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Postpartum meloxicam administration to sows but not split-suckling increases piglet growth and reduces clinical incidence of disease in suckling piglets

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Abstract

Each suckling pig should receive ≥ 200 g of colostrum within the first 24 h of life, but with increased litter size this is now difficult to achieve. The aim of this study was to assess the effect of split-suckling and postpartum meloxicam provision to sows as a means of ensuring adequate colostrum intake, on growth and health in pigs pre- and postweaning. One hundred and four sows (Large White \times Landrace) and their litters, averaging 16.3 piglets born alive, were assigned to one of four treatments in a two-by-two factorial arrangement. Factors were provision of meloxicam (yes/no; Mel/N-Mel) and split-suckling (yes/no; Split/N-Split). Meloxicam was administered intramuscularly at 0.4 mg/kg body weight to sows on release of the placenta (~ 2 h postpartum). Split-suckling commenced 4 h after birth of the first piglet, with the six heaviest piglets removed from the sow for 1 h to allow the lightest piglets to suckle. This was repeated after 1.5 h. Pigs were weighed at birth and at days 1, 6, 14, and 27 after birth and at days 6, 14, 21, 28, 47, and 129 postweaning. Carcass data were collected at slaughter. Medication usage was recorded from birth to slaughter. There was a split-suckling by meloxicam interaction effect at days 1 to 6 ($P < 0.001$) and days 6 to 14 ($P < 0.001$) after birth. Meloxicam administration had no effect on average daily gain (ADG) when split-suckling was applied; however, when split-suckling was not applied, postpartum meloxicam administration increased ADG. There was a meloxicam \times split-suckling interaction for ADG from weaning to day 6 postweaning ($P = 0.03$). Meloxicam increased ADG when split-suckling was applied but not in its absence. Carcass weight was increased by meloxicam ($P = 0.01$) but was not affected by split-suckling ($P > 0.05$). Meloxicam use in sows reduced the number of clinical cases of disease ($P = 0.04$) in suckling pigs which tended to reduce the volume of antibiotics ($P = 0.08$) and anti-inflammatories ($P = 0.08$) administered. Split-suckling had no effect on medication usage in sows and piglets during lactation but increased their use from weaning to slaughter. In conclusion, postpartum administration of meloxicam to sows is an easily implemented strategy. It reduced clinical cases of disease, increased ADG in pigs during the first two weeks of life and early postweaning and increased carcass weight at slaughter. However, no split-suckling benefit was observed.

Lay Summary

Suckling pigs should receive ≥ 200 g of colostrum (the first secretion of the mammary gland after giving birth) within the first 24 h of life. This is challenging to achieve as the number of piglets born alive has increased over the last decade, but the sow's ability to produce colostrum has not increased. Split-suckling (removing advantaged pigs from the sow for a period of time to allow weaker littermates time to suckle without competition) and/or administering an anti-inflammatory pain-killer to sows after farrowing may help to ensure adequate colostrum intake, thereby ensuring optimal piglet growth and health. The objective of this study was to assess the effect of split-suckling and/or postpartum provision of meloxicam, a nonsteroidal anti-inflammatory, on growth and health in pigs. The provision of meloxicam to sows increased pig growth pre- and postweaning, and increased carcass weight at slaughter. Furthermore, meloxicam reduced disease and tended to reduce antibiotic and anti-inflammatory usage in pigs prior to weaning. Split-suckling reduced pig growth pre- and postweaning and did not impact carcass weight or medication usage prior to weaning. Providing meloxicam to sows postfarrowing is a simple effective strategy to increase pig growth and reduce the need for medication.

Key words: Antibiotic, farrowing, colostrum, weaning, large litters, anti-inflammatory

Abbreviations: ADFI, average daily feed intake; ADG, average daily gain; AMU, antimicrobial usage; BF, back fat; BW, body weight; ESFs, electronic sow feeders; G:F gain to feed ratio; IM, intramuscularly; NRC, National Research Council

Introduction

It is essential that all pigs receive at least 200 g of colostrum in the first 24 h of life (Devillers et al., 2011). This is because colostrum is not only an energy source for piglets, but it is also a source of passive immunity (Rutherford et

al., 2013). Litter size has increased from 12.3 to 14.7 born alive in the last 10 yr (Teagasc, 2022). Being born into a large litter reduces the chances of all piglets receiving adequate amounts of colostrum, as heavier and more vigorous pigs can monopolize the sows' teats in the first 48 h postpartum.

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Split-suckling is a strategy sometimes used to address this. Split-suckling involves removing the more advantaged pigs from the sow for a period of time to allow the smaller and weaker littermates time to suckle without competition. This ensures that all pigs have sufficient opportunity to consume an adequate quantity of colostrum. There are a number of ways to conduct split-suckling. One way is that the heaviest piglets are temporarily denied access to the sow, allowing the lighter piglets greater access to the sow's udder (Kyriazakis and Edwards, 1986; Donovan and Dritz, 2000; Alonso et al., 2012). Another way is to separate piglets based on birth order, with the first half of the litter born being temporarily removed to allow those born later greater access to the sow's udder (Morton et al., 2019). Recent studies suggest that conducting split-suckling of piglets during the first day of life is enough to improve neonatal growth (Morton et al., 2019) and reduce piglet mortality (Huser et al., 2015). Most piglet mortality occurs during the first days of life and is higher among the smaller/lighter piglets within the litter (Quiniou et al., 2002). Conducting split-suckling for three consecutive days has been shown to reduce piglet growth (Vandaele et al., 2020). These data suggest that the first day of life should be targeted when split-suckling is applied.

Pain management in sows following the farrowing process can increase suckling and therefore increase colostrum intake, consequently reducing neonatal mortality, as reviewed by Baxter et al. (2013). It has been suggested that postpartum anti-inflammatory treatment of sows may facilitate increased colostrum intake in neonatal pigs by minimizing discomfort and pain in the sows, thereby making them more receptive to suckling by their litter (Mainau et al., 2012). This increased colostrum intake leads to increased preweaning piglet growth and immunological status at weaning (Mainau et al., 2016). Furthermore, anti-inflammatory drugs such as meloxicam can be transferred to piglets through colostrum/milk, resulting in anti-inflammatory effects in piglets (Bates et al., 2014). Therefore, it is reasonable to assume that the resulting stronger, heavier and more immunologically equipped piglets might be more resistant to disease pressure, requiring less medicinal treatment, which could help in reducing antimicrobial usage (AMU) and subsequent development of antimicrobial resistance.

However, there is a lack of information on the effect of combining split-suckling and anti-inflammatory administration to sows postpartum on piglet growth rate, health, and AMU. The objective of this study was to determine the effect of split-suckling with/without postpartum provision of a nonsteroidal anti-inflammatory drug (meloxicam) to the sow, on colostrum intake, growth, health, and medicinal usage in suckling piglets. The residual effects of split-suckling and postpartum meloxicam administration to sows on postweaning growth, health, and medicinal usage to target slaughter weight (120 kg) were also determined. The hypothesis was that split-suckling and/or meloxicam would increase colostrum intake and preweaning growth and health and consequently reduce the need for injectable therapeutic (anti-inflammatory and antibiotic) use in both sows and piglets. Furthermore, it was hypothesized that these benefits would increase lifetime growth in pigs.

Materials and Methods

Ethical approval

This study was performed between March and December 2021, at the Teagasc Pig Development Department,

Moorepark, Fermoy, Co. Cork, Ireland. Ethical approval for this study was granted by the Teagasc Animal Ethics Committee (approval no. TAEC2020-272) and Waterford Institute of Technology Ethics Committee (approval no. WIT2021REC011). The project was authorized by the Irish Health Products Regulatory Authority (project authorization no. AE19132/P129). The experiment was conducted in accordance with the legislation for commercial pig production set out in the European communities (welfare of farmed animals) regulations 2010 and in Irish legislation (SI no. 311/2010).

Experimental design and animal management

One hundred and four sows (Large White × Landrace; PIC, Hermitage Genetics, Sion Road, Co. Kilkenny, Ireland) were used in this study, which was conducted in four batches. Sows were artificially inseminated at onset of standing estrus and again 24 h later using pooled semen (Topigs Norsvin Tempo; Premier Pig Genetics Limited, Ireland). Gestating sows were managed in a dynamic group of ~120 animals. Sows were introduced to the dynamic group 3 to 6 d after service. The pen had fully-slatted floors, insulated concrete lying bays, and two electronic sow feeders (ESFs; Schauer Feeding System [Competent 6], Prambachkirchen, Austria). Water was available ad libitum from single-bite drinkers in the ESFs and from five drinker bowls located around the group pen. On day 107 of gestation, sows were blocked within farrowing batch into 26 blocks of four sows on the basis of parity group (mean ± SD; 2.3 ± 0.99), number of born alive piglets at the previous farrowing (12 ± 7.7) and body weight (BW) (269.8 ± 31.58 kg). Sow parity group distribution was as follows: group one, parity 0 (24%); group two, parity 1 to 2 (31%); group three, parity 3 to 5 (33%); and group four, parity > 5 (12%). The experiment was a two-by-two factorial arrangement with the factors being split-suckling (yes/no; Split/N-Split) and provision of meloxicam postpartum (yes/no; Mel/N-Mel). Within block, sows were randomly assigned to the following treatments: 1) no split-suckling application and no postpartum provision of meloxicam to the sow (N-Split/N-Mel), 2) no split-suckling application and postpartum provision of meloxicam to the sow (N-Split/Mel), 3) split-suckling application and no postpartum provision of meloxicam to the sow (Split/N-Mel), and 4) split-suckling application and postpartum provision of meloxicam to the sow (Split/Mel).

Approximately 5 d before sows were due to farrow they were moved into standard farrowing crates in pens (dimension: 2.5 m × 1.8 m) with cast-iron slats under the sow and plastic slats for the piglets. Where meloxicam (Loxicom Injection, Norbrook, Newry, Northern Ireland) was provided to sows, it was administered intramuscularly (IM) at 0.4 mg/kg of BW on release of the placenta (~2 h postpartum) using a 10 mL syringe (Becton Dickinson, Franklin Lakes, New Jersey, USA) and a 1.65 × 38 mm needle (Agriject disposable needles, AgriHealth, Monaghan, Ireland). Where split-suckling was conducted it commenced 4 h after the birth of the first piglet with the six heaviest piglets removed from the sow for 1 h to allow the lightest piglets to suckle. During the separation time, the six heaviest piglets were marked and restrained in a bottomless wooden box placed on a water-heated pad (Big Dutchman heating plates, Vechta, Germany) beside the farrowing crate. This procedure was repeated after a period of 1.5 h.

Farrowing room temperature was maintained at ~24 °C. The temperature of the heat pads was 38 to 40 °C for the first 2 d after farrowing and was reduced by 1 °C each day to 30

°C at 10 d after farrowing and it was maintained at this until weaning. Artificial lighting was provided daily from 0800 to 1630 hours. Where possible, litter size was standardized between 24 and 48 h after parturition, with cross fostering only being conducted within treatment group, so that there was an average litter size of 14.3 ± 1.80 piglets per sow at 48 h postpartum. The final number of piglets remaining on each sow at 48 h postpartum was affected by the rearing capacity of the sow (i.e., the number of functional teats), the availability of foster sows to take surplus piglets, and the time of farrowing. Piglets' teeth were clipped within 24 h of birth. On day 5 postpartum tails were docked and all piglets were injected with 1 mL of iron (Gleptosil, Ceva Santé Animale, Libourne, France). Male pigs remained fully intact and piglets were weaned at day 28 ± 0.8 of lactation.

To study the residual effects of split-suckling and postpartum analgesia provision to sows in progeny, a subsample of 506 pigs (8.0 ± 1.36 kg) were selected at weaning (four to five male and female pigs per sow). Within each treatment group, pigs were formed into single sex groups of 10 to 12 pigs of even weight while ensuring that pigs from individual litters were not over-represented within the pen group. Pens were blocked on sow treatment, sex (entire male or female) and birth weight category (light birth weight [<1.25 kg] or heavy birth weight [>1.30 kg]). Pen groups for treatment N-Split/N-Mel ($n = 14$), treatment Split/N-Mel ($n = 11$), treatment Split/Mel ($n = 13$) and treatment N-Split/Mel ($n = 12$) were moved to weaner accommodation at weaning. Pigs were monitored to slaughter, with feed disappearance and pig weight recorded. Temperature in the weaner rooms was maintained at 28 °C during the first week after weaning and reduced by 2 °C each week to 22 °C at the end of 4 wk. Weaner pens were 2.5 m \times 2 m with fully-slatted plastic floors. Ventilation was from a punched ceiling with air exhausted via a variable speed fan linked to a thermostat which was controlled by computer (Big Dutchman 135). At day 47 postweaning, pen groups were moved to finisher accommodation, with pig weight recorded prior to slaughter and feed intakes monitored weekly to target slaughter weight. Temperature in the finisher rooms was maintained at 20 to 22 °C with the same type of ventilation system used as in the weaner house. Finisher pens were 4.2 m \times 2.4 m with a slatted concrete floor. All rooms were equipped with windows for natural light. Pigs in each experimental treatment group were slaughtered over 2 wk when they reached the target slaughter weight of ~120 kg live weight (average age at slaughter 157 d). The heaviest pigs in each pen group were slaughtered during the first week and the remaining pigs in the pen were slaughtered 7 d later.

Diet preparation and feeding

Diets were formulated to meet or exceed National Research Council (NRC) recommendations (NRC, 2012). The ingredient composition and nutrient content of the diets are shown in Table 1. During gestation, sows were fed a gestation diet (diet 1) in meal form at a feed allowance of 2.2 kg/d between days 0 to 90 of gestation. From day 90 of gestation to parturition, gestation feed allowance was increased to 2.7 kg/d. In the farrowing room, diets were fed using a computerized feed delivery system (DryExact Pro, Big Dutchman). Sows were fed a lactation diet (diet 2; Table 1) in meal form twice daily from farrowing to day 6 of lactation and three times daily from day 7 to weaning at 28 d. Sows were fed according to a lactation feeding curve which started at 60 MJ DE/d

at day 0 of lactation and gradually increased to 107, 125, 133, and 137 MJ DE/d at days 7, 14, 21, and 26 of lactation, respectively. During lactation, feeding curves for individual sows were adjusted up or down, as required, to ensure that sow feed intake was as close to ad libitum feeding as possible and to prevent feed wastage. Water was provided on an ad libitum basis to sows from a single-bite drinker in the feed trough and to suckling piglets from a bowl in the farrowing pen. Starter diet (diet 3; Table 1) was fed in pelleted form (3 mm diameter pellets) as creep feed to suckling pigs from day 14 after birth until weaning using a creep feeder (Easy pan; Rotecna, Lleida, Spain) placed at the bottom of the heat pad. Creep feed intake per litter was determined weekly. Between weaning and service, sows were provided with ad libitum access to a lactation diet and following insemination were restrictively fed a gestation diet (diet 1; Table 1), both in meal form.

Following weaning, pigs were fed a sequence of diets in accordance with their growth stage. Starter diet (diet 3; Table 1) was provided from weaning to day 6 postweaning, link diet (diet 4; Table 1) from days 6 to 17 postweaning, weaner diet (diet 5; Table 1) from days 17 to 47 postweaning, and a finisher diet (diet 6; Table 1) from day 47 postweaning to slaughter (~ day 157 of age). All diets fed postweaning were in pelleted form (3 mm diameter) and all were provided on an ad libitum basis. Each weaner pen had a single-space (33 cm) wet-dry feeder (Verba, Sint-Oedenrode, Netherlands) with inset nipple drinker. Each finisher pen had one shelf-type single-space (33 cm) wet-dry feeder (Verba) with inset nipple drinker. Water was available on an ad libitum basis from a single bowl drinker (Rotecna) per pen in weaner and finisher rooms. Pigs were inspected daily and any pig showing signs of ill health was treated appropriately. Assessment of clinical signs of disease and treatment protocols were followed in accordance with farm policies. All veterinary treatments were recorded including antibiotic and anti-inflammatory treatments.

Sow body weight and back fat thickness

Sow BW and back fat (BF) were recorded on day 110 of gestation, at weaning, and at their subsequent service (~day 6 postweaning). Sow BW was recorded using an electronic sow scales (EziWeigh 7i, O'Donovan Engineering, Coachford, Co. Cork, Ireland). Empty farrowing weight was calculated using the following equation from the NRC (1998):

$$\text{Empty farrowing weight} = [\text{Sow weight at day 110 of gestation} - (\text{total number of piglets born} \times 2.25)].$$

The value of 2.25 kg is an estimate of the increased weight in the gravid uterus and in mammary tissue attributed to each pig in a litter.

Back fat was measured using a digital BF indicator (Renco LEANMEATER, Renco Corporation, Golden Valley, MN, USA) by placing the probe of the digital indicator on the back of the sow at the level of the last rib, 6 cm from the side of the backbone. A reading was taken from the right and left side of the sow and the average reading was recorded.

Farrowing performance and preweaning piglet growth performance

The number of piglets born (total, live, stillborn, and mummified) was recorded for each litter at birth. Farrowing duration and time of birth of the first piglet were recorded for each

Table 1. Composition of the experimental diets (on an air-dry basis; kg/t)

Diet No. Diet type	1 Dry sow	2 Lactation	3 Starter	4 Link	5 Weaner	6 Finisher
Ingredients						
Barley	759.7	259.7	50.0	68.4	495.9	410.5
Wheat	0	455.2	0	100.0	216.8	390.0
Maize	0	0	231.0	300.0	0	0
Soybean meal	76.2	179.8	143.4	186.9	163.2	165.0
Full fat soybean meal	0	0	130.8	70.0	50.0	0
Lactoflo ¹	0	0	200.0	150.0	0	0
Skim milk powder	0	0	125.0	50.0	0	0
Soya hulls	125.3	0	0	0	0	0
Soya oil	14.0	66.0	85.0	38.2	40.0	11.0
Premix ²	1.5	1.5	3.0	3.0	3.0	1.0
L-Lysine HCl	2.3	5.0	6.2	6.7	5.9	4.3
DL-Methionine	0.4	1.5	3.6	3.2	2.2	1.0
L-Threonine	1.0	2.7	3.7	3.4	2.7	1.9
L-Tryptophan	0	0.8	1.4	1.3	0.6	0.2
L-Valine	0	2.7	1.3	1.3	0.6	0
Limestone flour	8.5	11.5	7.0	7.5	10.5	11.0
Mono dicalcium phosphate	7.0	8.5	5.5	7.0	5.5	1.0
Salt	4.0	5.0	3.0	3.0	3.0	3.0
Phytase ³	0.1	0.1	0.1	0.1	0.1	0.1
Chemical composition						
Dry matter ⁴	883.0	893.0	907.0	897.0	888.0	887.0
Crude protein ⁴	125.0	163.0	188.0	166.0	178.0	177.0
Ash ⁴	42.0	48.0	57.0	53.0	47.0	46.0
Ether extract ⁴	33.7	85.4	119.1	58.4	65.2	31.0
Crude fibre ⁴	87.0	26.0	16.0	33.0	32.0	38.0
Lysine ⁵	7.8	11.5	16.2	15.0	13.0	10.9
Methionine ⁵	2.4	3.9	7.0	6.1	4.7	3.4
Cystine ⁵	2.5	3.0	2.7	2.9	3.1	3.1
Threonine ⁵	5.6	8.3	10.9	10.1	8.8	7.6
Tryptophan ⁵	3.7	3.4	2.7	2.2	1.5	2.8
Digestible energy, MJ/kg ⁵	12.51	14.86	16.20	15.00	14.27	13.73
Net energy, MJ/kg ⁵	8.86	10.90	12.06	10.94	10.30	9.80
SID lysine ^{5,6}	6.6	10.7	15.3	14.1	12.0	10.0
Total calcium ⁵	7.2	8.3	8.2	7.5	7.4	6.5
Digestible phosphorus ⁵	3.5	3.8	4.6	4.2	3.3	2.5

¹Lactoflo, nonhygroscopic whey permeate powder (Volac, Royston, United Kingdom).

²Premix provided per kilogram of complete diet (diets 1, 2, and 3): Cu from copper sulfate, 100 mg; Fe from ferrous sulfate monohydrate, 90 mg; Mn from manganese oxide, 47 mg; Zn from zinc oxide, 120 mg; I from potassium iodate, 0.6 mg; Se from sodium selenite, 0.3 mg; vitamin A as retinyl acetate, 2.1 mg; vitamin D3 as cholecalciferol, 25 µg; vitamin E as DL-alpha-tocopheryl acetate, 100 mg; vitamin K, 4 mg; vitamin B12, 15 µg; riboflavin, 2 mg; nicotinic acid, 12 mg; pantothenic acid, 10 mg; choline chloride, 250 mg; vitamin B1, 2 mg; and vitamin B6, 3 mg.

Premix provided per kilogram of complete diet (diet 4): Cu from copper sulfate, 15 mg; Fe from ferrous sulfate monohydrate, 24 mg; Mn from manganese oxide, 31 mg; Zn from zinc oxide, 80 mg; I from potassium iodate, 0.3 mg; Se from sodium selenite, 0.2 mg; vitamin A as retinyl acetate, 0.7 mg; vitamin D3 as cholecalciferol, 12.5 µg; vitamin E as DL-alpha-tocopheryl acetate, 40 mg; vitamin K, 4 mg; vitamin B12, 15 µg; riboflavin, 2 mg; nicotinic acid, 12 mg; pantothenic acid, 10 mg; vitamin B1, 2 mg; and vitamin B6, 3 mg.

Premix provided per kg of complete diet (diets 5 and 6): Cu from copper sulfate, 15 mg; Fe from ferrous sulfate monohydrate, 70 mg; Mn from manganese oxide, 62 mg; Zn from zinc oxide, 80 mg; I from potassium iodate, 0.6 mg; Se from sodium selenite, 0.2 mg; vitamin A as retinyl acetate, 3.44 mg; vitamin D3 as cholecalciferol, 25 mg; vitamin E as DL-alpha-tocopheryl acetate, 100 mg; vitamin K, 2 mg; vitamin B12, 15 µg; riboflavin, 5 mg; nicotinic acid, 12 mg; pantothenic acid, 10 mg; choline chloride, 500 mg; Biotin, 200 µg; folic acid, 5mg; vitamin B1, 2 mg; and vitamin B6, 3 mg.

³The diet contained 1,000 phytase units (FYT) per kg feed (RONOZYME HiPhos GT; DSM, Belfast, UK).

⁴Analysed nutrient composition.

⁵Calculated nutrient composition.

⁶Standardized ileal digestible lysine.

sow. The weight and sex of each piglet was recorded at birth when each piglet was tagged for identification purposes. Piglets were individually weighed at birth and 24 h after birth

and on days 7, 14, and 27 postpartum using an electronic piglet scale (Defender 3000 XtremeW, O'Donovan Engineering) and these data were used to determine the litter weight

Table 2. Effect of split-suckling and/or postpartum meloxicam provision to sows on piglet weight and growth during the suckling periods

Split-suckling (Split)	N-Split		Split		SEM	P-value		
	N-Mel	Mel	N-Mel	Mel		Mel	Split	Mel × Split
Number of sows	23	23	20	23				
Litter weight, kg								
Day 0 (birth)	22.3	22.2	21.2	22.7	0.82	0.32	0.71	0.51
Day 1	21.5	22.0	20.7	22.1	0.68	0.10	0.54	0.32
Day 6	30.7 ^B	33.9 ^A	29.4 ^B	32.0 ^{A,B}	1.26	0.02	0.19	0.06
Day 14	56.6 ^B	62.9 ^A	55.4 ^B	58.1 ^{A,B}	2.14	0.04	0.17	0.07
Day 27	105.6	111.4	102.1	107.2	3.99	0.17	0.34	0.34
Overall					1.61	0.07	0.26	0.88
Mean piglet BW ¹ , kg								
Day 0	1.42	1.35	1.48	1.41	0.054	0.12	0.16	0.23
Day 1	1.45	1.41	1.53	1.44	0.054	0.12	0.22	0.27
Day 6	2.20 ^b	2.36 ^a	2.22 ^b	2.22 ^b	0.057	0.06	0.21	0.04
Day 14	4.12 ^b	4.56 ^a	4.20 ^b	4.19 ^b	0.057	<0.001	<0.01	<0.001
Day 27	7.80 ^c	8.37 ^a	7.85 ^c	7.98 ^b	0.057	<0.001	<0.001	<0.001
Overall					0.039	<0.001	0.01	<0.001
ADG ² , g/pig/d								
Days 0 to 1	47 ^c	70 ^a	65 ^{a,b}	52 ^{b,c}	6.9	0.39	0.99	0.02
Days 1 to 6	158 ^b	184 ^a	162 ^b	160 ^b	5.0	<0.001	<0.01	<0.001
Days 6 to 14	237 ^b	266 ^a	247 ^b	238 ^b	5.7	0.03	0.04	<0.001
Days 14 to 27	260	256	262	263	5.8	0.73	0.36	0.72
Overall	176	194	184	178	4.4	<0.01	0.12	<0.001

¹Body weight.²Average daily gain.^{a,b,c}Values within a row that do not share a common superscript are significantly different ($P \leq 0.05$).^{A,B}Values within a row that do not share a common superscript tended to differ ($0.05 < P \leq 0.10$).

at each weighing, and piglet preweaning average daily gain (ADG). Piglet mortality between birth and weaning was also recorded.

Postweaning pig growth performance

Pen groups were weighed on days 6, 14, 21, 28, and 47 post-weaning and individual pig weights were recorded just prior to slaughter (at ~day 129 postweaning) using an electronic scale (EziWeigh 7i, O'Donovan Engineering). Pigs were fasted for 15 to 18 h prior to slaughter before weighing. Feed disappearance was recorded on a pen basis from weaning to slaughter at the same time points that pig weights were recorded. These data were used to determine the ADG, average daily feed intake (ADFI), and gain to feed (G:F) per pen.

Carcass data

Pigs were transported 95 km to the abattoir (Dawn Pork & Bacon, Grannagh, Co. Waterford, Ireland) where they were killed by exsanguination after CO₂ stunning. At the abattoir, carcass cold weight of individual pigs was calculated by multiplying the hot carcass weight, recorded within 45 min of the pig being exsanguinated, by 0.98. Back fat and muscle depth, measured at 6 cm from the edge of the split back at the level of the third and fourth last rib were determined using a Hennessy Grading Probe (Hennessy and Chong, Auckland, New Zealand). Lean meat content was estimated according to the following formula: Estimated lean meat content (%) = 60.3 - 0.847x + 0.147y, where x = fat depth (mm);

y = muscle depth (mm) (Department of Agriculture and Food and Rural Development, 2001).

The following equations were used to determine parameters of interest relating to carcass growth (Lawlor and Lynch, 2005):

$$C = \frac{[(CW - WW \times 0.65) \times 1,000]}{D1}$$

$$CE = \frac{C}{FI}$$

$$L = \frac{(CW \times CL \times 10)}{D2}$$

Where C = carcass ADG (from weaning to slaughter), CW = carcass weight (kg), WW = weaning weight (kg), D1 = number of days from weaning to slaughter, CE = Carcass G:F, FI = daily feed intake (g), L = Lean ADG (from birth to slaughter), CL = carcass lean meat percentage, and D2 = number of days from birth to slaughter.

Colostrum intake

Colostrum intake was estimated 24 h after the birth of the last piglet using the equation of Theil et al. (2014) as follows: Colostrum intake (g) = -106 + (2.26 × WG) + (200 × BWB) + (0.111 × D) - [1,414 × (WG/D)] + [0.0182 × (WG/BWB)] where WG is piglet weight gain (g) from birth to 24 h of life, BWB is piglet BW at birth (kg) and D is the duration

in minutes of suckling between birth of the last piglet and weighing at ~ 24 h (1,440 min).

Milk sampling and compositional analysis

On day 14 of lactation, milk samples were collected from sows ($n = 13$ sows/treatment) by milking the first four teats immediately distal to the sow's head on one side of the udder following administration of a 1 mL (10 IU) IM injection of oxytocin (Oxytocin, AgriHealth) to induce milk let-down. Samples for compositional analysis were stored at -20°C until analysis. Milk samples were defrosted at room temperature. When fully thawed, samples were mixed by inverting several times to disrupt settled solids, and mixed well. Each sample was analyzed for total solids, lactose, fat and protein content by near-infrared absorption using a Bentley Dairyspec FT (Bentley Instruments Inc., Chaska, MN, USA).

Health monitoring

Fecal consistency scores were determined for piglets at days 1, 7, 14, 21, and 28 before weaning and at days 6, 14, 21, 28, 47, and 129 postweaning (the latter was just prior to slaughter). A four-point scoring system (Casey et al., 2007) was used and the average score from five pigs was determined as the average score for each crate/pen. In brief: 0 = normal (dry pelleted feces), 1 = soft (soft with shape), 2 = mild diarrhea (very soft or viscous liquid), and 3 = severe diarrhea (watery or with blood).

Antibiotic and anti-inflammatory usage was recorded in sows during lactation and in pigs during each production stage from birth until they reached target slaughter weight. Medication was administered when joint-ill, lameness, malaise or diarrhea were observed in piglets and when malaise or vaginal discharge was observed in sows. Only one antibiotic (Unicillin, Univet Limited, Cootehill, Co. Cavan, Ireland) and one anti-inflammatory (Loxicom, Norbrook), were used during this experiment. Animal ID, pen number, product name, product code, dose administered (mL), frequency of administration, date of administration, and reason for use were recorded when an animal was treated. From this, the total number of piglet injections per litter, the average volume of medication (antibiotic and anti-inflammatory) administered per pig on a litter basis and per sow, and the total number of piglet clinical cases (i.e., when an animal was treated one or more times) per litter were calculated preweaning. The average volume of medication (antibiotic and anti-inflammatory) administered per pig on a pen basis was calculated postweaning, for both the weaner and finisher periods.

Statistical analysis

All data were tested for normality using the Univariate procedure. Residuals were inspected in all models to confirm normality. Model fit was determined by choosing models with the minimum finite-sample-corrected Akaike Information Criteria.

Growth parameters preweaning (ADG, BW, and litter weight), growth parameters postweaning (BW, ADFI, ADG, and G:F), carcass quality, deaths or removals, colostrum intake, sow BW, sow BF, weaning to service interval, milk composition, total number of piglet injections per litter, average volume of medication (antibiotic and anti-inflammatory) administered per pig on a litter basis and per sow, total number of piglet clinical cases per litter preweaning and average volume of medication (antibiotic and anti-inflammatory)

administered per pig on a pen basis postweaning were analyzed in SAS using the linear mixed models procedure (PROC MIXED) in the Statistical Analysis Systems (SAS) software package version 9.4 (SAS Institute Inc., Cary, NC, US) for a two-by-two factorial arrangement. The incidence of diarrhea in the farrowing houses from days 2 to 28 was analyzed using the PROC Genmod procedure of SAS for a two-by-two factorial arrangement. Data from batches one, two, three, and four were analyzed together as all measurements were recorded at the same time points.

For piglet preweaning growth parameters, sow BW, sow BF and weaning to service interval, split-suckling, meloxicam provision and their associated interactions were included in the model as fixed effects. For analysis of preweaning piglet growth parameters; piglet birth weight and litter size at 48 h were included as covariates, when significant in the model. For analysis of sow BW; sow BW at day 110 of gestation was included as a covariate in the model. For analysis of sow BF; BF at day 110 of gestation was included as a covariate in the model. For analysis of weaning to service interval; parity rank was included in the model as a covariate. For analysis of preweaning growth, sow BW and sow BF; day was included in the model as the repeated variable. Block was included as a random effect. Pig nested within sow/litter was the experimental unit for preweaning piglet growth parameters and sow/litter was the experimental unit for analysis of sow BW, sow BF, weaning to service interval and litter weight.

For the analysis of the total number of piglet injections per litter, the average volume of medication (antibiotic and anti-inflammatory) administered per pig on a litter basis and per sow, the total number of piglet clinical cases of disease per litter preweaning, colostrum intake per pig, number of deaths and removals per litter (birth to weaning and 48 h to weaning); split-suckling, meloxicam provision and their associated interactions were included in the model as fixed effects. As cross fostering was completed at 48 h; litter size at 48 h was included in the model as a covariate for the analysis of the number of deaths between 48 h and weaning. For analysis of the number of clinical cases per litter; birth weight was included in the model as a covariate. Block was included as a random effect and sow/litter was the experimental unit.

For the analysis of diarrhea incidence; split-suckling, meloxicam provision, day and the associated two-way and three-way interactions were included in the model. A fecal score of two or greater was considered representative of diarrhea.

For the analysis of milk composition; split-suckling, meloxicam provision and their associated interactions were included in the model as fixed effects. Parity rank was included in the model as a covariate when significant in the model. The sow was the experimental unit.

To determine the effect of sow treatment (split-suckling and meloxicam provision) on piglet colostrum intake, ADG from birth to weaning and weaning weight for pigs from each birth weight category, low (<1.25 kg) and high (>1.25 kg); the model included birth weight category (low and high), sow treatment (split-suckling or meloxicam provision) and their associated interactions as fixed effects. Block was included as a random effect and pig nested within sow/litter was the experimental unit.

For postweaning growth parameters; split-suckling, meloxicam provision, and their associated interactions were

included in the model as fixed effects. Weaning weight was included in the model as a covariate when significant in the model. Day was included as a repeated variable in the model and block was included as a random effect. The pen group was considered the experimental unit. For carcass quality data and the average volume of medication (antibiotic and anti-inflammatory) administered per pig on a pen basis postweaning (for both the weaner and finisher periods) the model was the same but day was not included as a repeated variable.

In all cases, differences between least square means were investigated using the t-test after Tukey adjustment for multiple comparisons. Results are presented in the text and tables as the least square means together with their pooled standard error. Differences between treatments were considered significant for $P \leq 0.05$, whereas $0.05 < P \leq 0.10$ was considered as a tendency.

Results

Pig removals and deaths

In total, 15 sows were removed from the study. Four sows were removed before applying the experimental treatment because the number of piglets born alive was <9 (one in the N-Split/Mel treatment and three in the Split/N-Mel treatment). Three sows were removed because they aborted in the farrowing house more than 3 d before their expected farrowing date (one from the N-Split/N-Mel treatment, one from the Split/N-Mel treatment, and one from the Split/Mel treatment). Eight sows were removed because they were medicated around farrowing due to sickness or because of farrowing complications (two from the N-Split/N-Mel treatment, two from the N-Split/Mel treatment, two from the Split/N-Mel treatment and two from the Split/Split treatment). All removals were unrelated to experimental treatment.

Eighteen percent of all piglets on trial died preweaning. Among the dead piglets, 36% died in the first 24 h, 46% between days 1 and 6, 8% between days 6 and 14 and 10% between days 14 and 27. Preweaning mortality was 16%, 14%, 18%, and 21% for N-Split/N-Mel, N-Split/Mel, Split/N-Mel, and Split/Mel treatments, respectively. Deaths during the first 24 h and from days 1 to 6 were mainly due to starvation or crushing. After day 6, causes of mortality were more variable and included crushing, starvation, injury, and sudden death.

Three percent of all pigs on trial died postweaning. Among the dead pigs, 38% of the pigs died between days 28 and 47 postweaning and 62% died after day 47 postweaning. Postweaning mortality was 0%, 6%, 3%, and 2% for N-Split/N-Mel, N-Split/Mel, Split/N-Mel, and Split/Mel treatments, respectively. Deaths and removals were due to starvation, lameness, or injury (only one animal).

Sow growth and reproductive performance

Sow body weight and back fat thickness

Meloxicam \times split-suckling interactions for sow weight, BF depth, and reproductive performance from farrowing to service are shown in [Supplementary Table S1](#). No meloxicam \times split-suckling interaction ($P > 0.05$) was found for any variable of interest. Sows from the meloxicam group tended to be lighter at weaning than those which did not receive meloxicam (235.4 vs. 241.6, SEM = 2.39 kg; $P = 0.06$). Treatment did not influence sow BF depth or weaning to service interval ($P > 0.05$; [Supplementary Table S1](#)).

Litter size, fostered, and preweaning deaths

Meloxicam \times split-suckling interactions for sow litter size, deaths per litter and the number of piglets fostered are shown in [Supplementary Table S2](#) and treatment main effects are in [Supplementary Tables S3 and S4](#). There was no meloxicam \times split-suckling interaction for litter size at birth, 48 h after birth or at weaning and for the number of piglets fostered or deaths per litter ($P > 0.05$). Meloxicam administration ($P > 0.05$) or split suckling ($P > 0.05$) had no effect on any parameter of interest.

Preweaning piglet growth performance

Meloxicam \times split-suckling interactions for piglet weight and growth during the suckling period are shown in [Table 2](#) and treatment main effects in [Supplementary Tables S5 and S6](#). There was no meloxicam \times split-suckling interaction for litter weight during the whole lactation period ($P > 0.05$). Litters from the meloxicam group were heavier at day 6 (33.0 vs. 30.0, SEM = 0.93 kg; $P = 0.02$) and day 14 (60.5 vs. 56.0, SEM = 1.54 kg; $P = 0.04$) after birth than litters of sows which did not receive meloxicam. Split-suckling did not affect litter weight at any time ($P > 0.05$).

There was no meloxicam \times split-suckling interaction for average pig weight at birth (day 0) and day 1 after birth ($P > 0.05$). There was a meloxicam \times split-suckling interaction for pig weight at day 6 ($P = 0.04$), 14 ($P < 0.001$) and 27 ($P < 0.001$) after birth and overall ($P < 0.001$). At days 6 and 14 postpartum, meloxicam had no effect on piglet weight when split-suckling was applied; however, when split-suckling was not applied, meloxicam increased piglet weight ($P < 0.05$). At day 27, whether split-suckling was applied or not, meloxicam increased piglet weight ($P < 0.001$); however, the increase in weight was significantly higher when split-suckling was not practiced. Meloxicam tended to increase piglet weight at day 6 (2.29 vs. 2.21, SEM = 0.046 kg; $P = 0.06$), and increased piglet weight at day 14 (4.38 vs. 4.16, SEM = 0.047 kg; $P < 0.001$) and day 27 (8.18 vs. 7.83, SEM = 0.047 kg; $P < 0.001$) after birth. Overall, meloxicam administration increased piglet weight ($P < 0.001$). Split-suckling reduced piglet weight at day 14 (4.20 vs. 4.34, SEM = 0.046 kg; $P < 0.01$) and day 27 (7.92 vs. 8.09, SEM = 0.047 kg; $P < 0.001$). Overall, split-suckling reduced piglet weight ($P = 0.01$).

There was a meloxicam \times split-suckling interaction for piglet ADG from days 1 to 6 ($P < 0.001$), from days 6 to 14 ($P < 0.001$) and overall ($P < 0.001$). From days 1 to 6 and 6 to 14, meloxicam had no effect on ADG when split-suckling was applied; however, when split-suckling was not applied, it increased ADG. Meloxicam increased ADG from days 1 to 6 (171 vs. 160, SEM = 4.4 g/d; $P < 0.001$), days 6 to 14 (252 vs. 242, SEM = 4.8 g/d; $P = 0.03$), and overall ($P < 0.01$). Split-suckling reduced ADG from days 1 to 6 (161 vs. 171, SEM = 4.4 g/d; $P < 0.01$) and days 6 to 14 (242 vs. 252, SEM = 4.7 g/d; $P = 0.04$). Overall, split-suckling did not affect ADG ($P = 0.12$).

The effect of birth weight category and treatment on ADG from birth to weaning and weight at weaning are presented in [Supplementary Tables S7 and S8](#). There was no meloxicam \times weight category interaction for pig ADG from birth to weaning ($P > 0.05$) or for pig weight at weaning ($P > 0.05$). There was a split-suckling \times weight category interaction for ADG from birth to weaning ($P < 0.01$). Heavy pigs at birth

Table 3. Effect of split-suckling and/or postpartum meloxicam provision to sows on pig growth and feed intake from weaning to slaughter

Split-suckling (split)	N-split		Split		SEM	P-value		
	N-Mel	Mel	N-Mel	Mel		Mel	Split	Mel × Split
Number of pens	14	12	11	13				
BW ¹ , kg								
Day 0 (weaning)	8.2	7.8	8.3	8.4	0.80	0.83	0.66	0.94
Day 6 postweaning	9.3	9.0	9.1	9.8	0.80	0.73	0.72	0.88
Day 14 postweaning	12.0	11.7	11.6	12.4	0.80	0.72	0.80	0.89
Day 21 postweaning	15.2	15.0	14.8	15.6	0.80	0.73	0.93	0.92
Day 28 postweaning	18.9	19.1	18.9	19.5	0.80	0.60	0.83	0.94
Day 47 postweaning	33.0	33.2	32.5	33.8	0.80	0.34	0.93	0.70
Day of slaughter (day 157 of age)	119.2 ^b	122.4 ^a	116.9 ^c	121.0 ^a	0.80	<0.001	0.02	<0.001
Overall					0.52	0.12	0.84	0.39
ADFI ² , g/pig/d								
Days 0 to 6	221	205	187	213	11.3	0.60	0.20	0.12
Days 6 to 14	477	483	430	460	19.6	0.36	0.07	0.23
Days 14 to 21	610	655	601	618	25.8	0.22	0.36	0.46
Days 21 to 28	833	881	821	831	35.9	0.42	0.38	0.65
Days 28 to 47	1,083	1,075	1,045	1,083	33.6	0.65	0.65	0.84
Day 47 to slaughter	2,409	2,383	2,321	2,390	56.0	0.70	0.48	0.72
Overall					22.7	0.37	0.24	0.60
ADG ³ , g/pig/d								
Days 0 to 6	210 ^b	208 ^b	191 ^b	248 ^a	14.4	0.04	0.45	0.03
Days 6 to 14	348	331	336	349	20.0	0.90	0.89	0.88
Days 14 to 21	471	469	466	456	24.6	0.81	0.71	0.97
Days 21 to 28	530	576	588	568	40.8	0.74	0.54	0.75
Days 28 to 47	672	661	656	688	18.2	0.53	0.76	0.57
Days 47 to slaughter	1,062	1,090	1,030	1,070	19.2	0.07	0.16	0.18
Overall	549	556	544	563	12.7	0.25	0.91	0.60
G:F ⁴ , g/g								
Days 0 to 6	0.95 ^b	1.04 ^{ab}	1.03 ^{ab}	1.15 ^a	0.050	0.04	0.06	0.04
Days 6 to 14	0.73	0.72	0.77	0.74	0.025	0.48	0.25	0.61
Days 14 to 21	0.76	0.74	0.76	0.73	0.028	0.28	0.89	0.74
Days 21 to 28	0.63	0.66	0.70	0.67	0.034	0.99	0.28	0.61
Days 28 to 47	0.62	0.63	0.63	0.63	0.010	0.61	0.77	0.92
Day 47 to slaughter	0.44 ^B	0.47 ^A	0.44 ^B	0.44 ^B	0.009	0.10	0.14	0.09
Overall					0.014	0.35	0.07	0.67

¹Body weight.²Average daily feed intake.³Average daily gain.⁴G:F gain to feed ratio.^{a,b,c}Values within a row that do not share a common superscript are significantly different ($P \leq 0.05$).^{A,B}Values within a row that do not share a common superscript tended to differ ($0.05 < P \leq 0.10$).

had a lower ADG when split-suckling was applied, while split-suckling had no effect on the ADG of light birth weight pigs. There was a split-suckling × weight category interaction for pig weight at weaning ($P = 0.02$). Heavy pigs at birth had a lower weaning weight when split-suckling was applied, while split-suckling had no effect on the weaning weight of light birth weight pigs.

Postweaning pig growth and carcass quality

Meloxicam × split-suckling interactions for feed intake and pig growth from weaning to slaughter are shown in Table 3 and treatment main effects in Supplementary Tables S9 and S10.

Pig weight

There was no meloxicam × split-suckling interaction for pig weight at any time point, except slaughter ($P < 0.001$). Split-suckling reduced pig weight at slaughter when meloxicam was not applied; however, meloxicam increased pig weight at slaughter whether split-suckling was applied or not. Meloxicam had no effect on pig weight at any time point, except at slaughter when it increased weight (121.7 vs. 118.1; SEM = 0.57 kg; $P < 0.001$). Overall, pig weight was not affected by meloxicam. Split-suckling had no effect on pig weight at any time point, except at slaughter when it reduced weight (119.0 vs. 120.8; SEM = 0.58 kg; $P = 0.02$). Overall, pig weight postweaning was not affected by split-suckling ($P > 0.05$).

Pig feed intake

There was no meloxicam × split-suckling interaction for pig ADFI from weaning to day 6, days 6 to 14, days 14 to 21, days 21 to 28, days 28 to 47, day 47 to slaughter, and overall ($P > 0.05$). Meloxicam had no effect on pig ADFI from weaning to day 6, days 6 to 14, days 14 to 21, days 21 to 28, days 28 to 47, day 47 to slaughter, and overall ($P > 0.05$). Split-suckling tended to reduce pig ADFI from days 6 to 14 ($P = 0.07$) but had no effect during any of the other time periods or overall ($P > 0.05$).

Pig growth

There was a meloxicam × split-suckling interaction for pig ADG from weaning to day 6 postweaning ($P = 0.03$). Meloxicam increased ADG when split-suckling was conducted but not when split-suckling was not conducted. Meloxicam increased ADG from weaning to day 6 postweaning (228 vs. 200; SEM = 11.0 g/d; $P = 0.04$) and tended to increase ADG from day 47 to slaughter (1,079 vs. 1,046; SEM = 14.2 g/d; $P = 0.07$) but had no effect during any of the other time periods or overall ($P > 0.05$). Split-suckling had no effect on pig ADG during any time period or overall.

Pig feed efficiency

There was a meloxicam × split-suckling interaction for G:F from weaning to day 6 postweaning ($P = 0.04$). Combining meloxicam and split-suckling increased G:F whereas the provision of either alone, did not affect G:F. There was a tendency for a meloxicam × split-suckling interaction for G:F from day 47 to slaughter ($P = 0.09$). Meloxicam administration without split-suckling tended to increase G:F compared to meloxicam with split-suckling. There was no meloxicam × split-suckling interaction for pig G:F for any of the other time periods or overall ($P > 0.05$). From weaning to day 6, meloxicam increased G:F (1.10 vs. 0.99; SEM = 0.035 g/g; $P = 0.04$). From day 46 to slaughter, meloxicam tended to increase G:F (0.46 vs. 0.44; SEM 0.006 g/g; $P = 0.10$). Meloxicam did not affect G:F during any of the other time periods or overall ($P > 0.05$). From weaning to day 6, split-suckling tended to increase G:F

ratio (1.09 vs. 0.99; SEM = 0.020 g/g; $P = 0.06$). However, split-suckling did not affect G:F during any of the other time periods. Overall, split-suckling tended to increase the G:F ratio ($P = 0.07$).

Carcass data

Meloxicam × split-suckling interactions for carcass parameters are shown in Table 4 and treatment main effects in Supplementary Tables S11 and S12. There was no meloxicam × split-suckling interaction for carcass weight, fat depth, muscle depth, lean meat percentage, kill out percentage, carcass G:F from weaning to slaughter, or lean ADG ($P > 0.05$). There was a meloxicam × split-suckling interaction for carcass ADG from weaning to slaughter ($P < 0.01$). Meloxicam decreased carcass ADG when split-suckling was applied. There was no meloxicam effect on fat depth, muscle depth, lean meat percentage, kill out percentage, carcass G:F from weaning to slaughter or lean ADG. Meloxicam increased carcass weight (93.0 vs. 90.2 kg; SEM 0.75 kg; $P = 0.01$) and carcass ADG from weaning to slaughter (872 vs. 838; SEM 2.4 g/g; $P < 0.001$). Split-suckling had no effect on carcass weight, muscle depth, kill out percentage, carcass G:F from weaning to slaughter or lean ADG. It reduced fat depth (13.1 vs. 14.4; SEM 0.30 mm; $P < 0.01$), increased lean meat percentage (58.8 vs. 58.0; SEM 0.24%; $P = 0.02$), and reduced carcass ADG from weaning to slaughter (844 vs. 865; SEM 3.3 g/g; $P < 0.01$).

Sow and pig health

Colostrum intake and milk composition

Meloxicam × split-suckling interactions for piglet colostrum intake are shown in Table 5 and treatment main effects in Supplementary Tables S13 and S14. There was no meloxicam × split-suckling interaction for piglet colostrum intake ($P > 0.05$). Split-suckling had no effect on piglet colostrum intake ($P > 0.05$). However, meloxicam tended to increase colostrum intake (345 vs. 327; SEM = 7.2 g/pig; $P = 0.06$). The effect of birth weight category and treatment on colostrum intake are presented in Supplementary Tables S15 and S16. There was no meloxicam × weight category interaction

Table 4. Effect of split-suckling application and/or meloxicam provision to sows postpartum on pig carcass parameters

Split-suckling (split)	N-split		Split		SEM	P-value		
	N-Mel	Mel	N-Mel	Mel		Mel	Split	Mel × Split
Number of pens	14	12	11	13				
Cold carcass weight, kg	90.9	93.0	89.4	93.0	1.07	0.01	0.53	0.50
Fat depth, mm	14.0	14.7	12.9	13.4	0.43	0.15	<0.01	0.80
Muscle depth, mm	54.3	55.9	54.7	54.7	0.77	0.30	0.62	0.31
Lean meat, %	58.1	57.8	59.0	58.7	0.33	0.34	0.02	0.99
Kill out, %	76.1	76.5	76.5	76.5	0.40	0.65	0.68	0.68
Carcass ADG weaning to slaughter, g/d ^{1,2}	667	671	649	682	9.4	0.06	0.72	0.15
Carcass G:F weaning to slaughter, g/g ^{3,4}	0.37	0.38	0.37	0.37	0.006	0.12	0.69	0.31
Lean ADG, g/d ⁵	412	411	407	424	5.77	0.17	0.45	0.13

¹ADG, average daily gain.

²Carcass ADG (from weaning to slaughter)=[(carcass weight in kg—weaning weight in kg × 0.65) × 1,000]/number of days from weaning to slaughter (Lawlor and Lynch, 2005).

³G:F, gain to feed.

⁴Carcass G:F (from weaning to slaughter) was calculated as follows: carcass G:F=carcass ADG (g)/ daily feed intake (g) (Lawlor and Lynch, 2005).

⁵Lean ADG (from birth to slaughter)=(carcass weight × carcass lean meat percentage × 10)/number of days to slaughter (Lawlor and Lynch, 2005).

Table 5. Effect of split-suckling and/or postpartum meloxicam provision to sows on piglet diarrhea incidence preweaning, colostrum intake, preweaning antibiotic and anti-inflammatory treatment of sows and piglets and number of clinical cases of disease

Split-suckling (split)	N-split		Split		SEM	P-value		
	N-Mel	Mel	N-Mel	Mel		Mel	Split	Mel × Split
Number of sows	23	23	20	23				
Diarrhea incidence, % (days 2 to 28) ¹	12.8	17.1	5.5	4.8	3.02	0.81	<0.01	0.53
Colostrum intake per pig, g ²	334	352	320	338	9.8	0.06	0.14	0.99
Number of clinical cases of disease per litter ³	1.7	1.0	2.6	1.1	0.55	0.04	0.36	0.49
Number of injections per litter	4.7	2.5	6.5	3.2	1.48	0.06	0.38	0.70
Antibiotic usage per sow, mL ⁴	21.0	12.7	24.8	12.0	6.98	0.13	0.82	0.75
Antibiotic usage per pig, mL ⁵	0.2	0.1	0.3	0.1	0.06	0.08	0.27	0.70
Anti-inflammatory usage per sow, mL ⁶	1.6	0.9	4.0	0.3	1.11	0.06	0.39	0.19
Anti-inflammatory usage per pig, mL ⁷	0.03	0.01	0.04	0.02	0.010	0.08	0.35	0.89

¹A fecal score of 2 or greater was considered representative of diarrhea.

²Estimated value: colostrum intake (g) = $-106 + (2.26 \times \text{WG}) + (200 \times \text{BWB}) + (0.111 \times D) - (1,414 \times (\text{WG}/D)) + (0.0182 \times (\text{WG}/\text{BWB}))$, where WG is piglet weight gain (g), BWB is piglet body weight at birth (kg) and D is the duration of colostrum suckling (min) (Theil et al., 2014).

³Number of piglets per litter treated one or more times.

⁴Volume of antibiotic administered per sow.

⁵Volume of antibiotic administered per piglet.

⁶Volume of anti-inflammatory administered per sow.

⁷Volume of anti-inflammatory administered per piglet.

effect on colostrum intake ($P > 0.05$). There was a tendency for a split-suckling × weight category interaction effect on colostrum intake ($P = 0.08$). Heavy pigs at birth tended to have a lower colostrum intake when split-suckling was applied. Split-suckling had no effect on the colostrum intake of light birth weight pigs ($P > 0.05$).

Meloxicam × split-suckling interactions for the composition of sow milk at day 14 postpartum are shown in [Supplementary Table S17](#). There was no meloxicam × split-suckling interaction for the total solids, lactose, fat, or protein content of sow milk ($P > 0.05$). Neither postpartum meloxicam administration nor split-suckling had an effect on any of the compositional parameters ($P > 0.05$).

Preweaning diarrhea incidence, antibiotic and anti-inflammatory treatment and clinical cases of disease

Meloxicam × split-suckling interactions for diarrhea incidence from days 2 to 28 after birth, the total number of clinical cases of disease per litter, the total number of injections per litter preweaning, and the average volume of medication (antibiotic and anti-inflammatory) administered per pig on a litter basis and per sow are shown in [Table 5](#) and treatment main effects in [Supplementary Tables S13 and S14](#). There was no meloxicam × split-suckling interaction for diarrhea incidence from days 2 to 28 ($P > 0.05$). Meloxicam had no effect on diarrhea incidence from days 2 to 28 ($P > 0.05$). Split-suckling decreased diarrhea incidence from days 2 to 28 (5.1 vs. 14.8; SEM = 2.19%; $P < 0.01$).

There was no meloxicam × split-suckling interaction for the average volume of antibiotic used per sow, the average volume of antibiotic used per pig, the average volume of anti-inflammatory used per sow, the average volume of anti-inflammatory used per pig, total number of injections per litter and total number of clinical cases of disease per litter ($P > 0.05$). Split-suckling had no effect on the average volume of antibiotic or anti-inflammatory used per sow or per pig, the total number of injections per litter, and the total

number of clinical cases per litter ($P > 0.05$). Meloxicam had no effect on the average volume of antibiotic used per sow ($P > 0.05$) but it tended to reduce the average volume of antibiotic used per pig (0.1 vs. 0.2; SEM = 0.05 mL/pig; $P = 0.08$). Meloxicam tended to reduce the average volume of anti-inflammatory used per sow (0.61 vs. 2.78; SEM = 0.785 mL/sow; $P = 0.06$) and the number of injections per litter (2.8 vs. 5.6; SEM = 1.06; $P = 0.06$). It reduced the number of clinical cases per litter (1.0 vs. 2.1; SEM = 0.40; $P = 0.04$) and tended to reduce the average volume of anti-inflammatory used per pig (0.02 vs. 0.04; SEM = 0.007 mL/pig; $P = 0.08$).

Postweaning fecal consistency scores and antibiotic and anti-inflammatory treatment

Statistical analysis of the effect of treatment on postweaning diarrhea could not be conducted, as the occurrence of fecal consistency scores > zero was rare (a score of two or greater is required to be considered diarrhea). Out of the 250 fecal consistency scores assigned up to day 28 postweaning, a score of one was given fourteen times to the N-Split/N-Mel treatment, five times to the N-Split/Mel, eleven times to the Split/N-Mel and eight times to the Split/Mel. A score of two (considered diarrhea) was given three times to the N-Split/N-Mel, once to the N-Split/Mel, four times to the Split/N-Mel and five times to the Split/Mel. A score of three (considered diarrhea) was given three times to the N-Split/N-Mel, zero times to the N-Split/Mel, zero times to the Split/N-Mel and once to the Split/Mel. No scores higher than zero were given after 28 d postweaning.

Meloxicam × split-suckling interactions for postweaning antibiotic and anti-inflammatory treatments in pigs are shown in [Table 6](#) and treatment main effects in [Supplementary Tables S18 and S19](#). There was no meloxicam × split-suckling interaction effect on antibiotic or anti-inflammatory usage per pig during either the weaner or finisher periods or during the entire period from weaning to slaughter ($P > 0.05$). Neither meloxicam nor split-suckling affected antibiotic or anti-inflammatory usage per

Table 6. Effect of split-suckling and/or postpartum meloxicam provision to sows on postweaning antibiotic and anti-inflammatory treatments in pigs

Split-suckling (split)	N-split		Split		SEM	P-value		
	N-Mel	Mel	N-Mel	Mel		Mel	Split	Mel × Split
Meloxicam (Mel)								
Number of pens	14	12	11	13				
Weaner period								
Antibiotic usage per pig, mL ¹	0.11	0.10	0.10	0.27	0.057	0.16	0.18	0.11
Anti-inflammatory usage per pig, mL ²	0.06	0.05	0.05	0.13	0.028	0.16	0.18	0.11
Finisher period								
Antibiotic usage per pig, mL ¹	0.06	0.41	0.52	0.66	0.183	0.20	0.06	0.58
Anti-inflammatory usage per pig, mL ²	0.02	0.14	0.17	0.22	0.061	0.20	0.06	0.58
Weaning to slaughter period								
Antibiotic usage per pig, mL ¹	0.17	0.50	0.61	0.93	0.185	0.09	0.02	0.97
Anti-inflammatory usage per pig, mL ²	0.08	0.18	0.22	0.35	0.640	0.07	0.02	0.84

¹Volume of antibiotic administered to each pig.

²Volume of anti-inflammatory administered to each pig.

pig during the weaner period ($P > 0.05$). Meloxicam had no effect on antibiotic or anti-inflammatory usage per pig during the finisher period ($P > 0.05$). Split-suckling tended to increase antibiotic (0.59 vs. 0.23; SEM 0.152 mL/pig; $P = 0.06$) and anti-inflammatory usage per pig (0.20 vs. 0.08; SEM 0.043 mL/pig; $P = 0.06$) during the finisher period. It also increased antibiotic (0.77 vs. 0.34; SEM 0.130 mL/pig; $P = 0.02$) and anti-inflammatory usage per pig (0.29 vs. 0.13; SEM 0.064 mL/pig; $P = 0.02$) during the period from weaning to slaughter. Meloxicam tended to increase antibiotic (0.72 vs. 0.40; SEM 0.130 mL/pig; $P = 0.09$) and anti-inflammatory usage per pig (0.27 vs. 0.15; SEM 0.045 mL/pig; $P = 0.07$) during the weaning to slaughter period.

Discussion

To our knowledge, this study is the first to determine the effect of split suckling, postpartum provision of meloxicam to sows, and their interaction on pig growth and health to slaughter weight in pigs. Both strategies aim to increase piglet colostrum intake and as a consequence increase pig growth and health. Successful strategies may help to increase lifetime growth and reduce antibiotic usage in pigs born into large litters. This is important now that there are restrictions on the use of antibiotics and pharmacological levels of zinc oxide in pig production.

Pig growth

In the current study, meloxicam was provided to sows after release of the placenta (at the end of farrowing), as earlier meloxicam administration could inhibit the release of prostaglandins, thereby increasing farrowing duration (Rao and Knaus, 2008). Data in the literature suggests that meloxicam can reduce inflammatory pain (Engelhardt et al., 1995) and this was expected in the current study since administration was conducted at a time when the inflammatory process was established. The increase in colostrum and milk intake in piglets following meloxicam administration to sows, assumed from weaning weight, supports the hypothesis that pain relief was provided to the sows, thereby facilitating nursing activity.

Prewaning piglet growth was improved by meloxicam administration. Sows from the meloxicam group had a lower BW at weaning, most likely indicating increased mobilization of body resources during lactation. It is likely that this resulted in increased milk production in these sows (Strathe et al., 2017). Increased preweaning growth in piglets from these sows, particularly when split-suckling was not practiced, supports this. The benefit of providing meloxicam postpartum to sows on piglet ADG observed in the current study is similar to results from previous studies where meloxicam was administered orally to sows at the beginning of farrowing (Mainau et al., 2016; Navarro et al., 2021). However, in other studies, when meloxicam was administered by IM injection at the same dose and time as in the current study, no effect on piglet ADG from birth to weaning was observed (Mainau et al., 2012). However, our study design differed from that of Mainau et al. (2012) where weaning age was 21 d postpartum rather than 28 d. Furthermore, the number of piglets born alive was 12.2 compared with 16.3 in the current study, and this most likely explains why results differed across studies. Interestingly, Mainau et al. (2012) found that the preweaning ADG of low BW piglets (e.g., BW < 1,180 g) from multiparous sows, with a number of piglets born alive of ~14.2, was increased in response to meloxicam administration. This study indicated that lighter piglets from large litters benefit most from meloxicam administration to sows; however, this was not found to be the case in the current study.

Based on the study results and those from the literature, it is evident that preweaning piglet growth can be increased when meloxicam is provided IM to sows as soon as possible after birth of the last piglet (Mainau et al., 2012; our study) or orally at the beginning of farrowing (Mainau et al., 2016; Navarro et al., 2021). A single dose (Mainau et al., 2012; Mainau et al., 2016; Navarro et al., 2021; our study) at these times appears to be more effective than repeated administration (Schoos et al., 2020) before or after farrowing. Furthermore, administration too late after farrowing should be avoided (Tenbergen et al., 2014).

In the current study, split-suckling reduced preweaning ADG and BW at weaning when the six heaviest piglets were twice excluded from suckling the sow for a period of 1.5 h. On closer examination of the data, split-suckling decreased

colostrum intake, ADG from birth to weaning and BW at weaning in high birth weight piglets (>1.25 kg). The reduction of colostrum intake in heavy pigs likely contributed to reduced piglet growth. Likewise, Vandaele et al. (2020) found that piglet growth was reduced when they implemented an intensive regime (removing the heaviest piglets for three consecutive days every 3 h for a period of 12 h/d). It could be argued that similar to Vandaele et al. (2020), the protocol implemented in the current study was overly intensive. With a similar protocol to the one implemented in our study, but with only one separation period Morton et al. (2019), found that weight gain and BW at day 7 postpartum was increased when the six heaviest piglets were excluded from the sow for a period of 1.5 h. Taken together, these results suggest that separating heavy piglets more than once, as we did, is too intensive and therefore, detrimental. On the other hand, others have found no growth response even when split-suckling was less intensive (Donovan and Dritz, 2000; Muns et al., 2015).

In the current study, the application of split-suckling also negated the effect of meloxicam on piglet growth and BW. As outlined above, split-suckling reduced colostrum intake and weaning weight in heavy birth weight pigs and it appears that meloxicam administration could not compensate for the negative impact of split-suckling these pigs. There is no consensus in the literature regarding the optimum protocol for split-suckling in terms of separation time, frequency of separation, and type of piglets to be separated. The findings of the current study indicate that the duration and frequency of split-suckling implemented were not effective. It may be that the removal of piglets was performed too frequently and/or that split-suckling commenced too early in the piglets' lives. However, split-suckling was purposely commenced 4 h after the birth of the first piglet, as the quality of colostrum in terms of immunoglobulin content drops rapidly > 4 h postpartum (Klobasa et al., 1987).

To our knowledge, most of the work performed to date on provision of meloxicam to sows has only evaluated the impact on piglet growth up to weaning. However, the current study demonstrated that BW at slaughter, as well as carcass weight and carcass ADG from weaning to slaughter, were increased as a result of postpartum meloxicam provision to sows. Meloxicam administration in this study increased piglet weaning weight. Heavier piglets at weaning have previously been found to have increased postweaning and lifetime growth (Collins et al., 2017), possibly explaining the increased slaughter weight observed in the current study. Additionally, G:F and ADG were increased during the first week postweaning. No histology measurements were taken; however, G:F is a good proxy for digestive and absorptive capacity of the intestinal tract following weaning. The better feed efficiency observed early postweaning could also have contributed to the heavier weight obtained at slaughter. In line with this, the decreased pig BW at slaughter and carcass ADG found in the current study as a result of split-suckling is most likely a consequence of the reduced preweaning growth and weaning BW found in these pigs.

Pig health

The current study demonstrates that providing postpartum meloxicam to sows decreased the number of clinical cases and injections required in suckling pigs, and tended to decrease preweaning antibiotic and anti-inflammatory treat-

ments per piglet. Colostrum intake tended to increase in pigs raised by sows which received meloxicam and the reduced need for medication in these piglets is most likely due to the increase in passive immunity. Colostrum intake is critical for the development of piglet immunity, as it contains immunoglobulins, 80% of which are immunoglobulin (Ig) G, which is of primary importance for the transfer of passive immunity from the sow to the piglets (Curtis and Bourne, 1971). In our study, estimated colostrum intake per pig in the first 24 h was 73% higher than the 200 g which is regarded as the minimum intake after birth to ensure piglet survival (Devillers et al., 2011). Although not evaluated, it is likely that the immunological status of piglets reared by sows administered meloxicam was improved due to increased colostrum intake. This is in line with the study from Mainau et al. (2016) which showed that administration of meloxicam to sows at the beginning of the farrowing process resulted in increased plasma IgG concentration in piglets 24 h after birth. Additionally, transmammary transfer of meloxicam from sows to piglets has previously been demonstrated (Bates et al., 2014) which could also help to explain the reduced number of clinical cases of disease and injections required per litter. The combination of increased passive immunity and the anti-inflammatory pain relief provided through the colostrum/milk to piglets from sows supplemented with meloxicam are both likely drivers for the resulting increased preweaning piglet growth. It was expected that practicing split-suckling would increase colostrum intake in light birth weight piglets; however, this was not the case and it actually reduced colostrum intake in heavy birth weight piglets. Therefore, it is not surprising that split-suckling reduced preweaning growth and that clinical cases of disease and the requirement for medication usage were not reduced. To our knowledge, our study is the first to monitor medication usage in pigs in response to split-suckling.

Preweaning mortality observed in the present study was higher than the Irish industry average of 11.1%, which is likely explained by the higher number of piglets born alive in the present study, which was 16.3 on average compared to the industry average of 14.8 (Teagasc, 2022). In agreement with other studies (Mainau et al., 2012, 2016; Navarro et al., 2021), there was no effect of meloxicam provision to the sow on piglet preweaning mortality. The current study was conducted in a high health status herd where sanitary conditions were good and this most likely explains the lack of effect of meloxicam on mortality. However, when mastitis-metritis-agalactia syndrome was an issue in a previous study, meloxicam reduced piglet mortality from 32 to 14% when it replaced flunixin as the anti-inflammatory used (Hirsch et al., 2003). Likewise, split-suckling, as conducted in the current study, did not reduce preweaning piglet mortality and this is in agreement with the results of Muns et al. (2015). Only one treatment in the current study had a preweaning mortality rate higher than 20%, the rate above which causes of mortality should be paid particular attention (Koketsu et al., 2021) and this was where litters were split-suckled. Split-suckling might have been expected to reduce mortality, especially since the practice reduced diarrhea incidence by one third; however, it involves a disturbance of both piglets and the sow and this likely negated any positive effect on preweaning piglet mortality (Muns et al., 2015). In our study, split-suckling piglets involved personnel lifting pigs on four separate occasions during the first hours after birth and temporary removal of

the heaviest littermates reduced colostrum intake in these pigs at this critical time.

Unlike the situation preweaning, postpartum analgesia had little effect on medication usage during the postweaning period. This is possibly not surprising since the effect of meloxicam would have long since waned by this time. However, split-suckling increased medication usage during the weaning to slaughter period, thereby demonstrating a negative residual effect from this practice. Colostrum intake was reduced in heavy birth weight pigs in response to split-suckling and this most likely explains this increased postweaning medication usage in pigs that had been split-suckled.

Conclusion

In conclusion, a single IM injection of meloxicam provided to sows as soon as possible after delivery of the placenta can increase colostrum intake. This likely led to the observed reduction in clinical cases of disease, increased ADG in pigs during the first two weeks of life and early postweaning and increased carcass weight at slaughter. Furthermore, the strategy tended to reduce preweaning antibiotic and anti-inflammatory usage in pigs. Contrary to this, commencing split-suckling 4 h after birth of the first piglet by twice removing the six heaviest piglets from the sow, reduced pig growth prior to weaning and up to slaughter, having no effect on preweaning medication usage. In conclusion, postpartum meloxicam administration to sows is recommended as a strategy to increase lifetime pig growth and health whereas split-suckling, as conducted in the current study, is not advised.

Supplementary Data

Supplementary data are available at *Journal of Animal Science* online.

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Conflict of interest statement

The authors declare no conflict of interest.

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