Research Square

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Screening piglets at risk of mortality and poor growth using body weight and morphometric measurements

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Research Article

Keywords: swine, growth performance, fallback, pre-weaning mortality, survival, abdominal circumference

Posted Date: November 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11594533/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

High pre-weaning mortality in intensive pig farming raises urgent ethical concerns and is a large source of lost revenue for farmers. Malnourishment is a major predisposing factor that increases the risk of starvation, hypothermia, and being crushed by the sow. Birth weight is considered the best predictor of pre-weaning survival and growth, but morphometric measurements may reflect nutritional status more accurately. Farmers also need practical screening tools to support their decisions. This study therefore aimed to establish which body measurement best identifies piglets at risk of mortality and poor growth early in life, and to determine the best time to screen and the best proportion of piglets to select. Body weight of 388 piglets from 26 litters was recorded on days 1, 2 and 21 post-partum. On days 1 and 2, abdominal circumference and crown-rump length were also measured, and body mass index and ponderal index were derived from these. Piglets were classified as 'at-risk' if they died before day 21 or if their day 21 body weight was in the lowest 15% of survivors. The strength of association and the predictive performance of each measurement were assessed using single-measure generalised linear mixed models and leave-one-litter-out cross-validation.

Results

Body weight and abdominal circumference had the strongest associations with being at-risk, with odds ratios per standard deviation below the mean of 4.07 (95% bootstrap quantile confidence interval: 2.86–6.51) and 3.75 (2.70–5.80), respectively. They also showed the best predictive performance, with areas under the receiver operating characteristic curve of 0.789 (0.728–0.846) and 0.786 (0.732–0.835), respectively. Selecting the 20% or 40% of piglets with the highest predicted risk identified about half and three-quarters of at-risk piglets, at false-positive rates of 0.11–0.12 and 0.31, respectively. Measuring on day 2 rather than day 1 did not improve discrimination.

Conclusions

Body weight and abdominal circumference can be used interchangeably to identify at-risk piglets on day 1 post-partum. However, it is still unclear what would happen to piglets selected for intervention. Reducing the prevalence of at-risk piglets in the first place is a more sustainable way to lower pre-weaning mortality.

Background

Pre-weaning mortality rates in conventional pig production are 15–20% [1]. These deaths represent an urgent ethical concern and a persistent drain on income for pig farmers. The majority of pre-weaning deaths occur within the first 72 h post-partum (**pp**) [2]. Although pre-weaning mortality is multi-factorial,

a major predisposing factor is the piglet's inability to acquire sufficient nutrients. Malnourished piglets are less responsive and display poor thermoregulatory abilities, increasing their risk of being crushed by the sow, adding to the mortality risks of starvation and hypothermia [1, 2].

Malnourished piglets will 'fall back' in growth and appear smaller compared to their littermates. Early identification of piglets at risk of poor growth may improve their survival prospects by allowing timely and informed management interventions. Birth weight is generally considered as the most important predictor of pre-weaning survival [3] and growth performance in pigs [4, 5]. However, body shape and proportionality measures, such as body mass index and ponderal index, also inform on mortality risk [6]. Furthermore, in low-birth-weight piglets, abdominal circumference and BMI predicted pre-weaning growth more accurately than birth weight [7, 8]. Such morphometric measurements may better relate to actual nutritional status than weight by reflecting gut contents and colostrum intake more accurately than overall body mass.

However, for a measure to be useful as an on-farm screening tool, it must be practical to obtain and act on. Morphometric indices, such as BMI, require both weighing and measuring, increasing workload on the stockperson. In addition, the optimal screening window remains unclear, given that suckling patterns and colostrum intake are still being established shortly pp [9]. Measuring later could be more informative but may come at the cost of missing some at-risk individuals who will already have died by that point. Another trade-off concerns the proportion of piglets selected for intervention, which sets the balance between true-positive and false-positive rates. Therefore, our aims were: 1) establishing which single measurement best identifies at-risk piglets and comparing this to morphometric indices; 2) investigating whether measuring on day 2 pp is advantageous over day 1; and 3) determining how sensitivity and specificity change with selection rate.

Methods

Housing and management

This observational study was conducted at the Teagasc Pig Research Facility in Moorepark, Fermoy, Co. Cork, Ireland between October 2025 and February 2026 on 26 litters opportunistically selected from three breeding cohorts (9, 10 and 7 litters, respectively).

Sows (all Large White × Landrace, PIC®, Hermitage Genetics, Sion Road, Co. Kilkenny, Ireland, parity: 2.6 ± 1.62 [mean ± SD], range: 1–6) were group housed throughout gestation. Sows moved with their breeding cohort (batch of approximately 22 sows) into one of two identical farrowing rooms (12.9 × 8.3 m) one week prior to their estimated farrowing date. Farrowing was induced on day 113–114 of gestation using a synthetic prostaglandin (Planate).

Both farrowing rooms contained 14 standard farrowing pens (Big Dutchman International GmbH, Vechta, Germany), with 7 pens on either side of a common aisle. Windows on one side provided natural daylight, and artificial lighting was provided daily from 0800 to 1630 h. Ventilation in the farrowing rooms was

automatically controlled (Big Dutchman 135). Pens measured 2.50 × 1.80 m (length × width), providing 4.5 m^2 in total area. Sows were permanently confined in farrowing crates. Each pen featured a sow feeder and drinker, cast-iron slats under the sow and plastic slats with an embedded heat pad and a covered creep area providing a microclimate for piglets during early lactation. The creep cover was removed at approximately day 7 pp. During the farrowing week, room temperature was maintained at 23°C, and it was gradually reduced over the course of lactation to a minimum of 19.5°C. Solid-sided dividers separated pens, and no substrates were provided. Creep feed was provided *ad libitum* from day 10 pp, and piglets had continuous access to water via nipple drinkers.

Piglet data collection

Farm staff processed piglets by individually weighing (to the nearest 10 g), grinding needle teeth, and transponder ear tagging (LeeO, MSD Animal Health, Deventer, The Netherlands) at 18.4 ± 6.75 h pp (birth of the first piglet; mean ± SD). As per the farm's protocol, piglets with splay legs or piglets weighing < 800 g were euthanised. In two of the three batches, piglets were tail docked at processing. In accordance with conventional commercial practice in Ireland, male piglets were not castrated. During processing (hereafter referred to as 'D1'), we recorded morphometric measurements (to the nearest 1 cm) in addition to body weight (**BW**; kg), comprising abdominal circumference (**AC**), and crown-rump length (**CRL**; Fig. 1). AC (cm) was measured as the widest point around the piglets' midsection, with the measuring tape perpendicular to the piglets' axis. CRL (cm) was measured from the occipital ridge of the skull to the tail base with a measuring tape. After all litters in the breeding cohort were processed, piglets were cross-fostered to equalise litter sizes where possible. Piglets from non-study sows were not cross-fostered onto study sows. All piglets received an iron injection on day 3 pp. BW, AC, and CRL were measured again on day 2 pp (D2), and BW alone on day 21 pp (D21). Piglets were weaned at 28 (± 1.1) days pp.

Data processing and statistical analyses

We conducted all data processing and statistical analyses in R (version 4.4.2, [10]). Following Douglas et al. [7], we derived two indices of body shape at D1 and D2 from the corresponding BW and CRL: body mass index (**BMI**; $BW/(CRL/100)^2$) and ponderal index (**PI**; $BW/(CRL/100)^3$). Piglets were classified as 'at-risk' if they (i) died or were euthanised before D21 weighing, or (ii) attained a body weight in the lowest 15% of D21 survivors, a threshold consistent with published poor-growth prevalence [11].

For each measure (BW, AC, CRL, BMI, PI) at both timepoints (D1, D2), we fitted a binomial generalised linear mixed-effects model (**GLMM**) using the lme4 package [12], relating risk status to a single (z-score standardised) predictor with sex as a fixed covariate and a random intercept for rearing litter. D1 models included all classifiable piglets (n = 388). D2 models were restricted to piglets alive at D2 (n = 383). Model assumptions were assessed using the DHARMa R package [13]. The model in lme4 syntax was:

$$risk\ status\ \sim\ predictor + sex\ + (1|\,litter)$$

Association strength

Model coefficients are reported as odds ratios (**OR**s) per SD below the mean (*i.e.*, the inverse of the model OR), so that values above 1 indicate increased risk for lighter or smaller piglets. Corresponding 95% bootstrap quantile confidence intervals (**95% CI**) were obtained by parametric bootstrapping using the confint function with the boot method (10^4 resamples). This is considered to provide a more reliable indication of statistical significance than *P*-values based on Wald statistics [12]. A significant difference from the null hypothesis at the 0.05 level is indicated when the 95% CI does not include the null value (1 for ORs).

Predictive performance

Predictive accuracy was assessed by leave-one-litter-out cross-validation (**LOLO-CV**), with predicted at-risk probabilities for the held-out litter obtained using population-level predictions (fixed effects only). Discrimination was quantified as the area under the receiver operating characteristic curve (**ROC-AUC**), computed from the pooled out-of-fold predictions with 95% CIs from a litter-clustered bootstrap (10^4 resamples). Discrimination was considered significantly better than chance when the 95% CI of the AUC did not include 0.5.

To test whether measuring at D2 rather than D1 improved discrimination, we compared each measure's single-measure model between the two timepoints. Because the samples differ by the piglets that died before D2, each AUC was computed on the piglets scored by its own model. All AUC-based CIs used the same set of litter resamples (10^4), so differences were paired at litter level. A difference in AUC was considered significant when its 95% CI did not include 0.

We derived operating points from the pooled out-of-fold LOLO-CV predictions. Piglets were ranked by predicted at-risk probability (primary measure + sex covariate). A selection rate was defined as the fraction of all piglets selected (i.e., those with the highest predicted probability). Since only whole piglets can be selected, each target rate was set to the nearest achievable fraction given the sample (n = 388 for D1; n = 383 for D2). At each selection rate we computed the true-positive rate (**TPR**; proportion of at-risk piglets correctly selected) and false-positive rate (**FPR**; proportion of not-at-risk piglets incorrectly selected). Operating points were evaluated over selection rates of 10–40% for the best performing measures at D1 and D2.

Results

Across the 26 litters, 467 piglets were born alive (17 stillborn, 1 mummified) of which 18 died before processing. During processing, another 27 piglets were euthanised. Of the 422 processed piglets, 34 were cross-fostered onto non-study sows to equalise litter sizes, leaving 388 piglets in the analysis

sample. During the remainder of lactation, 30 piglets died/were euthanised before D21, of which five before D2. Not considering piglets cross-fostered onto non-study sows, the pre-weaning mortality rate (up to D21) in our sample was 17.3%. Of the 358 piglets surviving to D21, 53 were classified as 'at-risk' based on the bottom 15% BW criterion. Figure 2A shows the distribution of each measure at D1 and D2 by risk status, and Supplementary Table 1 gives the corresponding means and SDs.

Association strength

Every measure recorded at D1 was associated with risk status except PI (Fig. 2B). The odds that piglets become at risk increased by a factor of 4.07 for every SD decrease in BW (95% CI: 2.86–6.51). The second strongest association was with AC (3.75, 2.70–5.80), followed by BMI (3.06, 2.06–4.96) and CRL (2.51, 1.81–3.73). We did not find statistical support for an association between D1 PI and risk status (1.37, 0.99–1.99).

The same pattern held at D2, with every measure except PI associated with risk status and the associations uniformly stronger than at D1 (BW OR 5.41, 95% CI: 3.62–9.60; AC 4.88, 3.30–8.44; BMI 3.40, 2.36–5.32; CRL 3.22, 2.24–5.11). We again did not find statistical support for an association between D2 PI and risk status (1.36, 0.98–1.94). Across all models (D1 and D2), we also did not find statistical support for an association between sex and risk status (males vs. females; OR range: 1.16–1.63, all 95% CIs include 1).

Predictive performance

Discrimination of risk status is shown in Fig. 3A as ROC-AUC for single-measure models at D1 and D2. The full ROC curves are shown in Fig. 4. Using the D1 measure, BW (AUC: 0.789, 95% CI: 0.728–0.846) and AC (AUC: 0.786, 95% CI: 0.732–0.835) discriminated best, with BMI (AUC: 0.684, 95% CI: 0.606–0.760) and CRL (AUC: 0.667, 95% CI: 0.562–0.770) lower. We did not find statistical support for any discriminative power of PI above chance (AUC: 0.492, 95% CI 0.410–0.583).

We did not find statistical support for an effect of moving measurements to D2 on discrimination for any measure (all 95% CIs include zero; Fig. 3B). The largest point gain was for CRL (ΔAUC: +0.063, 95% CI: -0.018–0.132), with smaller changes for the others (BW + 0.020, 95% CI: -0.003–0.046; AC + 0.004, -0.036–0.045; BMI + 0.019, -0.097–0.144; PI + 0.018, -0.099–0.137).

Operating points for the two best measures (BW and AC) at D1 across selection rates of 10–40% are given in Table 1. Sensitivity rose roughly in step with the selection rate for both: selecting the 20% of piglets at highest predicted risk (by the BW or AC model) recovered just over half of at-risk piglets (TPRs of 0.51 and 0.52, respectively) for FPRs of 0.11–0.12. At a 40% selection rate, sensitivity reached ca. 0.75, with BW and AC converging on the same operating point. Operating points at D2 were closely similar.

To put this in practical terms: per 100 piglets screened at D1, selecting 20% would select about 11 piglets that went on to die or show poor growth and 9 that did not, while missing about 11 at-risk piglets. Selecting 40% would select 16 at-risk and 24 not-at-risk piglets, while missing 5. Importantly however, at D1, ranking on raw AC (as a stockperson would) could not resolve the sample into the target fractions, as many piglets shared the same value. Achievable selection rates jumped from 17% to 32% and then to 49%, so rates of 20%, 30% and 40% could not be achieved.

Table 1
TPR and FPR for AC and BW at D1 and D2 across selection rates of 10–40%.

Selection rate [1]	**BW**		**AC**	
	TPR	**FPR**	**TPR**	**FPR**
Day 1 (n = 388)				
10%	0.265	0.056	0.313	0.043
20%	0.506	0.118	0.518	0.111
30%	0.627	0.210	0.651	0.203
40%	0.747	0.305	0.747	0.305
Day 2 (n = 383)				
10%	0.308	0.046	0.269	0.059
20%	0.474	0.131	0.487	0.128
30%	0.667	0.207	0.628	0.220
40%	0.782	0.302	0.756	0.308
AC: abdominal circumference; BW: body weight; TPR: true-positive rate; FPR: false-positive rate				

[1] Piglets were ranked by model-predicted risk (out-of-fold predictions from the BW or AC model, including sex). Because only whole piglets can be selected, each rate is the nearest achievable fraction of the sample; achieved rates were within 0.3 percentage points of the target.

Discussion

We investigated the use of morphometric measurements recorded in the first two days pp to predict survival and poor growth of piglets to 21 days of age. The pre-weaning mortality rate of ~ 17% was similar to rates reported in literature [1, 2]. BW and AC best identified piglets at risk of mortality and poor growth, performing comparably. This parity is notable because our at-risk outcome was partly defined by D21 BW (bottom 15% of survivors), giving D1/D2 BW a built-in advantage over morphometric measurements. That AC matched BW despite this handicap indicates that it carries at least as much information about survival and growth.

The comparable performance of AC likely reflects its link to recent nutritional intake. AC is thought to reflect gut fill [7], which is dominated by colostrum in the first days of life [14]. Because we recorded AC after the establishment of nursing, it may capture early colostrum intake – and consequently nutritional status – more directly than BW, which reflects overall body mass rather than recent feeding. However, this likely also makes AC sensitive to the timing of measurement relative to the last nursing [15].

Our findings are partly in line with previous studies. Birth weight is predictive of pre-weaning mortality [16–19] and early-life growth [20]. Douglas et al. [7] found that AC is also a good predictor of pre-weaning growth performance. However, they found that BW was outperformed by both BMI and AC for light birthweight piglets (≤ 1.25 kg). Similarly, Hales et al. [21] found that BMI predicted pre-weaning mortality better than BW, and Huting et al. [8] reported BMI and birthweight-relative-to-litter to best predict pre-weaning growth in light birthweight piglets. In contrast, we found that BW remained among the strongest predictors, level with AC, while BMI was considerably less informative in our sample.

These discrepancies may be explained by differences in study populations and prediction targets. Both Douglas et al. [7] and Huting et al. [8] stratified piglets into birthweight classes and predicted growth among survivors, whereas we did not stratify and our definition of 'at-risk' incorporated pre-weaning mortality. Moreover, restricting the BW range (as in [7, 8]) truncates the variance in weight, which limits its apparent predictive value and may allow body-shape indices to emerge as the stronger signal. However, a similar range restriction (in the opposite direction) operates in our own sample, since non-viable piglets were euthanised before classification. This truncates the low tail of BW, which would tend to depress rather than inflate BW's and AC's apparent predictive value. This limits the generalisability of our prevalence and operating points to herds with different culling practices.

Since AC and BW performed comparably, they may be used interchangeably depending on practicality. Where piglets are already weighed as part of routine processing, measuring AC adds unnecessary handling, increasing both animal stress and stockperson workload. Where weighing is not routine, obtaining AC with a measuring tape may be quicker than bringing scales into the farrowing house. However, AC requires two people, may be more prone to measuring error, and – as mentioned earlier – may be more sensitive to the interval since the last suckle [15]. Previous work suggested that experienced stockpersons may visually identify at-risk piglets from body shape [7, 8], but whether AC specifically can be gauged reliably by eye warrants further investigation. Thus, neither measure appears universally preferable, and the choice may depend on a farm's existing routines and protocols.

Measuring at D2 did not meaningfully improve at-risk discrimination over D1 for any measure. Since five piglets died between the two time points, measuring at D1 seems preferable. However, 18 piglets died even before the D1 measurement, and Hales et al. [21] also reported that mortality was concentrated within the first day pp. Many of these piglets were likely non-viable and would otherwise have been euthanised at processing. Therefore, from a producer perspective, their loss before D1 may make little difference. However, from a welfare perspective, identifying such piglets earlier would allow timely euthanasia and shorten their suffering. Thus, even D1 leaves part of the mortality burden beyond the

reach of any screening measure, and whether processing is the optimal screening time remains an open question.

The reported operating points characterise how much risk signal BW and AC carry but should not be read as screening rules ready for use. At D1, selecting the 20% at highest predicted risk recovered about half of at-risk piglets at a FPR of ~ 0.10. Selecting 40% raised sensitivity to ~ 0.75 at a FPR of ~ 0.30. The 40% point sat furthest from the chance line, which makes it preferred under equal misclassification costs. In practice a missed at-risk piglet (a false negative) is likely more costly than an incorrectly selected piglet (a false positive). On the other hand, selecting nearly half of the litter for intervention is unlikely to be practical and defeats its purpose. In any case, the reported operating points come from ranking every piglet by model-predicted risk and selecting a fixed fraction, which requires measuring the whole litter.

More practical would be a hard cut-off (e.g., select any piglet below a set AC or BW), which a stockperson can apply to individual animals. Because sex was not associated with risk status, thresholding on a raw value is in principle a reasonable substitute (or sex-specific thresholds, given that other studies did find sex-effects; [16]). However, a threshold based on our sample size would be unstable and would need validation in a larger, representative population (e.g., [18, 19]). Additionally, our AC resolution (1 cm) is too coarse to place a precise threshold, with the selected fraction jumping from 17% to 32% for a one-step change in cut-off (ca. half a SD). AC should therefore be recorded at a finer resolution (at least 0.5 cm), with further work to test whether this yields enough spread for a workable cut-off for intervention.

The intervention itself remains perhaps the largest open question. Non-invasive interventions (e.g., feed supplements) may justify higher selection rates than invasive ones (e.g., cross-fostering, colostrum gavage; [1]). However, the economic costs of an intervention will also influence decision making. Ultimately, all intervention strategies manage the consequences of low viability rather than reduce its incidence. A more effective approach would be to prevent at-risk piglets arising in the first place, for instance through selection for higher and more uniform birth weights and more robust piglets [22].

Conclusions

On day 1 post-partum, both body weight and abdominal circumference can be used to screen piglets at risk of poor growth and mortality, performing comparably and better than other morphometric measurements and indices. Measuring on day 2 did not improve discrimination for any measure. Separation between true- and false-positive rates was greatest at a selection rate of around 40%. However, the optimal rate may depend on the intended intervention. Furthermore, when measured to the nearest cm, abdominal circumference may not provide enough variation to use a rank-based cut-off. Ultimately, reducing the prevalence of at-risk piglets in the first place through alternative breeding goals would be a more sustainable route towards lowering pre-weaning mortality.

Abbreviations

95% CI
95% bootstrap quantile confidence interval
AC
abdominal circumference
AUC
area under the curve
BMI
body mass index
BW
body weight
CRL
crown-rump length
FPR
false-positive rate
GLMM
generalised linear mixed-effects model
LOLO-CV
leave-one-litter-out cross-validation
OR
odds ratio
PI
ponderal index
pp
post-partum
ROC-AUC
area under the receiver operating characteristic curve
SD
standard deviation
TPR
true-positive rate

Declarations

Ethics approval

Experimental work was authorised by the Teagasc Animal Ethics Committee (Approval no. TAEC0725-565).

Competing interest

The authors declare that they have no competing interests.

Funding

This work is supported by grant no. 2024-68014-42559 from the USDA National Institute of Food and Agriculture, Ireland's Department of Agriculture, Food and the Marine, and the Northern Ireland Department of Agriculture, Environment, and Rural Affairs as part of the US-Ireland Research and Development Partnership.

Author Contribution

SPB: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. CD: Investigation, Writing - Review & Editing. LAB: Conceptualization, Resources, Writing - Review & Editing, Supervision, Project administration, Funding acquisition.

Acknowledgement

We would like to sincerely thank all farm staff of the Teagasc Pig Research Facility for the care of the experimental animals.

Data Availability

The datasets generated and analysed during the current study are available in the Zenodo repository, [WILL BE MADE PUBLIC UPON PUBLICATION OF THE MANUSCRIPT].

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Figures

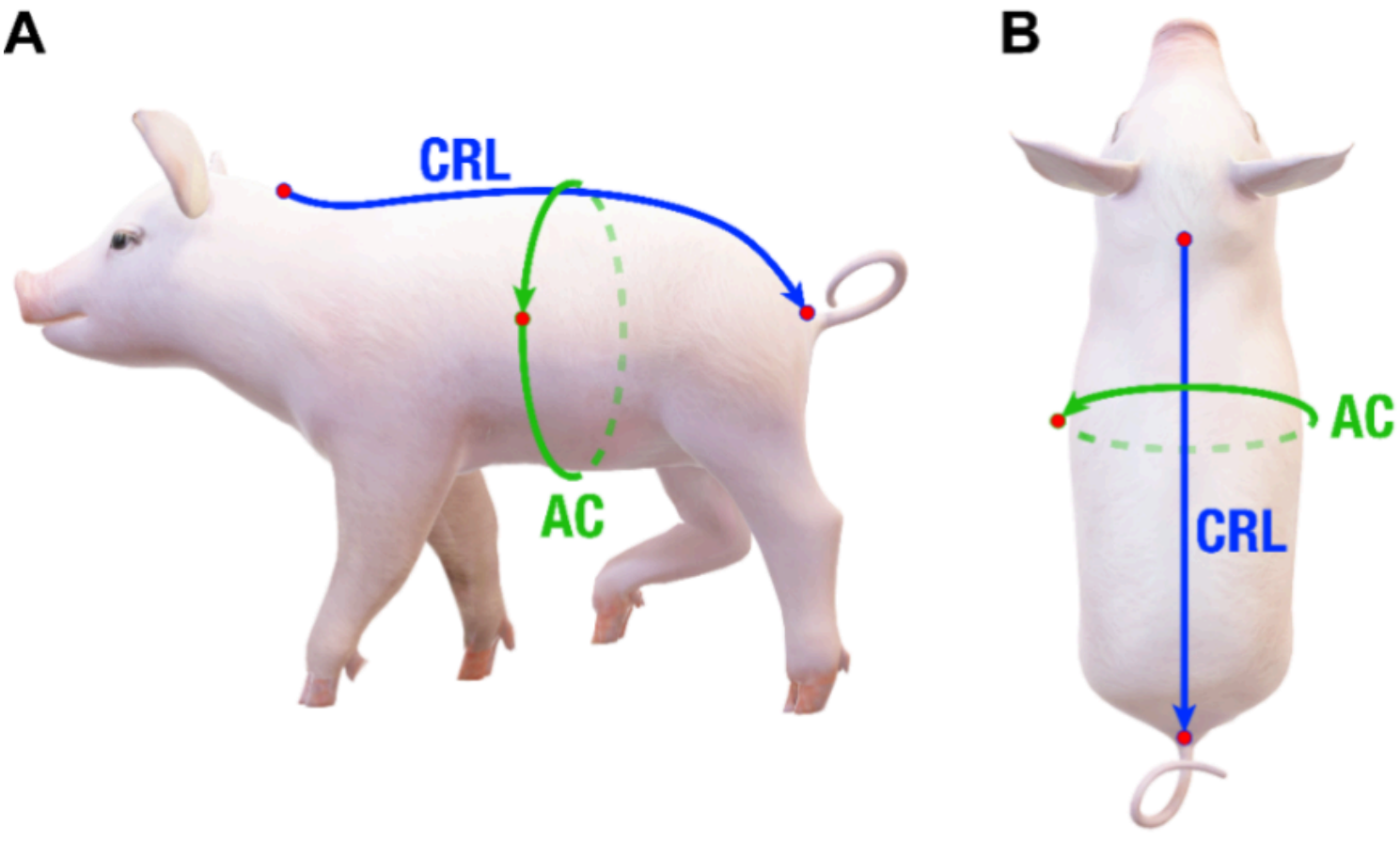


Figure 1

Piglet abdominal circumference and crown-rump length. 3D model "Piglet" by grs via Sketchfab (https://skfb.ly/ouROy), licensed under CC BY 4.0; rendered to 2D and annotated.

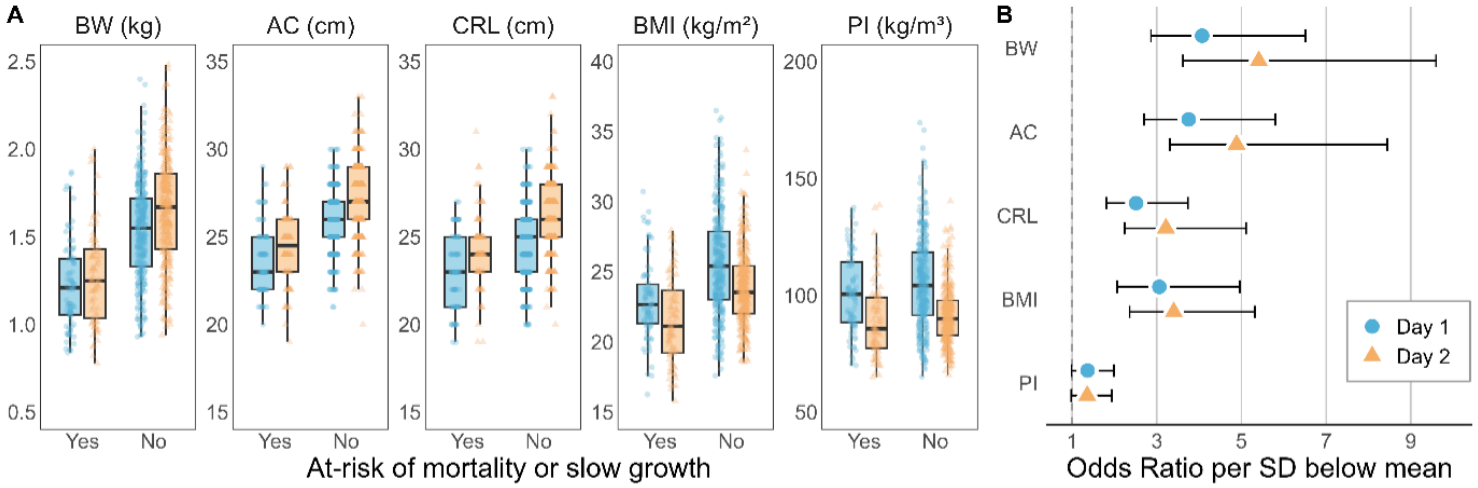


Figure 2

A – Distribution of morphometric measures at D1 and D2. **B** – Association between morphometric measures and risk status. GLMM estimated ORs (shapes) with 95% CI (error bars) per 1 SD decrease below the mean at D1 (blue ●) and D2 (orange ▲). A significant effect at the 0.05 level is indicated when the 95% CI of the OR does not include 1.

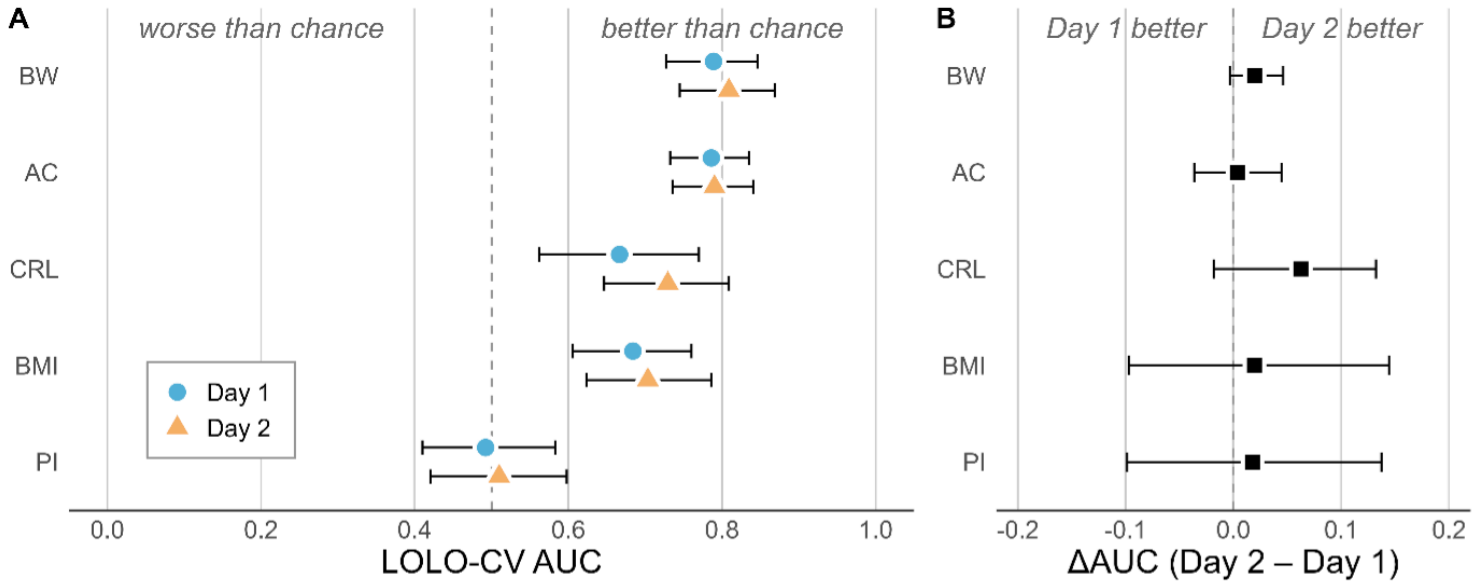


Figure 3

A – Per-measure LOLO-CV AUC (shapes) with 95% CI (error bars) for single-measure GLMMs at D1 (blue ●) or D2 (orange ▲). A significant effect at the 0.05 level is indicated when the 95% CI of the AUC does not include 0.5 (chance). **B** – Difference in AUC (ΔAUC; black ■) with 95% CI (error bars) between the D2 and D1 models (D2–D1; positive values favour D2). A significant effect at the 0.05 level is indicated when the 95% CI of the ΔAUC does not include 0.

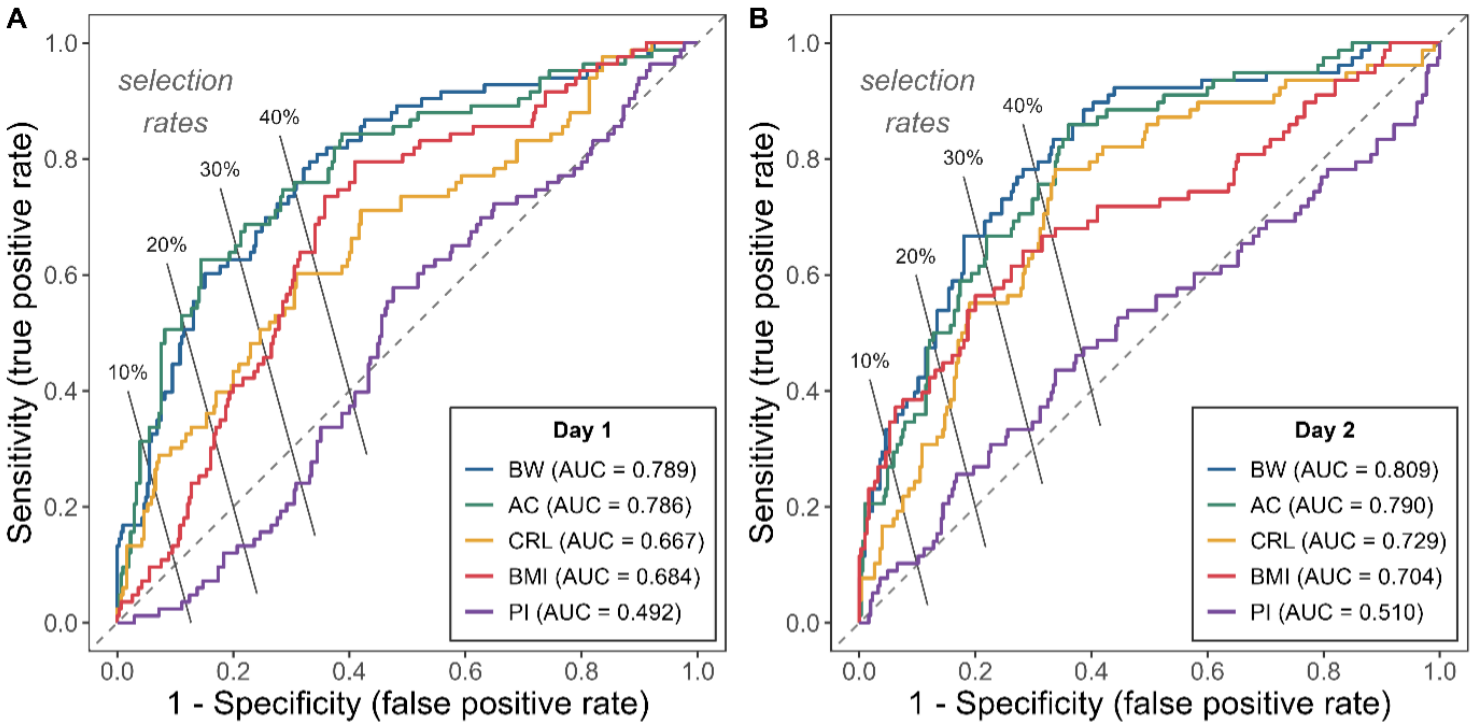


Figure 4

Discrimination of risk status by each measure at **A** – D1 and **B** – D2. Coloured lines represent pooled LOLO-CV ROC curves. The dashed diagonal represents chance (AUC 0.5). Solid diagonal grey lines mark the operating points at which the indicated fraction of all piglets is selected, at the observed at-risk prevalence (P = 0.21 at D1; P = 0.20 at D2).

Supplementary Files

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- supplementaryinformation.docx