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Effect of litter birth weight standardization before first suckling on colostrum intake, passive immunization, pre-weaning survival, and growth of the piglets

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A B S T R A C T

Within-litter variation in birth weight is a relevant factor in pig production. This study aimed at comparing pre-weaning mortality, colostrum intake (**CI**), passive immunization, and growth of piglets from litters of uniform (**UN**) or heterogeneous (**HET**) birth weights. The study included 52 multiparous sows (Large White × Landrace) and their litters. Two types of litters were constituted based on birth weight, namely: UN or HET, the control group, using piglets from two to three sows farrowing approximately at the same time. At birth, piglets were weighed, identified, and placed in a box under an IR lamp. At the end of farrowing, piglets were re-weighed and allotted to groups UN or HET (12 per litter) with average weights of 1 394 and 1 390 g, respectively, and allowed to suckle (time 0). They were re-weighed 24 h later to estimate CI and sows' colostrum yield. At time 0, the average intra-litter CV (%) in weight of experimental litters were 9.3 ± 0.8 (SEM) and 27.8 ± 0.7 in groups UN and HET, respectively ($P < 0.001$). At 2 days of age, blood samples were taken from the piglets of 11 litters five UN and six HET) and serum Immunoglobulin G (**IgG**) contents were determined. Mean CI/piglet/litter was similar in both groups, that is, 415 ± 13 in UN and 395 ± 13 g in HET ($P = 0.28$), but was less variable in UN litters (CV = 22.4 ± 2 vs 36.0 ± 2%, $P < 0.001$). The IgG levels at 2 days of age were higher in piglets from UN litters (22.5 ± 0.8 vs 18.4 ± 0.7 g/l; $P < 0.001$) but the CV of IgG levels was not different between litter type ($P = 0.46$). Mortality up to 21 days of age was lower in UN litters (6.4 vs 11.9%, $P = 0.03$). The BW at 21 days was not different between litter type ($P = 0.25$) but it was less variable among piglets from UN litters (CV: 17.1 ± 1.3 vs 25.7 ± 1.3%; $P = 0.01$). Results reveal that CI is less variable and mortality is lower in piglets from litters of UN birth weight. The results infer that genetic improvement to decrease variation in birth weight within-litter could have a positive effect on homogeneous CI and thus contribute to reducing piglet mortality.

Implications

Pre-weaning mortality of piglets represents both welfare and an economic problem in the pig industry. Main results of this study show that litter homogenization, by cross-foresting since the end of the farrowing presents advantages both on colostrum intake variability and on pre-weaning survival. Although cross-fostering at farrowing cannot be advisable because of practical and potential immunity constraints, the genetic improvement to reduce within-litter variation in birth weight is recommended to increase pre-weaning survival of the piglets and consequently the pig farms productivity.

Introduction

The heterogeneity of birth weight (**BW0**) is an essential trait of sow productivity. The within-litter CV of piglets' BW0 ranges usually from 18 to 26% (Quesnel et al., 2008; Declerck et al., 2017; Zeng et al., 2019; Moreira et al., 2020) yet as high as 51% (Quesnel et al., 2008). Within-litter variation in BW0 is positively correlated with pre-weaning mortality (Milligan et al., 2002; Quiniou et al., 2002; Wolf et al., 2008) and variation in weaning weight (Milligan et al., 2002; Muns et al., 2014). When compared to their heavier litter-mates, the lighter piglets are at disadvantage with regard to access to the mammary glands. Therefore, they consume less colostrum (Ferrari et al., 2014; Declerck et al., 2017; Le Dividich et al., 2017), leading to higher pre-weaning mortality rates (Muns et al., 2013; Charneca et al., 2015; Le Dividich et al., 2017; Zeng et al., 2019).

High within-litter variation in BW0 is associated with a greater proportion of low BW0 piglets in the litter (Quiniou et al., 2002; Quesnel

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et al., 2008). Low birth weight piglets have less glycogen reserve at birth (Theil et al., 2011; Vanden Hole et al., 2019) and have a larger surface area to volume ratio, making them more susceptible to hypothermia and hypoglycemia during the first 24 h of postnatal life (Baxter et al., 2008). Colostrum intake (**CI**) is a key factor to ensure adequate nutritional and/or immunological status (Le Dividich et al., 2005; Quesnel et al., 2012; Decaluwé et al., 2014). Therefore, Quesnel et al. (2012) suggested that piglets need a minimum intake of 200 g colostrum in the first 24 h to significantly reduce pre-weaning mortality, to provide passive immunity and to allow a slight weight gain. These authors also suggested that an intake of 250 g colostrum in the same period would contribute to good health and adequate pre and postweaning growth.

At the farm level, cross-fostering is commonly performed (Baxter et al., 2013) to standardize litters in terms of number and/or weight, but it is frequently practiced when the colostral phase is in the advanced stage or finished (Le Dividich, 1999). Studies by Bishop (2011) and Heim et al. (2012) showed that when practiced at about 24 h postfarrowing, cross-fostering has no significant effect on pre-weaning mortality. However, to the best of our knowledge, there are no studies on the consequences of litter standardization at birth. Therefore, this study, with preliminary results presented in a conference poster (Charneca et al., 2013), aimed to investigate the effects of litter birth weight standardization before first sucking on CI, immunization, pre-weaning mortality, and growth of the piglets.

Material and methods

This study was carried out in accordance with the regulations and ethical guidelines set by the Portuguese Animal Nutrition and Welfare Commission (DGAV—Directorate-General for Food and Veterinary, Lisbon, Portugal) following the 2010/63/EU Directive.

Farm and animals

The experiment was carried out in a private intensive pig farm located close to Évora (Portugal), with a mean herd size of 1 000 Large-White and Landrace sows (Topigs 20). Multiparous sows were artificially inseminated with Piétrain semen (Top Pi) in a 3 weeks batch system (130–150 sows per batch). Farrowings took place in the 20 farrowing rooms of the farm, and piglets were weaned on average at 28 days of age. Gestating sows were housed in a group, 10–12 sows per group, and moved to the farrowing crate at 5–7 days prior to the expected date of farrowing. The farrowing crates had a PVC slatted floor (under the sow and piglets) and the creep area was heated by a 175 W IR lamp. They were also equipped with a sow feeder and low-pressure nipple-drinkers (for sow and piglets) with a continuous supply of water.

Management of sows and piglets

During gestation, sows were fed 3 kg/day of a standard gestation diet (8.91 MJ Net energy/kg, 15.1% CP, 0.8% lysine) until about day 75 of gestation and 3.3 kg afterward until they moved to the farrowing crate, while feed allowance was gradually reduced from 3.3 kg/day until no feed supply on the day of farrowing. After farrowing, sows were fed with 2.2 kg/day of a standard lactation diet (9.62 MJ Net energy/kg, 16% CP, and 0.9% lysine). The feed allowance was increased by 1.2 kg each 3 days of lactation, to a maximum of about 7 kg from day 12 of lactation until weaning. According to the standard procedures of the farm, on the 2nd (±1) day after birth, piglets were tail-docked, teeth were ground and piglets were injected with 2 ml of Ferrovet (200 mg of iron dextran + 30 μg of vitamin B12). A solid prestarter diet (9.86 MJ Net energy/kg, 17.5% CP, and 1.32% lysine) was provided to the piglets from 7 days old until weaning. Farrowings were usually monitored by farmworkers and oxytocin was administrated via intramuscular injection when the birth interval between piglets exceeded ~1 h.

Experimental procedures

In this trial, farrowings were not induced and were supervised by the research team. No gilts were used in this trial because a different farming protocol is applied in this case, requiring the use of all functional teats in their first lactation and we would be unable to specify the initial litter size. The uniform (**UN**) and heterogeneous (**HET**) litter birth weight were obtained using piglets from two, occasionally three simultaneous farrowings (with about a maximum of 1–1.5 h of difference since onset). A total of 52 experimental litters were used (26 UN and 26 HET) from four farrowing batches. At birth, all live-born piglets were roughly dried, weighed to the nearest 1 g using an electronic balance (Kern FTB 15K0.5L) equipped with an integration system, identified (ear tag), and birth time and sex were registered. The sex and the weight of stillborn piglets as well as the number of mummified piglets were recorded for reproductive data collection. All live-born piglets were then put inside a PVC box, under the IR lamp and inside the creep area of the farrowing crate, to provide an environment close to thermo-neutrality. At the end of farrowing, piglets were reweighed (BW0) and cross-fostered to obtain the experimental litters of 12 piglets each. Piglets with BW0 lower than 700 g were not used because they are often considered as a runt and frequently euthanized. The time span between birth and first suckling was 251 and 58 min in UN and 247 and 54 min, respectively for first born and last born piglet of the litter. The number of 12 piglets per sow was set to assure that in each litter all piglets had access to functional teats. All supernumerary piglets were adopted by sows not used in the study. The experimental litters' set-up aimed to have a piglet within-litter CV equal or lower than 10% in UN litters and equal or higher than 20% in HET litters. The choice of piglets and sows was conditioned to obtain similar average parity and a close average weight of piglets on both experimental groups. Piglets were then allowed to freely suckle from the sows (time 0). If the farrowing was too prolonged and there were no sufficient born piglets to set-up the experimental litters, the sow was not considered for the study. All experimental piglets were individually weighed 24 h after time 0 for CI estimation. Piglets that died after the experimental litter was allowed to suckle, were weighed as soon as they were found dead, with the time interval between death and weighing ranging from a few minutes to about 18 h. These piglets were not necropsied. At 2 days of age, blood samples (1.0–1.5 ml) were taken by vena cava puncture from all piglets of 11 litters (five UN and six HET). Blood was allowed to clot at room temperature, centrifuged (1 400 × g), then the serum was removed and kept at −20 °C until analyzed. Due to differences in farrowing dates and partial weaning, not all piglets were weaned at 28 days of age. Therefore, and because most of the effects of litter type on survival and growth could be assessed at 21 days, at that age all piglets were reweighed and the trial finished.

Calculations and analyses

The farrowing duration was considered as the lapse of time between birth of the first and of the last piglet. Individual CI of the newborn piglets was estimated from piglet weight variation between birth and 24 h and using the prediction equation of Devillers et al. (2004b). Colostrum yield (**CY**) during the first 24 h after farrowing was calculated by adding CIs for each piglet of the litter. The concentrations of Immunoglobulin G (**IgG**) in the piglets' serum were analyzed in triplicate using a commercial kit (Pig IgG ELISA Quantitation kit, Bethyl Laboratories, Montgomery, USA, ref. E100-104), according to an adaptation by I. Oswald (UR66 Pharmacologie-Toxicologie, INRA, Toulouse, France). The validated procedure was described by Devillers et al. (2004a).

Statistical analyses

Data were analyzed using IBM SPSS Statistics software (version 22, 2013). For an overview of reproductive traits and original litter traits, descriptive statistics were performed. The within-litter-CV and average birth weight comparison between smaller and larger original litters was made using the average alive born piglets of all litters as the limit value. The GLM procedure with the one-way ANOVA was used considering litter size ≤13 born alive piglets ($n = 28$) or (≥14 born alive piglets ($n = 24$) as fixed effect and batch as a random effect. The experimental litters were compared with the same procedure but using treatment (UN or HET) as a fixed effect and batch as a random effect.

After litters were created, there were 38.8% cross-fostered piglets and 61.2% resident piglets ($P < 0.001$) considering all litters. Although cross-fostering was made before any suckling, a comparison between cross-fostered and not cross-fostered (resident) piglets was made on their birth and 24 h weight, growth performance, and immunization. The GLM procedure with the one-way ANOVA was used, having piglet type (cross-forest vs resident) as a fixed factor.

Regression analysis was made to determine the relationship between CY and litter weight and a correlation procedure was used between CY and within-litter weight variation.

The within-litter regressions between CI, birth weight and IgG levels were determined using the residues (of CI, birth weight and IgG) obtained by ANOVA using litter as a fixed effect. Comparisons of piglet mortality rates were assessed using χ^2 tests. Unless otherwise mentioned, all values are mean ± SEM. Differences were considered significant for a P-value < 0.05.

Results

The reproductive and productive traits of sows and piglets in the original litters are presented in Table 1.

Larger litters presented higher within-litter birth weight CV than smaller litters ($P = 0.03$). Inversely, the average BW0 of born alive piglets was lower in larger litters ($P = 0.008$) (Table 2).

The results related to experimental litter characteristics, average CI and CY, and IgG levels of piglets are presented in Table 3. The average weight of piglets at cross-fostering was similar between groups. However, due to the experimental procedures, there was a difference in the within-litter CV, being lower than 10% in UN litters and higher than 27% in HET litters ($P < 0.001$). Overall, the average CI was 405 ± 66 g (mean ± SD). There was no difference between litter types (UN vs HET; $P = 0.28$) in CI but CI was more variable in HET litters ($P < 0.001$). The average of the minimal CI was higher in UN than in HET litters ($P < 0.001$) while the average of maximal CI was lower in UN than in HET litters ($P = 0.04$). Overall, CY averaged 4699 ± 795 g (mean ± SD), ranging from 3 091 to 6 264 g. The average IgG level in piglets' serum at 48 h of age was 20.3 ± 6.2 g/l (mean ± SD), being. higher in piglets from UN litters when compared to those from HET litters ($P < 0.001$). However, the within-litter CV of IgG levels was not different between litter types ($P = 0.46$).

The slope of the within-litter regression between birth weight and CI was lower in UN than in HET litters (0.23 ± 0.04 vs 0.29 ± 0.01, $P < 0.001$). Considering all litters, CY was positively related with litter weight at cross-fostering ($R^2 = 0.135$; $P = 0.007$) but that correlation was only significant in UN litters ($R^2 = 0.443$; $P = 0.02$). Colostrum yield and variability of piglet's birth weight after cross-fostering was negatively correlated in the present study (−0.275; $P = 0.05$). Within-litter regression equations relating IgG, BW0, and CI showed that the overall IgG concentration was not correlated with BW0 of the piglets ($R^2 = 0.001$; $P = 0.76$) but tended to be correlated with piglets' CI ($R^2 = 0.026$; $P = 0.08$). There were no differences ($P > 0.05$) between cross-fostered and not cross-fostered piglets on IgG levels both globally or by litter type.

Compared to the cross-fostered animals, the resident piglets were heavier at birth ($P = 0.002$) and at 24 h ($P = 0.004$) but no significant differences were observed regarding weight gain from birth to 24 h ($P = 0.40$), CI ($P = 0.27$), weight at 21 days ($P = 0.27$) and mortality rate from 0 to 21 days ($P = 0.15$; Table 4).

The mortality rate and characteristics of the litters at 21 days are presented in Table 5. Mortality rate until 21 days was, on average, 9.1%, but it was lower ($P = 0.02$) in UN litters when compared to HET litters (6.4%

Table 1
Reproductive and productive traits of sows and piglets of the original litters.

	Minimum—maximum	Mean	SD
Parity	2–8	4.0	1.5
Total born	9–19	14.0	2.5
Born alive	9–18	13.3	2.4
Stillborn	0–4	0.8	1.1
Farrowing duration (min)	102–430	239	81
Within-litter mean birth weight (g)	989–1 815	1 427	213
Within-litter birth weight CV (%)	4.0–36.4	19.5	7.4

Table 2
Effects of litter size on mean birth weight of piglets and within-litter birth weight variation in the original litters.

	Litter size (born alive)		RSD	P-value
	≤13 ($n = 24$)	≥14 ($n = 28$)		
Piglet mean birth weight (g)	1 511	1 353	203	0.01
Within-litter birth weight CV (%)	17.0	21.6	7.2	0.03

Table 3
Experimental sows and litter characteristics, average colostrum yield, colostrum intake,[1] and piglets IgG levels.

	Litter type		RSD	P-value
	Uniform (UN)	Heterogeneous (HET)		
Number of litters	26	26	–	–
Mean parity of sows	3.9	4.0	1.6	0.83
Weight of piglets (g)	1394	1390	142	0.91
Weight range (g)	799–2028	700–2178	–	–
Within litter CV (%)	9.3	27.8	3.8	<0.001
Litter weight gain 0–24 h (g)	1783	1454	943	0.22
Mortality 0–24 h (%)	2.2	4.5	–	0.18
Colostrum intake (CI, g)	415	395	70	0.28
Coefficient of variation of colostrum intake (%)	22.4	36.0	9.1	<0.001
Litter minimal CI (g)[2]	283	191	97	<0.001
Litter maximal CI (g)[3]	535	567	79	0.04
Colostrum yield (CY, g)	4875	4525	792	0.12
Colostrum yield CV (%)	14.4	18.9	–	–
Piglet IgG level (g/l)[4]	22.5	18.4	5.9	<0.001
Within-litter IgG CV (%)[4]	26.2	23.9	4.8	0.46

Abbreviation: IgG, Immunoglobulin G.
[1] Colostrum intake was estimated only in piglets alive at 24 h.
[2] Average CI of the two piglets per litter with lower CI.
[3] Average CI of the two piglets per litter with higher CI.
[4] Data from five UN and six HET litters.

Table 4
Comparison of resident and cross-fostered piglets initial and final characteristics and performance.

	Piglet type		RSD	P-value
	Resident	Cross-fostered		
Birth weight (g)	1425	1347	310	0.002
Weight at 24 h (g)	1616	1529	360	0.004
Weight gain 0–24 h (g)	178	171	95	0.40
Colostrum intake (g)	409	397	133	0.27
Weight at 21 days (g)	6264	6125	1472	0.27
Mortality rate 0–21 days (%)	7.7	11.2	–	0.15

Table 5
Mortality rate of the piglets and litter characteristics at 21 days of age.

	Litter type		RSD	*P*-value
	Uniform (UN)	Heterogeneous (HET)		
Number of litters	26	26	–	–
Litter size	11.2	10.6	1.1	0.045
Litter total weight (kg)	68.8	66.7	9.4	0.42
Mean piglet weight (g)	6115	6324	642	0.25
Within-litter CV (%)	17.1	25.7	6.6	<0.001
Litter weight gain 0–21 days (kg)	52.1	50.0	8.8	0.40
Mortality rate (0–21 days, %)	6.4	11.9	–	0.020

vs 11.9%). Therefore, UN litters were larger at 21 days than HET litters ($P = 0.045$). They also presented a lower within-litter CV of their piglets weights ($P < 0.001$) but no differences were observed regarding litter weight gain from 0 to 21 days ($P = 0.40$) and litter weight at 21 days ($P = 0.42$). During the first 24 h after birth, 3.4% of piglets died (37.4% of total losses), and among these lost piglets 52% weighed less than 1 kg at birth and 76% lost weight between birth and death. The percentage of dead piglets with a BW0 lower than their litter average was comparable in both groups (65% in UN and 84% in HET, $P = 0.20$). Considering the piglets that died after 24 h (13 in UN and 23 in HET), 55% consumed less than 250 g of colostrum in the first 24 h and HET litters presented a higher number of piglets (3 in UN vs 17 in HET, $P = 0.009$) that consumed less than 200 g of colostrum in the first 24 h.

Discussion

The most relevant result of the present study was the significant reduction in pre-weaning mortality of the piglets when litters were standardized for birth weight before first suckling. The mortality rate until 21 days observed in the present study was almost half in UN when compared to HET litters, which represents extra 17 piglets alive at 21 days considering all UN litters.

As in the present study, several works associate low BW0 and/or low CI with increased pre-weaning mortality of the piglets (Decaluwé et al., 2014; Ferrari et al., 2014; Le Dividich et al., 2017). Also in agreement with previous studies (Devillers et al., 2011; Ferrari et al., 2014; Declerck et al., 2017; Le Dividich et al., 2017), the present study observed a positive relationship between piglets' BW0 and CI.

Although the average BW0 and CI were not different between the UN and HET groups, both traits were more variable in HET group, which most likely explain the observed difference in the mortality rate between these two groups and emphasizes the importance of litter standardization at birth to reduce pre-weaning piglet mortality in contrast to cross-fostering at 24 h postfarrowing which did not observe any benefit to reduce pre-weaning mortality of the piglets (Bishop, 2011; Heim et al., 2012).

In the current study, the percentage of dead piglets with BW0 lower than their litter average was similar between litter types, but the majority of piglets from HET litters that died after 24 h had ingested less than 200 g colostrum, the minimum value suggested by Quesnel et al. (2012) to significantly reduce the risk of death before weaning. Therefore, in HET litters the essential factors that seem to influence pre-weaning mortality are the relative birth weight (related to litter average weight) and CI, whereas in UN litters the most important factor seems to be the relative birth weight.

It is of vital importance that piglets ingest adequate amounts of colostrum to provide enough energy and passive immunity to ensure their survival and development (Le Dividich et al., 2005; Quesnel et al., 2012). The slope of the regression relating birth weight and CI was lower in UN litters when compared to HET litters. In UN litters each 100 g increase in BW0 was associated with a 23 g increase in CI, while the correspondent value in HET litters was 29 g. This means that in more HET litters, piglets with higher weights (higher than the litter average) have an advantage regarding CI, while in more UN litters the benefits of being heavier are not as important for CI. It is important to note that CI of the two piglets with the lowest CI for that litter was significantly higher in UN litters when compared to HET litters. Conversely, the to piglets with the highest CI within a litter ingested larger amounts of colostrum in HET litters than those in UN litters. Considering the proposed intake of 200 g colostrum to significantly reduce the pre-weaning mortality of the piglets (Quesnel et al., 2012), all piglets in the UN group ingested more than this threshold level, which was not the case in the HET group. Mean IgG serum levels at 48 h were in line with those observed in several studies between 24 and 72 h of age (Devillers et al., 2011; Le Dividich et al., 2017). The absence of differences in the CV of IgG serum concentrations between litter type in the presence of the higher CV for CI in HET litters, might be related to the weak relation between IgG levels and CI observed in both litter types and also observed by Devillers et al. (2011) and Le Dividich et al. (2017). This weak relation is probably related to the various decreasing patterns of colostrum IgG concentrations, not measured in this trial but reported in other studies (Devillers et al., 2004a; Charneca et al., 2015) and the various intake behaviors of piglets over time. Because IgG was only determined in a sub-set of litters and many piglet losses occurred before blood sampling, there is no sufficient data to compare IgG levels of surviving and dying piglets. High mortality has been correlated with low levels of serum IgG (Devillers et al., 2011). However, these mortalities may simply be associated with insufficient nutrition rather than disease. As an example, the study by Devillers et al. (2011) showed that piglets dying during the first three postnatal days had 44% less serum IgG concentrations at 2 days of age than survivors, but had consumed 2.3 times less colostrum (147 vs 333 g) and hence energy. Also, Rootwelt et al. (2012) failed to see an association between IgG levels at day 1 after birth and survival until weaning. Finally, there were no differences between cross-fostered and resident piglets on IgG levels in the current study. However, it is important to mention that cross-fostering before suckling, as it was made in the present study, may have consequences for the piglets. Besides immunoglobulins, colostrum is rich in maternal cells (mainly lymphocytes and epithelial cells) that can be absorbed by their offspring (Le Jan et al., 1995). According to Bandrick et al. (2014) immunoglobulins and immune cells are critical components of colostral immunity, however, the cells can only be transferred to the piglets if they ingest colostrum from their biological mothers. These cells participate in the antigen-specific response in piglets, therefore, cross-fostering practiced before the 1st suckling may negatively affect the transfer of cellular immunity and the health of the progeny. At 21 days of age, the total litter weight, average piglet weight, and weight gain were not different between litter types, therefore overall growth performance was not influenced. At 21 days the within litter weight CV remained significantly higher in HET litters than UN litters. However, while there was a slight decrease of CV in HET litters between experimental litters setup and day 21, we have observed an important increase of CV in UN litters in the same period. The CV decrease in HET litters can be related to the death of the lighter piglets whereas the CV increase in UN litters can be explained by differences between individual glands milk production and/or differences in the stimulation efforts of the individual piglets, as previously observed by Muns et al. (2014).

Globally, the present results indicate that cross-fostering at birth aiming to decrease litter heterogeneity in BW can have a highly beneficial impact on pre-weaning survival. However, such cross fostering before the 1st suckling is very difficult or impossible to do at the farm level and may have negative consequences on the immunity of the piglet, therefore it is not applicable or recommended at the practical level. In contrast, because the homogeneity of the litter has some heritability (Kapell et al., 2011), the inclusion of this trait in selection schemes may be the best tool to have more homogenous litters leading to a higher pre-weaning survival rate, thus increasing the productivity of sows.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository.

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Author contributions

RC: Conceptualization, Investigation, Writing—original draft, review & editing, Funding acquisition; JN: Investigation, Writing—review & editing; AF: Investigation; JLD: Conceptualization, Methodology, Supervision, Writing—review & editing.

Declaration of interest

None.

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