

Influence of Feeding Frequency on Body Weight and Glucose Tolerance in the Pig¹ (40090)

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An alteration in the meal pattern of animals has been reported to influence body composition, glucose tolerance and circulating lipid levels in a number of studies (1-4); however, these observations have not been confirmed in other studies (5-8). The present study was designed to evaluate the influence of meal pattern on body weight, body composition, glucose tolerance and several plasma metabolites in growing pigs. The pig was chosen as the animal model because of the physiological similarities between the pig and the human (9).

Materials and methods. Four castrated male Yorkshire pigs and four female Yorkshire-Hampshire crossbred pigs were assigned to each of two treatments. Pigs were housed in individual stalls (46 × 137 cm) with concrete-slat floors. Water was available ad libitum from an automatic watering device.

Eight pigs were allowed access to diet for 4 hr daily for the first 7 days and then were fed one 4-hr meal every 48 hr for the next 165 days. Based on the average food intake of the four castrated male pigs, each of the four other castrated male pigs were fed an identical total amount of food but as two equally-sized meals per day. Likewise, four female pigs were similarly pair-fed twice daily. Pigs fed two meals per day consumed their entire meal within a few minutes after it was offered. Pigs were weighed every 8 days. The corn-soybean meal based diet contained 16% protein for the first 120 days of the experiment and 13% protein thereafter. The diet was initially fed in ground form but was pelleted after the first 60 days to facilitate diet weigh-back. One pig fed four meals per

48 hr died; however, the cause of death was not related to the experiment.

An intravenous glucose tolerance test was conducted after the pigs had been meal-fed for 150 days. Each pig received 900g diet 24 hr prior to the glucose tolerance test. Pigs were restrained in a padded sling prior to the test. An indwelling needle catheter⁴ was established in an ear vein and 0.75 g glucose (40% glucose in saline) per kg body weight was injected. Blood samples were obtained from the needle catheter at timed intervals after the glucose load.

To obtain estimates of the levels of several plasma metabolites blood samples were obtained by puncture of the anterior vena cava just prior to a regularly scheduled meal. Plasma glucose,⁵ triglycerides⁶ and cholesterol (10) levels were determined as described.

Biopsy adipose tissue samples were obtained (11) 4 hr after a regularly scheduled meal. Malic enzyme (EC 1.1.1.40) activity was determined on the 50,000g supernatant fluid (12). Protein content of the supernatant fluid was determined by the method of Lowry *et al.* (13).

Pigs were killed and carcass data determined by standard procedures (14). The weight of muscle was also calculated (15).

The data were treated statistically by the student's *t* test.

Results and discussion. Within 20 days the pigs were each able to consume 1 kg of diet in a 4-hr period (Fig. 1). Food intake increased to 4 kg in a 4-hr period by the end of the study. Pigs fed more frequently consumed their meals within a few minutes after it was offered. Body weight of the pigs remained relatively constant for the first 30-40 days and then increased (Fig. 1). Total body

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⁴ Becton, Dickinson & Co., Rutherford, New Jersey.

⁵ Glucostat, Worthington Biochemical Corp., Freehold, New Jersey.

⁶ Technicon Autoanalyzer Triglyceride Procedure, Tarrytown, New York.

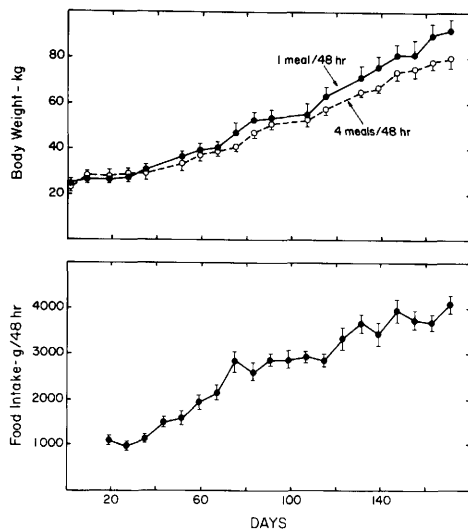


FIG. 1. Body weight and food intake of pigs. Values represent mean \pm SEM for eight pigs fed one meal and seven pigs fed four meals per 48 hr. Pigs fed four meals per 48 hr were pair-fed to those receiving one meal per 48 hr.

weight gain was not influenced by the feeding frequency (Table I). The pigs gained approximately 0.35 kg per day. They would have been expected to gain approximately 0.65 kg per day had they been fed *ad libitum*. Pigs have also been pair-fed one versus several meals per day; no differences in carcass weight gain were observed (16–18). Likewise, dogs fed one or four meals per 48 hr exhibited no differences in body weight (8). These experiments as well as others (2, 7) suggest that an alteration in meal frequency does not influence body weight, provided the animals are pair-fed.

Estimates of body fat and muscle content of the pigs were obtained at the end of the study (Table I). Meal frequency did not influence the results. Rats force-fed two meals per day accumulate more body fat than *ad libitum* fed rats (1, 2). It has also been suggested that humans consuming fewer meals per day have a tendency to be fatter (1). However, in the present study with pair-fed pigs and in other similar studies with dogs (8) and rats (7) meal frequency did not influence body fat. The reason(s) for the pronounced influence of meal-frequency on body fat when rats are force-fed, as opposed to minimal influences when animals are pair-fed meals, remains to be elucidated.

Pigs were fed a 900 g meal 24 hr prior to

TABLE I. INFLUENCE OF MEAL FREQUENCY ON BODY WEIGHT GAIN AND ON CARCASS MEASUREMENTS IN THE PIG.^a

	Meals per 48 hr	
	1	4
Initial body wt, kg	24.14 \pm 1.79	23.63 \pm 1.64 ^b
Body wt gain, kg	63.47 \pm 4.29	54.22 \pm 2.84 ^b
Carcass wt, kg	60.40 \pm 4.03	55.29 \pm 3.08 ^b
Backfat thickness, cm	1.98 \pm 0.26	1.71 \pm 0.40 ^b
Fat trim, kg	5.75 \pm 0.84	4.49 \pm 0.74 ^b
Longissimus dorsi area, cm ²	30.2 \pm 0.80	26.6 \pm 1.40 ^b
Muscle, kg	36.60 \pm 1.44	32.23 \pm 2.35 ^b

^a Mean \pm SEM for eight pigs fed one meal and seven pigs fed four meals per 48 hr.

^b Values were not significantly different from pigs fed one meal per 48 hr, $P > 0.05$.

the glucose tolerance test to standardize the postabsorptive state at the time of the glucose load. All pigs cleared the glucose with equal efficiency; meal frequency did not influence the changes in plasma glucose following the glucose load (Fig. 2). Similar results have been reported in meal-fed dogs (8). Likewise, an alteration in meal pattern had only a minimal influence on glucose tolerance in the chicken (6) and rat (5) when food intake prior to the test was controlled. Failure to control food intake among the treatment groups may alter the results (5, 6, 8). Humans have been reported to exhibit an impaired glucose tolerance when meal frequency is decreased (1, 4). These results have not been reproduced in the rat, chicken, dog or pig. It is not possible at this time to determine the cause for these differences in response to meal frequency.

Plasma glucose, triglyceride and cholesterol levels were determined just prior to a regularly scheduled meal (Table II). Thus, 44 hr had elapsed since pigs fed once every other day had finished a meal whereas pigs fed more frequently finished a meal 12 hr prior to the sampling. The plasma metabolites measured were not influenced by meal frequency. In a previous report serum cholesterol levels tended to be slightly higher in pigs fed *ad libitum* than in pigs fed one 2-hr meal per day (19). Similarly, dogs fed two meals per day had higher plasma cholesterol levels than did dogs fed one meal every other day (8). However, in a number of other studies (1, 4, 17) circulating cholesterol levels are either not changed or are decreased as meal frequency is increased. It appears that meal-frequency generally has a minimal influence

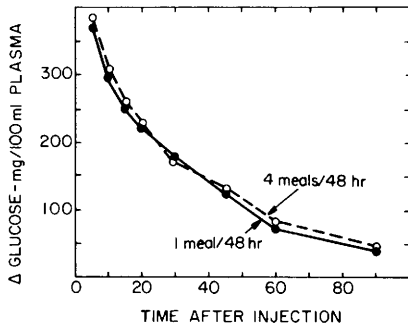


FIG. 2. Intravenous glucose tolerance in pigs fed one or four meals per 48 hr. All pigs received 900 g diet 24 hr prior to the test. Each pig was injected with 0.75 g glucose (a 40% glucose solution in saline) per kg body weight. Blood samples were obtained at timed intervals during the next 90 min. Results are expressed as increase in plasma glucose above zero-time values. Each point represents the mean for eight pigs fed one meal and seven pigs fed four meals per 48 hr. Zero-time values were 88 ± 7 and 71 ± 2 mg glucose per 100 ml plasma for pigs fed one and four meals per 48 hr, respectively.

TABLE II. INFLUENCE OF MEAL FREQUENCY ON SEVERAL PLASMA METABOLITES AND ON MALIC ENZYME ACTIVITY IN PIG ADIPOSE TISSUE.^a

	Meals per 48 hr	
	1	4
Plasma. ^b		
Glucose	99 ± 3	102 ± 5
Triglycerides	48 ± 3	59 ± 8
Cholesterol	108 ± 6	98 ± 4
Adipose. ^c		
Malic enzyme	118 ± 12	66 ± 6^d

^a Mean \pm SEM for eight pigs fed one meal and seven pigs fed four meals per 48 hr.

^b Values expressed as mg per 100 ml plasma.

^c Enzyme activity expressed as nmoles substrate utilized per minute per mg protein at 25°.

^d Significantly different from values obtained when one meal per 48 hr was fed, $P < 0.05$.

on circulating cholesterol levels. Plasma triglyceride levels were not altered in the pigs in agreement with other reports (4, 8).

Malic enzyme activity in the pig adipose tissue was assayed as an indicator of lipogenic capacity. Pigs fed less frequently exhibited an elevated enzyme activity (Table II). The magnitude of the difference in enzyme activity between the two groups is similar to a previous report (14). The elevated lipogenic capacity of the pigs fed less frequently would allow a portion of the energy in the high-carbohydrate diet to be stored as fat immediately after the meal. This fat could then be

mobilized to supply a source of energy during the postabsorptive state; consequently, the increased lipogenic capacity would not necessarily result in increased body fat.

Summary. Pigs were pair-fed one or four meals per 48 hr for 5.5 months. Meal frequency did not influence body weight gain, body composition, glucose tolerance or plasma glucose, cholesterol or triglyceride levels. Pigs fed less frequently exhibited elevated malic enzyme activity in adipose tissue.

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