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Gastric Pressures in Pigs During Eating and Drinking

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HOUPT, T. R. *Gastric pressures in pigs during eating and drinking.* PHYSIOL BEHAV **56**(2) 311–317, 1994.—Pressures were measured with miniature transducers positioned within the gastric lumen of six young pigs, 20–40 kg, eating and drinking operantly. The pigs were free to move about, lie down, sleep, eat, and drink without disturbance. 1) At the end of 4–5-h fasts (with no drinking), mean pressure within the stomach was 12 cm H_2O, then rose during 22-min eating bouts to 22 cm H_2O. 2) At the end of 16–18-h periods of food and water deprivation, intragastric pressure was 9 cm H_2O. When water was drunk, pressures rose only to 13 cm H_2O, then fell. When food was then eaten, pressures rose during 29-min meals to 22 cm H_2O. 3) During spontaneous eating and drinking, intermeal pressures were maintained at 22–25 cm H_2O, fell by 4–5 cm H_2O just as eating or drinking began, then rose slowly, but only to the preingestive pressure level by the end of the bout. These results indicate that during spontaneous eating and drinking, gastric distention per se plays a smaller direct role in causing satiety than it does during meals ingested after a period of food deprivation.

Pig Satiety Gastric distention Gastric pressures Drinking Eating

THE subjective impression of the full stomach at the end of a meal is surely the origin of the oldest explanation for satiety: gastric distention signals central feeding control systems when sufficient food has been ingested, and feeding behavior stops. A similar hypothesis can be applied to the control of drinking. The presence of appropriate neuroanatomical and neurophysiological arrangements, that is, sensory receptors for stretch in the wall of the stomach, afferent fibers to the CNS, and the central mechanism for control of eating, has long been well established (28). However, a theoretical leap has often been taken from neurophysiological findings to behavioral explanations; for example, results from findings on anesthetized animals have been used to explain normal ingestive behavior (26). Of course, many studies indicate that it is possible to inhibit eating by increasing pressure within the stomach (5,8,9,18). However, such studies often employed balloons placed within the stomach that were inflated to demonstrate the inhibition, and in some studies the pressures effected were probably excessive, causing discomfort. Further, liquid meals were often used where ingestion of nutrients was confounded by possible differences between drinking and eating. In any case, the relevance of gastric distention to normal satiety has not been clear, particularly in animals under spontaneous, ad lib conditions where they could eat and drink whenever they wanted. In part, this may be because the normal physiological pressure variations in the stomach under common feeding patterns have not been extensively studied.

The objective of the present study was to measure intragastric pressures in young pigs while they were eating and drinking operantly: i) just after a 4–5-h fast without drinking; ii) after a 16–18-h fast with no water; and iii) during spontaneous ad lib eating and drinking. The pigs were free to move about in a small pen. The results support the concept of gastric distention causing satiety during ingestion following periods of food or water deprivation, but suggest that distention per se is less likely to be a major factor under conditions of spontaneous, ad lib eating and drinking.

METHOD

Animals

The subjects of these experiments were six young, sexually immature, female pigs. The pigs were obtained from the Cornell Swine Barn at about 20 kg in weight, and they grew during the experiments to about 40 kg. The pigs were housed individually in indoor pens (2.1 × 2.9 m). Room temperature was maintained at 22–23°C and the lights came on at 0700 h and went off at 1900 h. The pigs obtained feed and room-temperature tap water operantly by pressing panel switches with their snouts, an activity they took to readily. Feed and water deliveries were recorded on an event recorder. Ten panel presses were required to deliver one reinforcement of 8–15 g of feed or 15–25 ml of water. The feed and water bowls were 45 cm apart and the panel switches were adjacent to each bowl. The feed was a high-quality pelleted pig starter ration containing 18% protein, 4% fat, 3% fiber, and 0.36% sodium (Pro:Lean Squealer Pellets, Agway, Ithaca, NY). Feed and water were available at all times except as otherwise noted in individual experiments.

The pigs were handled frequently and soon became quite tame and accustomed to the researchers. During these experiments where intragastric pressures were measured continuously, the pigs were restricted to a subpen (0.9 × 1.4 m) that was large enough for them to turn about, lie down, take a few steps, sleep, and eat and drink. The operant feed and water delivery systems were within the subpen.

Surgery

Halothane anesthesia was induced with a face cone, taking care to excite the pig as little as possible and using minimal restraint. An endotracheal tube was then inserted and the pig was maintained on closed-circuit halothane/oxygen anesthesia. Standard sterile surgical procedures were used. The catheter to be implanted was of polyurethane, 4.1 mm o.d., 2.3 mm i.d., 80 cm long. The tip of the catheter was forced through the center of a circular piece of synthetic mesh (Merselene, Ethicon) 5–6 cm in diameter, and the catheter was secured with silicone rubber cement so that the mesh disk was at a 30° angle to the catheter, 6–8 cm from the tip. A midline abdominal incision was made and the stomach was located. A small incision was made a few cm aborally to the boundary between the thin-walled body of the stomach and the thicker antrum, and the catheter was inserted orad to position the tip within the lumen of the body of the stomach. The approximate position of the catheter is shown in Fig. 1. A seal was effected with double purse-string sutures and then the mesh material was tacked at several points with sutures to the serosa of the stomach. This made a very effective seal and no signs of leakage were detected on postmortem examination or before. The free end of the catheter was brought through a small incision in the ventral abdominal wall, then under a belly band of adhesive tape to the dorsum of the trunk.

When not in use, the catheter was filled with saline and closed with a glass plug. Long-acting penicillin (Bacillin, Wyeth–Ayerst Laboratories) and meperidine (Demerol, Sanofi Winthrop Pharmaceuticals) were given IM before recovery from anesthesia. Only limited amounts of soft, wet food were given for 1–2 days. The pigs tolerated this procedure well and signs of discomfort or digestive tract upset were uncommon. Within 3–4 days normal eating and drinking resumed and after another 4–5 days the experiments began.

Intragastric Pressure Measurements

Miniature pressure transducers (Mikro-Tip, Model SPC-350, Millar Instruments, Inc., Houston) that were small enough (Fr 5) to be passed down the polyurethane catheter were used in conjunction with a polygraph (Model 7C Polygraph, Grass Instrument Co., Quincy, MA). Before each measurement session, the pressure transducer was calibrated by inserting it into a column of water sequentially at different depths (0–30 cm in 5-cm steps), and the pen deflections on the polygraph record were labeled. The polyurethane catheter was lubricated with surgical jelly by injecting a little into the lumen; then the transducer and its leads were slipped in, keeping careful note of the length inserted. When a length had been inserted that would put the tip of the transducer about 1 cm beyond the end of the catheter, the transducer leads were gently clamped within the catheter. The leads were suspended above the pig by long elastic strings attached to the ceiling, brought to the outside of the pen to a control box (Wheatstone bridge), and then to the input of the polygraph.

Pressure recordings from the stomach were very sensitive with this system, easily recording variations due to breathing, body movements, and even the heart beat. Variations of interest, however, were always slow changes in pressure over several seconds. Brief, rapid fluctuations were dampened out with the polygraph electronic filter by setting the one-half high-frequency filter at 0.5, that is, 50% attenuation of any rapid pressure changes of 0.5 cycles/s or higher, and nearly complete dampening above 1 cycle/s. Recordings of gastric contractions and other slow pressure changes, as well as fluctuations due to gross body movements, were little affected. An experimenter was always present, and changes in body posture, vocalizations, rooting motions, etc., were marked on the record as they occurred. Feeding and drinking activity was also noted on that record.

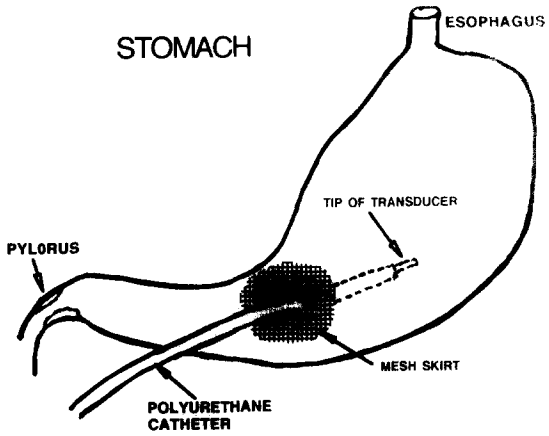

FIG. 1. Sketch of stomach indicating position of implanted catheter and miniature transducer.

The stomach of the pig normally requires about 24 h to empty (21), and after 18 h of fasting some semiliquid content was present (confirmed by postmortem examination on several pigs). The miniature pressure transducers were surrounded by this ingesta in all experiments.

Procedures: Deprivation Experiments

A fast or water-deprivation period was initiated by removing the panel switches. The pig was put into the subpen 0.5 h before the deprivation was scheduled to end. Then the pressure transducer was inserted and recording began. Intragastric pressure was recorded for at least 10 min before feed and/or water were made available. The recording then continued as the pig ate and drank and for at least 10 min after ingestion stopped.

Water was available operantly during the 4–5-h fasts, but with the exception of one brief sip by one pig, no pig ever drank during the fast. After feed was turned on, eating began and continued for about 22 min. Drinking usually did not occur until the meal ended. Both water and feed were withheld during the 16–18-h deprivation experiments. At the end of this period, water was first made available, but only one pig drank at this time. A 20-min pause was then allowed before food was made available. Eating began immediately and continued for an average of 29 min. Water drinking often occurred near the end of this prolonged meal, and then again after the meal. A small subset of similar experiments was done on two pigs to which feed and water were presented in open bowls, and in these experiments water was drunk when presented at the end of the 16–18-h deprivation period.

Procedures: Spontaneous Ingestive Behavior

In this procedure the pig was confined to the subpen, the pressure recording system was set up, and intragastric pressures were recorded continuously for periods of up to 8 h. The pig was free to eat and drink operantly at any time, and pressure changes were measured during several bouts of eating, drinking, or mixed eating and drinking.

Analysis of Pressure Records

Pressure measurements were made repeatedly on each pig for each feeding condition. The polygraph recordings showed con-

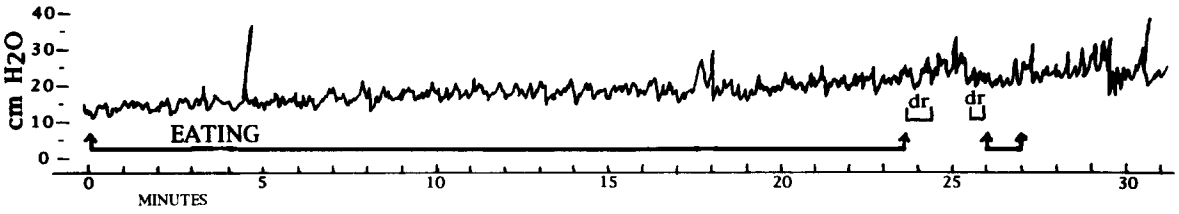

FIG. 2. Tracing of a polygraph record of intragastric pressure during a meal eaten after a 5-h fast (pig D-91). Food presented at zero time. Two brief drinking bouts are indicated by "dr." Pressure was 12 cm H_2O when the meal began and 23 cm H_2O when the main bout of eating ended.

siderably jagged, cyclic variations. A tracing of such a record is shown in Fig. 2 for a meal following a 5-h fast. Despite occasional erratic deflections, the general trend of pressure change in this figure is easily discerned: a steady rise from an initial preeating level of 12 cm H_2O to 23 cm H_2O, when eating stopped. There was then a brief drink and a final short eating bout, but the final pressure was no higher. To quantitate the pattern more precisely and to facilitate comparisons between experiments, average pressures were determined for successive short time spans across the polygraph records. Most such time periods were each 1 min in duration, but they ranged from 0.5 to 4 min. For this purpose, the area in cm^2 beneath the curve for a selected time span was measured with a mechanical planimeter (Compensating Polar Planimeter, Keuffel & Esser Co., New York); this area was then divided by the distance in cm along the time axis to get mean height of that time span. The height of the time period in cm was then converted to its pressure equivalent. These mean values were then plotted against time to give a line representing pressure changes before, during, and after each meal or drink.

Statistical Analysis

The slope and correlation coefficient of the regression of the pressure changes on the time segments during each ingestive bout studied were calculated using Minitab Statistical Software (29). The similarity of patterns of pressure changes during the various feeding and drinking procedures was tested using a general linear model (GLM) analysis of variance (ANOVA) procedure of the SAS system designed for data with different numbers of animals under each treatment and with different numbers of replications on each animal (30). The contrast statement of the GLM program was used to gauge significance of differences between treatments.

RESULTS

The results of these pressure measurements during ingestive bouts were exhibited in two ways: as simple pressure plots against real time (Fig. 3), and as summary plots of mean values for all experiments with a normalized time scale (Fig. 4). In a particular pig, meal and drink durations were similar; however, between pigs the variations of meal and drink sizes were often considerable, making it awkward to represent pressure records as plots against real time. To summarize all results for all pigs for each procedure, each eating or drinking bout (or mixed bout) was divided into eight equal time segments. For each eating bout the real time duration of each segment would vary according to the total length of the ingestive bout; however, the results of such plots make comparisons of the patterns of pressure changes during the ingestive bouts easier to comprehend. The pressures shown on these plots based on dividing each eating or drinking bout into eight time segments could then be averaged within each pig and then for all pigs for that ingestive condition. Time segments were also extended before and after ingestive bouts. The final result was a summary pressure curve for each ingestive condition illustrating the pattern for all pigs.

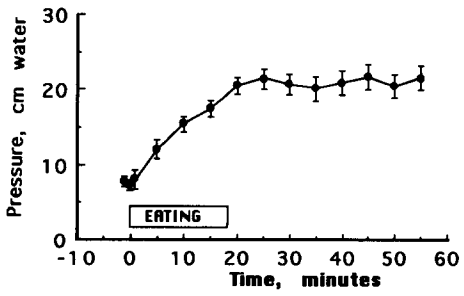

FIG. 3. Gastric pressure changes during meals eaten after 4–5-h fasts. Values shown are the means ± SE of 14 such meals eaten by pig R-90. Food was presented at zero time; mean duration of meals was 18 mins.

After a Period of Food and Water Deprivation

As noted above, a tracing of a polygraph record taken during a meal following a 5-h fast is shown in Fig. 2. A plot of mean pressures in 14 repeat experiments in one pig (Fig. 3) illustrates the pattern of change in real time, whereas the general pattern found in a total of 36 experiments on five pigs based on meals divided into eight time segments is shown in Fig. 4. The pressure shown for each time segment is that for the end point of the segment, (i.e., zero is when eating begins). Pressures rose during these meals from initial pressures of 11.9 ± 1.9 cm H_2O (mean

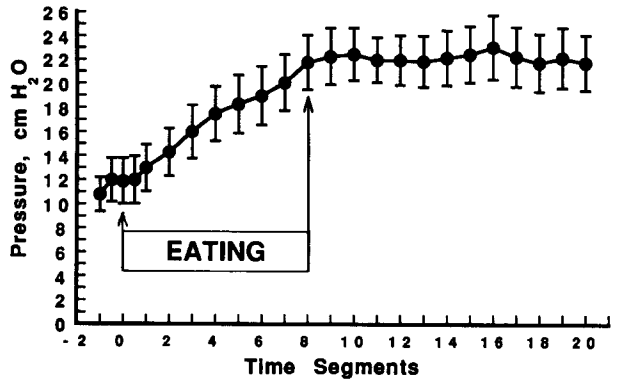

FIG. 4. Mean gastric pressure changes during meals after 4–5-h fasts, calculated from 36 meals in five pigs. Each meal was divided into eight segments and values at those times were used to calculate mean values for each pig. Shown are the means ± SE of those individual pig means (n = 5 pigs). Average duration of the meals was 21.6 ± 1.8 min (±SD) and each segment averaged 2.7 ± 0.5 min. Mean meal size was 430 g or 12.5 ± 1.7 g/kg b.wt. (±SE).

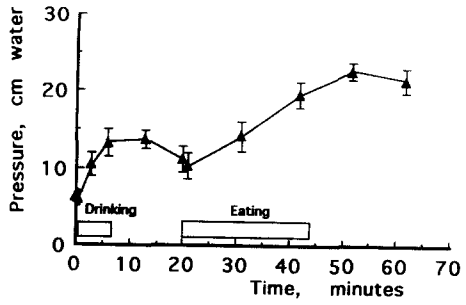

FIG. 5. Mean ± SE intragastric pressures first while drinking, then while eating after 16-h periods of both water and food deprivation. Calculated from nine such experiments on pig I-91, which was the only pig studied that drank appreciable amounts of water before eating under operant conditions. Water presented at zero time and then food at the 20-min mark. A mean of 714 ml (21 ml/kg b.wt.) was drunk, and 514 g (15.1 g/kg b.wt.) of food eaten.

± SE) to the meal's end when pressures reached 21.5 ± 2.3 cm H_2O. The rise of pressure during eating had a mean slope of 1.2 cm H_2O/time segment (about 0.44 cm H_2O/min), and the mean coefficient of correlation was 0.90.

The results after a longer period of deprivation are similar. Three pigs were subjected to 16–18-h periods of food and water deprivation, and then offered first water, and a few minutes later, food. However, only one of these pigs drank appreciable amounts of water before eating. The results on that one pig are shown in Fig. 5. Mean intragastric pressure in this pig was 6 cm H_2O at the end of this extended deprivation period, then rose to about 13 cm H_2O after drinking, began to fall a few minutes later, then rose again as the meal began, reaching 20 cm H_2O at the end of the meal. There was a small further rise in the few minutes after the meal ended before a decline began. A summary graph of mean results from 13 experiments on all three pigs is shown in Fig. 6. Note that there appears to be a small fall in intragastric pressure just before and as eating began. This was sometimes evident even before food or water entered the mouth. Eating caused a rise in intragastric pressure from an initial 11.6 ± 0.7 cm H_2O up to 20.8 ± 0.8 cm H_2O as the meal ended. Rate of pressure rise during eating was 1.2 cm H_2O/time segment (0.30 cm H_2O/min), and mean coefficient of correlation was 0.87.

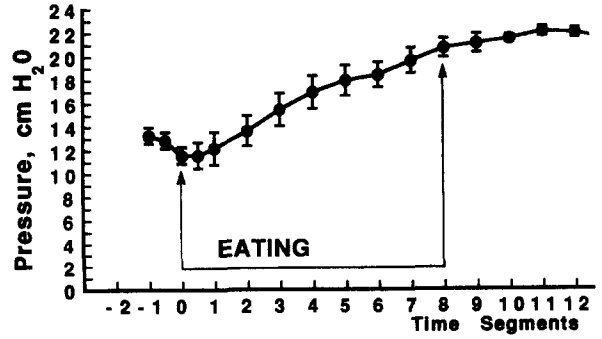

FIG. 6. Intragastric pressures during 15 meals in three pigs after 16 h without food or water. Water was presented 20 min before food was presented, but only one pig drank appreciable amounts. Mean values calculated for each pig, then means of those means ±SE calculated and shown on this figure. Average duration of meals was 29 min and that of each segment was 3.6 ± 0.4 (SD) min. Mean meal size was 516 g (15.9 ± 2.6 g/kg b.wt. ± SE).

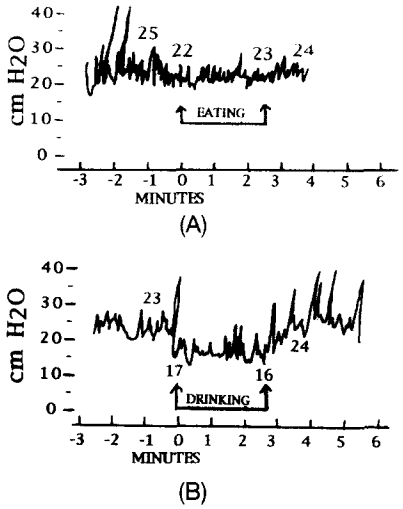

FIG. 7. Tracings of polygraph records of intragastric pressures during spontaneous bouts of eating (A) and drinking (B). Numbers on tracing indicate mean pressures for 1 min before ingestion began, just as it began, just as it ended, and finally 1 min after ingestion stopped.

During Spontaneous Eating and Drinking

When the pigs were free to eat or drink at will, ingestive bouts tended to be brief and of a mixed nature. Some bouts consisted of eating only with no associated drinking, many consisted of both eating and drinking with a mix of preprandial, intrameal, and postprandial drinking bouts, and finally occasional drinking bouts occurred with no eating. Average bout durations were: 4.8 min for eating bouts, 2.4 min for drinking bouts, and 8.0 min for mixed eating and drinking bouts. Shown in Fig. 7 are tracings of an eating bout [Fig. 7(A)] and a drinking [Fig. 7(B)] bout. However, bout duration varied greatly, and summary plots in real time

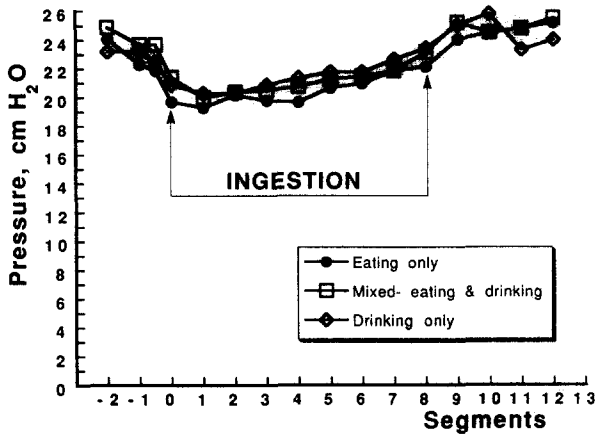

FIG. 8. Spontaneous, ad lib conditions. Mean values for gastric pressures during bouts: of eating (six pigs, n = 27), of drinking (five pigs, n = 16), and of mixed eating and drinking (six pigs, n = 56) (n = total number of replications). Each individual bout was divided into eight segments to get values that could be used to calculate mean values over the course of each type of ingestion. Mean duration of each segment was 0.6 min for eating only (4.8 min total for bout), 0.4 min for drinking only (2.4 min total), and 1.0 min for mixed bouts (8.0 min total). Size of ingestive bouts was 115 g (3.1 g/kg b.wt.) for eating only, 377 ml (9.5 ml/kg b.wt.) for drinking only, and 100 g (2.7 g/kg b.wt.) and 251 ml (6.2 ml/kg b.wt.) for mixed eating and drinking.

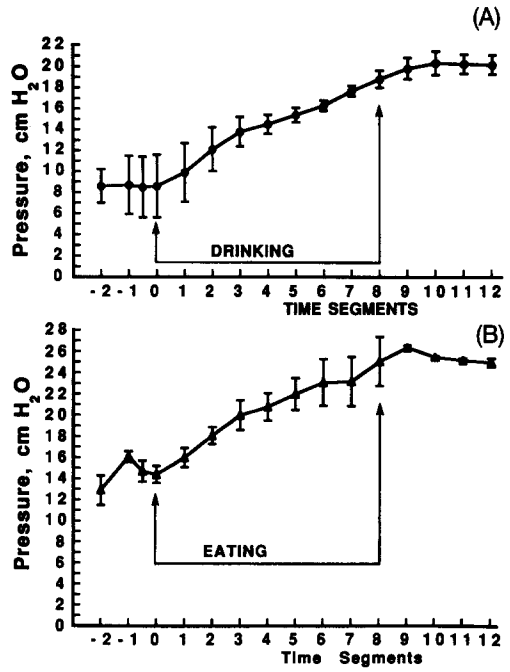

FIG. 9. Gastric pressures first during drinking (A) and then eating (B) from open bowls following a 16-h period of food and water deprivation. Water was presented first, then food pellets were presented 15 min after the end of the drinking bout [i.e., at zero in (B)]. Ingestive bouts were each divided into eight segments: mean duration of these time segments was 0.5 min for drinking (4 min total for the bout) and 2.4 min for eating (19 min total). Mean meal size was 718 g or 23.5 ± 6.8 g/kg b.wt. Mean values ± SE derived from seven experiments on two pigs.

were less useful for comparisons. Instead, in Fig. 8 are shown the patterns of pressure changes during eating, drinking, and mixed eating and drinking bouts based on the division of each bout into eight equal time segments. Note that the initial level of pressure within the stomach was continually elevated under ad lib eating and drinking conditions (23–25 cm H_2O) compared to the pressures following fasts (12 cm H_2O). The similarity of pressure changes during spontaneous ingestive bouts whether eating, drinking, or a mix of both is remarkable: upon the initiation of eating or drinking, or just before, a slight fall of intragastric pressure occurs to 20–21 cm H_2O, followed by a slow rise during the bout, but with a final pressure as the bout ends only up to the preingestion level of 22–24 cm H_2O.

After the initial fall, the rates of pressure rise during ingestion appear to be lower during these brief spontaneous eating and drinking bouts, averaging 0.26 cm H_2O/time segment during bouts of mixed eating and drinking, 0.36 during eating only, and 0.53 during drinking only. The real time rise, however, was actually slightly higher than during ingestion that followed fast periods. During spontaneous eating, pressure rose at the rate of 0.5 cm H_2O/min and during spontaneous drinking, 1.2 cm H_2O/min; during eating after 4–5-h and 16–18-h fasts rates were 0.4 and 0.3 cm H_2O/min, respectively. Correlation coefficients were lower during these brief spontaneous ingestive bouts: 0.65 (mixed eating and drinking); 0.62 (eating); and 0.75 (drinking).

Eating and Drinking From Open Bowls After Fasts

In seven experiments on two pigs feed and water were provided in open bowls at the end of 16-h fasts with water deprivation. First, water was presented, then 15 min after the drinking bout ended, food pellets were offered. The results of this procedure are shown in Fig. 9. During drinking from an open bowl [Fig. 9(A)], pressure rose from 8.5 up to 19 cm H_2O (a 10.5 cm H_2O rise; $p < 0.001$, $r = 0.89$). The bout duration was only 4 min. During operant drinking by one pig after similar food and water deprivation (Fig. 5), pressure rose only 7 cm H_2O during bouts lasting 7 min.

During eating bouts taken from open bowls [Fig. 9(B)], pressure rose on the average from 14 up to 25 cm H_2O (an 11 cm H_2O rise; $p < 0.001$, $r = 0.91$). These pressure changes differ little from those in which the pigs ate operantly after a 16-h deprivation (Fig. 6), when pressure rose during 29-min meals from a mean of 11 up to 21 cm H_2O (a 10 cm H_2O rise). But the meals eaten from open bowls were shorter and larger.

Pattern Comparisons

The parameters of the ingestive bouts are summarized in Table 1. Intragastric pressures just as eating or drinking began depended upon whether the pig had been fasted or not. Pressure was about 12 cm H_2O after fasting, whether for 4–5 h or 16–18 h, but 20–23 cm H20 under spontaneous ad lib conditions ($p < 0.001$). Perhaps of greater interest were the final pressures attained in the stomach just as the ingestion bouts ended. For the various conditions, final pressures at satiety were similar, being in the range of 21–25 cm H_2O. None of these values was significantly different from any other ($p > 0.05$).

Intragastric pressures rose during eating following 4–5- or 16–18-h fasts at about the same rate. Further, comparison of all fasted conditions with any of the spontaneous conditions (eating, drinking, or mixed bouts) showed that slopes in real time were

TABLE 1

SUMMARY: INGESTIVE BOUT PARAMETERS

	Operantly		Open Bowel	Spontaneous (Operantly)		
	After 4–5-h Fast	After 16–18-h Fast	After 16–18-h Fast	Eating	Drinking	Mixed
Meal length (min)	21.6	29	19	4.8	—	8.0
Meal size (g/kg b.wt.)	12.5 ± 1.7	15.9 ± 2.6	23.5 ± 6.8	3.1 ± 0.6	—	2.7 ± 0.6
Initial pressure (cm H_2O)	11.9 ± 1.9	11.6 ± 0.7	14.4 ± 0.8	19.7 ± 1.7	22.5 ± 2.4	21.4 ± 1.7
Final pressure (cm H_2O)	21.5 ± 2.3	20.8 ± 0.8	25.1 ± 2.3	22.2 ± 1.9	23.5 ± 2.4	23.2 ± 1.9
Drink length (min)	—	—	4	—	2.4	—
Drink size (ml/kg b.wt.)	—	—	40 ± 28	—	9.5 ± 2.2	6.2 ± 0.9

Values are mean ± SE.

not different. Finally, the slopes of pressure changes during eating from full bowls were the same as those during operant feeding, despite the greater size of those meals, eaten at a more rapid rate.

DISCUSSION

These measurements of intragastric pressure during ingestion of food and water showed that the pattern as the stomach fills differed depending on whether the ingestive bout was preceded by a fast or thirst or the bout occurred spontaneously while the animal had food and water freely available. After a period of water and food deprivation, intragastric pressure was low at 9–12 cm H_2O, and then it rose to an end-of-meal pressure of about 22 cm H_2O. During spontaneous ad lib eating and drinking, intragastric pressure was typically maintained at a relatively high level: 23–25 cm H_2O; but then pressure fell precipitously by 4–5 cm H_2O as the meal or drink began. As eating or drinking proceeded, pressure rose until at the end of the bout it was near the prebout level of 22–25 cm H_2O. The pressure fall just as the meal or drink began was presumably caused by receptive relaxation via vagal efferents. This reflex relaxation occurs in association with swallowing and begins before food or water actually enter the stomach (4,25,35).

Despite the different patterns of pressure changes among these differing feeding conditions, certain similarities were evident. First, the eating or drinking bouts typically ended at a pressure of 22–24 cm H_2O, regardless of the initial pressure and of meal or drink size. Second, the rates of pressure rise during eating were similar: 0.3–0.5 cm H_2O/min; note, however, that during spontaneous drinking the rate was higher, at 1.2 cm H_2O/min.

How do the pressures found in these pigs compare with those measured in other species? Measurement conditions in earlier studies varied considerably. Hertz (14) in 1911 reported that inflation of the stomach in conscious people gave a sensation of fullness or tightness at about 16–19 cm H_2O. Relation of these pressures to satiety was not considered. More recently (3), human patients subjected to gastric pressures by a balloon reported that they felt the distention in the range 13–27 cm H_2O (mean = 20 cm H_2O). Often meals have been in the form of nutrient liquids. Geliebter et al. (9,10) found that ingestion of a liquid meal had little effect on intragastric pressure. The fact that the stomach was empty initially and that the liquid loads would empty rapidly presumably explain the lack of gastric distention in those experiments. Young and Deutsch (35) got similar results in rats fasted 16 h and then given a liquid nutrient meal: initial pressure was 0, and 2 min into the drinking bout pressure reached 7 cm H_2O, and then plateaued. These scattered reports (and many others) either tend to confirm our values for intragastric pressure in relation to satiety or seem irrelevant because of the physical nature of the diet or because of other differences in methods or conditions. There are few reports on gastric pressure measurements in pigs. After an 18-h fast, a pressure of 4.5 ± 2.0 cm H_2O was found in anesthetized pigs. After filling a balloon placed in the stomach with a volume of 1000 ml, intragastric pressure rose to 25.3 ± 3.9 cm H_2O (33).

Placing a small transducer in the lumen of the stomach had the advantage of directly measuring true intragastric pressures. This is essential for a study on animals free to walk about, eat, drink, lie down, etc. Extensive preliminary studies of gastric pressures in pigs eating and drinking had been made earlier using open-tipped catheters connected to an external pressure transducer. But the animal's body movements had to be restricted, and the external transducer had to be continually adjusted, as the body moved, to keep it at exactly the same level as the open tip within the stomach. The results obtained were found to be unsatisfactory, and those efforts and data were abandoned in favor of the use of the miniature transducers. The position in the middle of the lumen of the gastric corpus was selected because most studies have found this part of the stomach to be most sensitive to stretch (1).

In the present study, intragastric pressure has been used as a measure of gastric distention with the assumption that stretch of the gastric wall will stimulate sensory receptors that in turn initiate a flow of impulses in vagal afferents. But what of the relationship between intragastric pressure and volume? Many studies of gastric distention use volume of content or volume ingested as the measure of distention. An increase in intragastric volume will generally result in some increase in pressure. However, it is believed that gastric stretch receptors are either arranged in-series with the smooth muscles cells of the gastric wall (6,16,17) or function as in-series sensors despite an in-parallel arrangement (12). If the tone of intramural smooth muscle cells varies, this would be expected to vary the degree of stretch applied to the stretch receptors. That is, an increase in tone could, with no change in intragastric volume, stimulate the stretch receptors and increase afferent impulse firing rate. In this case, although content volume might be unchanged, intragastric pressure would rise in proportion to the degree of stretch applied to the sensory mechanism (2). The resultant flow of afferent impulses would in turn increase the activity of the satiety system of the hypothalamus (32). Therefore, it would seem that measurement of intragastric pressure is a more appropriate index of gastric distention and its inhibitory influence on eating. The part of the stomach most responsive to distention is the thin-walled, proximal body rather than the distal muscular antrum (2,3).

It is tempting to surmise that ingestive behavior is modulated by vagal afferents stimulated by simple gastric distention, but this is clearly not so. First, postgastric factors are also involved in satiety [e.g., (34)]. Second, various agents influence the sensitivity of gastric stretch receptors or of gastric smooth muscle tone (gastrin, epinephrine, etc.), which would change sensory impulse flow from the stretch receptive mechanisms without a concomitant change in wall tension. One of the most striking such modulation factors is cholecystokinin (CCK). Cholecystokinin rises in the blood at the time of meals in pigs (23), and in other species it has been shown to increase afferent flow from gastric stretch receptors (6,31). It follows that during a meal afferent impulse flow to the CNS—and enhancement of satiety—can occur without an increase in wall tension (24). In those meals where receptive relaxation is relieving wall tension, the surge of CCK released as chyme reaches the duodenum, will nevertheless maintain or perhaps increase that afferent impulse flow. The neural satiety effect from the stomach is due to a combination of stretch and CCK. However, not all studies of gastric distention support the concept of these vagal afferents causing satiety; for example, vagotomy may fail to block this gastric satiety (22), or nutrients in the stomach may cause satiety without distention (7,11). For the case of CCK, there is also evidence that its satiety effect is in part independent of gastric vagal afferents (27).

Third, other neural reflex activity from other parts of the gastrointestinal tract and via sympathetic fibers can influence responses to gastric distention (13). Finally, although the preponderance of opinion seems to favor in-series gastric sketch receptors as the primary system in gastric satiety, studies in which the rate and pattern of gastric distention were varied and then sensory perception of that distention assessed, have led to quite different and more complex conclusions as to the nature of the distention sensing system (20).

The drinking of water after a 16–18-h period of water and food deprivation caused only a small rise of gastric pressure. After this prolonged fast, the stomach would be partially empty, and under these conditions ingested water would empty rapidly, within a very few minutes (15,19). This is presumably the explanation of why pressures after ingestion of amounts of water roughly equivalent to food eaten failed to cause a comparable rise in pressure. Whether the presence of water in the stomach effects an inhibition of further drinking by stimulating distention receptors in the stomach wall would seem less likely. There is the possibility under these circumstances that the relatively large amounts of water that have passed to the duodenum while the drinking bout is in progress might be more effective in inhibiting further drinking, and so limit the size of the bout. This might be by causing distention of the duodenum or stimulation of water receptors (osmoreceptors) in the duodenal wall, or, as absorption of water begins, in the hepatic portal bed. The mechanisms of rapid drinking satiety are uncertain and remain to be determined. Certainly drinking does cease before most of the ingested water can be absorbed.

In conclusion, the results of these measurements of intragastric pressures during eating and drinking suggest that gastric distention could play a direct role in causing rapid satiety during large meals or water drinking bouts that follow periods of deprivation, but that during spontaneous eating and drinking, when the animals can eat or drink at will, the role of gastric distention is more complex, involving factors other than simple pressure change. The afferent neural flow to the CNS due to gastric distention may act as a final common pathway for a variety of satiety signals.

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