Effects of tail docking and tail biting on performance and welfare of growing–finishing pigs in a confinement housing system¹

Y. Z. Li,^{*2} H. F. Zhang,^{*} L. J. Johnston,^{*} W. Martin,[†] J. D. Peterson,[‡] and J. F. Coetzee[‡]

^{*}West Central Research and Outreach Center, University of Minnesota, Morris, 56267; [†]University of Minnesota Extension, St. Paul 55108; and [‡]Veterinary Diagnostic and Production Animal Medicine, College of Veterinary Medicine, Iowa State University, Ames 50010

ABSTRACT: A study was conducted to evaluate the effect of tail docking on the welfare and performance of victimized pigs by tail biting and tail biters. Pigs ($n = 240$; 25.7 ± 2.9 kg average weight), including 120 pigs that were tail docked at birth and 120 pigs that remained with intact tails, were used. Pigs were housed in 8 pens of 30 pigs in a confinement barn for 16 wk, with 4 pens each housing pigs of both sexes with docked or intact tails. Tail biters and victimized pigs with damaged tails were identified during outbreaks of tail biting. Growth performance was monitored, and skin lesions on the tail, ears, and body were assessed. Blood samples were collected from focal tail biters, victimized pigs, and nonvictimized pigs for analysis of total serum protein, IgG, and substance P concentrations. When pigs were marketed, carcass weights and the number of pigs with carcass trim loss were recorded. During the growing–finishing period, 48% of pigs with docked tails and 89% of pigs with intact tails experienced lesions on their tails, including 5% of docked pigs and 30% of intact pigs identified as victimized pigs that experi-

enced puncture wounds with signs of infection on their tails or loss of tails ($P < 0.001$). Victimized pigs tended to gain less weight ($P = 0.07$) between 17 and 21 wk of age than other pigs when tail biting prevailed in this study. Victimized pigs were more frequently ($P = 0.04$) sold for less than full value and had a lower dressing percentage ($P < 0.001$) compared with nonvictimized pigs. For victimized pigs, total serum protein and IgG concentrations were elevated 5 d after tails were injured, suggesting that tail damage can cause inflammation, which may lead to carcass abscesses and trim loss. Compared with victimized pigs and nonvictimized pigs, tail biters had lower total serum protein ($P = 0.01$) and IgG ($P = 0.01$) concentrations, indicating that tail biters may experience poor immune functions. Results of this study demonstrated that tail docking reduced tail damage in pigs kept in a confinement system. Tail damage can cause inflammation and reduce the value of market pigs. More research is needed to test whether compromised immune functions predispose pigs to tail biting.

Key words: immunoglobulin G, pigs, skin lesions, tail biting, tail docking, total serum protein

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doi:10.2527/jas2017.1571

INTRODUCTION

Tail biting is a common problem in swine production and can cause considerable economic losses for pork producers and major welfare complications for pigs (Harley et al., 2014). Tail biting is considered an

abnormal behavior caused by stress and frustration in the pig (EFSA, 2007; Brunberg et al., 2016) and can be triggered by multiple factors, including genetics, nutrition, environment, and management (D'Eath et al., 2014). Lack of manipulable materials, slatted floors, and crowding at the feeder have been identified as major risk factors for tail biting (EFSA, 2007; D'Eath et al., 2014). All of the risk factors can be present under confinement production conditions (barren environment with fully slatted floors). Because tail biting is difficult to predict (Ursinus et al., 2014a; Larsen et al., 2016), currently, the most common prevention

¹The authors greatly appreciate the National Pork Board and the Pork Check-Off for financial support of this project.

²Corresponding author: yuzhili@umn.edu

Received March 20, 2017.

Accepted September 2, 2017.

method for tail biting in the United States is tail docking. Although tail docking reduces the incidence of tail biting, it is a painful procedure for the pig (Herskin et al., 2016). The long-term effect of tail docking may include formation of traumatic neuromas, which may increase sensitivity of the docked tail (Herskin et al., 2015; Sandercock et al., 2016). In addition, tail docking deals with the abnormal actions only by suppressing the behavior of tail biting; it does not remove the underlying welfare problems that trigger the motivations of tail biting (Brunberg et al., 2016). Due to animal welfare concerns, tail docking on a routine basis is prohibited by the European Union (EC, 2001). Because most research on tail biting is conducted in Europe (Taylor et al., 2012; D'Eath et al., 2014), the objective of this study was to evaluate the impact of tail biting on welfare and performance of victimized pigs and tail biters under confinement conditions in the United States when tail docking was or was not performed.

MATERIALS AND METHODS

This project was conducted at the University of Minnesota West Central Research and Outreach Center in Morris, MN. The Institutional Animal Care and Use Committee (IACUC) of the University of Minnesota reviewed and approved the experimental protocol for this project (IACUC number 1412-32165A).

Animals, Housing, and Management

Pigs ($n = 352$; Landrace $\times$ Yorkshire $\times$ Duroc) born on the research farm within 1 wk were used for the study. Piglets were born in a confinement farrowing barn where piglets and the sow were kept in individual pens with farrowing crates on plastic-coated woven wire floors. Within 24 h after farrowing, all piglets were weighed, their teeth were clipped, and they were ear tagged and injected with iron, and the male pigs were castrated without receiving any anesthetics or analgetics. At the same time, tail docking was performed on half of the piglets within each litter, balanced for sex, and the other half of the litter remained with intact tails. To select piglets for tail docking, piglets in each litter were haphazardly picked and every another pig within the same sex was tail docked. Tail docking was performed by a trained animal caretaker using sharp side cutters. Docking occurred 1.3 to 2.5 cm from the base of the tail according to the common procedure of the industry (Widowski, 2002). Cross-fostering was conducted within 24 h after farrowing to avoid live litter sizes greater than 14 piglets. During cross-fostering, piglets with birth weight greater than the mean piglet birth weight within the litter were moved to a foster sow to ensure their compatibility in the recipient

litter. Room temperature in the farrowing barn was maintained by a computer-controlled ventilation system at $20 \pm 1^\circ\text{C}$, and piglets were provided with supplemented heat by electric heat lamps. There was a nipple drinker in each pen for piglets, but no creep feed was provided during the lactation period. Piglets were weaned at 4 wk of age and transferred to a confinement nursery barn. In the nursery barn, pigs from different litters were mixed and sorted by weight and sex. Eight pigs of the same sex from 3 to 4 litters were allocated to each pen, and BW was balanced to achieve a similar average weight and weight variation (CV) within a pen across all pens. Each nursery pen provided floor space allowance of $0.34 \text{ m}^2/\text{pig}$, excluding the space occupied by the feeder, on plastic-coated woven wire floors. The nursery pen was equipped with a 5-space dry feeder and 1 bowl drinker. Room temperature in the nursery barn was maintained at $28 \pm 1^\circ\text{C}$ when pigs entered the barn and was decreased to $23 \pm 1^\circ\text{C}$ over the subsequent 5-wk period. At 9 wk of age, pigs were moved to a confinement growing–finishing barn and housed in pens of 30 pigs on fully slatted concrete floors. Floor space allowance was $0.72 \text{ m}^2/\text{pig}$, excluding the space occupied by the feeder. Each pen in the growing–finishing barn was equipped with a 3-space dry feeder and 2 nipple drinkers. Average room temperature was 25.7°C (SD 1.54, range 21.7 to 30°C) during the study period in the growing–finishing barn.

During both the nursery and the growing–finishing period, all pigs had free access to corn–soybean meal diets fed in mash form and formulated according to NRC recommendations (NRC, 2012) and water. Neither ractopamine nor any other growth-enhancing additive was used throughout the growing–finishing period to avoid any possible influences on the behavior of pigs that might be related to tail biting. A computerized controller and a mechanical ventilation system maintained air quality and room temperatures as close to recommended targets as possible in each barn (NPB, 2016a). Room temperature at the floor level was recorded at 15-min intervals by a Hobo Data Logger (HOBO Pro-V2, Temp/RH; Onset Computer Corporation, Bourne, MA) in both barns. Lights in the barn were on for 8 h daily starting at 0800 h in both the nursery and the growing–finishing barns. From birth to the end of the study, pigs were checked at least once daily to ensure that they had free access to feed and fresh water and were in good health. To mimic confinement production systems in the United States, no environmental enrichment or rooting materials were provided throughout the study.

Experimental Design

The experiment was conducted in a confinement growing–finishing barn. Pigs in the control group were

tail docked, and pigs in the treatment group remained with their tails intact. At 9 wk of age, 240 pigs, with equal number of barrows and gilts from each treatment group, that had no tail damage were selected for data collection. Eight pens (4.7 by 4.6 m) in 1 room were used, with 4 pens of 30 pigs for each treatment. Within each treatment, pigs were sorted by weight and sex and randomly allocated to each pen. For randomization, pigs of the same sex were classified into 15 groups of 4 pigs with similar BW. Then, pigs in each group were randomly allocated into 1 of 4 pens using a random number generator. Pen groups were thus formed with equal numbers of barrows and gilts and similar mean weight and within-pen variation (CV) across all pens. Pigs remained in their designated pens for 16 wk until they were 25 wk of age. When any pigs were moved to hospital pens due to compromised health, they were weighed and the reason for removal was recorded. For every 2 pigs removed, the pen size was reduced by 1.41 m² (4.7 by 0.3 m) to maintain floor space allowance as consistent as possible throughout the study.

Data Collection

Tail Damage and Outbreaks of Tail Biting. Tail damage and skin lesions were assessed by 2 researchers throughout the study. Before data collection started, a training session was conducted in the nursery barn to minimize subjective variation between the researchers. During the training session, 16 pigs of each tail docking treatment were selected based on their tail damage and skin lesions to achieve a wide range of skin lesion scores. The researchers separately assessed the pigs in their home pens until they agreed on the injury scores for each pig. During the data collection period in the growing–finishing barn, the 2 researchers simultaneously assessed pigs in a pen, each assessing 15 pigs per pen. Tail damage was assessed when pigs were allocated to pens in the growing–finishing barn, every 4 wk thereafter, and at the conclusion of the study, when 10% of pigs reached 131 kg or greater at 25 wk of age. Tail damage was assessed using a modified 0-to-4 scoring system based on the method of Kritas and Morrison (2004): score 0 = no damage, score 1 = healed lesions (scars or small scabs), score 2 = evidence of chewing or puncture wounds with visible blood but no signs of infection, score 3 = evidence of chewing or puncture wounds with visible blood and signs of infection or partial loss of the tail without signs of infection, and score 4 = partial or total loss of the tail with signs of infection. Pigs were checked for visible blood on their tails through routine daily observation of animals. Once any pig with visible blood on their tail was found in a pen, the pen was considered to have an outbreak of tail bit-

ing. When an outbreak of tail biting occurred, pigs in all pens ($n = 8$) were assessed for tail damage. For pigs in the pen with an outbreak of tail biting, tail damage was assessed daily to monitor the progress of the outbreak. The assessment of tail damage in the tail biting pen was conducted until all pigs in the pen achieved a tail score of 0 or 1, and the outbreak of tail biting was considered over. The number of outbreaks of tail biting that occurred in each pen during the entire growing–finishing period was recorded. Pigs with tail score 3 or 4 were removed to hospital pens. To maintain the number of pigs in test pens, pigs with tail score 2 were not removed but were closely observed and assessed daily for changes in tail scores. For the same reason, in most cases, tail biters (see Classification of Tail Biters, Victimized Pigs, and Nonvictimized Pigs below) were not removed, except those that were repetitively identified in pens that had recurring outbreaks. Once moved to hospital pens, pigs remained in the hospital pens until they were marketed or euthanized due to compromised welfare. In hospital pens, pigs were group-housed and provided with deep straw bedding (15 to 20 cm in depth) and more floor space (2 to 3 m²/pig) to help them recover from tail injuries. When infections occurred in hospital pens, the pigs were treated with antibiotics as directed by a veterinarian. In cases where pigs did not show any response to antibiotics within an appropriate time, 3 to 5 d, pigs were humanely euthanized with a captive bolt gun by a trained technician according to the procedure of *On-Farm Euthanasia of Swine* (NPB, 2016b).

Skin Lesions, Morbidity, and Mortality. Tail biting may be associated with other abnormal behaviors, such as ear biting, flank biting, and belly nosing (Brunberg et al., 2011), which can cause skin lesions in pigs. Skin lesions on the ears and the body were assessed for all pigs at the same time that tail scores were assessed. For assessment of skin lesions on the ears, the scoring system used included score 0 = no lesion, score 1 = healed lesion (scars or small scabs), score 2 = puncture wounds with visible blood but no signs of infection, and score 3 = puncture wounds with visible blood and signs of infection. For assessment of skin lesions on the body, the body surface was divided by imaginary lines into 3 zones: the head, the shoulders, and the remaining parts of the body, as in a previous study (Li and Johnston, 2009), excluding the tail. Each zone received a score based on the number of scratches on it: score 0 = no scratch, score 1 = 1 to 3 scratches, score 2 = 4 to 6 scratches, and score 3 = more than 6 scratches. Scratches were defined as superficial without visible blood (Widowski et al., 2003). Over the 16 wk of the growing–finishing period, all pigs were assessed for lesion scores 14 times, including 9 times on the first day of tail biting outbreaks. These data were used for

calculation of average scores for skin lesions on the tail, ears, and the body between the 2 treatment groups. Pigs in pens with tail biting outbreaks were assessed for tail damage 15 to 18 times, depending on the frequency and progress of the outbreaks. For each individual pig, the maximal tail lesion score was analyzed to determine the severity of tail damage that the pig had experienced. The maximal tail score represents the worst tail damage that a pig experienced at any time point during the 16 wk of the study period. Morbidity (as measured by the number of pigs moved to hospital pens) and mortality were recorded throughout the study period.

Classification of Tail Biters, Victimized Pigs, and Nonvictimized Pigs. Tail biters were identified through live observations. At the first observation of tail biting in a pen (visible blood on a tail), live observations were conducted by 2 trained researchers to identify and confirm tail biters. The observations were conducted for 1 h in the morning and 1 h in the afternoon for 2 consecutive days. During the observations, events of tail biting and identification of tail biters were recorded. Tail biting was defined as a pig having the tail of another pig in its mouth and biting or pulling hard enough to cause a reaction by the other pig (Statham et al., 2009). Tail biters were recognized by the observers as pigs that performed tail biting at least twice as often as their pen mates during the observation periods. Pigs that had tail score 3 or 4 at any point during the growing–finishing period were classified as victimized pigs. Pigs that were neither tail biters nor victimized pigs were considered nonvictimized pigs. Within nonvictimized pigs, pigs that had a tail score of 1 or 2 at any time point were categorized as pigs that experienced mild tail lesions, and pigs that had a tail score of 0 throughout the study were categorized as pigs that had never experienced tail lesions.

Total Serum Protein, IgG, and Substance P Concentrations of Victimized Pigs and Tail Biters. Pigs that were victims of tail biting can experience pain and infection caused by injured tails. Tail biters may also endure stress and a compromised immune system that predispose them to tail biting (Brunberg et al., 2016). To assess effects of tail biting on infection, immunity, and pain of these pigs, concentrations of total serum protein, IgG, and substance P were measured. Throughout the study, blood samples were collected from 11 tail biters, 30 victimized pigs, and 27 nonvictimized pigs from the home pen of victimized pigs. For victimized pigs, blood samples were collected on the day they were first scored 3 or 4 for tail damage (d 1) and then on d 3 and 5. Blood was collected from tail biters and nonvictimized pigs on d 3 once tail biters were confirmed through 2 d of live observations. Equal numbers of nonvictimized barrows and gilts that did not have any injury on their tails and were not observed

performing tail biting were sampled from the home pen of victimized pigs. During blood sampling, pigs were temporarily removed from their pens to a collection arena in the next room. Two tubes (a serum tube and an EDTA tube) of blood (7 mL each) were collected from each pig using vacuum tubes (Becton, Dickinson and Company, Franklin Lakes, NJ) through blind jugular venipuncture. Blood samples in serum tubes were used for measurement of total serum protein and IgG concentrations, and blood samples in EDTA tubes were used for analysis of substance P. To separate serum, blood in serum tubes was allowed to clot for 10 to 15 min at room temperature and then centrifuged at 4°C for 15 min at $1,400 \times g$. Total serum protein and IgG were measured in triplicate using a digital refractometer (Palm Abbe 202X; MISCO Refractometer, Solon, OH). The range of detection for total serum protein and IgG was 5.0 to 140.0 g/L, with a precision of 1.0 g/L. For analysis of substance P concentrations, 1 mM benzamidine (a solution to stabilize enzyme and proteins) was added to each EDTA tube, and blood samples were placed on ice immediately after collection. Within 60 min after collection, blood was centrifuged at 4°C for 15 min at $1,500 \times g$. Plasma was extracted and transferred to cryovial tubes and stored at -80°C for further analysis. Plasma concentrations for substance P were analyzed using a double antibody system with a primary antibody vs. substance P (1:60,000) purchased from Phoenix Pharmaceuticals Inc. (Burlingame, CA; lot number 1286-1) and 125I-Substance P (20,000 counts per minute, lot number BX62460) purchased from PerkinElmer, Inc. (Waltham, MA). Methods of analysis were consistent with those previously described by Van Engen et al. (2014). Protease inhibitors EDTA (13 mM) and benzamidine (1 mM) were used in the RIA. The range of detection for substance P was 10 to 640 pg/mL, with a CV for intra-assay variability of 7.4% and interassay variability of 18.1%.

Growth Performance, Carcass Weight, Dressing Percentage, and Trim Loss. Pigs were individually weighed on entering the growing–finishing barn and then every 4 wk thereafter and at the conclusion of the study. Feed additions to each pen were weighed and recorded. Excess feed in the feeder was weighed when pigs were weighed. Average daily gain of individual pigs, average daily feed disappearance, and G:F in each pen were calculated for each 4-wk period and for the entire growing–finishing period. Before marketing, all pigs were tattooed for individual identification at the packing plant. For pigs that were harvested, carcass weights were recorded and dressing percentage was calculated. In addition, the number of pigs with carcass trim loss and the reasons for pigs that were not harvested were noted at the packing plant.

Data Analysis

The data were analyzed using the FREQ, MIXED, and GLIMMIX procedures of the SAS 9.4 software (SAS Inst. Inc., Cary, NC). The prevalence of tail damage, distribution of maximal tail lesion score, and morbidity data were analyzed using the FREQ procedure with χ^2 analysis. Growth performance data were analyzed using the MIXED procedure with repeated measures for day of weighing. The remaining data were analyzed using the GLIMMIX procedure. Within the GLIMMIX procedure, the Poisson regression model was used for analysis of count data (tail damage score and lesion score) and the Gaussian model was used for analysis of continuous data (concentrations of total serum protein, IgG, and substance P). For analysis of differences among tail biters, victimized pigs, and non-victimized pigs, the model included pig category (biter, victimized, or nonvictimized) as a fixed effect, with pig category nested within pen, which served as the experimental unit for performance and carcass data, and individual pig served as the experimental unit for total serum protein, IgG, and substance P data. For nonvictimized pigs, differences between pigs that experienced tail lesions (score 1 and 2) and pigs that did not experience tail lesions (score 0) were tested. For this purpose, the model included 4 levels of pig categories (biter, victimized, pigs that experienced tail lesions, and pigs that did not experience tail lesions). There was no statistical difference between pigs that experienced tail lesions and pigs that did not experience tail lesions, so data from the 2 groups were combined and used in the final model for nonvictimized pigs. Differences among means were tested by the adjusted Tukey test, and significant differences were identified at $P < 0.05$ and trends at $P < 0.10$. Data are reported as least squares means and SE.

RESULTS

During the 16 wk of the growing–finishing period, 15 outbreaks of tail biting occurred, including 4 outbreaks in 3 pens of pigs with docked tails and 11 outbreaks in pens of pigs with intact tails ($\chi^2 = 5.1$, 1 df, $P = 0.08$ for difference between treatment groups). Among the 11 outbreaks in pens of pigs with intact tails, 2 pens experienced 1 outbreak each and 4 and 5 outbreaks occurred in the other 2 pens, respectively. The distribution of maximal tail lesion scores differed ($P < 0.001$; Table 1) between the 2 treatment groups. Among pigs with docked tails, 53% were never observed with any tail damage (tail score 0) throughout the entire growing–finishing period. In contrast, 11% of pigs with intact tails were never observed with tail damage over the same period. More pigs with intact tails were removed to hospital pens (23 vs. 7%; $\chi^2 = 13.8$, 1 df, $P = 0.001$;

Table 1. Tail damage in growing–finishing pigs with docked or intact tails in a confinement barn (barren environment with fully slatted floors)

Item	Tail docking ^{1,2}		χ^2	df	P-value
	Docked	Intact			
Number of pigs	120	120			
Number of pens	4	4			
Maximal tail lesion score ²					
Score 0	63 ³ (52.5%) ⁴	13 (10.8%)	76.2	4	<0.001
Score 1	48 (40.0%)	45 (37.5%)			
Score 2	3 (2.5%)	26 (21.7%)			
Score 3	3 (2.5%)	23 (19.2%)			
Score 4	3 (2.5%)	13 (10.8%)			

¹Tail docking (1.3 to 2.5 cm from the base of the tail) occurred within 24 h after farrowing.

²Tail lesions were assessed every 4 wk and during outbreaks of tail biting when pigs were 9 to 25 wk old using a 0 to 4 scale system. The lesion scores listed were the maximum score for each pig over all the periods recorded. The scoring system was 0 = no damage, 1 = healed lesions without visible blood, 2 = evidence of chewing and puncture wounds without signs of infection, 3 = evidence of chewing and puncture wounds with signs of infection or partial loss of the tail without signs of infection, 4 = partial or total loss of the tail with signs of infection.

³Number of pigs.

⁴Percentage of the total number of pigs allocated to each treatment group.

Table 2) than pigs with docked tails. This included 21% of pigs with intact tails and 5% of pigs with docked tails removed for tail damage or tail biting. Consequently, the percentage of pigs that were harvested for full value was numerically (90 vs. 97%; $P = 0.14$) lower for pigs with intact tails than for pigs with docked tails.

Twelve tail biters were identified during outbreaks of tail biting during the growing–finishing period (Table 3). The tail biters were from 2 pens of each treatment, with 4 biters from pens of pigs with docked tails (2 pigs/pen) and 8 biters from pens of pigs with intact tails (4 pigs/pen). On average, tail biters performed tail biting 22.5 times (ranging from 8 to 54 times) over the 2 h of observation. Overall, 43 pigs from 7 pens had maximal tail scores of 3 or 4 at any point during the growing–finishing period and were classified as victimized pigs. Among the victimized pigs, 6 were from 3 pens of pigs with docked tails (2 pigs/pen) and 37 were from 4 pens of pigs with intact tails (5, 5, 12, and 15 pigs each pen, respectively). The remaining 185 pigs were categorized as nonvictimized pigs. Thirty-three percent of tail biters and 70% of victimized pigs ($P = 0.03$; Table 3) were barrows. Victimized pigs had lower ADG ($P = 0.02$) between wk 17 and 21 of age compared with tail biters and nonvictimized pigs, and lower dressing percentage ($P = 0.001$) than nonvictimized pigs. No differences were detected in BW at marketing, HCW, or ADG for the entire growing–finishing period among the categories of pigs. Compared with nonvictimized pigs and tail biters, victimized pigs tended to be more frequently sold for less

Table 2. Growing–finishing pigs housed in a confinement barn that were removed from their home pens, harvested at market weight, and euthanized or that died due to compromised health

Item	Tail docking ¹		χ^2	df	P-value
	Docked	Intact			
Number of pigs	120	120			
Pigs removed to hospital pens					
Total	8 ² (6.7%) ³	28 (23.0%)	13.8	1	0.001
For tail biting or tail damage	6 (5.0%)	25 (20.8%)			
Pigs harvested					
Harvested without trim loss	116 (96.7%)	108 (90.0%)	5.5	3	0.14
Harvested with trim loss	2 (1.7%)	3 (2.5%)			
Not harvested ⁴	0	3 (2.5%)			
Died or euthanized	2 (1.7%)	6 (5.0%)			

¹Tail docking (1.3 to 2.5 cm from the base of the tail) occurred within 24 h after farrowing.

²Number of pigs.

³Percentage of the total number of pigs that were allocated to each treatment group.

⁴One pig was harvested but the carcass was condemned, 1 pig was mistakenly identified as a boar, and 1 pig was not sent to harvest due to its extremely light BW at the conclusion of the experiment.

than full value due to carcass trim loss, condemnation at the packing plant, or mortality ($P = 0.10$; Table 4).

Tail biters had lower levels of total serum protein ($P = 0.01$; Table 5) and IgG ($P = 0.01$) concentrations than victimized pigs and nonvictimized pigs. There were no differences in concentrations of total serum protein and IgG between victimized pigs and nonvictimized pigs. No differences in substance P concentrations were detected among the 3 categories of pigs.

For victimized pigs, there were no differences in total serum protein or IgG between d 1 and 3 after their tails were injured (Table 6). Total serum protein ($P = 0.002$) and IgG ($P = 0.002$) concentrations were elevated on d 5 compared with d 1 and 3. Substance P did not change over the 5-d period after tail damage.

DISCUSSION

The current study confirms that tail docking reduced but did not eliminate tail damage in a confinement barn. Clearly, pigs with docked tails had fewer victimized pigs with severe tail damage compared with pigs with intact tails in the current study. These observations are consistent with previous studies (Paoli et al., 2016; Scollo et al., 2016). In the current study, 47% of pigs with docked tails and 89% of pig with intact tails experienced skin lesions on the tail at some time point during the growing–finishing period under the commercial-like production conditions imposed. The frequency of tail lesions observed in both docked and intact pigs in the current study is much higher than in other studies (Kritas and Morrison, 2004; Harley et al., 2014), indicating that these pigs might be exposed to major risk factors for tail biting. Pigs in the current study were kept in a barren environment on fully slatted floors

without access to manipulable materials. Fully slatted floors, no manipulable substances, and overcrowding at the feeder have been identified as major risk factors for development of tail biting (Taylor et al., 2012; D'Eath et al., 2014). All 3 major risk factors were present in the current study, which could be important contributors to the high prevalence of tail biting. On the other hand, it is worthwhile to note that most pigs experienced only mild tail lesions in the current study. For instance, 40% of docked pigs and 38% of intact pigs were scored 1 for tail lesions at some point during the growing–finishing period. These pigs probably would be undetected during visits to commercial farms, resulting in a higher prevalence of tail biting in the current study than in a previous study (Kritas and Morrison, 2004) conducted on a commercial farm in the Midwestern United States. Similar to our results, Ursinus et al. (2014a) reported that 83% of pigs with intact tails in a confinement facility experienced temporal tail damage. Likewise, Holling et al. (2016) noted that 76% of undocked pigs experienced tail lesions at the end of the finishing period in confinement production systems in Germany. In contrast, the prevalence of tail biting at packing plants was reported as 1.6% among undocked pigs in Sweden when straw was provided as manipulable material on partially slatted floors (Wallgren et al., 2016). Although both providing manipulable materials to pigs and housing pigs on partially slatted floors contributed to the lower incidence of tail biting in Wallgren et al.'s (2016) study, it is worthwhile to note that their data came from packing plants, which may also have contributed to the lower incidence of tail biting. Data collected at packing plants can underestimate the incidence of tail damage. This is because only pigs with sever tail damage can be detected and pigs with minor tail injuries on the farm

Table 3. Growth performance of tail biters, pigs with tail damage, and pigs without tail damage in a confinement barn

Item	Pig category				<i>P</i> -value
	Tail biters ¹	No tail lesion ²	Mild tail lesions ³	Victimized ⁴	
Number of pigs	12	73	112	43	
Percent of barrows ⁵	33	49	46	70	0.03 ⁶
Weight, kg					
Initial (9 wk of age)	24 (0.9)	25 (0.3)	25 (0.3)	25 (0.5)	0.64
End (25 wk of age)	126 (3.0)	125 (1.3)	128 (1.0)	125 (1.7)	0.38
ADG, g					
wk 9–25	870 (27.2)	858 (10)	876 (8)	855 (13)	0.41
wk 17–21	952 (50) ^a	950 (23) ^a	966 (18) ^a	867 (29) ^b	0.02
Average skin lesion score ⁷					
Body ⁸	0.66 (0.24)	0.71 (0.10)	0.74 (0.08)	0.75 (0.13)	0.99
Ears ⁹	0.64 (0.23)	0.77 (0.10)	0.81 (0.08)	0.74 (0.13)	0.91
Tail ¹⁰	0.21 (0.10) ^{bc}	0.07 (0.07) ^c	0.36 (0.07) ^b	0.68 (0.08) ^a	<0.001
Carcass					
Pigs harvested	12	71	108	38	–
HCW, kg	96 (2.5)	95 (1.0)	97 (0.8)	94 (1.4)	0.12
Dressing, %	75 (0.6) ^{ab}	76 (0.3) ^a	76 (0.2) ^a	74 (0.3) ^b	<0.001

^{a–c}Least squares means (SE) within a row with different superscripts differ ($P < 0.05$).

¹Tail biters were identified by live observations as pigs that performed tail biting at least twice as often as their pen mates during the observation periods of tail biting outbreaks.

²Pigs with a tail lesion score of 0 (no damage) throughout the study.

³Pigs with a tail lesion score of 1 or 2 at any time point of the study.

⁴Pigs with a tail lesion score of 3 or 4 at any time point of the study.

⁵Percentage of barrows in each pig category.

⁶ $\chi^2 = 8.94$, 3 df.

⁷Skin lesions were assessed every 4 wk when pigs were 9 to 25 wk old. The lesion scores listed are average scores over all the periods recorded.

⁸Body surface was divided by imaginary lines into 3 zones (head, shoulders, and body). Each zone received a score based on the number of scratches observed in the zone (0 = no scratch, 1 = 1 to 3 scratches, 2 = 4 to 6 scratches, and 3 = >6 scratches). The scores listed are average scores across the 3 zones.

⁹Each ear received a score based on the severity of skin lesions observed on the ear (0 = no damage, 1 = healed lesions without visible blood, 2 = evidence of chewing and puncture wounds with visible blood but no signs of infection, and 3 = evidence of chewing and puncture wounds with signs of infection). The scores listed are average scores of 2 ears.

¹⁰Tail lesions were assessed using the following scale: 0 = no damage, 1 = healed lesions without visible blood, 2 = puncture wounds without signs of infection, 3 = puncture wounds with signs of infection or partial loss of the tail without signs of infection, and 4 = partial or total loss of the tail with signs of infection.

are likely undetectable at the packing plant. In a recently published survey (Valros et al., 2016), pig farmers in Finland recognized feeding-related issues as the most dangerous risk factor for development of tail biting. Nevertheless, both studies confirmed the importance of manipulable material, floor type, and management of feeding systems to reduce tail biting in pigs.

Comparing tail biters with victimized pigs, our data show that more gilts than barrows became biters and more barrows than gilts became victimized pigs. Effects of sex on tail biting have been previously reported (Zonderland et al., 2010; Larsen et al., 2016). Data from packing plants (Keeling et al., 2012; Harley et al., 2014) suggest that male pigs have more skin lesions than female pigs and are more likely subject to carcass trim loss. Some researchers (Taylor et al., 2010) speculated that tail biting may be related to sexual maturity, with gilts targeting big barrows as they enter the growing stage. In addition, Taylor et al. (2010) suggested that tail biting can be a strategy that smaller pigs use to com-

pete for feed or other resources in a pen. We could not detect differences in BW between tail biters and victimized pigs in the current study. Compared with other pigs, victimized pigs had lower ADG between wk 17 and 21 of age when tail biting prevailed in the current study. During this 4-wk period, 9 outbreaks of tail biting occurred in 6 pens, which accounted for 56% of total tail biting outbreaks that occurred over the entire 16 wk of the growing–finishing period. It is possible that victimized pigs that were repetitively bitten might have been reluctant to approach the feeder to eat, causing reduced feed intake and ADG. Pigs with injured tails may be reluctant to stand in front of the feeder where they can attract other pigs that might bite their tails. Wallenbeck and Keeling (2013) observed that victimized pigs visited feeders less often than other pigs, resulting in reduced ADFI. Likewise, Munsterhjelm et al. (2015) reported that pigs with tail biting lesions had reduced feed intake before, during, and after the period of being bitten, resulting in reduced ADFI. In an on-farm study,

Table 4. Growing–finishing pigs raised in a confinement barn that were harvested at marketing, died, or were euthanized due to compromised health

Item	Pig category				χ^2	df	P-value
	Tail biters ¹	No tail lesion ²	Mild tail lesions ³	Victimized ⁴			
Number of pigs	12	73	112	43			
Pigs harvested							
Harvested without trim loss	12 ⁵ (100%) ⁶	70 (95.9%)	107 (95.5%)	35 (81.4%)	14.6	9	0.10
Harvested with trim loss	0	1 (1.4%)	1 (0.9%)	3 (7.0%)			
Not harvested ⁷	0	0	2 (1.8%)	1 (2.3%)			
Died or euthanized	0	2 (2.7%)	2 (1.8%)	4 (9.3%)			

¹Tail biters were identified by live observations during outbreaks of tail biting in the growing–finishing barn.

²Pigs with a tail lesion score of 0 (no damage) throughout the study.

³Pigs with a tail lesion score of 1 or 2 at any time point of the study.

⁴Pigs with a tail lesion score of 3 or 4 at any time point of the study.

⁵Number of pigs.

⁶Percentage of the total number of pigs in each category.

⁷One victimized pig was harvested but the carcass was condemned, 1 pig with mild tail lesions was mistakenly identified as a boar, and another pig with mild tail lesions was not sent to harvest due to its extremely light BW at conclusion of the experiment.

Sinisalo et al. (2012) reported that victimized pigs had 1 to 3% lower ADG than other pigs but had no difference in feed efficiency, suggesting that the reduced ADG might be attributed to reduced feed intake.

In the current study, victimized pigs tended to be more frequently sold for less than full value (and even lost value) compared with other pigs, which was associated with mortality, carcass condemnation, and carcass trim loss possibly caused by abscesses. The carcass of 1 victimized pig was condemned, which was the only case of carcass condemnation that occurred in this study. These results demonstrate that tail damage may reduce the value of market pigs. In agreement with our results, Hunter et al. (2011) reported that pigs with bitten tails had higher levels of carcass abscesses. Similarly, Harley et al. (2014) noted that carcasses can be trimmed by 12 kg in pigs with severe tail lesions and by 1.2 kg in pigs with mild lesions. Marques et al. (2012) reported that 67% of carcass trim loss was from pigs with bitten tails. They also found that pigs with bitten tails were more likely to have abscesses, lung lesions, or arthritis in the carcass, suggesting that tail infection resulting from tail injuries could become systemic. In the current study, we observed that serum protein and IgG concentrations were elevated in victimized pigs 5 d after tails were injured. The elevated serum protein and IgG were signs of inflammation, suggesting that tails damaged from biting can cause inflammation in pigs. The inflammation may contribute to carcass abscess, resulting in trim loss and condemnation. Similar to our results, Munsterhjelm et al. (2013b) reported elevated total serum protein levels in victimized pigs compared with nonvictimized pigs. In addition, Heinonen et al. (2010) noted that victimized pigs exhibited elevated acute phase proteins compared with nonvictimized pigs. We also compared serum concentra-

tions of substance P among victimized pigs, tail biters, and nonvictimized pigs in the current study. Substance P is a neuropeptide that is associated with the integration of pain and stress in animals (Coetzee et al., 2008) and has been used as a pain indicator in pigs (Sutherland et al., 2012). Individuals that experience significant pain usually have elevated concentrations of substance P in their blood (Meintjes, 2012). However, in the current study, we could not detect differences between victimized pigs and nonvictimized pigs. In agreement with our results, Sutherland et al. (2012) did not detect differences in substance P concentrations between piglets castrated with and without anesthesia. Substance P may not be sensitive enough to measure pain in pigs subjected to tail biting.

In the current study, we observed lower levels of total serum protein and IgG in tail biters than in other pigs. Low levels of serum protein and IgG may indicate poor immune functions (Munsterhjelm et al., 2013b; Hao et al., 2015). Munsterhjelm et al. (2013a) noted that tail biters may experience chronic stress, as indicated by altered cortisol levels. Chronic stress can lead to compromised immune function. It is possible that tail biters experienced compromised immune function due to chronic stress, which may predispose them to tail biting. Recently, Brunberg et al. (2016) suggested a potential underlining mechanism of tail biting that involves stress, immunity, and gut microbiota. After reviewing research in human psychology, physiology, and behavior of both lab and farm animals, Brunberg et al. (2016) argue that gut microbiota may play a central role by affecting the stress-related hypothalamic–pituitary–adrenal (HPA) axis and immune systems, which, in turn, affect the behavior of the individuals. They built their hypothesis on evidence that pathogenic gut microbiota, such as *Escherichia coli*, can stimulate the HPA axis and activate

Table 5. Total serum protein, IgG, and substance P concentrations in tail biters, victimized pigs, and non-victimized pigs during outbreaks of tail biting in a confinement barn

Item	Pig category			P-value
	Tail biters ¹	No tail lesion ²	Victimized ³	
Number of pigs	11	27	30	
Weight, kg				
At blood sampling	59.0 (5.32)	59.1 (4.57)	60.0 (3.64)	0.30
Blood analysis				
Total serum protein, g/L	60.3 (1.5) ^b	66.1 (1.1) ^a	64.5 (1.1) ^a	0.01
IgG, g/L	10.6 (0.9) ^b	14.0 (0.6) ^a	13.1 (0.6) ^a	0.01
Substance P, pg/mL	198.1 (14.1)	191.1 (9.0)	178.8 (9.3)	0.45 ⁴

^{a,b}Means (SE) within a row with different superscripts differ ($P < 0.05$).

¹Tail biters were identified by live observations during outbreaks of tail biting in the growing–finishing barn.

²Pigs with a tail lesion score of 0 and pen mates of victimized pigs.

³Pigs with a tail lesion score of 3 or 4 on the day when blood samples were collected.

⁴Substance P was affected by gender (203.7 ± 8.7 pg/mL for barrows and 175.0 ± 9.3 pg/mL for gilts; $P = 0.03$).

immune systems, which may be associated with development of abnormal behaviors (Desbonnet et al., 2014). In contrast, some probiotics may increase tryptophan levels and have positive effects on behavior and coping strategies on the individual (Foster and McVey Neufeld, 2013). Both tryptophan (a precursor of serotonin) and serotonin are considered indicators of stress and mood in both humans and animals (Carrasco and Van De Kar, 2003; Ursinus et al., 2014b). Pigs that are susceptible to stress have lower levels of serotonin in their brains than stress-tolerant pigs (Adeola et al., 1993), probably due to higher level of demand for serotonin by stressed pigs. Valros et al. (2015) reported a link between tail biting and central monoamine metabolism. They noted that compared with other pigs, tail biters had higher metabolism of serotonin, suggesting that tail biters that experienced stress and frustration may use more serotonin than other pigs. Likewise, Brunberg et al. (2013) reported involvement of the brain system in development of tail biting. They demonstrated that expressions of brain genes that influence fat deposition, social behavior, and seeking behavior differ among tail biters, victimized pigs, and neutral pigs. This study by Brunberg et al. (2013) suggests that suppression of some behaviors, such as seeking behavior, may be a risk factor for tail biting. However, the risk is greater for tail biters than for other pigs due to differences in their brain gene expression. These researchers argue that pigs, as omnivores, may ingest various ingredients by exploring diverse environments under natural conditions, resulting in diverse gut microbiota. However, under confinement production conditions with a barren environment, pigs may expe-

Table 6. Total serum protein, IgG, and substance P concentrations of victimized pigs¹ during outbreaks of tail biting in a confinement barn

Item	Days after tails injured			P-value
	Day 1 ²	Day 3	Day 5	
Number of pigs	30	26 ³	18 ³	
Blood analysis				
Total serum protein, g/L	64.5 (1.1) ^b	65.8 (1.1) ^b	70.9 (1.4) ^a	0.002
IgG, g/L	13.1 (0.6) ^b	13.9 (0.7) ^b	16.8 (0.8) ^a	0.002
Substance P, pg/mL	178.8 (9.2)	181.9 (9.9)	171.9 (13.4)	0.83

^{a,b}Means (SE) within a row with different superscripts differ ($P < 0.05$).

¹Pigs with tail lesion score of 3 or 4.

²The day when victimized pigs first scored 3 or 4 for tail damage.

³Blood samples were not collected from some victimized pigs for 3 d because their tails were healed (lesion score = 1) before Day 5.

rience reduced diversity of their gut microbiota, which may stimulate the HPA axis and affect immune systems. The impaired gut microbiota, through affecting the HPA axis and immune systems, may result in development of abnormal behavior such as tail biting in some vulnerable pigs, such as tail biters. So environment enrichment is critical to reducing tail biting because it might be essential for maintaining healthy gut microbiota. Although the hypothesis is built on synthesizing current knowledge in disparate fields of study, it provides new insight into our understanding of tail biters. More controlled studies are needed to test this hypothesis through research in physiology, immunology, and behavioral development of both tail biters and victimized pigs.

In summary, tail docking does not eliminate but significantly reduces tail damage in growing–finishing pigs in the confinement housing system used in the current study. Compared with pigs with docked tails, pigs with intact tails experienced tail damage more frequently and with greater severity. Victimized pigs with damaged tails experienced inflammation, which may lead to abscess formation and reduced market value of the pig. Tail biters experienced lower IgG and serum protein concentrations, suggesting that they may experience compromised immune functions. More research is needed to test whether compromised immune functions predispose pigs to tail biting.

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