12-1987

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Recommended Citation

Fraser, D. (1987). Mineral-deficient diets and the pig's attraction to blood: implications for tail-biting. Canadian Journal of Animal Science, 67(4), 909-918.

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KEYWORDS

pigs, tail-biting, abnormal behavior, salt, sodium, mineral deficiency

ABSTRACT

In two experiments, individually penned growing pigs were exposed daily to two "tail models” (lengths of cotton cord about the size of a pig's tail), one of which had been impregnated with pigs' blood. When fed a balanced "control" diet, the pigs chewed significantly more on the blood-covered model than on the plain one, but with large individual differences between animals. Four weeks of receiving a diet lacking all mineral supplements (iodized salt, dicalcium phosphate, limestone, iron, zinc, manganese, copper, and selenium) caused a pronounced increase in chewing the blood-covered model, and 4 wk of recovery on the control diet reduced, but did not completely eliminate, the enhanced attraction to blood. In a second experiment, a similar heightened response to blood was produced by omitting only iodized salt from the diet, whereas omission of all other mineral supplements led to a much smaller and statistically nonsignificant change. Although the causes of tail-biting are undoubtedly complex, the results suggest that heightened appetite for salt could make pigs particularly attracted to pen-mates with injured tails.

A growing pig will seldom quail
From chewing on his neighbor's tail.
At first, this unendearing act
Arises simply from the fact
That pigs by nature root and chew
When they have nothing else to do;
But thus engaged, a pig may find
That neighbors, bitten from behind,
Secrete a red liqueur whose flavor
Many swine appear to savor:
At first a nip, and next a swallow,
Then nastier results may follow.

This hypothesis on the development of tail-biting has emerged (albeit in prose) from a number of sources. Van Putten (1969) first argued that tail-biting is derived from the quiet exploratory chewing that pigs in an environment of low complexity often direct at their pen-mates. Sambraus (1985) and others have suggested that the eventual development of a bleeding wound leads to intensified biting. This has been

supported by the finding that pigs chew more on a blood-impregnated object than on a similar object lacking blood (Fraser 1987).

Surveys and anecdotal reports have often implicated dietary mineral deficiencies or imbalances as likely contributing factors in tail-biting outbreaks. Iron, copper, calcium, phosphorus, and salt (NaCl) are often mentioned (Gadd 1967; Ewbank 1913; Smith and Penny 1981; Vollmar 1985). Although pigs require only about 0.2% NaCl in the diet for maximum weight gain (e.g., Alcantara et al. 1980; Honeyfield et al. 1985), NaCl is often provided at 0.5% of the diet for growing pigs, and it is sometimes suggested that an increase to 0.75 or 1% can reduce the incidence of tail-biting (Gadd 1967; Fritschen and Hogg 1983).

In the following experiments, pigs were exposed to simple "tail models" – lengths of cotton cord about the size of a pig's tail – which could be impregnated with blood. The models were used to study whether mineral deficiencies in the diet cause increased attraction to a source of blood.

MATERIALS AND METHODS

Two experiments used 48 Yorkshire pigs (20 females and 28 castrated males) from the Animal Research Centre's minimum disease herd. Pigs were aged 61--75 d at the beginning of the experiments. About 5 d before observations began, the animals were moved from large group pens into individual pens measuring 0.91 x 1.83 m. Eight such pens were used, and the experiments consisted of successive replicates of eight pigs each. Food and water were continuously available. The room was maintained at about 20-25°C, with one 16-h period of light (about 40 1x) per day.

The "tail models" consisted of sections of unwaxed white cotton sash cord (Braided Cotton Sash Cord, No. 16, Barry Boulerice Inc., Dollard des Ormeaux, Quebec) 18 crn long and 1.3 cm in diameter. The gate of each animal's pen was fitted with a clear plastic panel with two 2.5-cm holes that allowed easy attachment and removal of two tail models 30 cm apart and 38 cm above the floor. When attached to the panel, the models could be chewed by the pig in the pen, while an observer watched through the clear plastic. In each observation period the pigs were presented with one plain and one blood-covered model. The latter had been soaked overnight in fresh, whole, pig's blood (with 340 mg disodium EDTA per litre of blood added as an anticoagulant) and allowed to dry in the air for at least 24 h. Plain tail models received no treatment. After being used in one observation period, the models were thoroughly laundered, dried, and (for blood-covered models) resoaked in blood before being used again.

On the 3 or 4 d before observations began, the observer familiarized the pigs with the procedure by allowing them to chew on a tail model in his presence. For the normal daily observation periods, two tail models were attached simultaneously to the plastic panel for 24 min. During this time, a click sounded every 6 s, and the observer (always the same person) noted whether the pig was chewing on either model at the time of the click. Chewing was scored only if the model was inside the pig's mouth; other types of contact with the models were ignored. The observer scored two neighboring pigs simultaneously during observation periods. Tail models were removed at the end of the 24 min. Each pig was observed during one 24-min period per day, 5 d per week in each week of observations. The positions of the plain and blood-covered models were alternated daily. Based on the results, each pig was given two scores for each daily 24-min period. One represented the number of observations in which the animal was chewing the blood-covered model, and the other represented chewing the plain model. With observations at 6-s intervals, the maximum possible daily score was 240.

As a check on the reliability of the recording method, 16 of the 24-min periods, selected as convenient, were scored by two observers independently. On both measures (chewing the plain model, and chewing

the blood-covered model), the scores per 24-min trial were in close agreement for the two observers (r = 0.99).

The standard diet (used for all pigs before the experiment began, and as the control diet) included 57% corn, 25% barley, 17% soybean meal (at 48% crude protein), 2% tallow, 1.5% Lignosol (Reed Ltd., Lignin Products, Quebec, Canada) used as a pelleting agent, and 0.5% vitamin premix which supplied, per kilogram of diet, 8250 IU vitamin A, 550 IU vitamin D_3, 27 IU vitamin E, 4.4 mg vitamin K, 3.0 mg thiamine, 8.0 mg riboflavin, 33.0 mg pantothenic acid (D form), 44.0 mg niacin, 500 mg choline, 250 µg biotin, and 28 µg vitamin B_{12}.

The remaining 3% of the control diet consisted of mineral ingredients: 1.0% dicalcium phosphate (18% Ca, 20% P), 1.0% limestone (38% Ca), 0.5% iodized salt, and 0.5% trace mineral premix which suppled, per kilogram of diet, 80 mg iron, 50 mg zinc, 20 mg manganese, 6 mg copper, and 0.1 mg selenium. For the experimental diets, some or all of the mineral ingredients were omitted, and the amounts of corn, barley, and soybean meal were increased proportionally to make up the difference.

A sample of each diet was analyzed by Analytical Chemistry Services, Land Resource Research Centre, Agriculture Canada, for major mineral nutrients and for trace rninerals that were expected to vary according to diet composition (Table 1). Phosphorus was analyzed by acid decomposition light absorption spectrometry, selenium by acid decomposition fluorometry, and chloride by Schoniger flask combustion coulometric titrimetry. All other analyses were by acid decomposition atomic absorption spectrometry generally following the methods of the Association of Official Analytical Chemists (1980). Two samples of whole pig blood, used to soak the tail models, were air dried and analyzed in the same ways. One sample contained the usual amount of EDTA, and the other contained no anticoagulant.

Drinking water was available to the pigs throughout the experiments. It contained about 17 ppm Ca, 1-3 ppm of P, Mg, Na, Zn, and Cl, less than 1 ppm K, Fe, Cu, and Mn, and about 1 ppb Se.

Table 1. Levels of mineral nutrients of the two diets in exp. 1, the four diets in exp. 2, and in a sample of pig blood (without anticoagulant)

Element	Experiment 1		Experiment 2				Blood
	Control	Mineral deficient	Control	Mineral deficient	Salt deficient	Salt only	
			($g\ kg^{-1}$)				
Na	2.15	0.24	2.16	0.12	0.09	2.20	10.27
K	7.97	8.38	8.17	8.63	8.18	8.19	10.19
Ca	7.54	2.21	7.17	1.83	7.28	3.42	0.36
Mg	1.76	1.70	1.56	1.56	1.65	1.64	0.30
P	6.28	4.25	6.48	4.21	6.35	4.22	2.66
Cl	3.68	0.89	3.89	0.80	0.72	3.52	13.72
			($mg\ kg^{-1}$)				
Fe	236	100	221	59	220	71	2003
Mn	45	26	51	16	44	19	1.5
Zn	94	40	91	35	101	36	21
Cu	---	---	13	9	15	8	6
Se	0.18	0.14	0.16	0.08	0.19	0.08	0.90

Experiment 1

In the first experiment, pigs were fed either the control diet or a diet from which all mineral supplements had been omitted. Levels of mineral nutrients in the diets are shown in Table 1. Two males and two females were used from each of four litters for a total of 16 animals weighing 15.8 ± 0.4 kg (mean ± SE) at the start of the experiment. Eight pigs (from two litters) were tested as the first replicate, followed by a second replicate of eight more.

The experiment lasted 9 wk. with observations made 5 d per week in each of weeks 1, 3, 5, 7 and 9. During week 1, all pigs remained on the control diet. At the end of week 1, half the pigs were assigned to the experimental treatment; these animals received the mineral-deficient diet for the next 4 wk (weeks 2-5, with observations in weeks 3 and 5), and were then returned to the control diet for 4 wk (weeks 6-9, with observations in weeks 7 and 9). The other pigs continued to receive the control diet throughout, with observations made at the same time as the experimental animals.

Because of the large individual differences in response to the tail models, the pigs were assigned to treatments based on their scores for chewing on the blood-covered model in the first week, but in a manner which was also balanced as to litter and sex. To achieve this, the higher-scoring male and the lower-scoring female were assigned to the experimental treatment in one litter per replicate, and to the control treatment in the other litter. Pigs were weighed at the beginning of the experiment and at the end of each week of behavioral observations.

Because individual days within a week were not a factor of interest, the daily scores for chewing each type of tail model were averaged to produce weekly scores for each pig. These weekly scores were analyzed, for each week separately, by analysis of variance using the following factors: replicates (1 d.f.), litters within replicates (2 d.f.), sex (1 d.f.), treatment (1 d.f.), and the interaction of sex and treatment (1 d.f.), with 9 degrees of freedom for error. Weight gains, calculated during weeks 1-5 and weeks 6-9, were analyzed using a similar model, with initial weight included as a covariate.

Experiment 2

The second experiment involved four diets: (1) the control diet from exp. 1, (2) the mineral-deficient diet from exp. 1, (3) a salt-deficient diet, the same as the control diet but lacking the 0.5% iodized NaCl, and (4) a "salt only" diet, lacking the other mineral supplements (dicalcium phosphate, limestone, and trace mineral premix) but with iodized NaCl present at 0.5%. Levels of mineral nutrients in the diets are shown in Table 1.

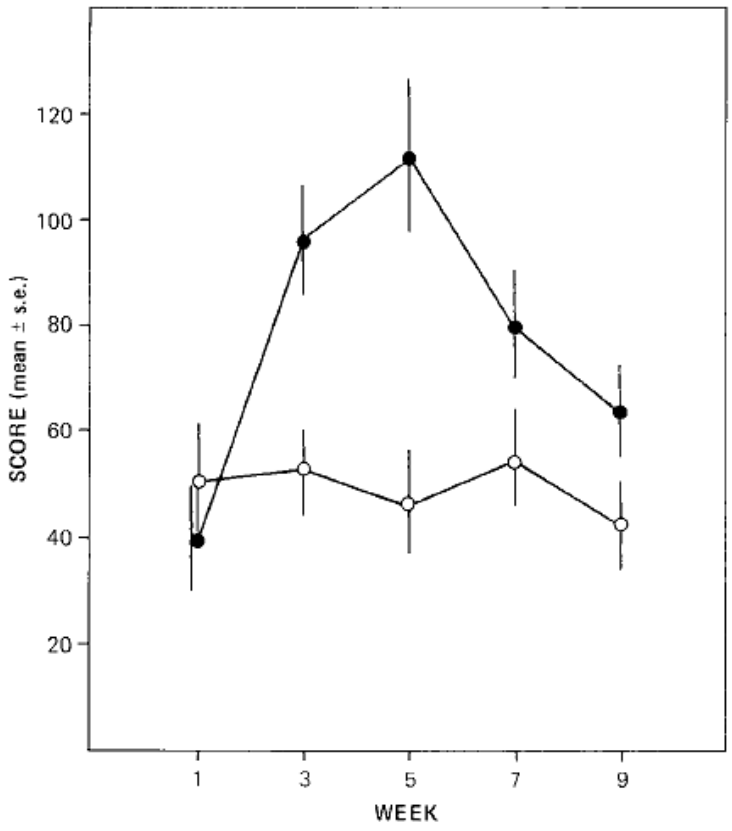
The experiment used 32 pigs: four like-sexed litter-mates from each of eight litters. Males were used in five litters, and females in three, as dictated by availability. The pigs weighed 26.6 ± 0.8 kg (mean ± SE) at the start of the experiment. Four replicates of two litters (eight pigs) were done in sequence.

The experimental period lasted 5 wk, with observations made 5 d per week in weeks 1, 3 and 5. All pigs received the control diet until the end of week 1. Then one pig from each litter was assigned to each of the four diets in the following way. The four pigs in each litter were ranked from 1 to 4 based on their scores for chewing the blood-covered model in week 1: the four ranks were then assigned to the four diets with equal frequency by use of a Latin square. Hence, the diet comparison was balanced as to litter and sex, and (as closely as possible) for the pigs' initial reactions to the blood-covered model. The pigs were weighed at the beginning of the experiment and at the end of each week of observations.

For each pig, a weekly score for chewing each type of tail model was calculated as the mean of the five daily scores. The weekly scores were analyzed, for each week separately, by analysis of variance using

the following factors: replicates (3 d.f.), litters within replicates (4 d.f.), diets (3 d.f.), and error (21 d.f.). Sex differences were not tested, as only like-sexed litter-mates were used. The pigs' weight gains, during the 4 wk on the experimental diets, were analyzed using a similar model, with initial weight included as a covariate.

Fig. 1. Mean score per day for chewing the blood-covered model in exp. 1. Eight pigs (dark circles) were fed the control diet in week 1, the mineral-deficient diet in weeks 2-5, and the control diet in weeks 6 9. Eight matched control pigs (open circles) received the control diet throughout. The score is defined as the number of instantaneous observations (maximum of 240) in which the pig was chewing on the blood-covered model.



RESULTS

Compared to all diets, blood contained a high concentration of Na, Cl, Fe, and Se (Table 1). The chemical composition of the blood was not altered appreciably by addition of disodium EDTA anticoagulant; in particular, the Na content of the sample with EDTA was determined as 10.36 mg kg^{-1}, versus 10.27 in the pure sample, a difference of < 1% and within the analytical tolerance of the assay.

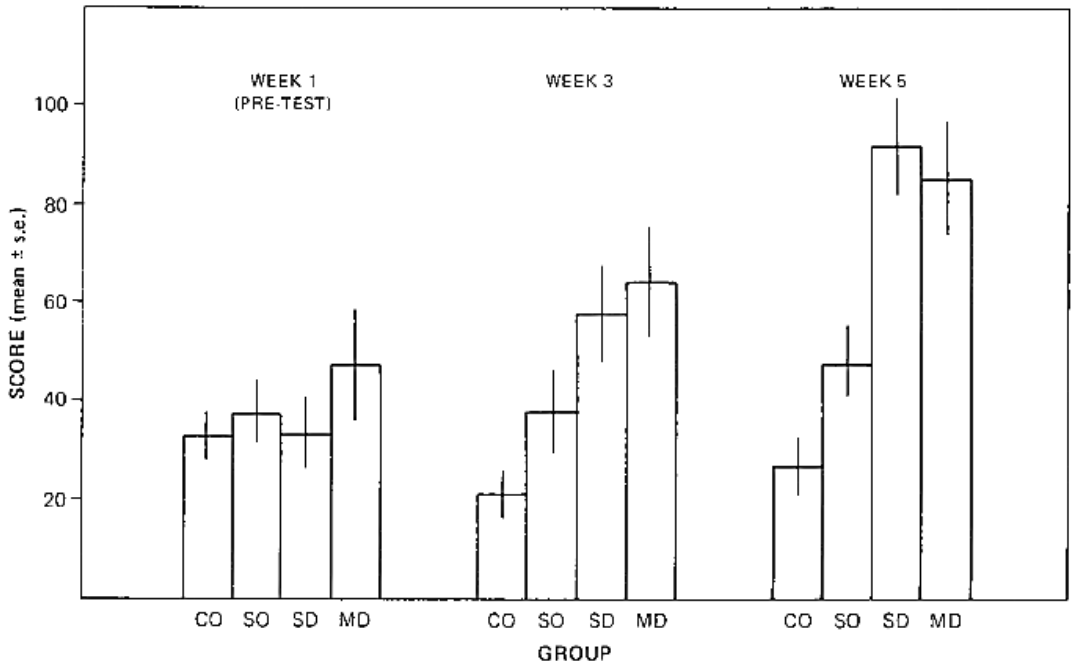
Experiment 1

When changed to the mineral-deficient diet during weeks 2-5, the eight pigs showed a pronounced increase in chewing on the blood-covered tail model (Fig. 1). When returned to the control diet in weeks 6-9, the amount of chewing; decreased, but remained somewhat higher than that shown by the eight pigs fed the control diet throughout. Scores for chewing the plain tail model remained relatively low throughout the experiment (mean daily score of 26 and 24 for experimental and control pigs, respectively), with no appreciable differences between weeks or diets.

Analysis of variance showed a significant difference between treatments (diets) in amount of chewing on the blood-covered model in both week 3 ($P < 0.01$) and week 5 ($P < 0.01$). The difference tended to persist at a lower level in weeks 7 and 9 when the experimental pigs were once again receiving the control diet ($P < 0.10$). No other main effects or interactions reached the 5% level of significance in any week, except a difference between replicates in week 1 ($P < 0.02$). Diet had no significant effect on chewing the plain model.

During their 4 wk on the mineral-deficient diet, the eight pigs gained 639 ± 44g d^{-1} (mean + SE), compared with 720 ± 39 g d^{-1} for the pigs on the control diet. During the final 4 wk, when all pigs were returned to the control diet, the two groups gained 875 ± 13 and 866 ± 46 g d^{-1}, respectively. Analysis of variance showed no significant difference between treatments in weight gain ($P > 0.10$).

Fig. 2. Mean score per day for chewing the blood-covered model in exp. 2. All pigs received the control diet in week 1. Thereafter, group CO continued to receive the control diet, group SO received the salt-only diet, group SD received the salt-deficient diet, and group MD received the mineral-deficient diet.



Experiment 2

In week 3, during their second week on the experimental diets, the amount of chewing on the blood-impregnated models had already begun to differ between the four diet groups ($P < 0.02$). In week 5, the pigs on the mineral-deficient diet and the salt-deficient diet chewed the blood-impregnated tail more than the pigs on the other two diets (Fig. 2). Analysis of variance of results from week 5 showed a significant difference between diets ($P < 0.001$), but no other significant effects or interactions. Duncan's test showed that the pigs on the mineral-deficient and salt-deficient diets scored significantly higher than the pigs on the other two diets, while no other comparisons reached the 5% level of significance.

Scores for chewing the plain model averaged 12, 18, 16 and 26 per day for pigs on the control, salt-only, salt-deficient, and mineral-deficient diets, respectively. These scores showed no general trends over the course of the experiment. In week 3, diet appeared to influence the amount of chewing on the plain model

($P < 0.05$), with the pigs on the mineral-deficient diet having scores about twice as high as the other groups. However, this difference had essentially disappeared by week 5.

The four groups differed considerably in weight gain. Gain averaged 1029 ± 51 g d^{-1} (mean ± SE) on the control diet, 960 ± 38 on the salt-only diet, 742 ± 60 on the salt-deficient diet, and 879 ± 36 on the mineral-deficient diet. Analysis of variance showed significant differences between diets ($P < 0.001$) and between litters within replicates ($P < 0.01$).

Further Analysis of Control Pigs

In exp. 2, the eight pigs on the control diet were from eight different litters, and their behavior illustrated the large individual differences in the pig's response to blood in the absence of any dietary insufficiency. Some of the animals showed a strong, consistent attraction to the blood-covered model, with up to 87% of chewing directed to this model (Table 2). Others showed no significant preference for one type of model over the other. The pigs also varied greatly in the total amount of chewing they performed, with mean daily scores ranging from 9 to 71 (Table 2). The two variables (total chewing per day and percentage preference for the blood-covered model) were not significantly correlated.

In exp. 1, the control pigs consisted of one male and one female from each of four litters, thus permitting a small but balanced comparison of individual differences based on sex and litter of origin. Males and females did not differ consistently in any measure, but there appeared to be some litter differences in the degree of preference for the blood-covered model: one litter accounted for both pigs with the lowest preference scores, and another litter accounted for the third and fourth lowest scores. As in exp. 2, the control pigs showed a wide range of results, with mean daily scores ranging from 18 to 123 for total chewing, and percentage preference ranging from 91% (highly significant preference for the blood-covered model) to 53%.

Table 2. Results (mean ± SE of 15 daily values) of two behavioral measures for the eight pigs which received the control diet throughout exp. 2

Pig number	Percentage of chewing directed at blood-covered model	Daily score for chewing models†
918	87 ± 3***	52 ± 6
903	82 ± 4***	34 ± 9
1214	78 ± 5**	24 ± 7
185	77 ± 4***	30 ± 6
397	67 ± 4***	71 ± 6
412	61 ± 5	41 ± 5
154	59 ± 5*	9 ± 2
1224	57 ± 4	50 ± 6

Significantly more chewing on the blood-covered model (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$) as shown by Student's *t*-test, two-tailed, treating the 15 test days as independent.

†Plain and blood-covered models combined; maximum possible score of 240.

DISCUSSION

In both experiments, omission from the diet of all mineral supplements was followed by a striking increase in the pigs' attraction to blood. In exp. 2, an equivalent effect was achieved by providing a diet lacking iodized NaCl alone. If NaCl was present in the diet, the omission of all other mineral supplements had a smaller and statistically nonsignificant effect. There is, however, room for further work to determine

whether long-term mineral deficiencies other than NaCl can eventually produce heightened attraction to blood.

Compared to the diets offered, blood contains a high concentration of sodium, chloride, iron, and selenium (Table 1). The attraction to blood evoked by the mineral-deficient diets was most likely due in large part to the well-known sodium appetite that develops under conditions of low sodium intake (Denton 1982).

Nonetheless, pigs fed the control diet throughout the experiments showed a weaker but still pronounced preference for chewing on the blood-covered model, as reported previously for younger pigs (Fraser 1987). As in the previous work, the animals showed large individual differences on two variables: (1) the degree of preference for the blood-covered model, and (2) the overall amount of chewing directed at the models. Large individual differences in attraction to blood may help to explain why, in a tail-biting outbreak, most of the biting is done by certain pen-mates, while others, subjected to the same diet and environment, may completely refrain from biting.

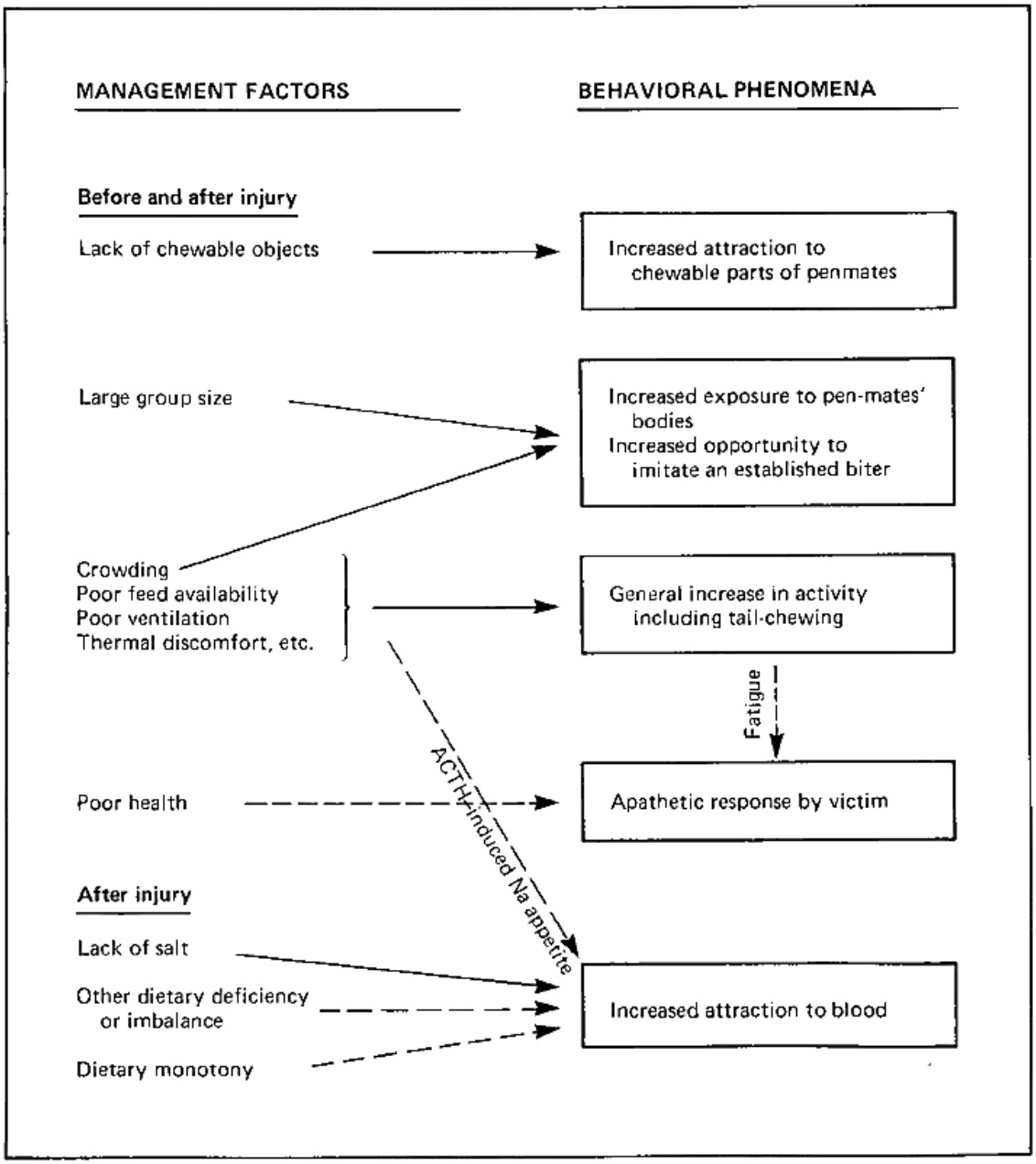
Apart from suggesting how diet might influence tail-biting, the results also have implications for the widely-recognized role of "stress" in causing this behavioral problem. In sheep, rabbits, and rats, high levels of ACTH in the blood lead to a marked increase in sodium appetite (Weisinger et al. 1978, 1980; Denton 1982). In these species, stressors such as cold, crowding, and physical restraint, which tend to cause higher output of ACTH, are presumably capable of causing heightened attraction to sodium (see Denton 1982). If the pig follows this pattern, then various stressors could increase the animals' attraction to blood by means of an ACTH-induced increase in sodium appetite.

Because the causation of tail-biting appears to be complex, it is important to clarify how an attraction to blood may fit with other causal factors. Figure 3 summarizes a working hypothesis on how various management factors may influence behavioral phenomena that arguably increase the likelihood of a tail-biting outbreak.

The model suggests that a lack of straw of other chewable objects causes pigs to direct some of their normal exploratory and manipulatory behavior to the bodies of their pen-mates (Van Putten 1969, 1980). Large group size and over-crowding provide pigs with greater exposure to pen-mates (and therefore a greater opportunity to bite tails) as well as more opportunity to learn the behavior by imitating other pigs (see Blackshaw 1981). Crowding, fighting, hunger, and other causes of discomfort may make the animals generally more restless and thus increase the frequency of many activities including chewing on tails. For example, Boon et al. (1983) noted restless activity of pigs when temporary power failures led to a drop in ambient temperature. Ill health, or fatigue from excessive restless activity, may cause the recipient of tail-biting to react apathetically so that the behavior is more likely to persist to the point of causing injury.

Once the chewing of tails has caused a bleeding wound, then an attraction to blood could add a further impetus for the behavior to continue or escalate. At this stage, a lack of salt in the diet will increase the animals' attraction to blood, and various causes of stress might have a similar effect. Other dietary problems, such as low levels of fiber or protein, might also contribute (Gadd 1967), but experimental evidence is lacking (Ewbank 1973). Finally, for an omnivore such as the pig, a monotonous diet may cause an object which provides a different flavor, such as that of blood, to be attractive simply because of its novelty.

Fig. 3. Proposed model suggesting how management factors may influence behavioral phenomena favoring tail-biting. The more speculative relationships are shown with broken lines.



The relationship between real tail-biting and the experimental simulation using artificial tail models is speculative. Obviously, tail-biting should be a more serious matter if pigs are highly attracted to the taste of blood. However, this attraction is only one of many factors, and the degree of its importance remains to be established. The approach does, however, generate some testable predictions: (1) that tail-biting outbreaks should be more serious under conditions (dietary, or possibly stress-related) that cause a pronounced appetite for salt; and (2) that providing alternative sources of salt would reduce tail-biting under such conditions. It may also be that a chewable object, carrying a flavor that competes well with blood for the pig's attention, should be a useful device to help prevent or mitigate tail-biting problems.

ACKNOWLEDGMENTS

I am most indebted to Mr. R. A. Arcand who faithfully collected the 211 200 behavioral observations on which this report is based, and to the staff of the Animal Research Centre pig unit and feed mill for their helpful cooperation. The chemical analysis was kindly performed by Analytical Chemistry Services, Land Resource Research Centre, Agriculture Canada, Ottawa. Dr. B. K. Thompson kindly advised on the statistical analysis. Drs. John Patience and Jeff Rushen provided valuable comments on the manuscript.

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