (range 0.92 – 0.97) and 14.8 kg (range 11.8 – 19.1 kg), respectively. Although still an extremely good predictor of live-weight for HF and JE heifers (RPE 11.5 and 12.5, respectively), the equation that predicted live-weight using a single LBM, namely HG, resulted in inferior fitting statistics compared to the equation that utilized two and three LBM. Including all three LBM as a polynomial in the prediction equation improved RPE values by 3.4 and 3.6% for HF and JE heifers, respectively, compared to the equation that utilized one LBM. The equation that regressed live-weight on BV was also found to accurately predict

Table 2
Comparison between the actual and predicted live-weight (kg) of HF (A) and JE (B) heifers for the different simulations using within herd validation, respectively.

(A)					Proportion of the MSPE					
	Measured	**Predicted**	**Slope**	**RMSPE**	**Mean**	**Line**	**Random**	**RPE**	**CCC**	**C bias**
Girth	166. 5	166.6	1.00	19.1	0.3	0.1	99.6	11.5	0.97	1.00
Body volume [1]	166. 5	166.6	1.00	15.0	0.1	0.6	99.4	9.0	0.98	1.00
Length, Girth, Height, Length^2, Girth^2 and Height^2	166.4	166.4	1.00	13.5	0.5	0.5	99.0	8.1	0.98	1.00
(B)					Proportion of the MSPE					
	Measured	**Predicted**	**Slope**	**RMSPE**	**Mean**	**Line**	**Random**	**RPE**	**CCC**	**C bias**
Girth	130.6	130.6	1.00	16.3	0.6	0.4	99.0	12.5	0.96	1.00
Body volume[1]	130.6	130.6	1.00	13.5	1.8	0.8	97.4	10.3	0.97	1.00
Length, Girth, Height, Length^2, Girth^2 and Height^2	130.6	130.5	1.00	11.7	0.2	0.1	99.8	8.9	0.98	1.00

[1] Body volume was regressed on live-weight whereby the formula to calculate cylinder volume was utilized
[2] RMSPE = root mean square prediction error; MSPE = mean square prediction error; RPE = relative predicted error; CCC = concordance correlation coefficient; Cbias = bias of the concordance correlation coefficient

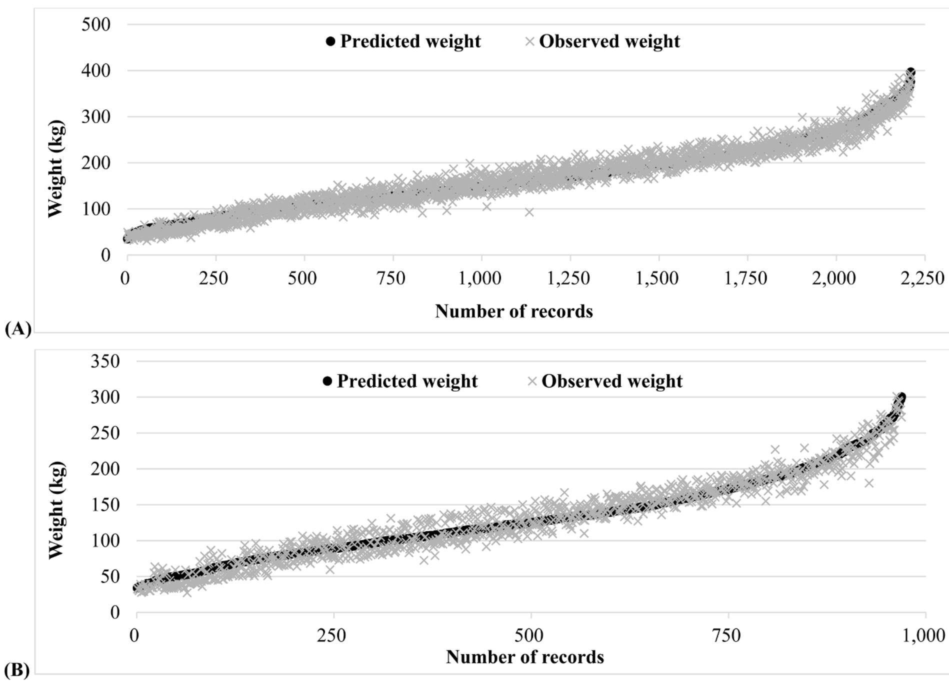


Fig. 2. Comparison between observed live-weight (x) and predicted live-weight (●) of Holstein-Friesian (A) and Jersey (B) heifers.

live-weight, with RPE values of 9.0 and 10.3% for HF and JE heifers, respectively. The regression equations used to predict live-weight for HF and JE heifers are presented in Table 3.

Table 3
Regression equations created using the lengths (L), girths (G), heights (H) and body volumes (BV) of HF (A) and JE (B) heifers, respectively.

(A)			
	Equation	**R^2**	**RMSE**
Girth	-235.2 + 3.2 (G)	0.93	19.13
Body volume	8.3 + 0.0012 (BV)	0.96	15.06
Length, Girth, Height, Length^2, Girth^2 and Height^2	-89.2 - 3.3 (L) -1.2 (G) + 4.3 (H) + 0.027 (L^2) + 0.010 (G^2) + 0.009 (H^2)	0.97	13.23
(B)			
	Equation	**R^2**	**RMSE**
Girth	-198.6 + 2.7 (G)	0.92	16.31
Body volume	7.1 + 0.0011 (BV)	0.95	13.37
Length, Girth, Height, Length^2, Girth^2 and Height^2	-7.5 - 3.4 (L) + 0.1 (G) + 1.4 (H) + 0.0028 (L^2) + 0.004 (G^2) + 0.003 (H^2)	0.96	11.79

[1]RMSE = root mean square error

4. Discussion

The aim of the present study was to develop equations to predict live-weight of growing dairy heifers in a pasture-based system. Equations have been developed previously (Heinrichs et al., 1992), however, these animals were reared in confinement heifer rearing systems where precision nutrition ensures greater efficiency of nutrient utilization (Zanton and Heinrichs, 2008). In pasture-based heifer rearing systems, such as that in Ireland, heifers are offered a predominately grazed-grass diet, with concentrate supplementation when grass growth and quality are poor. Consequently, heifers reared in pasture-based systems follow a seasonal pattern of growth (Handcock et al., 2019). Similar to Heinrichs et al. (1992) HG was highly correlated ($R^2 > 0.92$ and RPE 11.5 and 12.5% for HF and JE, respectively) with live-weight, and was therefore used to develop a simple equation for the prediction of live-weight. The use of a single LBM to predict live-weight may be useful for farmers who wish to monitor growth of their heifers but may not have time to measure several dimensions of skeletal growth. The inclusion of two or more LBM in the regression equation slightly improved live-weight prediction: the regression equation for BV utilized HG and BL and was found to predict HF and JE heifer live-weight to within 13.4 and 15.1 kg of live-weight, respectively. Body volume was previously found to be highly correlated with live-weight of native Indonesian cows (Paputungan et al., 2015), however, to the best of the authors knowledge, BV has never been used to predict live-weight of pasture-based heifers. Similar to Reis et al. (2008), including three independent LBM in the equation increased prediction accuracy. Furthermore, polynomial regression of BL, HG and WH on live-weight improved the fit statistics further with an R^2 of 0.97 and 0.96 and RMSE of 13.2 and 11.8 kg for HF and JE heifers, respectively. However, the polynomial regression equation was only marginally better than the BV equation, therefore, from a practicality perspective, the BV equation is more appropriate for a labor-intensive dairy farm.

5. Conclusion

The equations developed in this study are all highly effective in their prediction of live-weight of pasture-based HF and JE dairy heifers. The equation, which utilizes BV of the heifer, is proposed as the most suitable predictor of live-weight. Despite utilizing just two LBM, it displays a high accuracy of prediction and will enable dairy farmers to monitor the growth of their heifers in the absence of a weighing scale.

Author Statement

All authors have seen and approved the final version of the manuscript being submitted. This article is the authors' original work, has not received prior publication and is not under consideration for publication elsewhere.

Declaration of Competing Interest

The authors declare no conflict of interest.

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