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Gastric Emptying of Liquid Test Meals of Various Temperatures in the Dog[1] (41384)

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Abstract. Liquid test meal emptying characteristics at various temperatures were studied by implanting a thermistor temperature probe within the gastroduodenal junction of three chronic dog preparations. Three hundred-milliliter test meals of 200 mOsm citrate and citrate + oleic acid were administered to unanesthetized dogs via a gastric tube. Each meal, at 5, 15, 25, and 45° was replicated three times in each dog. Meals at 5° and 45° entered the small bowel at 10.6° and 42.2°, respectively. The rate of return of the test meal temperature to body temperature of the citrate meal was not affected by meal temperature. In contrast, the return of the citrate–fat meal was rapid at 5°. With both meals, meal temperature did not alter the initiation of emptying. The emptying rate ($t_{1/2}$) showed a significant, but weak correlation with temperature. Our study indicates that liquids can enter the duodenum at temperatures significantly different from body temperature.

There are only a few studies that describe the stomach emptying characteristics of liquid meals at different temperatures. Williams and Wilike indicated that temperature does not influence the rate (1), while other investigators suggested an influence (2–4). We recently developed a temperature probe that can be implanted chronically into the gastroduodenal junction of the dog. This has allowed us to monitor continuously the temperature of the gastric effluent as affected by liquid test meals of different temperatures.

The purpose of the present study was to monitor the emptying rate and temperature profiles of the gastric effluent of liquid meals. We hoped to find if the temperature of the meal influenced the gastric half-life of a liquid meal, the initial onset of emptying, the temperature of liquids that empty into the duodenum, and the rate of return of the meal to body temperature.

Materials and Methods. *Probe construction.* A thermistor probe was developed to monitor the temperature of the gastric effluent in the dog. It consisted of a thermistor (GC 32J3, Fenwal Electronics, Framingham, Mass.) mounted at the end of a shaft of a stainless steel 19-gauge hypodermic tube. This unit was installed in the center of a Teflon cannula, which was 2 cm long by 1 cm in diameter with a 3-cm flange. A similar cannula without the thermistor has been implanted in the gastroduodenal junction of the cat and dog (5).

The thermistor was coated with conothane (Conap Inc., Olean, N.Y.) to protect it from erosion by the stomach contents. Eighteen-inch lead wires were soldered to the thermistor leads and waterproofed with conothane. The lead wire was anchored through a hole in the flange of the cannula. The recording end of the lead wire was soldered to an electrical connector which was imbedded in a dental acrylic support. This facilitated animal implantation and recording as described previously (6).

A constant current source supplied the thermistor and the output voltage was recorded by a DC channel on a Beckman dynagraph. The entire unit was dry sterilized at 105° for 4 hr, preparing it for implant.

Surgical procedures. Three mongrel dogs were used in this study. Sodium pentobarbital at 30 mg/kg iv was used to anesthetize the dogs. The lead wires and probe were brought subcutaneously from behind the scapula to the left lateral upper quadrant of the abdomen. The connector plug was im-

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planted subcutaneously behind the scapula. A midline incision was made and the wires and probe were brought into the abdominal cavity. A 2-cm gastric incision 2 cm orad to the gastroduodenal junction was made to implant the probe. Four double-needle 3-O Tevdec sutures were placed equidistant through the flange of the probe. The sutures were then brought through the mucosal to the serosal side of the terminal antrum. To prevent the sutures from pulling through the tissue, a small square of nylon mesh was used under the suture ties on the serosal surface. The probe was placed with the thermistor tip at the center of the gastroduodenal junction. The gastric incision was closed with a double layer of 2-O chromic sutures. The midline was closed and the animal was allowed to recover for 14 days before being used in the experiments. These implanted dogs including the probe were found viable for up to 3 months, after which the cannula usually became dislodged.

Stomach emptying procedure. Two standardized test meals as previously described (7) with the addition of ^{51}Cr as a nonabsorbable marker were used. These 300-ml 200 mOsm meals consisted of a citrate solution with an emptying half-life ($t_{1/2}$) of ~10 min and a citrate–fat meal with an emptying half-life of ~30 min, both at 25°, i.e., room temperature. Triplicate samples of each of the two meals at 5, 15, 25, and 45° were studied. The sequence of administration of the two meals at the various temperatures was randomized.

Before the experiment, each dog was fasted for 18–24 hr, but allowed water *ad libitum*. The dog was placed in a recording stand and the electrical connection from the temperature probe was made to the current source and the recorder. A gastric tube was placed into the dog's stomach and at least 50 ml of room temperature water was used to rinse the stomach of any food particles. We waited until the dog's temperature returned to normal as monitored by the probe or a minimum of 5 min. The gastric tube was replaced and 300 ml of the meal was allowed to drain into the dog's stomach by gravity. The meal was delivered in less than 30 sec. After 10 min for the citrate meal or 30 min for the citrate–fat meal, the gastric tube was replaced and the stomach contents withdrawn. A 50-ml aliquot of water again was used for a rinse and this sample was kept for analysis. Duplicate 2-ml samples of each specimen of initial meal, stomach content at time of withdrawal, and the rinse, were counted for ^{51}Cr in a Packard auto-gamma scintillation spectrometer (Model 5326). The volume of the original meal left in the dog at time of withdrawal of the contents was calculated using the following equation:

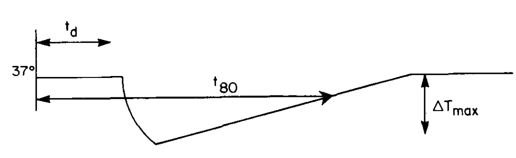
$$V \text{ remaining} = \frac{\text{counts stomach content}}{\text{counts initial meal}} V \text{ stomach} + \frac{\text{counts rinse}}{\text{counts initial meal}} V \text{ rinse}.$$

In most cases, two experiments were done in one day in each dog, in which case 2 hr were allowed from the end of the first run and the start of the second.

Each of the dogs was examined for its stomach-emptying characteristics with the citrate–fat meal at room temperature before and after surgery. No significant difference was found for the mean of the three dogs (115 ml before vs 118 ml after), confirming Stemper and Cooke's observations that the cannula does not alter stomach emptying (5).

Physical properties. There was the possibility that the viscosity and surface tension of the test meals changing with temperature could influence the stomach emptying. The viscosity of the two meals at the four temperatures was measured with a pipette viscometer. Because of the possibility of micelle structure change, surface tension in the fat meals was measured by the flat plate method. Neither the viscosities nor the surface tensions of the test meals changed relative to distilled water over the temperature range studied.

Data analysis. The output of the probe as



recorded by the dynagraph was studied for several characteristics.

The delayed time (t_d) was defined as the time between when the meal infusion was started and when the probe sensed the meal temperature change as indicated by the first pen deflection from the dog's normal ambient temperature of 37°. The maximum temperature deviation (ΔT_{max}) was defined as the difference in the dog's body temperature, 37°, and the lowest or highest temperature seen by the probe. The recovery time (t_{80}) is defined as the time needed to recover 80% of the ΔT_{max} with zero time at initiation of infusion.

The statistical significance of stomach emptying, T_d, t_{80}, ΔT_{max} were analyzed by analysis of variance and compared by Duncan's multiple range test.

Results. The placement of the cannula in the gastroduodenal junction had no significant effect on the rate of emptying of a citrate–fat test meal (see Methods). Cooling of the two test meals tended to slow the rate of gastric emptying (Fig. 1). A three-way (treatment, between animals, and between observations) ANOVA showed no significant difference ($P > 0.25$). The analysis of the regression coefficient of volume remaining at $t_{1/2}$ vs temperature showed a significant correlation ($r = -0.697$, $df = 8$, $P < 0.05$). The slope of the line through the points is equal to 0.6 ml/°C. This slope would indicate that 25 ml difference would occur between the extreme temperature range of 5° and 45°. This is probably of little physiological significance since it represents only 8% of the total initial volume.

Both meals empty at temperatures that are closer to the initial meal temperature than to body temperature of 37° (Fig. 2). However, there was a trend for the meals at all four temperatures to come to body temperature before emptying. For example, the two meals with an initial temperature of 5° exited the stomach at approximately 10° (Fig. 2). In spite of the different emptying rates of the two test meals, both meals had similar initial effluent temperatures, as seen in Fig. 2.

There was a differential effect between the two meals for their rate of return, t_{80}, toward body temperature (Fig. 3). The warmest (45°) citrate–fat test meal was sig-

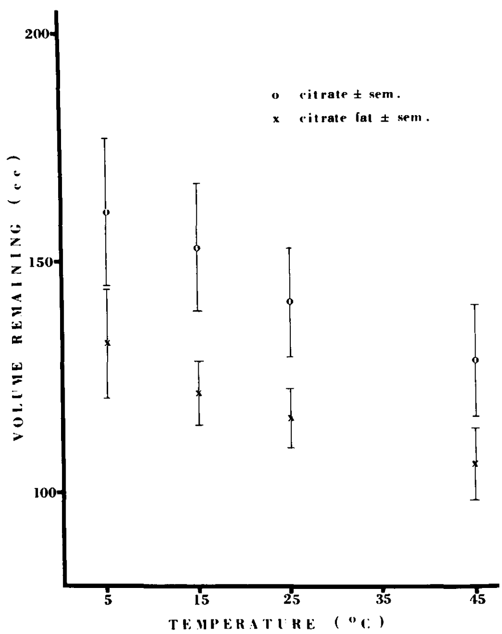


FIG. 1. Stomach emptying is expressed as the mean volume remaining after 30 min for the citrate-fat and 10 min for the citrate meals at the various temperatures.

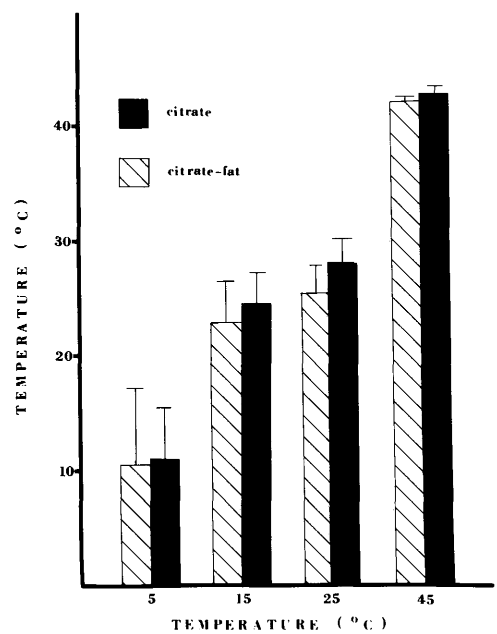


FIG. 2. Initial test meal temperatures (X axes) versus emptying temperature (Y axes), of the two test meals introduced into the stomach at 5, 15, 25, and 45°.

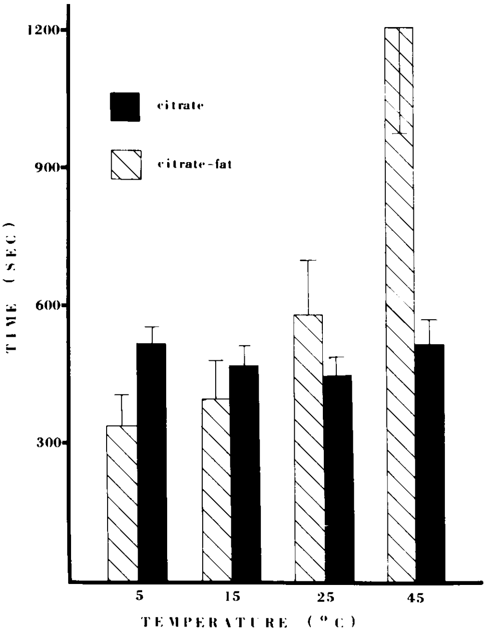


FIG. 3. The time required for the test meals to return to 80%, t_{80}, of their maximum temperature change (ΔT_{max}).

nificantly delayed in its return toward body temperature in comparison to the same meal at the other three temperatures ($P < 0.05$, ANOVA, Duncan's multiple range test). This delay in t_{80} tends to be present for the other three temperatures, exhibiting a temperature responsive effect. In contrast, meal temperature had no significant effect on the t_{80} of the citrate meal (Fig. 3).

There was no significant difference in the delay time (t_d) of the two meals at the various temperatures. The overall mean for the two meals at the various temperatures was 16 sec.

Discussion. A probe was designed to continuously monitor the temperature of liquid test meals as they leave the stomach. The unit had no effect on the gross emptying characteristics of the meals. This confirms that a cannula may be placed in the gastroduodenal junction without altering the emptying characteristics of liquids. Our thermistor was affixed to a cannula similar to the one used by Stemper and Cooke (5). This is in agreement with the concept that the gastroduodenal junction has no role in the control of emptying of liquids (5, 7).

Our data indicate that temperature of the test meal had no influence on the initial emptying (Td). However, raising the temperature from 5° to 45° did tend to increase the rate of gastric emptying. This increase is of questionable physiological importance. A study in the monkey was done (1) where different temperature test meals had a significant, but only a brief effect on the motor activity of the antrum of the monkey. Our results in the dog confirm the observation in the monkey that temperature of a liquid does not significantly alter gastric emptying. A study in man implying that cold liquids empty faster than hot liquids was not confirmed when the data were analyzed by statistical methods (4). A clinical trial (3) suggests that cold water (5°) does empty more rapidly than warm (45°); however, calculation of the reported mean of the 5° data indicated an arithmetic error in both the mean and standard deviation. Recalculation of the data produced only a trend to empty faster with colder liquids. Tests in the rat are in conflict with our data obtained in dogs (2). Possibly, there may be a species difference in the stomach emptying response to temperature. There appears to be no response in monkeys and probably man, a small effect in dogs, and a substantial effect in rats.

The observation that the 45° citrate–fat meal showed a much delayed return to body temperature (t_{80}) suggested that a mechanism other than simple conduction to surrounding tissue may influence the heat transferred out of the meal. A likely candidate for this mechanism is the transfer of heat to the mucosal blood supply which is then carried out into the body. If the blood flow slowed, the rate of temperature return would decrease. A model of this heat transfer system can be made with several simple assumptions: (i) All of the heat is transferred to the blood, (ii) the blood leaving the mucosa is the same temperature as the meal, (iii) the meal is at a uniform temperature, (iv) the physical characteristics of the meal and blood do not change with temperature. A model based on classical heat transfer calculations predicts blood flows that range from 90 ml/min at 5° to 20 ml/min at 45° with a value of 30 ml/min at 37°. While the temperature of an ingested liquid meal may not show a substantial effect on the emptying rate of the meal, it does seem to affect the gastric mucosal blood flow. Paradoxically, the gastric mucosal blood vessels tend to relax with cooling and constrict with heat, opposite to the skin vessel response.

Two test meals with different rates of emptying (citrate $t_{1/2}$ approximately 10 min, citrate–fat $t_{1/2}$ approximately 30 min) were used to challenge temperature influences. The rapid emptying meal would show delaying effect while the slow emptying meal would show an enhancement of the emptying rate if responsive to temperature changes. Since temperature showed such a small influence on the stomach emptying, the postulated small bowel receptors probably do not respond to temperature. Similarly, the stomach does not appear to have temperature receptors, since the initial emptying (t_d) was not different for all four temperatures of either meal.

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