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The Relationship Between Stature and Live Weight of Dairy Cows Between Birth and Maturity

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Simple Summary: Milk yield and the ability to get pregnant are strongly associated with cow live weight and size. However, there are limited data published describing the prediction of cow size at birth. Therefore, the aim of this study was to examine the relationship between cow shape and live weight of female dairy cattle between birth and maturity. Forty dairy cows with records of cow shape and live weight from birth up until two years of age, underwent follow-up measurements for live weight, height, length, girth circumference and leg length on four occasions between 42 and 52 months of age. Measures of height, leg and body length at fourth mating had a greater correlation with measures at birth compared to girth and live weight. The lower correlation between birth and maturity measures for girth and live weight indicates growth of these measures is affected by environmental factors and emphasises the importance of adequate nutrition to maximise cow size.

Abstract: Lactational and reproductive performance are strongly associated with cow live weight and capacity. However, there are limited data published describing capacity (thoracic) growth and the prediction of final stature and capacity from measurements at birth. Therefore, the aim of this study was to examine the relationship between stature and live weight of female dairy cattle between birth and maturity. Forty dairy cows, with records of stature and capacity from birth up until two years of age, underwent follow-up measurements for live weight, height at withers, wither-rump length, girth circumference and leg length on four occasions between 42 and 52 months of age. Measures of wither height, leg length and wither rump length at fourth mating had the strongest association with measures at birth ($R^2 > 0.90$) compared to girth and live weight ($R^2 = 0.88$ and 0.82, respectively). The weaker association between birth and maturity measures for girth is likely a reflection of the stronger relationship with live weight resulting in a later maturity (approximately 810 days) compared to linear measures such as height (approximately 730 days). Therefore, to maximise capacity, adequate nutrition is required until approximately 810 days of age when capacity growth is most sensitive to environmental input.

Keywords: bone; girth; height; nutrition; growth; mature size

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1. Introduction

Both reproductive and lactational performance are strongly associated with cow live weight. Cows that are heavier at puberty and first calving are reported to subsequently have greater pregnancy rates and reproductive performance compared to lighter cows in the herd [1,2]. Most studies that use cow live weight as a predictor of milk production do not take into account the stature or shape of the cow [1,3]. Therefore, a cow may be "tall and skinny" but have the same live weight as a "short fat cow". One approach to account for this is the use of body condition score (BCS) to estimate fat deposition. Within the literature, BCS is also positively correlated with lactation and reproductive performance [4,5]. However, BCS is a measure at one time point and changes throughout the season based on stage of lactation and seasonal pasture growth. Stature measures of height and girth (capacity) are not affected by seasonal changes and reflect the frame size of the cow, thus removing the effect body condition can have on live weight measures [6].

It has been hypothesised that the height of the calf is associated with subsequent lactational performance, with taller calves producing more milk across multiple lactations than shorter calves when adjusted for live weight [7,8]. Stature growth in cattle up until 23 months follows the typical pattern of growth in mammals [9]. Similar to other herbivorous mammals [10], the bones in the distal limb of cattle, such as the metacarpus, have limited capacity for longitudinal growth and cease longitudinal growth at one year of age [11]. Whereas bones in the proximal limb and thorax related to capacity, such as the humerus, are capable of longitudinal and appositional growth after two years of age [11]. It has been estimated that the humerus ceases longitudinal growth (estimated to maturity by physeal closure) at approximately 3.5–4 years of age [12]. Thus, the growth and development of the humerus could still be affected by changes in nutrient supply during the cow's second or even third year of life [9,11,12].

Potential mature size can also be affected by nutritional supply over different growth phases, whereby times of nutritional deficit affect mature size through growth pauses prior to physeal closure. The dairy systems of New Zealand have a heavy reliance on grazed pasture which can result in heifers (cows less than 2 years old) undergoing a growth check during winter due to poor pasture quality and availability [13]. This seasonal growth check was described by Handcock, et al. [14], whereby heifers that had a seasonal growth check in winter had a subsequent period of compensatory growth that resulted in a taller animal than those that grew in a linear growth pattern. This growth check has been identified as a risk factor for spontaneous humeral fractures in first lactation dairy heifers in New Zealand. Studies examining humeri from heifers affected by these fractures have reported the presence of growth arrest lines and reduced bone density suggesting a recent period of restricted bone growth [15,16]. Therefore, the winter prior to first calving has been identified as a key period for humeral growth [15,17].

The effect of nutrition has also been examined in calves whereby calves exposed to a period of undernutrition in utero had a smaller stature size and lower bone density at birth, compared with calves that were not exposed to a period of undernutrition [18]. The relative magnitude and timing of the nutritional deficit could independently and synergistically alter the extent of the growth check and how stature growth is impacted.

Stature growth after first calving of dairy cows has not been described in detail and is required to estimate the timing of bone growth in relation to nutrition due to changes in on-farm seasons. In addition, measures are required after first calving to determine if the shape and stature of a cow in early life can predict the stature and shape of the cow at maturity and indicate when a mature (cessation of growth) state has been achieved. Therefore, the aim of this study was to examine the relationship between stature and live weight of female dairy cattle between birth and maturity among different breeds.

2. Materials and Methods

This experiment was conducted with the approval of Massey University Animal Ethics Committee (MUAEC 19/81- birth to 23 months and MUAEC 23/01 from three to four years of age).

The cohort of animals consisted of 40 Holstein–Friesian (F), Jersey (J) and crossbred (HxJ) heifers that remained in the herd from the cohort of 57 heifers measured in Gibson, et al. [9]. Heifers were born during the 2019 spring calving season at Massey University's Dairy One farm and 40 were still present on the same farm during the 2023 milking season. There was attrition due to failure to conceive and low production (n = 17).

Calf measure data from birth to 23 months of age were retrieved from the dataset used by Gibson et al. [9]. For analysis, heifers were classified into one of three breed groups based on pedigree records for each calf. The breeds were defined as follows: Heifers that were at least 15/16 (93.8%) F were classed as F (n = 8); heifers that were at least 15/16 (93.8%) J were classified as J (n = 9); heifers that did not meet the requirements of either F or J were classified as HxJ (n = 23).

2.1. Sampling and Measurements

Cows were measured on 4 occasions during 2023: at pregnancy diagnosis of their 3rd pregnancy (1280 days/42 months), dry-off of their 2nd lactation (1370 days/45 months of age), calving of their 3rd calf and start of 3rd third lactation (1460 days/48 months of age) and 4th mating (1540 days/52 months of age). Their 4th mating was considered maturity for all measures. On each measure day, cows were weighed using a Tru-test weigh bridge (Tru Test, Auckland, New Zealand) to the nearest kilogram. When contained in the weigh crate, single linear measures to the nearest one centimetre were obtained using a flexible tape measure (Korband, Lincolnshire, UK) as outlined in Gibson, et al. [9]. Linear measurements were obtained for wither height (from ground to point of wither), heart girth, wither-rump length (wither to tuber ischii) and leg length (left front leg, from ground to point of olecranon). Thoracic height was calculated by subtracting leg length from wither height.

2.2. Statistical Analysis

Statistical analysis was conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Using the NLMixed procedure, a von Bertalanffy growth function was applied to the data to produce growth curves for weight and stature measurements (data not presented).

The general equation was:

$$Y = L\infty(1 - b \times \exp(-k \times \text{age}))^3$$

where Y was the trait measured at a certain age (months), exp is the base of the natural logarithms, and L, b and k are parameters to be estimated. Starting parameters were b = 0.61, k = 0.0041 and L∞ was set to 450, 140, 75, 120, 180, for live weight, wither height, leg length, crown-rump length, heart girth, respectively.

Fourth-order Legendre polynomials were constructed to predict weight and stature measures at a given age excluding wither-rump length which were modelled using a fifth-order Legendre polynomial. Individual polynomials were constructed using the solutions for each individual animal fitted as a random function. Predictions were made for given ages were based on key milestones in cow production which were; birth (0 days), weaning (100 days), 1 year of age (365 days), 1st mating (450 days), 1st calving (730 days), 2nd mating (810 days), 1st dry off (1000 days), 2nd calving (1100 days), 3rd mating (1180 days), 2nd dry off (1370 days), 3rd calving (1460 days) and 4th mating (1540 days). Data were also analysed using the Proc GLM procedure for each milestone with the fixed effect of breed group. Correlations between stature measurements were evaluated using the Corr procedure.

3. Results

Live weight and all stature measures at birth were highly correlated with measures at 3rd calving (Table 1). Height, wither rump length and leg length at birth were strongly correlated with their respective measures at maturity ($R^2 \geq 0.90$).

Table 1. Regression values for stature measures for Holstein–Friesian (F) heifers, Holstein–Friesian-cross–Jersey (FxJ) and Jersey (J) cows from between birth and maturity.

Maturity / Birth	Live Weight	Heart Girth	Wither Height	Wither-Rump Length	Leg Length
Live weight	**0.82**	0.77	0.79	0.79	0.84
Heart girth	0.85	**0.88**	0.80	0.72	0.83
Wither height	0.80	0.75	**0.90**	0.73	0.95
Wither-rump length	0.86	0.74	0.77	**0.94**	0.84
Leg length	0.77	0.70	0.85	0.75	**0.95**

At one year of age, cows were only 60–62% of their mature live weight and approximately 82–84% of their mature girth circumference (Table 2). Measures of wither height and leg length were almost at mature size by one year of age with measures at or above 89% of maximal measurement.

Table 2. Proportion of estimated mature size at key production stages by breed for leg length, height, wither rump length, girth and liveweight for Holstein–Friesian (F), Holstein–Friesian-cross–Jersey (FxJ) and Jersey (J) dairy cows from birth to 4th mating. A value of 1 indicates mature size was achieved.

		Leg Length			Wither Height			Wither-Rump Length			Heart Girth			Live Weight		
Key Milestone	**Age (Days)**	**J**	**FxJ**	**F**	**J**	**FxJ**	**F**	**J**	**FxJ**	**F**	**J**	**FxJ**	**F**	**J**	**FxJ**	**F**
Birth	1	0.67	0.67	0.66	0.55	0.55	0.56	0.44	0.44	0.45	0.40	0.40	0.42	0.06	0.06	0.07
Weaning	100	0.81	0.80	0.79	0.69	0.68	0.70	0.61	0.60	0.61	0.56	0.56	0.56	0.20	0.20	0.20
1 year old	365	0.97	0.95	0.94	0.90	0.89	0.90	0.88	0.86	0.85	0.84	0.83	0.82	0.62	0.62	0.60
1st mating	450	0.98	0.97	0.96	0.93	0.92	0.93	0.92	0.90	0.90	0.89	0.88	0.87	0.72	0.71	0.69
1st calving	730	1	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.96	0.96	0.95	0.90	0.90	0.88
2nd mating	810		1	0.99	0.99	0.98	0.99	0.98	0.98	0.98	0.97	0.97	0.97	0.93	0.92	0.91
1st dry off	1000			1	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.96	0.96	0.95
2nd calving	1100				1	1	1	1	0.99	0.99	0.99	0.99	0.99	0.98	0.97	0.97
3rd mating	1180								1	0.99	0.99	0.99	0.99	0.98	0.98	0.98
2nd dry off	1370									1	1	1	1	0.99	0.99	0.99
3rd calving	1460													0.99	0.99	0.99
4th mating	1540													1	1	1

Leg length growth slowed at the youngest age at just over a year (377–431 days, Table 3), and reached maximal measurement first; in contrast, live weight continued to increase across the measurement period.

Table 3. Inflection points (in days of age) for liveweight, girth, height, wither rump length and leg length growth curves for Holstein–Friesian (F), Holstein–Friesian-cross–Jersey (FxJ) and Jersey (J) cows.

Knee of Curve	J	FxJ	F
Live weight	609	612	631
Heart girth	503	516	527
Wither-rump length	469	493	500
Wither height	473	484	476
Leg length	377	409	431

4. Discussion

All measures at the 4th mating (maturity) were strongly correlated with birth values which reflects earlier observations for these cows when examined until first calving (23 months) [9]. Measures that effectively relate to height (wither height, leg length and wither to rump length) had the strongest associations between birth and 4th mating values. These strong associations reflect the high heritability estimates published for these values within the literature [8,19] and the limited impact environmental variables such as nutrition, either early in life or later post-puberty, have on these values. Cows in the current study grew at a greater rate than industry standards [9], hence nutrition would not have limited the attainment of mature height.

Across many mammalian species, where even in situations of severe and sustained under nutrition, individuals will always achieve predicted height. Predicted height or final height occurs earlier than final capacity and in this population of pasture-managed dairy cows, was achieved around the time of first calving at 730 days old (24 months). The majority of contributions to wither height is driven by the longitudinal growth in the limbs and subsequently in the proximal limb and thorax. The attainment of the threshold of 96–98% of final length in the limb at 450 days (15 months), earlier than any of the other measurements, reflected the earlier closure of the growth plates in the long bones within the limb and that wither height early in life is predominantly due to leg length and then increases in thoracic capacity [9]. The strong association of final height with birth values, and the reported high heritability for wither height [8], indicates that there is limited opportunity to manipulate this aspect of cow size via nutrition. Thus, if milk production is associated with body size and live weight, the potential for increased capacity (body size) relies on the promotion of growth associated with the thoracic limb and thorax.

Final wither-rump length, which equates to the human equivalent of sitting height, was achieved at an older age than wither height and reflects that the growth plates in the vertebrae are some of the last bones to cease growth [10]. The relative increase in wither-rump length was small and thus, cow length is unlikely to be a variable with great plasticity or capability to contribute to greater cow capacity and relative efficiency of milk production.

Final heart girth and live weight measures occurred later than stature measures and had the lowest association with measures at birth. These data demonstrate that heart girth and live weight are not only plastic and sensitive to environmental input until approximately 810 days, but the magnitude of the response may also be temporally sensitive at different periods of growth. In dairy cattle, girth has a greater association with live weight than wither height [20], as girth describes both the width and thoracic height of the cow. The close relationship between girth and live weight is also reflected in the later timing of bone maturity in the proximal limb and thoracic cavity. For example the humerus is a late maturing bone located in the thoracic cavity which is highly correlated girth size [21], versus bones in the distal limb, such as the metacarpus, which are associated with increases in height.

Growth in the metacarpus (distal limb) in cows as measured by changes in length and bone morphology has been estimated to cease at approximately one year of age [11]. In the current study, the slowing of leg length and wither height at one year of age is in agreement with this estimation. The humerus (proximal limb), in comparison, continues to grow until at least two years of age, as evidenced by increases in girth size. The difference in maturity of these bones reflects their location and function within the limb. The humerus is surrounded by muscle and is located within the proximal limb/thoracic cavity. Therefore, increases in live weight and capacity would provoke a greater relative bone response in the humerus than in the metacarpus [11]. The current study estimated that the heifers were approximately 50% of their mature height at their birth but less than 10% of their mature live weight. In early life, increases in live weight are driven by increases in long bone growth resulting in increases in height [9,22]. At puberty, longitudinal bone growth is slowed and increases in live weight is driven by increases in capacity (axial skeleton) [23]. This growth model is reflective of the current results where increases in height after birth were rapid, resulting in 89–90% of mature height being attained but only 60–62% of mature weight by one year of age. This is similar to other mammalian species such as horses where they are born at approximately 60% of their mature height and 10% of their mature live weight and are 92% of their mature height but only 61% of their mature live weight at one year of age [24].

Measures of leg length, wither height and wither-rump length at birth were highly correlated with the respective measures at maturity, indicating a relatively conserved growth pattern [25]. With appendicular bones being a greater proportion of their mature size at birth compared to axial bones, the growth trajectory is well conserved and less affected by perturbations in live weight gain from environmental factors such as nutrition and disease. This trend has also been observed in human studies where birth length and mature height had a greater association than birth weight and mature weight [26].

It is well established that nutrition plays a crucial role in bone growth and development [27,28]. However, the magnitude of any nutritional deficit is dependent on the stage of growth, severity of the restriction and its duration. In the current study, there were no obvious signs of a growth check in the first two years of life when the majority of growth occurs. However, if the heifers had undergone a significant growth check, the mature live weight and stature shape may have differed. In New Zealand's pasture-based systems, winter is often associated with a period of reduced growth due to decreased pasture growth, quality and supply. It is common for heifers to have a period of decreased growth during winter which tends to be more severe in the second winter than the first [29]. In the first winter (10–12 months of age), long bones, such as the metacarpus, reach maturity, so deficits in nutrition will have negligible effects on their growth trajectory. However, increases in live weight after one year of age continues to drive increases in capacity (e.g., humerus), so perturbations in live weight gain are likely to impact longitudinal growth of proximal bones. In a study by Handcock, et al. [14], heifers that were grown in a seasonal manner at 6–15 months of age, were lighter and attained puberty later than heifers that grew in a linear manner. At 21 months of age, heifers grown in a seasonal manner were lighter than heifers grown in a linear manner. However, when adjusted for live weight, heifers that grew in a seasonal manner were taller at 21 months of age. This result suggests a compensatory growth mechanism by heifers in the seasonal group whereby skeletal growth was achieved, but the ability to achieve the genetic potential for live weight was constrained. Conversely, in a study by Barash, et al. [30] where heifers were fed a "stair-step" regime consisting of a restricted diet followed by a compensatory diet, heifers were a similar live weight compared to heifers fed a constant diet. However, heifers fed the "stair-step" diet had a shorter hip height, suggesting a restriction in longitudinal bone growth and the promotion of fat deposition over muscle gain. Although the results of these studies differ, the overall trend suggests that animals that experience a check in growth are likely to have an alteration in the development of bone, muscle and fat composition. The effect of nutrition is likely to be dependent on the timing of the restriction within the developmental window, as well as the severity and length of the restriction.

A condition in New Zealand that has been linked to the seasonal nature of pasture supply is spontaneous humeral fractures in first lactation dairy heifers. The second winter has been identified as a risk factor for this type of fracture [31]. When examining bone morphology from affected heifers, the humerus shows signs of osteoporosis and growth arrest lines [15,17], whereas the metacarpus does not show the same signs. Observations of the early timing of bone maturity and lack of environmental impacts on growth in the metacarpus reinforces the lack of pathology in metacarpals from affected heifers. Conversely, the presence of the growth arrest lines and osteoporosis in the humerus highlights the importance of the second winter nutrition to achieve peak bone mass in the humerus. Given the importance of the second winter for heifer growth, future research should aim to examine how the growth check in the second winter affects stature growth.

5. Conclusions

The results of this study indicate that measuring calves at birth is a good predictor of these values at maturity (52 months old) in dairy cattle. Measures of capacity, such as heart girth and live weight, while still associated with measures at birth, had lower associations with measures at maturity. The lower associations of live weight and heart girth with values at birth reflect the greater opportunity for improvement in these capacity values with positive management strategies. Optimising nutrition, particularly prior to maturity, could increase capacity and therefore increase potential milk yield given the observation that milk yield appears to be influenced by measures of capacity. However, additional research is required to quantify the magnitude of the strength of the association of stature measures at birth and maturity with future lactational and reproductive performance.

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