Acta Agriculturae Scandinavica, Section A — Animal Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/saga20

Constructing a simulated udder for neonatal piglets as an alternative to nurse sows

Anna Hvid, Charlotte Amdi, Mogens Hinge & Vivi Aarestrup Moustsen

https://doi.org/10.1080/09064702.2023.2191601

Constructing a simulated udder for neonatal piglets as an alternative to nurse sows

Anna Hvid[a], Charlotte Amdi[a], Mogens Hinge[b] and Vivi Aarestrup Moustsen[c]

[a]Department of Veterinary and Animal Sciences, University of Copenhagen, Copenhagen, Denmark; [b]Department of Biological and Chemical Engineering, Aarhus University, Aarhus, Denmark; [c]SEGES Innovation, Aarhus, Denmark

ABSTRACT
An incubator with a simulated udder was constructed using information on piglet-sensory stimuli preferences. Neonatal piglets were randomly assigned to water in troughs ($n = 38$), milk-replacer ($n = 36$) or bovine-colostrum in simulated udder ($n = 39$). Weight was measured at 0, 0.5, 1, 2, 4, 6 and 8 hours, and rectal temperature at 0, 0.5, 1, 2 and 8 hours. An interaction between time and treatment affected weight change ($P < 0.001$), where all piglets lost weight during the first hour., Piglets with access to water continued loosing weight (82.1 ± 32.8 g over 8 h), milk-replacer-piglets gained 88.6 ± 53.2 g and bovine-colostrum-piglets gained 55.7 ± 66.5 g over 8 h. Overall, piglets with access to the simulated udder gained weight during their first eight hours postpartum. An interaction between temperature at first handling and time (P < 0.001) as well as an interaction between time and treatment ($P < 0.001$) affected temperature. Further development of the method could reduce the need for nurse sows.

ARTICLE HISTORY
Received 5 December 2022
Accepted 13 March 2023

KEYWORDS
Neonatal piglet; simulated udder; nutrition; milk replacer; bovine colostrum; weight gain

Introduction

Cross fostering and the use of nurse sows is a common practice in Danish pig production, as the size of most litters greatly exceeds the capacity of the sow (Moustsen & Nielsen, 2017; Hansen, 2021). However, this can create stress and decreased growth for the piglets due to increased fighting and decreased nutritional intake, as well as a longer lactation period for nurse sows, leading to increased production costs and possibly longer time in a crate (Robert & Martineau, 2001; Baxter et al., 2013). Piglets with poor opportunities to suckle the sow have increased risk of dying from starvation, crushing and hypothermia (Quesnel et al., 2012). Milk cups have been used to supply additional milk to litters, but are rarely used by piglets before seven days, and thus do not help the neonatal piglets in the first critical days (Sørensen, 2017; Kobek-Kjeldager et al., 2020).

Experiments testing for piglet preference of sensory stimuli revealed that piglets prefer a soft and warm udder, and that they learn to recognise the smell of their dam shortly postpartum (Welch & Baxter, 1986; Morrow-Tesch & McGlone, 1990a, 1990b; Parfet & Gonyou, 1991; Horrell & Hodgson, 1992). Sow vocalisations are important in suckling behaviour, and interruptions to this might disturb the suckling patterns of the piglets (Castrén et al., 1989; Algers & Jensen, 1991). Knowledge on neonatal piglet taste preference is scarce. The usage of visual stimuli is important in locating the udder, but seems to be limited in the search for a teat (Hartsock & Graves, 1976).

Simulated udders, with varying levers of udder mimicking qualities, have been tested in various setups, but have also proven hard to use for neonatal piglets, and have not been shown to be a better alternative to nurse sows due to lack of use, lacking hygiene and high labour intensity (Lecce, 1969; Jeppesen, 1981; Nielsen, 1995).

Therefore, the aim of the experiment was to utilise knowledge on piglet senses and suckling behaviour to construct a simulated udder that neonatal piglets would consider an alternative to the udder of their dam, and that they could suckle, as well as investigating their preference in nutritional source. The hypothesis was that the piglets could utilise the simulated udder to gain weight during their first hours postpartum, and could achieve a similar weight gain drinking bovine colostrum or milk replacer.

Materials and methods

Animals and housing

Experiments were conducted on a Danish conventional pig farm over the course of four weeks, with sows

CONTACT Charlotte Amdi vam@seges.dk

crated at farrowing. Pigs were DxLY crossbreed. The herd had 1600 annual sows and an average litter size of 18.4 liveborn piglets per litter. Piglets used in the study were removed from their dam immediately postpartum, as soon as they broke their umbilical cord. If this took more than a few minutes, the cords were broken manually before the piglets were removed. Piglets were only used if their birth weight was above 800 g, and they had not moved to the udder of the sow. The first three liveborn piglets in a litter were not used, as they were deemed important to the stimulation of colostrum secretion in the sow. Gender of piglet was not considered, and eligible piglets were allocated to treatments purely based on timing, with no regard to vitality or other factors. Parity of sow was recorded, but not considered at allocation of the piglets. Some sows provided piglets for more than one treatment. Each treatment held three piglets at a time, and these piglets were as close in birth time as possible, with no piglets within treatment being more than 15 minutes apart. There was no significant difference in weight or rectal temperature between groups at first handling (Table 1).

Experimental setup

The experiment was conducted using two incubators. One incubator measuring 90 × 56 × 38 cm, with three solid sides and one side with steel mesh, was used for bovine colostrum and milk replacer piglets. The incubator was split in two with a wooden board, housing three piglets on each side. A second incubator with three solid sides and one side with steel mesh, measuring 70 × 56 × 38 cm and also housing three piglets, was used for water piglets. Both incubators were placed in the pens of sows that had farrowed recently, with the steel mesh facing towards the crated sow. The bottoms of the incubators had a heating mat, and were covered in straw. The incubators were covered with moveable plexiglass lids to maintain temperature in the incubator. The incubator for colostrum and milk replacer piglets had a simulated udder mounted on the side facing the sow, on a wooden frame at a height of 15 cm from the bottom to the teat, not including the layer of straw. The simulated udder consisted of six concave udder components, moulded in silicone (hardness 30 Shore A). The udder components were dyed lightly pink, and each measured 14 × 10 cm. The teat part consisted of rubber tips from baby bottles (MAM, tip size 2) glued on using transparent silicone sealant, which created a hollow space within the tips. The udder components were mounted with rubber bands on a sponge for pliability. Two heating pads per udder component were placed between the udder component and the sponge (see Figure 1) and the udder components were heated to a surface temperature of 34.6°C. The incubator for water piglets had three troughs with water mounted on the steel mesh facing the sow (see Figure 1).

Tubes (diameter 8 mm) lead from the backside of the udder components, through the sponges and to the outside of the incubator with simulated udder. For the first half of the data collection, the liquid was stored in 300 mL plastic syringes, while the latter part of the data collection had tubes secured in the lid of 500 mL soda bottles. Plastic syringes and bottles were fastened on the front of the incubator with rubber bands. By keeping the liquid storage airtight, the slight negative pressure prevented the teats from leaking, while still ensuring air removal from the hollow space in the teat when a piglet had used the teat (see Figure 2).

Figure 1. The incubator with simulated udder, split in two for bovine colostrum and milk replacer piglets (left picture) and the incubator for water piglets with troughs (right picture), both seen from above.

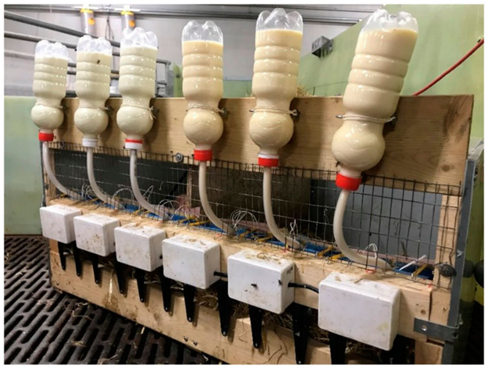

Figure 2. The front of the incubator with simulated udder, with milk replacer (white tint, left side of photo) and bovine colostrum (white with yellow tint, right side of photo), with liquid storage in bottles and wiring for heating pads in the white boxes.

Treatments, measurements and procedure

The experiment tested three feed options; bovine colostrum, milk replacer and water. Colostrum and milk replacer piglets had access to the simulated udder, while water piglets instead had access to water in troughs. Bovine colostrum was obtained from dairy cattle, and was primarily from the first 24 h after calving. Milk replacer was mixed from one part NutriMilk Premium E milk replacer powder (Nutrimin A/S, Denmark) and four parts water. Both colostrum and milk replacer were at room temperature when filled in bottles. Bottles were filled at the start of an experiment, and were refilled if necessary. One udder component or bottle was not completely airtight, resulting in slight leakage. Straw in the incubators was changed if wet, and water in troughs was changed if dirtied.

The start of an experiment for one treatment group was initiated by collecting three eligible piglets of close birth time. Piglets were weighed on a scale with ± 1 g accuracy (Bjerringbro Vægte ApS, Denmark) and had rectal temperature measured with a thermometer with ± 0.1°C accuracy (Omron FlexTemp Smart thermometer) as soon as they broke the umbilical cord. Time from birth to time of first handling, when the piglets were weighed and had their temperature taken, was around 2–5 min, depending on time for umbilical cord breakage. A number was drawn on their backs with a marking stick and piglets were then placed in their assigned incubator. At 30 minutes and one hour from first handling, piglets were weighed and had their temperature measured. Thereafter, measuring times were standardised after the piglet in the incubator with the earliest time of first handling. Piglets were weighed at two, four, six and eight hours, and rectal temperatures were measured at two and eight hours. Once an experiment ended, piglets were returned to a farrowing sow. For experiments taking place in the latter two weeks of the experimental period, the amount of colostrum or milk replacer was measured at the beginning, every time a bottle was refilled and at the end. The total volume used for each experiment was calculated.

Piglets in the simulated udder treatments received training if they were not observed to use the teats by placing the piglets' snout on the teat, or by allowing the piglet to suckle a finger that was then quickly switched with the teat. Training sessions took between two and five minutes, depending on the piglets. When a piglet was observed suckling from the simulated udder, or when it had gained weight compared to its previous weighing, it received no further training. Most rounds had one to three training sessions before all three piglets had learned to use the simulated udder, and around half the piglets started using the simulated udder before any training was done.

Milk, water and straw were changed between each round, while the entire setup was dismounted and washed after two rounds. As colostrum proved to aggregate quicker in the tubes, most rounds with milk replacer were performed first, and rounds with colostrum were performed after, preventing potential aggregation from interfering with the milk flow.

Statistical data analysis

Data were analysed in R version 4.1.2. A significance level of $P < 0.05$ was used for statistical significance, while $P < 0.1$ was considered a statistical tendency. Effects that were not statistically significant were omitted from the models. The weight of the piglets at first handling was categorised into three groups; 'small' (800–1025 g), 'medium' (1026–1350 g) and 'large' (<1350 g). Each piglet in the experiment was analysed as an experimental unit. One piglet was omitted from the data, as it tore off its umbilical cord prematurely.

Two models were constructed to assess the data, one for bodyweight change and one for rectal temperature. For bodyweight, the primary response variable was weight change (numeric), while weight group at first handling (factorial), time (factorial), treatment (factorial), piglet (factorial) and parity of the sow (factorial) were explanatory variables. Weight change referred to change in weight between two consecutive points of times, and was not pooled over time. Weight group at first handling, time and treatment were included as fixed effects, while piglet and parity of the sow were included as random effects. For rectal temperature, the primary response variable was temperature (numerical), while temperature at first handling (numerical), treatment (factorial), time (factorial) and piglet (factorial) were explanatory variables. Temperature at first handling, treatment and time were included as fixed effect, while piglet was a random effect.

As the data were expected to show a progression over time, the initial was linear mixed effect models with the serial correlation structure. These allow both fixed and random effects and assume a Gaussian serial correlation structure. Model reductions were done by systematically reducing the models and testing against the previous model using 'anova', and evaluating the models based on *p*-values and AIC-values. The final models were linear mixed effects models with both fixed and random effects, using 'lmer' (lme4 package). To acquire estimates, 'emmeans' (emmeans package) was used. Estimates were Tukey Kramer adjusted. Results from the models were presented as estimated means ± SEM (Standard error of the mean). Model validation plots consisted of residual plots and QQ plots, and did not reject the assumption of normal distribution and variance homogeneity.

The initial model for bodyweight development was a linear mixed effects model with a serial correlation structure:

$$Y_{ijklmn} = \alpha_i + \beta_j + \gamma_k + \delta_{ij} + \epsilon_{ik} + \zeta_{jk} + \eta_{ijk} + A_l + B_m + D_n + e_{ijklmn} \quad (1)$$

where Y_{ijklmn} is the response variable weight change, α_i is the fixed effect of weight group at first handling, β_j is the fixed effect of time (j = 0.5, 1, 2, 4, 6, 8), γ_k is the fixed effect of treatment (k = Water, Milk replacer, Colostrum), δ_{ij} is the interaction between weight group at first handling (i) and time (j), ϵ_{ik} is the interaction between weight group at first handling (i) and treatment (k), ζ_{jk} is the interaction between time (j) and treatment (k), η_{ijk} is the interaction between weight group at first handling (i), time (j) and treatment (k), A_l is the random effect of parity of the sow (l = 1, 2, 3, 4, 5, 8), B_m is the random effect of piglet (m = 1, 2 … , 113), D_n is the Gaussian serial correlation structure and $e_{ijklmn} \sim N(0, \sigma^2)$ is the random error component.

Through model reduction, the final model for bodyweight development was found to be a linear mixed effects model:

$$Y_{jkm} = \beta_j + \gamma_k + \zeta_{jk} + B_m + e_{jkm} \quad (2)$$

where Y_{jkm} is the response variable weight change and $e_{jkm} \sim N(0, \sigma^2)$ is the random error component. No significant effect was found in the interaction between weight group at first handling (i) and time (j), of the interaction between weight group at first handling (i) and treatment (k), of the interaction between weight group at first handling (i), time (j) and treatment (k), of parity of the sow or of a Gaussian serial correlation structure.

The initial model for rectal temperature development was a linear mixed effects model with the serial correlation structure:

$$Y_{ijklm} = \alpha_i + \beta_j + \gamma_k + \delta_{ij} + \epsilon_{ik} + \zeta_{jk} + \eta_{ijk} + A_l + D_m + e_{ijklm} \quad (3)$$

where Y_{ijklm} is the response variable rectal temperature, α_i is the fixed effect of temperature at first handling, β_j is the fixed effect of time (j = 0, 0.5, 1, 2, 8), δ_{ij} is the interaction between temperature at first handling and time (j), ϵ_{ik} is the interaction between temperature at first handling and treatment (k), ζ_{jk} is the interaction between time (j) and treatment (k), η_{ijk} is the interaction between temperature at first handling, time (j) and treatment (k), A_l is the random effect of piglet (l = 1, 2 … , 113), D_m is the Gaussian serial correlation structure and $e_{ijklm} \sim N(0, \sigma^2)$ is the random error component.

Through model reduction, the final model for rectal temperature was found to be a linear mixed effects model:

$$Y_{ijkl} = \alpha_i + \beta_j + \gamma_k + \delta_{ij} + \zeta_{jk} + A_l + e_{ijkl} \quad (4)$$

where Y_{ijkl} is the response variable rectal temperature and $e_{ijkl} \sim N(0, \sigma^2)$ is the random error component. No significant effect was found in the interaction between temperature at first handling and treatment, of the interaction between temperature at first handling, time and treatment or of a Gaussian serial correlation structure.

Results

Measurements of used liquid volume during the eight hours of experiment showed that in the incubator with milk replacer (measured for seven groups) the amount used averaged 2.52 ± 0.69 L per group of three piglets, while the incubator with bovine colostrum (measured for nine groups) averaged 2.31 ± 0.80 L per group of three piglets.

Weight change

On average, piglets with access to water lost 82.1 ± 32.8 g during their first eight hours of life, while piglets with access to milk replacer gained 88.6 ± 53.2 g and piglets with access to colostrum gained 55.7 ± 66.5 g. During the eight hours the piglets spent in their incubator, one piglet out of 38 piglets (2.6%) with access to water gained weight compared to their initial weight.

Of piglets with access to milk replacer, 34 out of 36 piglets (94.4%) gained weight. The two remaining piglets which did not overall gain weight still gained weight between six and eight hours. For piglets with access to bovine colostrum, 32 out of 39 piglets (82.1%) gained weight during the eight hours. Six of the remaining piglets still gained weight between four and six hours and/or six and eight hours. Weight of the piglets was measured at seven points of time. Individual weight developments are shown in Figure 3, while mean weights and SEM for each treatment is shown in Figure 4.

Using the weight change of the piglets with access to water as a baseline for weight development in piglets with no nutritional intake, piglets with access to milk replacer increased their weight with a total of 170.7 ± 73.6 g while piglets with access to bovine colostrum increased their weight with a total of 137.8 ± 55 g during their eight hours in the incubator.

Weight change was found to be significantly affected by the interaction between time and treatment ($P < 0.001$). During the first hour, all piglets tended to lose weight, regardless of treatment. Hereafter, both piglets with access to milk replacer and colostrum would gain weight, while piglets with access to water continued to lose weight. Estimates for weight developments are shown in Table 2.

No significant effect was found in the interaction between weight group at first handling, time and treatment ($P = 0.979$), of the interaction between weight group at first handling and time ($P = 0.139$), of weight group at first handling ($P = 0.725$), of parity ($P = 0.517$) or of a Gaussian serial correlation structure ($P = 1.0$). The interaction between weight group at first handling and treatment was found to be a statistical tendency ($P = 0.051$).

There were no significant differences in weight change between treatment groups at 30 minutes or one hour. At two hours, the water treatment was significantly lower than both the milk replacer treatment ($P < 0.001$) and the colostrum treatment ($P < 0.001$), but no significant difference between the milk replacer and colostrum treatments ($P = 0.351$). At four hours, all treatments were significantly different, with the water treatment being lower than both the milk replacer treatment ($P < 0.001$) and the colostrum treatment ($P < 0.001$), and the colostrum treatment being lower than the milk replacer treatment ($P = 0.043$). Similarly, for both six and eight hours, the water treatment was significantly lower than both the milk replacer treatment (both times $P < 0.001$) and the colostrum treatment (both times $P < 0.001$). There was no significant difference in weight change between the milk replacer and colostrum treatments at neither six ($P = 0.428$) or eight hours ($P = 0.990$).

Rectal temperature development

Rectal temperature of the piglets was measured at five points of time. Individual temperature developments

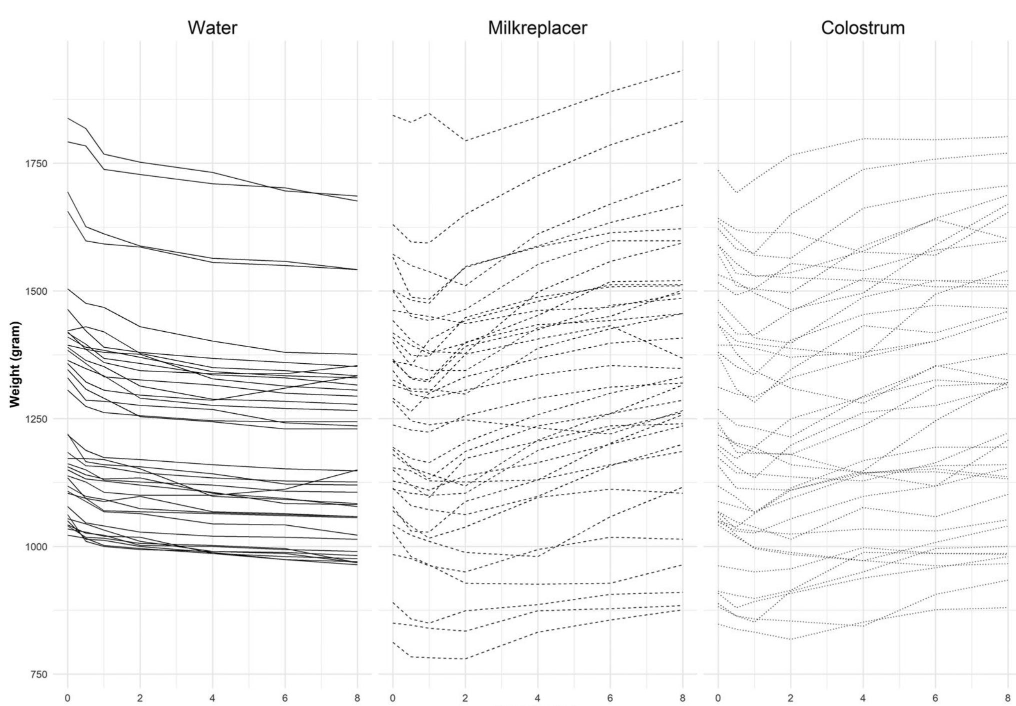

Figure 3. Individual weights of each piglet measured at 0, 0.5, 1, 2, 4, 6 and 8 h after first handling, divided by treatments.

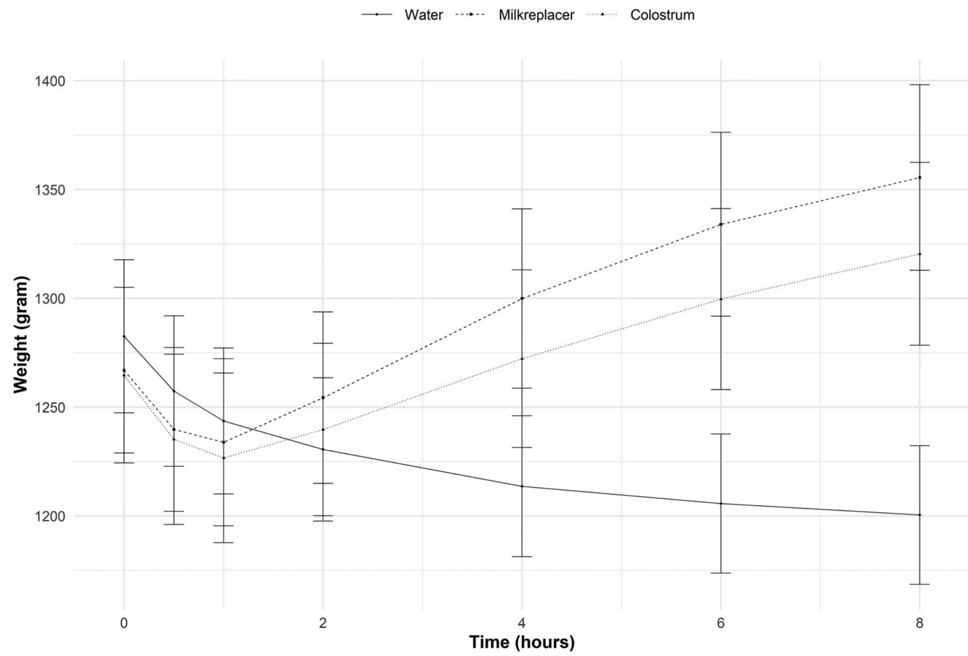

Figure 4. Average weights and SEM of piglets measured at 0, 0.5, 1, 2, 4, 6 and 8 h after first handling for each treatment.

are shown in Figure 5, while mean temperatures and SEM for each treatment are shown in Figure 6.

Temperature was found to be affected by the interaction between time and treatment ($P < 0.001$), as well as the interaction between temperature at first handling and time ($P < 0.001$). Temperature would decrease shortly postpartum regardless of treatment, with the temperature at 30 minutes often being the lowest point. Hereafter, temperatures increased again. Estimates of temperatures are shown in Table 3. As the model included the temperature at first handling, these estimates assumed a temperature at first handling of 36.5°C (mean of all piglets in the experiments).

Table 1. Number of sows and piglets used in the experiment and uncorrected averages for parity of sows and for piglet weight and rectal temperature at first handling, presented as mean ± SEM.

Treatment	Water	Milk replacer	Colostrum	Total
Number of piglets	38	36	39	113
Number of sows[a]	18	17	23	42
Parity of sow	3.1 ± 1.9	3.1 ± 1.2	3.5 ± 1.4	3.2 ± 1.6
Weight at first handling (g)	1283 ± 214	1267 ± 226	1265 ± 249	1271.4 ± 230.2[b]
Rectal temperature at first handling (°C)	36.4 ± 1.5	36.4 ± 1.7	36.8 ± 1.6	36.5 ± 1.6[c]

[a]Some sows provided several piglets, often for more than one treatment.
[b]$P = 0.998$ (based on a Kruskal-Wallis test testing whether samples originate from the same distribution).
[c]$P = 0.558$ (based on a Kruskal-Wallis test whether samples originate from the same distribution).

No significant effect was found of the interaction between temperature at first handling, time and treatment ($P = 0.307$), of the interaction between temperature at first handling and treatment ($P = 0.429$) or of a Gaussian serial correlation structure ($P = 1.0$).

There was no significant difference in rectal temperature between treatment groups at 30 minutes. The water treatment was significantly higher than the milk replacer treatment at one hour ($P = 0.043$). At two hours, the milk replacer treatment was significantly lower than both the colostrum treatment ($P = 0.002$) and the water treatment ($P = 0.004$). At eight hours, the water treatment was significantly lower than both the milk replacer treatment ($P = 0.001$) and the colostrum treatment ($P < 0.001$), but the milk replacer and colostrum treatments were not significantly different.

Table 2. Estimated marginal means for bodyweight change (g) from previous weight, based on treatment and time. SEM for water estimates is 3.8, SEM for milk replacer estimates is 3.9 and SEM for bovine colostrum estimates is 3.75.

	Water	Milk replacer	Colostrum
30 min	−25.16	−27.22	−29.49
1 h	−13.74	−5.89	−8.51
2 h	−13.05[a]	+20.50[b]	+13.03[b]
4 h	−16.95[a]	+45.56[b]	+32.56[c]
6 h	−7.95[a]	+34.11[b]	+27.38[b]
8 h	−5.26[a]	+21.50[b]	+20.77[b]

a, b, c: Values within a row with different superscript letters were significantly different between means ($P < 0.05$).

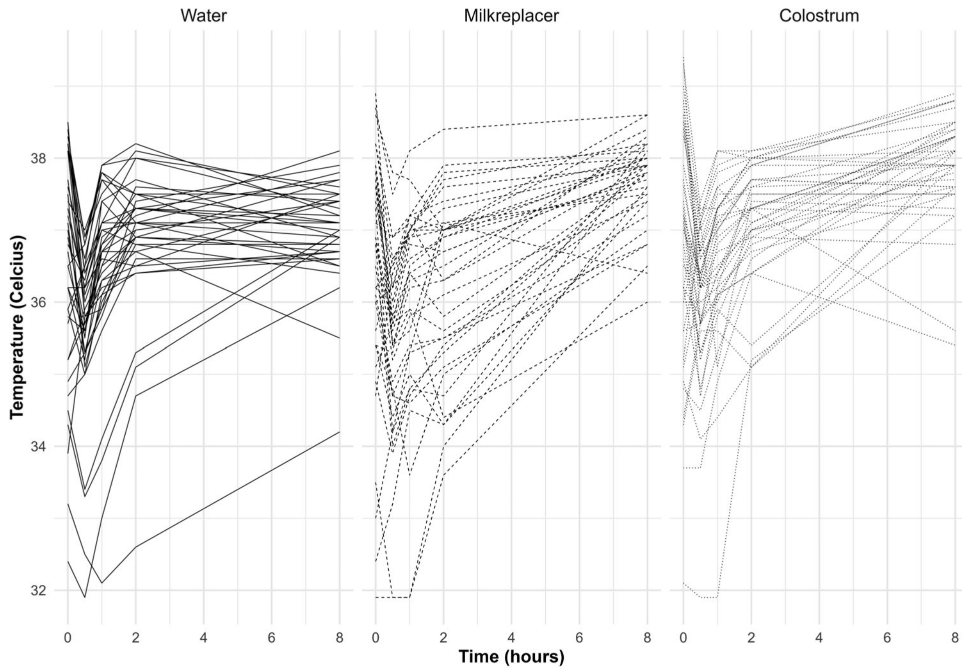

Figure 5. Individual temperatures of each piglet measured at 0, 0.5, 1, 2 and 8 h after first handling, divided by treatments.

Discussion

The simulated udder with its sensory stimuli fulfilled the aim of attracting piglets to suckle and gain weight when offered either bovine colostrum or milk replacer in the simulated udder. In addition, the experimental setup tested the different nutritional supplements of neonatal piglets by offering either bovine colostrum or milk replacer.

For the first hour, both piglets with access to bovine colostrum and milk replacer lost weight at a similar rate as piglets with access to water. However, hereafter almost all piglets with access to bovine colostrum and milk replacer started using the simulated udder, with 10.7% gaining weight between half an hour and one hour, and 53.4% gaining weight between one and two hours. This was in accordance with Castrén et al. (1991), who found that 69% of piglets gained weight between one and two hours postpartum when suckling their dam. In total, piglets with access to milk replacer gained an average of 88.8 g and piglets with access to bovine colostrum gained an average of 55.7 g. These results are comparable to those of Castrén et al. (1991), who found that sow reared piglets gained 96 g in their first eight hours, and to the findings of Amdi et al. (2013), who found an average gain over 12 hours of 96 g (i.e. 64 g in 8 hours, assuming an equal hourly intake). Based on these comparisons, it seems that the piglets suckling the simulated udder can achieve similar weight gains in their first eight hours as sow reared piglets.

Assuming density of both milk replacer and colostrum of 1 kg/l, the used volume per piglet was an average of 840 g milk replacer and 770 g colostrum during their eight hours stay in the incubator. Compared to the recommendation of Quesnel et al. (2012) of a 250-g intake per 24 h, the used volume in this study comes from both intake by the piglets and leakage from the udder components, as well as liquid being squirted from the udder components when piglets nuzzled at the teats. The actual intake was thus lower than the calculated amount. The piglets with access to water used as control lost weight very consistently, and it is therefore safe to assume that they provide a reliable baseline with which the weight gain results of piglets with access to milk replacer or bovine colostrum can be compared. This highlights that piglets with access to the simulated udder who gained weight have ingested enough nutrition to both negate the expected weight loss of piglets with no nutritional intake and gain weight during their eight hours in the incubator.

Data on temperature development showed that although milk replacer piglets had a significantly lower temperature than colostrum piglets at two hours (right around or shortly after most piglets started to drink), at eight hours, both colostrum and milk replacer piglets had a significantly higher temperature than water piglets, presumably because they had ingested nutrition. Xiong et al. (2018) found rectal temperature of piglets to be 38.7°C, 33.6°C, 34.4°C and 35.9°C at 0, 0.5, 1 and 2 h postpartum, showing a similar initial

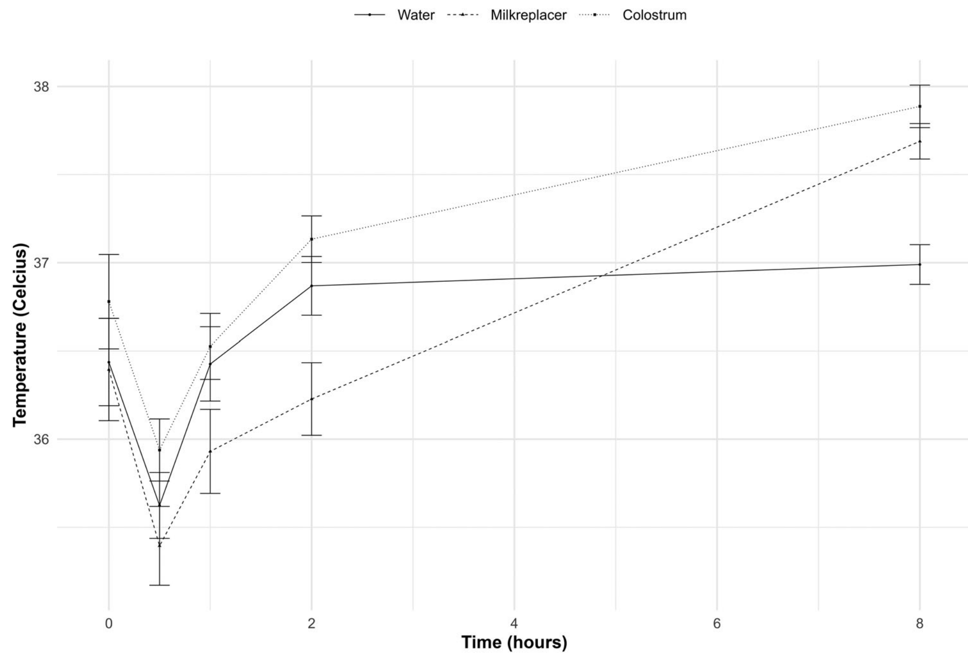

Figure 6. Mean temperatures and SEM measured at 0, 0.5, 1, 2 and 8 h after first handling, divided by treatments.

drop and gradual recovery in temperature immediately postpartum as observed in this study.

The success of the simulated udder can be seen as a strong indicator that the sensory stimuli presented by the simulated udder are important to the piglets in suckling shortly postpartum. Given the need for nutrition shortly postpartum, piglets do not have time to gradually learn how to locate the udder, but rather, must find the udder quickly guided by innate instincts. This simulated udder construction primarily made use of tactile and visual stimuli, and the placement in the pen allowed auditory stimuli. The final setup did not make use of olfactory stimuli mimicking the smell of the sow's udder. However, there might have been olfactory stimuli from the milk replacer and cow colostrum compared to the water. Gustatory stimuli (and possibly olfactory stimuli) preference by using two different sources of nutrition was included in the trial. As the simulated udder was considered a success, this implies that the main attractants to a simulated udder is warm and soft properties of the udder, a shaping of the udder that somewhat resembled an actual udder, as well as teats that were easy to suckle. This is in accordance with findings of Welch & Baxter (1986), who found that piglets preferred warm and soft surfaces over cold and hard surfaces, and of Tanaka et al. (1998) who found that visual stimuli were important in guiding the piglet to the udder. Although shown as important by Morrow-Tesch and McGlone (1990a), among others, olfactory stimuli were not included in the final experimental setup.

Table 3. Estimated marginal means for rectal temperature, based on treatment and time. Estimates assumed a temperature at first handling of 36.5°C. SEM for water estimates is 0.138, SEM for milk replacer estimates is 0.142 and SEM for colostrum estimates is 0.137.

	Water	Milk replacer	Colostrum
At first handling	36.5°C	36.5°C	36.5°C
30 min	35.7°C	35.5°C	35.8°C
1 h	36.5°C[a]	36.0°C[b]	36.4°C[ab]
2 h	36.9°C[a]	36.3°C[b]	37.1°C[a]
8 h	37.0°C[a]	37.7°C[b]	37.9°C[b]

a, b, c: Values within a row with different superscript letters were significantly different between means ($P < 0.05$).

Auditory stimuli were present in the form of sow grunting. Although not quantifiably assessed, observations of the piglets suggested that they were often active around the teats when the sow was grunting to her litter, but that they also suckled outside grunting times, especially when they had learned how to suckle the simulated udder. The effect of sow grunting is in accordance with findings of Castrén et al. (1989), who found more suckling related activity at the udder when sow grunt rates were high.

Training of the piglets to use the simulated udder seemed to take slightly longer for colostrum piglets compared with milk replacer piglets. This, in addition to the higher weight gain of the milk replacer piglets, suggests that the piglets were slightly more interested in ingesting milk replacer than colostrum, probably due to differences in taste (and possibly smell from drink leakage). This assumption is further supported by the liquid usage quantity being higher for milk replacer than colostrum, although leakage of udder components resulted in some uncertainty.

The teats seemed to be adequately functional and easy for the piglets to suckle. Some piglets needed a bit of training to learn how to use the simulated udder, but most piglets were quick to learn once they got their first taste of the milk. However, the design of the incubator did not provide a clear path for the piglets to follow to the teats of the simulated udder. Observations of udder seeking behaviour immediately postpartum suggests that piglets follow the outline of the sow, which was not possible for the piglets in the incubator (Welch & Baxter, 1986). Instead, these piglets had to either come across the teats by accident while moving around in the incubator, or actively approach the simulated udder, presumably guided by sight. Grunting of the sow might have helped draw piglets to the front of the incubator where the simulated udder was located, similarly to how the grunting draws piglets to the udder (Castrén et al., 1989). As a pen is even bigger than an incubator, piglets reared by the sow with supplementary nutrition might struggle even more to locate the supplementary option. Similarly, the dimensions of the udder components allowed piglets to both burrow beneath the simulated udder and attempt to climb on top of it to look out at the sow. As the sow is much larger than the piglets, she also presents more of a 'solid' wall for the piglets, that does not encourage piglets to attempt to pass neither over or under. This could have hindered some piglets in their usage of the simulated udder, as they might have found it hard to locate or were distracted by the possibility of passing it.

The use of this simulated udder seems promising, but there are still many facets that are yet to be investigated. The current experiment lasted the first eight hours postpartum and removed the piglets completely from the sow during this period, but for this to be a viable solution for implementation on a larger scale, the effects beyond eight hours need to be equally positive. Similarly, a more effective solution would have the simulated udder placed in the pen where piglets could access both the sow's udder and the simulated udder. This would allow piglets to suckle the sow's udder as much as they can and want, and supplement with milk from the simulated udder if necessary. However, this raises the question whether the piglets can use both, as the two options are, after all, not fully similar. Piglets might commit to one udder once they have tried it, and keep trying to use this udder instead of searching for an alternative if needed. Results by Kobek-Kjeldager et al. (2020) showed that when offered milk replacer in cups while at the sow, only a portion of piglets used both, while others used either one or the other. The piglets that used the cups were often the bigger ones which used the extra nutrition for increased growth, but the smaller piglets, which arguably needed it the most to lower risk of mortality, did not use the milk cups as much as hoped (Kobek-Kjeldager et al., 2020). Providing milk in a simulated udder for neonatal piglets at the sow might prove to follow a similar tendency. Additionally, a bigger litter size could be thought to increase fighting between piglets, as establishing a teat order would become more complicated when there are more piglets than functional teats.

Another struggle of using simulated udders presents itself as the choice of liquid offered, keeping both piglet taste preferences and nutritional value in mind. This study found that both milk replacer and bovine colostrum were acceptable to the piglets as an alternative to porcine colostrum, but that piglets may have preferred milk replacer over bovine colostrum, presumably due to differences in taste (and possibly smell from drink leakage). One of the main features of porcine colostrum is the immunoglobulin content that aids the piglet in passive immunisation (Devillers et al., 2011). These immunoglobulins are not present in milk replacer, while bovine colostrum does contain immunoglobulins, and piglets reared on bovine colostrum exhibit similar immune responses as sow reared piglets (Sugiharto et al., 2015). If milk replacer, which today does not contain immunoglobulins, is used in the simulated udder, piglets that primarily or exclusively use the simulated udder postpartum will miss a vital element that may leave them vulnerable to disease. It would seem that both milk replacer and bovine colostrum can be used as a viable alternative to porcine colostrum, but that they might pose challenges such as diarrhoea, lowered weight gain and lack of immunoglobulins for passive immunisation, suggesting further research on nutrient and immunoglobulin content in porcine colostrum alternatives is needed (De Vos et al., 2014; Sugiharto et al., 2015). Methods for future usage of the simulated udder could include piglets having access to both a sow and the simulated udder, as well as milk alternatives with a nutritional profile and immunoglobulin content that more closely mimics that of porcine colostrum than what is currently available.

The simulated udder was promising in terms of weight gain and rectal temperature; however, it was the first usage of this constructed udder, and there is a need for further research to make the udder applicable at large scale in commercial sow herds. This would include experiments with a larger time frame, to establish the effects on a longer term than eight hours, as well as experiments on how best to rear piglets with access to a simulated udder in the pen with their dam.

Conclusions

This experiment was successful in constructing a simulated udder that motivated neonatal piglets to suckle almost immediately postpartum. The simulated udder made use of visual stimuli (colour, shaping), tactile stimuli (warm surface, soft and pliable udder) and auditory stimuli (grunting from a nursing sow) to mimic the udder of a real sow. Weight change was affected by time and treatment, while temperature was affected by time, treatment and temperature at first handling. Piglets offered both milk replacer and colostrum from the simulated udder gained weight during their first eight hours compared to piglets with access to water, which lost weight. Results for weight gain were similar for bovine colostrum and milk replacer, although milk replacer piglets gained significantly more weight at four hours than colostrum piglets. Water piglets had a lower rectal temperature at eight hours, compared to colostrum and milk replacer piglets.

Acknowledgements

The authors acknowledge the staff at Overgaard Gods for helping with the pigs and the trial. In addition, Mathilde Tordrup Bach (Aarhus University) and Ann Freja Mørch Jensen (SEGES Innovation P/S), who helped during the experiment, and Jeanett Snitgaard Pelck (statistician, SEGES Innovation P/S) are acknowledged.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The authors declare that funding was received from the Danish Pig Levy Foundation, and that V.A.M. works for the SEGES Innovation P/S.

Data availability statement

Data is available on request.

References

Algers, B. & Jensen, P. (1991). Teat stimulation and milk production during early lactation in sows: effects of continuous noise. *Canadian Journal of Animal Science*, 71, 51–60. doi:10.4141/cjas91-006

Amdi, C., Krogh, U., Flummer, C., Oksbjerg, N., Hansen, C. & Theil, P. (2013). Intrauterine growth restricted piglets defined by their head shape ingest insufficient amounts of colostrum. *Journal of Animal Science*, 91, 5605–5613. doi:10.2527/jas.2013-6824

Baxter, E., Rutherford, K., Arnott, G., D'Eath, R., Turner, S., Jarvis, S., Sandøe, P., Moustsen, V., Thorup, F., Edwards, S. & Lawrence, A. (2013). The welfare implications of large litter size in the domestic pig II: Management factors. *Animal Welfare*, 22, 219–238. doi:10.7120/09627286.22.2.219

Castrén, H., Algers, B., Jensen, P. & Saloniemi, H. (1989). Suckling behaviour and milk consumption in newborn piglets as a response to sow grunting. *Applied Animal Behaviour Science*, 24, 227–238. doi:10.1016/0168-1591(89)90069-5

Castrén, H., Algers, B. & Saloniemi, H. (1991). Weight gain pattern in piglets during the first 24 h after farrowing. *Livestock Production Science*, 28, 321–330. doi:10.1016/0301-6226(91)90013-G

Devillers, N., Le Dividich, J. & Prunier, A. (2011). Influence of colostrum intake on piglet survival and immunity. *Animal*, 5, 1605–1612. doi:10.1017/S175173111100067X

De Vos, M., Huygelen, V., Willemen, S., Fransen, E., Casteleyn, C., Van Cruchten, S., Michiels, J. & Van Ginneken, C. (2014). Artificial rearing of piglets: effects on small intestinal morphology and digestion capacity. *Livestock Science*, 159, 165–173. doi:10.1016/j.livsci.2013.11.012

Hansen, C. (2021). Notat nr. 2115: Landsgennemsnit for produktivitet i produktionen af grise i 2020, available at: https://svineproduktion.dk/Publikationer/Kilder/Notater/2021/2115.

Hartsock, T. G. & Graves, H. B. (1976). Neonatal behavior and nutrition-related mortality in domestic swine. *Journal of Animal Science*, 42, 235–241. doi:10.2527/jas1976.421235x

Horrell, I. & Hodgson, J. (1992). The bases of sow-piglet identification. 2. Cues used by piglets to identify their dam and home pen. *Applied Animal Behaviour Science*, 33, 329–343. doi:10.1016/S0168-1591(05)80070-X

Jeppesen, L. E. (1981). An artificial sow to investigate the behaviour of sucking piglets. *Applied Animal Ethology*, 7, 359–367. doi:10.1016/0304-3762(81)90062-6

Kobek-Kjeldager, C., Moustsen, V. A., Theil, P. K. & Pedersen, L. J. (2020). Effect of large litter size and within-litter differences in piglet weight on the use of milk replacer in litters from hyper-prolific sows under two housing conditions. *Applied Animal Behaviour Science*, 230, 105046. doi:10.1016/j.applanim.2020.105046

Lecce, J. G. (1969). Rearing colostrum-free pigs in an automatic feeding device. *Journal of Animal Science*, 28, 27–33. doi:10.2527/jas1969.28127x

Morrow-Tesch, J. & McGlone, J. J. (1990a). Sensory systems and nipple attachment behavior in neonatal pigs. *Physiology & Behavior*, 47, 1–4. doi:10.1016/0031-9384(90)90034-2

Morrow-Tesch, J. & McGlone, J. J. (1990b). Sources of maternal odors and the development of odor preferences in baby pigs. *Journal of Animal Science*, 68, 3563–3571. doi:10.2527/1990.68113563x

Moustsen, V. A. & Nielsen, M. B. F. (2017). Meddelelse nr. 1117: Mælkekirtler og patter på danske søer, available at: https://svineproduktion.dk/publikationer/kilder/lu_medd/2017/1117.

Nielsen, N.-P. (1995). Notat nr. 9520: Ammesoen "Rosa", available at: https://svineproduktion.dk/publikationer/kilder/notater/notater/9520.

Parfet, K. A. & Gonyou, H. W. (1991). Attraction of newborn piglets to auditory, visual, olfactory and tactile stimuli. *Journal of Animal Science*, 69, 125–133. doi:10.2527/1991.691125x

Quesnel, H., Farmer, C. & Devillers, N. (2012). Colostrum intake: influence on piglet performance and factors of variation. *Livestock Science*, 146, 105–114. doi:10.1016/j.livsci.2012.03.010

Robert, S. & Martineau, G. P. (2001). Effects of repeated cross-fosterings on preweaning behavior and growth performance of piglets and on maternal behavior of sows1. *Journal of Animal Science*, 79, 88–93. doi:10.2527/2001.79188x

Sørensen, T. S. (2017). Meddelelse nr. 1111: Pattegrises brug af mælkekopper, available at: https://svineproduktion.dk/publikationer/kilder/lu_medd/2017/1111.

Sugiharto, S., Poulsen, A.-S. R., Canibe, N. & Lauridsen, C. (2015). Effect of bovine colostrum feeding in comparison with milk replacer and natural feeding on the immune responses and colonisation of enterotoxigenic Escherichia coli in the intestinal tissue of piglets. *British Journal of Nutrition*, 113, 923–934. doi:10.1017/S0007114514003201

Tanaka, T., Ochiai, N., Tanida, H. & Yoshimoto, T. (1998). The role of visual, auditory, and olfactory stimuli in teat seeking behavior of piglets. Animal Science and Technology (Japan), available at: https://web.archive.org/web/20181031070608id_/https://www.jstage.jst.go.jp/article/chikusan1924/69/9/69_9_854/_pdf.

Welch, A. R. & Baxter, M. R. (1986). Responses of newborn piglets to thermal and tactile properties of their environment. *Applied Animal Behaviour Science*, 15, 203–215. doi:10.1016/0168-1591(86)90091-2

Xiong, Y., Gates, R., Cooper, N. & Ellis, M. (2018). Neonatal piglet core body temperature model from surface temperature and environment measurements, available at: https://www.researchgate.net/publication/327812130_Neonatal_Piglet_Core_Body_Temperature_Model_from_Surface_Temperature_and_Environment_Measurements.