Evaluation of partial body weight for predicting body weight and average daily gain in growing beef cattle

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ABSTRACT: Information on body weight and average daily gain (ADG) of growing animals is key not only to monitoring performance, but also for use in genetic evaluations in the pursuit of achieving sustainable genetic gain. Accurate calculation of ADG, however, requires serial measures of body weight over at least 70 days. This can be resource intensive and thus alternative approaches to predicting individual animal ADG warrant investigation. One such approach is the use of continuously collected individual animal partial body weights. The objective of the present study was to determine the utility of partial body weights in predicting both body weight and ADG; a secondary objective was to deduce the appropriate length of test to determine ADG from partial body weight records. The dataset used consisted of partial body weights, predicted body weights and recorded body weights recorded for 8,972 growing cattle from a range of different breed types in 35 contemporary groups. The relationships among partial body weight, predicted body weight and recorded body weight at the beginning and end of the performance test were determined and calculated ADG per animal from each body weight measure were also compared. On average, partial body weight explained 90.7 ± 2.0% of the variation in recorded body weight at the beginning of the postweaning gain test and 87.9 ± 2.9% of the variation in recorded body weight at its end. The GrowSafe proprietary algorithm to predict body weight from the partial body weight strengthened these coefficients of determination to 95.1 ± 0.9% and 94.9 ± 0.8%, respectively. The ADG calculated from the partial body weight or from the predicted body weight were very strongly correlated (r = 0.95); correlations between these ADG values with those calculated from the recorded body weights were weaker at 0.81 and 0.78, respectively. For some applications, ADG may be measured with sufficient accuracy with a test period of 50 days using partial body weights. The intended inference space is to individual trials which have been represented in this study by contemporary groups of growing cattle from different genotypes.

Key words: live weight, performance test, prediction, real-time data capture, test length

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INTRODUCTION

Average daily gain (ADG) is an important component of production efficiency for growing beef cattle (Nielsen et al., 2013). The mathematical relationships among traits contributing to efficiency imply that for a pair of calves with the same initial body weight, the one with a faster ADG will reach a target market weight with fewer days on feed and thus could be more efficient due to the allocation of less feed to maintenance. Archer et al. (1997) and Marzocchi et al. (2020) found that a period of 70 days was needed to provide adequate precision in measuring the efficiency of growing calves. The primary reason for this length of time was to obtain a sufficiently precise measurement of ADG rather than feed intake. In contrast, Archer and Bergh (2000) indicated that a period of 42–56 days was adequate to measure ADG in growing calves. Kearney et al. (2004) also suggested that use of automated liveweight measurement would allow the duration of tests to be decreased to 56 days without reducing the precision of estimates of liveweight change. However, Culbertson et al. (2015) previously documented how a 56-day test period in growing beef cattle underestimates ADG. Therefore, the Beef Improvement Federation (2021) has adopted a 70-day test period as its de facto standard for measuring ADG in growing cattle.

Researchers have conjoined a weighing scale with a watering device to facilitate the recording of body weight in real time (Currie et al., 1989). However, this apparatus did not achieve widespread use until GrowSafe developed a system to capture partial body weight in real time as a means of increasing the frequency of observations that can be used to predict body weight or “in-pen body weight” and ADG (Benfield et al., 2017). Multiple companies currently market systems that passively capture body weight or partial body weight (Wang et al., 2021). Because bi-weekly weighing of animals on a 70-day test at approximately equally spaced intervals over the test period has been recommended to increase the accuracy of the ADG measurement (Crews and Carstens, 2012), more regular recording of body weight may also improve the accuracy of calculated ADG. In addition, processing animals through a conventional chute and scale system imposes some degree of stress (Cooke, 2014; Haskell et al., 2014; Lees et al., 2020) and is labor intensive. This stress and the associated labor costs (after safety concerns) can be averted if body weight can be measured without human intervention.

The objectives of the present study were to determine the utility of partial body weights in predicting both body weight and ADG as well as determine the appropriate length of test for predicting ADG from daily measures of partial body weight. The intended inference is to individual trials which have been represented in this study by contemporary groups of growing cattle.

MATERIALS AND METHODS

Data

Data for this study were provided by Vytelle Inc., the manufacturer of the GrowSafe equipment used to record partial body weights of growing beef animals. Vytelle captures these data in real time from equipment that has been installed at commercial and academic facilities internationally. Because the data arose from the database of an industry service provider, there was no prior evaluation of animal care and use for this particular study by an institutional animal care and use committee.

Benfield et al. (2017) described the technology used for the data collection. Briefly, a platform scale was positioned such that an individual animal must place its front feet on the scale in order to drink from a water trough (Figure 1). Multiple weighing units may be positioned adjacent to a single trough to allow more than one animal to drink at a time. The data used in the present study originated from 35 contemporary groups of beef animals from different genotypes on postweaning gain tests in various locations. The number of animals per contemporary group ranged from 4 to 123 and the duration of the test period was from 63 to 175 days. Bulls and heifers represented in the data were Bos indicus (Brahman),
The effect of the inter - the predicted body weight of the recorded body weight from its predicted value for the predicted body weight for the jth contemporary group. The PROC MIXED procedure (SAS Institute Inc., Cary North Carolina, USA) was used to estimate parameters for the model:

\[ y_{ijk} = g_i + m_j + gm_{ij} + e_{ijk} \]

wherein, \( y_{ijk} \) = a measure of ADG for the kth animal; \( g_i \) = the effect of the ith contemporary group (i = 1 to 35); \( m_j \) = the effect of the jth measure of ADG (j = 1 to 3); \( gm_{ij} \) = the effect of the interaction between the ith contemporary group and jth measurement; and \( e_{ijk} \) = the residual deviation of the ADG for the kth animal in the ith contemporary group calculated from the jth set of measurements from its predicted value. Within each contemporary group, the ADG calculated based on predicted body weight was contrasted with the value of ADG calculated from the recorded body weights. The correlations among the three measures of ADG were estimated within each contemporary group.

The test data from each contemporary group was truncated at 70 days on test as this reflects the standard length of test for measuring ADG with bi-weekly recorded body weights, against which evaluations of shorter duration were compared (Wang et al., 2006). The data for partial body weight were evaluated using a similar approach with and without imposing the criterion that the linear regression of weight on age for each animal had an \( R^2 \geq 0.9 \) (J. Basarab, University of Alberta, personal communication, 18 March 2021). This requirement was established for body weights recorded at 14-day intervals to ensure linear growth during the test period without hindrance from morbidity or nutritional restrictions (Basarab et al., 2003). Imposing the requirement that the regression of weight on age for each animal had an \( R^2 \geq 0.9 \) over a test period of 61 to 70 days resulted in the loss of 38.4% of the partial body weight data. For individual contemporary groups the loss ranged from to the analysis of variance, estimates of the correlations among partial body weight, predicted body weight and recorded body weight were calculated. The regression coefficient of recorded body weight on predicted body weight was tested against the a priori expected value of 1.0. The difference between recorded body weight and the predicted body weight was tested against the a priori expected value of 0.0. Similar analyses were conducted for the three weight traits recorded at the end of each test.

Next, three measures of ADG for each animal were calculated by linear regression based on observations of partial body weight, predicted body weight and recorded body weight. The three measures of ADG were then subjected to an analysis of variance using PROC MIXED (SAS Institute Inc., Cary North Carolina, USA) with the following model:

\[ y_{ijk} = g_i + m_j + gm_{ij} + e_{ijk} \]

The first analysis assessed the relationships between both the GrowSafe partial body weight and predicted body weight with the recorded body weight at the beginning of the test period (i.e., -2 < day < 4). There were a few contemporary groups with no recorded body weights on or about day 0; these groups were not used in this assessment. The PROC MIXED procedure (SAS Institute Inc., Cary North Carolina, USA) was used to estimate parameters for the model:

\[ y_{ij} = g_i + b'w_{ij} + b_iw_{ij} + e_{ij} \]

used to estimate the contemporary group-specific regression equations. In the above equations \( y_{ij} \) = the recorded body weight that was recorded for the jth animal at the beginning of the postweaning gain test; \( g_i \) = the ith contemporary group in which the jth animal was fed; \( w_{ij} \) = the partial body weight or predicted body weight of the jth animal; \( b' \) = the pooled regression coefficient of recorded body weight on either partial body weight or predicted body weight; \( b_i \) = the partial regression coefficient of recorded body weight on either partial body weight or predicted body weight for the ith contemporary group (to be estimated); and \( e_{ij} \) = the residual deviation of the recorded body weight from its predicted value for the jth animal in the ith contemporary group. Subsequent...
0% to 98%. It could be that the random day-to-day fluctuations in partial body weight compromise the use of an $R^2$ value as an editing criterion.

A grid search was initiated to estimate the appropriate length of test to determine ADG from daily partial body weight records. The starting point for the search was to split the data set at 35 days on test. The ADG calculated for the full test period was the dependent variable in a regression model that considered ADG calculated from the two parts of the test (i.e., the first 35 days and the latter 35 days) as independent variables. This regression analysis was done using sequential of Type 1 sums of squares such that the partial sum of squares for variation in full test period ADG explained by the ADG observed in the first period of the test was not adjusted for the ADG observed in the second period of the test. However, the partial sum of squares for variation in the full test period ADG explained by the ADG observed in the latter period of the test was adjusted for the ADG observed in the first period of the test. Subsequent to this analysis, the data for each animal was split at 50 days on test and the analysis was conducted again.

**RESULTS AND DISCUSSION**

**Utility of Partial Body Weights**

In analyses of variance for the assessment of partial body weight and predicted body weight as predictors of recorded body weight at the beginning of the test period, the interaction of the contemporary group with the regression effects were highly significant ($P < 0.01$). Partial body weight

| CG | N   | Partial body weight | Predicted body weight |
|----|-----|---------------------|-----------------------|
|    |     | $b \pm SE$          | $r_1$                 | $b = 1.0$ | $r_2$ | Difference (kg) |
| 1  | 32  | 1.738 ± 0.100       | 0.977                 | 0.995 ± 0.0376 | ns | 0.989 | −3.91 ± 2.01 |
| 2  | 34  | 1.827 ± 0.129       | 0.983                 | 1.099 ± 0.0510 | 0.992 | 4.78 ± 1.95 |
| 3  | 43  | 1.497 ± 0.090       | 0.950                 | 0.879 ± 0.0291 | 0.955 | −9.91 ± 1.48 |
| 4  | 20  | 1.833 ± 0.243       | 0.975                 | 1.075 ± 0.0937 | 0.978 | −3.22 ± 2.55 |
| 5  | 20  | 1.737 ± 0.374       | 0.923                 | 0.933 ± 0.1272 | 0.956 | −1.54 ± 2.55 |
| 6  | 26  | 1.773 ± 0.233       | 0.957                 | 1.032 ± 0.0882 | ns | 0.974 | −4.05 ± 2.23 |
| 7  | 31  | 1.864 ± 0.188       | 0.985                 | 1.067 ± 0.0708 | ns | 0.989 | −2.94 ± 2.04 |
| 8  | 15  | 1.732 ± 0.178       | 0.992                 | 0.995 ± 0.0677 | ns | 0.993 | −1.44 ± 2.94 |
| 9  | 9   | 1.669 ± 0.334       | 0.946                 | 1.008 ± 0.1205 | 0.960 | −0.39 ± 3.79 |
| 10 | 11  | 1.747 ± 0.182       | 0.999                 | 1.089 ± 0.0748 | 0.996 | −1.98 ± 3.43 |
| 11 | 11  | 1.798 ± 0.319       | 0.971                 | 1.106 ± 0.1279 | 0.985 | −7.68 ± 3.43 |
| 12 | 4   | 1.404 ± 1.162       | 0.985                 | 0.897 ± 0.4856 | 0.996 | 3.72 ± 5.69 |
| 13 | 25  | 1.645 ± 0.216       | 0.976                 | 1.000 ± 0.0861 | 0.983 | 3.01 ± 2.28 |
| 14 | 5   | 1.669 ± 0.373       | 0.987                 | 1.005 ± 0.1489 | 0.986 | −3.83 ± 5.09 |
| 15 | 23  | 1.621 ± 0.146       | 0.988                 | 1.015 ± 0.0606 | ns | 0.987 | 0.73 ± 2.37 |
| 16 | 33  | 1.517 ± 0.147       | 0.954                 | 1.045 ± 0.0759 | ns | 0.985 | 0.03 ± 2.01 |
| 17 | 97  | 1.617 ± 0.074       | 0.953                 | 0.992 ± 0.0291 | ns | 0.983 | 16.27 ± 1.16 |
| 18 | 56  | 1.720 ± 0.110       | 0.976                 | 1.048 ± 0.0442 | ns | 0.977 | 19.26 ± 1.52 |
| 19 | 33  | 1.820 ± 0.086       | 0.985                 | 1.008 ± 0.0314 | 0.993 | 1.46 ± 1.40 |
| 20 | 70  | 1.517 ± 0.052       | 0.936                 | 0.905 ± 0.0198 | 0.977 | 29.61 ± 0.96 |
| 21 | 23  | 0.849 ± 0.037       | 0.734                 | 0.843 ± 0.0196 | 0.921 | 13.53 ± 0.76 |
| 22 | 44  | 1.425 ± 0.063       | 0.909                 | 0.959 ± 0.0262 | 0.971 | 13.42 ± 1.21 |
| 23 | 47  | 1.612 ± 0.061       | 0.856                 | 0.919 ± 0.0228 | 0.865 | 3.09 ± 1.17 |
| 24 | 91  | 0.946 ± 0.037       | 0.771                 | 0.899 ± 0.0188 | 0.961 | 10.20 ± 0.85 |
| 25 | 102 | 1.735 ± 0.110       | 0.972                 | 1.016 ± 0.0419 | 0.986 | −3.39 ± 1.13 |
| 26 | 57  | 1.693 ± 0.068       | 0.993                 | 0.989 ± 0.0261 | 0.992 | 11.55 ± 1.51 |
| 27 | 123 | 1.754 ± 0.071       | 0.975                 | 0.960 ± 0.0255 | 0.980 | 4.09 ± 1.03 |
| 28 | 26  | 1.587 ± 0.132       | 0.978                 | 0.997 ± 0.0543 | 0.990 | 10.30 ± 2.23 |
| 29 | 58  | 1.817 ± 0.169       | 0.980                 | 1.022 ± 0.0629 | 0.977 | −2.78 ± 1.49 |

ns $P \geq 0.10$, ‘$P < 0.10$’, ‘$P < 0.05$’, ‘$P < 0.01$’ testing the null hypothesis that the regression of predicted body weight on recorded body weight $= 1.0$, and for testing the null hypothesis that the difference between recorded body weight and predicted body weight $= 0.0$. 

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explained 73.4–99.5% of the variation in recorded body weight, while predicted body weight explained 86.5–99.6% of the variation in recorded body weight (Table 1). Thus, it can be concluded that for greatest accuracy in the prediction of recorded body weight at the initiation of a postweaning gain test, the calibrations of the relationship between partial body weight and predicted body weight with recorded body weight should be specific to the contemporary group. In addition, relative to the regression of recorded body weight on partial body weight, the prediction of recorded body weight from predicted body weight increased the coefficient of determination from 0.91 to 0.95 and reduced the average standard error of the estimate from 0.19 to 0.07. For eight of the contemporary groups, the intercept of the regression equation for recorded body weight on partial body weight was positive \( P < 0.05 \). Thus, for these contemporary groups using a multiplicative adjustment to predict recorded body weight (i.e., predicted body weight) from partial body weight would result in an underestimate of the recorded body weight for animals with above or below average partial body weight, respectively. There were no negative estimates of this intercept that approached significance \( P > 0.10 \).

The pooled regression coefficient of recorded body weight on partial body weight was 1.82 ± 0.15 across all contemporary groups studied (Table 1). In contrast, Benfield et al. (2017) indicated that body weight in cattle may be estimated as partial body weight multiplied by a constant of 1.677 across sexes and breed types. The 95% confidence interval for the Benfield et al. (2017) estimate was approximately 1.3–2.1. All of the estimates obtained for the regression of recorded body weight on initial partial body weight in the present study fell within that range and the pooled regression coefficient estimated here is also not significantly different from that proposed by Benfield et al. (2017). For seven of the 29 contemporary groups in the present study, the partial body weight explained less than 90% of the variation in recorded body weight at the initiation of the test period. These coefficients of determination may be interpreted as indicating anomalous relationships between the recorded body weight and the partial body weight. The remarkably unusual regression coefficients relating partial body weight and recorded body weight that were obtained for contemporary groups 25 and 28 were due to a few erroneous observations of partial body weight in each of these two contemporary groups indicating a clear need for careful data management.

Also shown in Table 1 are estimates from the regression analyses of recorded body weight on predicted body weight as well as the mean difference between the recorded body weight and predicted body weight at the initiation of the test period. The pooled regression of predicted body weight on recorded body weight was \( 1.02 ± 0.05 \). For five of the contemporary groups (i.e., numbers 3, 24, 25, 27, 28), the regression of predicted body weight on the recorded body weight differed \( P < 0.01 \) from 1.0 which is its a priori expected value. Compared to the prediction of recorded body weight from partial body weight, the prediction of recorded body weight from the predicted body weight generated by the GrowSafe proprietary algorithms explained, on average, 4.4% more of the variation in recorded body weight. This outcome was anticipated because the prediction algorithm would presumably reduce the random variability in body weight compared to that which was present in the partial body weights. Positive (negative) values for the difference between the recorded body weight and predicted body weight indicate the recorded body weight was, on average, greater (less) than the predicted body weight. These disparities between the predicted body weight and recorded body weight differed from zero for approximately half the contemporary groups. It should be recognized that this mean difference in body weight per contemporary group does not necessarily reflect bias because both harbor systematic error in their respective recording. Such error could include human error, scale calibration, or indeed the effects of gut fill.

In the analyses of variance for the assessment of partial body weight or predicted body weight as predictors of recorded body weight at the end of the test period, the interaction of contemporary group effects with the regression coefficients were also significant \( P < 0.01 \). Thus, as for the initial weight, it can be concluded that for greatest accuracy in the prediction of recorded body weight at the end of a postweaning gain test, the calibration depicting the relationship between partial body weight and predicted body weight with recorded body weight should be estimated per contemporary group. Because the regression coefficients for recorded body weight on predicted body weight at the beginning and end of the test period are not perfectly correlated \( r = 0.77 \) implies changes in the prediction model coefficients are needed as the test progresses.

Estimates of the regression coefficients of recorded body weight on partial body weight recorded at the end of the test period are summarized.
in Table 2. The pooled regression of partial body weight at the end of test on recorded body weight was 1.73 ± 0.09. While this value is again numerically greater than the constant multiplier suggested by Benfield et al. (2017), it is not significantly different from that value. It is also not different from the regression of 1.82 estimated in the present study for the initiation of test. Relative to the regression of recorded body weight on partial body weight, the prediction of recorded body weight from predicted body weight increased the coefficient of determination from 0.85 to 0.95 and reduced the average standard error of the estimate from 0.20 to 0.06.

The fact that separate scaling factors are required per contemporary group is in direct contrast to the conclusion of Benfield et al. (2017) who stated that body weight may be estimated as a constant multiple of partial body weight across sexes and breed types with adequate accuracy and precision. Use of a multiplicative constant to predict recorded body weight from a partial body weight assumes that the regression of body weight on partial body weight is linear and that the line it represents passes through the origin. The latter assumption is violated for contemporary groups 3 \(P < 0.01\), 19 \(P < 0.01\), 24 \(P < 0.01\), 25 \(P < 0.01\), 26 \(P < 0.01\), 28 \(P < 0.01\), 32 \(P = 0.05\), and 34

Table 2. Estimates per contemporary group (CG where the number of records is given by N) from the regression analyses of recorded body weight on initial partial body weight and predicted body weight, estimates of the correlations of partial and predicted body weight with the recorded body weight, and the mean difference between the recorded body weight and predicted body weight at the end of the test period.

| CG | N  | Partial body weight | Predicted body weight | Difference (kg) |
|----|----|---------------------|-----------------------|----------------|
|    |    | \(b \pm SE\) \(r\) | \(b = 1.0\) \(r\)   |       |
| 1  | 32 | 1.702 ± 0.111 0.989 | 0.993 ± 0.041 ns 0.990 | −5.16 ± 2.17* |
| 2  | 34 | 1.895 ± 0.151 0.989 | 1.101 ± 0.055 0.992  | 3.97 ± 2.11†  |
| 3  | 43 | 1.527 ± 0.075 0.954 | 0.987 ± 0.021 ns 0.970 | 0.29 ± 1.87** |
| 4  | 54 | 1.588 ± 0.083 0.969 | 0.952 ± 0.031 ns 0.983 | −3.50 ± 1.67* |
| 5  | 22 | 1.838 ± 0.280 0.964 | 0.965 ± 0.049 ns 0.991 | −5.80 ± 2.62* |
| 6  | 20 | 0.775 ± 0.051 ** 0.943 | −0.45 ± 2.75ns 0.943 | −0.45 ± 2.75* |
| 7  | 26 | 1.773 ± 0.265 0.957 | 1.032 ± 0.096 ns 0.974 | −4.05 ± 2.41* |
| 8  | 16 | 1.688 ± 0.265 0.988 | 1.046 ± 0.050 ns 0.990 | 3.85 ± 3.07** |
| 9  | 27 | 1.771 ± 0.358 0.957 | 1.078 ± 0.050 ns 0.962 | −9.63 ± 2.37* |
| 10 | 15 | 1.653 ± 0.147 0.991 | 1.006 ± 0.057 ns 0.988 | 0.29 ± 1.77** |
| 11 | 9  | 1.669 ± 0.380 0.946 | 1.008 ± 0.131 ns 0.960 | −0.39 ± 4.10* |
| 12 | 11 | 1.747 ± 0.206 0.995 | 1.089 ± 0.081 ns 0.996 | −1.98 ± 3.71* |
| 13 | 11 | 1.798 ± 0.362 0.971 | 1.106 ± 0.139 ns 0.985 | −7.68 ± 3.71* |
| 14 | 4  | 1.465 ± 0.925 0.930 | 0.815 ± 0.319 ns 0.946 | 6.64 ± 6.14** |
| 15 | 25 | 1.746 ± 0.128 0.994 | 1.056 ± 0.049 ns 0.992 | 8.17 ± 2.46* |
| 16 | 5  | 1.545 ± 0.244 0.997 | 0.972 ± 0.097 ns 0.998 | −2.11 ± 5.50** |
| 17 | 23 | 1.571 ± 0.126 0.981 | 0.971 ± 0.049 ns 0.985 | 3.01 ± 2.56** |
| 18 | 33 | 1.632 ± 0.128 0.977 | 1.005 ± 0.050 ns 0.983 | 4.37 ± 2.14* |
| 19 | 98 | 0.792 ± 0.057 0.569 | 0.977 ± 0.025 ns 0.977 | 16.69 ± 1.24** |
| 20 | 56 | 1.711 ± 0.114 0.978 | 1.034 ± 0.043 ns 0.982 | 17.93 ± 1.64** |
| 21 | 23 | 1.324 ± 1.066 0.830 | 1.117 ± 0.044 ns 0.983 | 0.325 ± 2.17** |
| 22 | 71 | 1.437 ± 0.088 0.960 | 0.907 ± 0.020 ns 0.956 | 28.75 ± 1.47** |
| 23 | 71 | 0.787 ± 0.057 0.712 | 0.843 ± 0.030 ns 0.926 | 12.86 ± 1.15** |
| 24 | 44 | 0.778 ± 0.074 0.690 | 0.966 ± 0.041 ns 0.972 | 12.85 ± 1.85** |
| 25 | 47 | 1.647 ± 0.101 0.854 | 0.923 ± 0.035 ns 0.867 | 3.04 ± 1.79** |
| 26 | 44 | 1.064 ± 0.063 0.806 | 0.885 ± 0.028 ns 0.963 | 9.86 ± 1.29** |
| 27 | 91 | 1.794 ± 0.091 0.983 | 1.025 ± 0.033 ns 0.982 | 3.20 ± 1.22** |
| 28 | 57 | 1.681 ± 0.077 0.990 | 0.982 ± 0.028 ns 0.990 | 11.59 ± 1.63** |
| 29 | 123 | 1.791 ± 0.063 0.984 | 1.000 ± 0.022 ns 0.987 | 4.60 ± 1.11** |
| 30 | 26 | 1.533 ± 0.130 0.981 | 0.937 ± 0.050 ns 0.986 | 8.46 ± 2.41** |
| 31 | 58 | 1.789 ± 0.172 0.976 | 1.041 ± 0.056 ns 0.981 | −2.77 ± 1.61* |
| 32 | 39 | 1.546 ± 0.066 0.986 | 0.914 ± 0.025 ns 0.982 | −4.65 ± 1.97** |
| 33 | 31 | 1.726 ± 0.095 0.980 | 1.001 ± 0.034 ns 0.984 | −2.07 ± 2.21** |

ns \(P \geq 0.10\), † \(P < 0.10\), ‡ \(P < 0.05\), § \(P < 0.01\) testing the null hypothesis that the regression of predicted body weight on recorded body weight = 1.0, and for testing the null hypothesis that the difference between the recorded body weight and predicted body weight= 0.0.
That differ between animals that are relatively close
There may well be temporary environmental effects
Groups are defined for these age-specific measures.
Considered in future research is how contemporary
Weights. One complicating factor that needs to be
Can also be calculated directly using the partial body
Several phenotypes and estimated breeding values,
Collection of partial body weight is the capture
Variance from the prediction of body weight from partial body weight.
It has long been recognized that daily variation in
Body weight of beef cattle exists (Lush et al., 1928).
Hughes (1976) reported that content of the digestive
Tract is in constant flux and may weigh upwards of
25% of total body weight. Following the weighing of
1,018 growing cattle (mean age of 17 months) on 2
consecutive days, Kelly et al. (2019) reported a differ-
ce in body weight per animal between both days
To be in the range of −18 to 22 kg with a standard
deviation of 5.34 kg. The aforementioned differences
were attributed primarily to variation in gut fill. Thus,
the change in mass of the digesta can be one factor
that results in short-term inaccuracy in the measure-
ment of body weight which cannot be overcome by
Weighing the animals multiple times. Furthermore,
the body weight of beef cattle changes with the
time of day when they are weighed (Hughes, 1976;
Heitschmidt, 1982) as well as the prevailing weather
conditions at the time of weighing (Lush et al., 1928;
Hughes, 1976). The degree to which these effects can
be mitigated by the real-time regular capture of body
weight is unknown. However, the complexity of the
resulting data structure may suggest the opportunity
to employ advanced analytical approaches like ma-
cine learning to predict the body weight of indi-
vidual animals (Wang et al., 2021).
A potential application of the technology for pas-
sive collection of partial body weight is the capture
of an age-constant measure of weight. For example,
a measure of weight at 365-days could be recorded
at exactly that age obviating the need for interpo-
lation from weight records collected at flanking ages.
Several phenotypes and estimated breeding values,
such as residual feed intake (Koch et al., 1963) and
residual intake and gain (Berry and Crowley, 2012),
can also be calculated directly using the partial body
weights. One complicating factor that needs to be
considered in future research is how contemporary
groups are defined for these age-specific measures.
There may well be temporary environmental effects
that differ between animals that are relatively close
in age. In addition, the partial body weight or the
ADG in partial body weight could be incorporated
into multi-trait genetic evaluation directly as a correl-
ated trait without the need to actually predict body
weight from it. The best way to combine the different
data sources into genetic evaluations is predicted on
estimates of the genetic, residual and permanent en-
vironmental variance components for predicted and
recorded body weights. A strong genetic correlation
between the different measures is expected although a
larger residual variance in predicted body weight may
materialize. Therefore, an alternative strategy could be
to combine the predicted and recorded body weights
into a single trait weighting them differently based on
the estimated variance components for each measure.

Predicting ADG From Partial Body Weights

Summary statistics comparing the estimates of
ADG from partial body weight or predicted body
weight recorded daily throughout the test period versus
ADG calculated from recorded body weight recorded
periodically throughout the test period are in Table
3. As might be expected, the correlations of ADG
estimated from partial body weight with ADG esti-
mated from the predicted body weight (i.e., predicted
from partial the body weight data) were generally very
strong (\( r = 0.96 \)) with only one contemporary group
in which this correlation was < 0.8. The estimated cor-
relations of recorded body weight with partial body
weight and predicted body weight were weaker, aver-
ageing 0.81 ± 0.03 and 0.78 ± 0.04, respectively.
For 15 of the 35 contemporary groups, the
mean ADG calculated from recorded body weights
differed (\( P < 0.10 \)) from the mean ADG calculated
from predicted body weights (Table 3). The values
derived from predicted body weight generally being
greater than those from recorded body weight. These
differences may, however, be due to impreci-
sion in either method of weighing the animals.

Length of Test When ADG is Predicted From
Partial Body Weight

Many previous studies which attempted to deter-
mine the required minimum length of the test period
(e.g., Wang et al., 2006; Culbertson et al., 2015;
Ahlberg et al., 2018) for determining ADG made
use of the part-whole correlation that has an asym-
ptotic value of 1.0 as the length of the shortened test
period approached the length of the full test period.
This approach will invariably find that a shorter
test period will explain nearly all of the variation in
the full-length test. In the present study, a different
approach based on model-order dependent regression, was used. In this approach, the early part of the test preceded the later part when specifying the independent variables in the regression model. Thus, the sum of squares due to regression for the first part of the test was not adjusted for the latter part of the test, but the sum of squares due to regression for the latter part of the test was adjusted for the portion of the test that preceded it. Thus, results for the early part of the test are exactly analogous to those obtained in the previous studies, while the results for the latter part of the test document the information that is lost when the test is reduced in length. Results for the regression analysis when the test period was split approximately in half (35 days on test) are presented in Table 4. Tests of greater than 70 days duration were truncated at 70 days.

The results in Table 4 pertaining to the full test period indicate the degree to which growth was linear over time. The regression coefficients \( b_1 \) and \( b_2 \) reflect the ADG from predicted body weight from day 1 to day 35 of the test and from day 36 to the end of the test, respectively. The \( R^2 \) value is the coefficient of determination for the period.
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...and the partial $R^2$ indicates the value of the information from the latter part of the test in determining ADG across the full test. The deviation, which has an expected value of 0.0, indicates the difference between the prediction of final partial body weight from its regression on days on test during the first period of the test and its recorded value at the end of the test period. Estimates of ADG from the initial period of the test explained more than 90% of the variation in ADG across the full test period for only two contemporary groups (i.e., groups nine and 17). Furthermore, in only three contemporary groups did the ADG recorded in the latter portion of the test contribute less than 10% to the measurement of full test ADG. Overall, the first and second half of the full test period explained a similar proportion of the variation in ADG across the full test period ($R^2 = 56.7 ± 3.8$ vs. $56.0 ± 4.0$, respectively). In an analysis that included all contemporary groups fitted as fixed effects, ADG in the first half of the test period explained 51.5% of the within contemporary group variance. The ADG from the latter half of the test period explained 33.1% of the within contemporary group variance after accounting for ADG during the first half of the test. For only six of the 35 contemporary groups, the prediction of final partial body weight based on the first part of the test not different ($P > 0.10$) from its observed value.

Table 4. Results from the regression analyses per contemporary group (CG) relating average daily gain of partial body weight in two 35-day parts of the postweaning gain test to average daily gain during the full test period of approximately 70 days without prior editing to insure linearity of growth over the test period.

| CG | Length of test, d | Full test period | 35-day test –w/o editing based on $R^2$ |
|----|-------------------|------------------|---------------------------------------|
| 1  | 63                | R$^2$ = 88.8     | MS error, kg$^2$ = 6.326              |
| 2  | 63                | 0.79 ± 0.03      | 0.62 ± 0.02                           |
| 3  | 70                | 0.80 ± 0.05      | 0.10 ± 0.06                           |
| 4  | 73                | 1.18 ± 0.03      | 0.93 ± 0.03                           |
| 5  | 124               | 1.31 ± 0.03      | 1.14 ± 0.03                           |
| 6  | 124               | 1.11 ± 0.03      | 0.96 ± 0.02                           |
| 7  | 175               | 1.14 ± 0.04      | 0.99 ± 0.03                           |
| 8  | 76                | 0.96 ± 0.07      | 1.24 ± 0.08                           |
| 9  | 99                | 1.09 ± 0.03      | 0.92 ± 0.01                           |
| 10 | 98.9              | 1.04 ± 0.03      | 1.01 ± 0.05                           |
| 11 | 98.3              | 0.86 ± 0.05      | 1.10 ± 0.11                           |
| 12 | 97.4              | 0.76 ± 0.06      | 1.03 ± 0.08                           |
| 13 | 97.8              | 0.69 ± 0.05      | 0.91 ± 0.06                           |
| 14 | 99                | 1.08 ± 0.07      | 1.02 ± 0.07                           |
| 15 | 99.1              | 0.95 ± 0.04      | 1.07 ± 0.04                           |
| 16 | 98.8              | 1.10 ± 0.09      | 0.94 ± 0.09                           |
| 17 | 98.7              | 1.07 ± 0.04      | 0.90 ± 0.03                           |
| 18 | 98.7              | 1.03 ± 0.02      | 0.94 ± 0.03                           |
| 19 | 10.7              | 0.81 ± 0.02      | 0.76 ± 0.02                           |
| 20 | 57.3              | 0.66 ± 0.03      | 0.71 ± 0.02                           |
| 21 | 80.8              | 0.51 ± 0.04      | 0.81 ± 0.04                           |
| 22 | 69.9              | 0.69 ± 0.05      | 0.91 ± 0.06                           |
| 23 | 71.2              | 0.72 ± 0.02      | 0.98 ± 0.02                           |
| 24 | 81.2              | 0.75 ± 0.06      | 0.98 ± 0.02                           |
| 25 | 78.7              | 1.15 ± 0.04      | 1.30 ± 0.07                           |
| 26 | 97.2              | 1.29 ± 0.05      | 1.20 ± 0.05                           |
| 27 | 92.7              | 1.13 ± 0.02      | 1.12 ± 0.04                           |
| 28 | 92.7              | 0.54 ± 0.02      | 0.44 ± 0.01                           |
| 29 | 69.5              | 1.28 ± 0.04      | 1.26 ± 0.03                           |
| 30 | 85.0              | 0.30 ± 0.02      | 0.44 ± 0.01                           |
| 31 | 88.5              | 0.89 ± 0.03      | 0.88 ± 0.03                           |
| 32 | 94.9              | 0.89 ± 0.02      | 0.98 ± 0.02                           |
| 33 | 93.9              | 0.91 ± 0.03      | 0.73 ± 0.03                           |
| 34 | 94.4              | 0.45 ± 0.02      | 0.67 ± 0.02                           |
| 35 | 75.3              | 0.88 ± 0.06      | 0.66 ± 0.03                           |

...from day 1 to day 35, and the partial $R^2$ indicates the value of the information from the latter part of the test in determining ADG across the full test. The deviation, which has an expected value of 0.0, indicates the difference between the prediction of final partial body weight from its regression on days on test during the first period of the test and its recorded value at the end of the test period. Estimates of ADG from the initial period of the test explained more than 90% of the variation in ADG across the full test period for only two contemporary groups (i.e., groups nine and 17). Furthermore, in only three contemporary groups did the ADG recorded in the latter portion of the test contribute less than 10% to the measurement of full test ADG. Overall, the first and second half of the full test period explained a similar proportion of the variation in ADG across the full test period ($R^2 = 56.7 ± 3.8$ vs. $56.0 ± 4.0$, respectively). In an analysis that included all contemporary groups fitted as fixed effects, ADG in the first half of the test period explained 51.5% of the within contemporary group variance. The ADG from the latter half of the test period explained 33.1% of the within contemporary group variance after accounting for ADG during the first half of the test. For only six of the 35 contemporary groups, the prediction of final partial body weight based on the first part of the test not different ($P > 0.10$) from its observed value.
Imposing the requirement that the regression of partial body weight on age for each animal had to have an $R^2 \geq 0.9$ over a test period of 1–70 days to ensure the linearity of growth resulted in the loss of 38.4% of the partial body weight data (Table 5). Five contemporary groups were removed from the data set as a result of them containing fewer than four animals after this edit was imposed. It should be cautioned that this threshold was established based on weighing animals at two-week intervals throughout the test period (Crews and Carstens, 2012) rather than from daily weights.

Again, after requiring each individual animal to exhibit approximately linear growth across the test period, the first and second half of the full test period explained, on average, a similar proportion of the variation in the ADG of partial body weight across the full test period ($R^2 = 60.0 \pm 4.3$ vs. $56.9 \pm 4.4$, respectively). In 20 of the 30 contemporary groups, the mean deviation of predicted partial body weight from observed mean body weight at the end of the test period was significant.

It was therefore concluded that a 35-day test period with (daily) partial body weights was insufficient to characterize ADG during the postweaning period. Thus, a second test period of approximately

| CG | Length of test, d | Full test period | 35-day test --w/edit |
|----|------------------|-----------------|-------------------|
|    | $R^2$, % MS error (kg²) | $b_1$ | $b_2$ | R², % partial R², % deviation (d) | Probability (d = 0) |
| 1  | 63 88.8 6.33 | 1.16 ± 0.06 | 0.87 ± 0.06 | 78.7 | 32.2 | −4.00 ± 1.13 | 0.003 |
| 2  | 63 95.4 2.89 | 0.80 ± 0.02 | 0.62 ± 0.02 | 76.8 | 44.2 | −1.91 ± 0.45 | <0.001 |
| 3  | 70 91.8 5.74 | 0.88 ± 0.05 | 1.09 ± 0.05 | 74.0 | 66.1 | −6.54 ± 1.59 | <0.001 |
| 4  | 73 95.2 5.18 | 1.18 ± 0.03 | 0.95 ± 0.03 | 43.9 | 28.5 | −1.20 ± 0.90 | 0.189 |
| 5  | 124 99.3 3.74 | 1.31 ± 0.03 | 1.14 ± 0.03 | 71.8 | 61.3 | −2.47 ± 0.67 | 0.001 |
| 6  | 124 98.4 4.38 | 1.11 ± 0.03 | 0.96 ± 0.02 | 73.1 | 60.6 | −3.05 ± 0.75 | 0.001 |
| 7  | 175 98.0 5.94 | 1.14 ± 0.04 | 0.99 ± 0.03 | 81.9 | 83.9 | −2.76 ± 0.64 | <0.001 |
| 8  | 76 88.4 7.48 | 1.17 ± 0.08 | 1.14 ± 0.06 | 66.9 | 16.2 | −4.38 ± 1.87 | 0.033 |
| 9  | 123 99.0 3.56 | 1.09 ± 0.03 | 0.95 ± 0.03 | 91.1 | 63.1 | −3.01 ± 0.48 | <0.001 |

Table 5. Results from regression analysis per contemporary group (CG) relating average daily gain during the full test period of approximately 70 days to two 35-day periods of the postweaning gain test after editing the data to insure linearity of growth over the test period.

*Editing to insure linearity of growth during the test period resulted in some contemporary groups being reduced to fewer than four animals, in which case this analysis was not attempted.
50 days was evaluated. As before, the 50-day tests were evaluated with and without the quality control restriction of linear ADG in partial body weight. When the ADG in partial body weight of each animal was not edited for linearity, the first 50 days of the test period explained across contemporary groups, on average, 82.7 ± 2.7% of the variation in ADG over the full test period. The latter portion of the test explained an average of 25.9 ± 3.3% providing additional (P < 0.05) information informing the full-test ADG in 22 of the 35 contemporary groups. With each animal in the data set having an $R^2$ value greater than 0.9 for the linear regression of partial body weight on days on test resulted in coefficients of determination attributable to ADG from the initial and final portions of the test of 84.0 ± 3.3% and 27.4 ± 4.0%, respectively. The latter portion of the test explained an average of 25.9 ± 3.3% providing additional (P < 0.05) information informing the full-test ADG in 22 of the 35 contemporary groups. Without and with having edited the data from each animal for linearity of growth during the entire test period, the corresponding average deviations of the predicted final partial body weight from its observed value averaged −1.83 ± 1.22 kg ($P = 0.15$) and −1.13 ± 0.94 kg ($P = 0.24$), respectively. Based on these results, it was concluded that the latter portion of the test period still contributed significant information to the prediction of full-test ADG. However, in an analysis that included all contemporary groups fitted as fixed effects, ADG in the first 50 days of the test period explained 80.0% of the within contemporary group variance with the latter portion of the test explaining only an additional 2.0%. In evaluating a 43 day test, ADG in the first part of the test period explained 68.2% of the within contemporary group variance, while ADG from the latter half of the test period explained an additional 8.5% of the within contemporary group variance. Thus, based on the pooled analysis, a test period of 50 days may be deemed adequate while a test period of 43 days would not.

The minimum length of the test period is not entirely a statistical consideration relative to the test itself. If the goal of the postweaning gain test is to obtain the most precise estimate of ADG possible, then a lengthy test period is preferable. Because the animals on test are likely to vary in age, a longer test would provide a better opportunity to evaluate efficiency at a constant age or degree of maturity through statistical adjustment to the appropriate endpoint. However, there are potential economic and experimental benefits from a shorter test period (Manafiazar et al., 2017). A shorter test period has the advantage of increasing the chance that growth is linear over the duration of the test. It is recommended that the prescribed length of test should depend on the anticipated use of the resulting data. In the context of genetic evaluations and many experiments, power of the test can be increased and additional accuracy may result from testing more animals, even if the individual measurements themselves are less precise (Lush et al., 1928; Manafiazar et al., 2017). Thus, a test of 50 days may be suitable for many purposes. However, as the postweaning gain test is shortened, the impact of any inaccuracy in the prediction of body weight affecting ADG may be magnified if the body weight records early and late in the test are not similarly affected.

**CONCLUSION**

The work that has been reported herein is specific to one proprietary system and probably should not be extrapolated to competing technologies since differences in underlying algorithms used in the data capture and analysis are likely to exist. With any technology the individual researcher/bull test operator needs to be cognizant of potential for error in measures of body weight. Some users of the partial body weight technology are likely to lack the statistical expertise to determine the length of test that is desirable for their specific application. When the capacity of the facilities is the limiting constraint on the number of animals that can be tested, a 50-day test and testing more animals is likely result in greater power of the test for the hypothesis of interest. A shorter test period may also reduce the per animal cost of testing. However, if the number of animals that are available to test is the limiting factor, then a longer test is probably preferable. Predicting full body weight from partial body weight is likely to have acceptable accuracy in most applications, recognizing that there will be some degree of prediction error.

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Translation: Translate basic science to industry innovation.