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TECHNICAL NOTE

Assessment of gastric volume changes with sonometry compared with barostat

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Abstract *Aim: The aim was to investigate the validity of sonometry on the assessment of gastric volumes in comparison with gastric barostat.*
Method: Six dogs were implanted with gastric serosal electrodes, sonometric sensors, and a gastric cannula. Experiments were performed to assess sensor distance when an intragastric balloon was inflated with different volumes, after a meal with or without a balloon, and with gastric electrical stimulation.
Results: (i) The distance measured using sonometry was reproducible and stable, and there was a correlation between sensor distance and the gastric volume measured with barostat. (ii) Simultaneous recordings by sonometry and barostat showed a similar postprandial response, while the postprandial increase of the sensor distance was much smaller without the balloon (3.2 ± 0.2 mm vs 9.7 ± 1.5 mm, $P < 0.02$). (iii) The sensor distance was increased with gastric electrical stimulation.
Conclusions: Sonometry is able to detect gastric volume changes as validated by gastric perturbations with distensions, food ingestion and electrical stimulation. The postprandial increase in gastric volume measured by sonometry with barostat balloon is greater because of the presence of the intragastric balloon.

Keywords *barostat, gastric accommodation, gastric electrical stimulation, gastric volume change, sonometry.*

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INTRODUCTION

Gastric accommodation to a meal is a vagally mediated physiological reflex to accommodate the ingested food. Volumetric techniques to measure the gastric response to food ingestion have been proposed or validated.[1] The barostat is the gold standard method for the assessment of gastric accommodation.[2] However, the intragastric balloon used in the barostat system may affect gastric physiology.

Sonometry, or ultrasonomicrometry, has recently been introduced to assess gastrointestinal motility.[3] It assesses the movement of the stomach by measuring the distance of the two sensors placed on the organ. The aim of this study was to investigate the validity of sonometry in the assessment of gastric volume changes with or without food ingestion in comparison with the gastric barostat.

MATERIALS AND METHODS

Animals and surgical preparation

Six healthy female hound-mix dogs (18–24 kg) were involved in this study. As shown in Fig. 1, two ultrasound sensors were implanted on the serosa of the gastric fundus circumferentially approximately 1 cm apart and 4 cm distal to gastro-oesophageal junction. One pair of 28-gauge cardiac pacing electrodes (A&E Medical, Farmingdale, NJ, USA) was implanted on the serosa of the distal stomach 4 cm above the pylorus for gastric electrical stimulation (an intervention without food ingestion into the stomach). The connecting wires of the sensors and electrodes were brought out to the back of the animal through the abdominal wall subcutaneously for the detection of sensor distance by the ultrasound system. A cannula

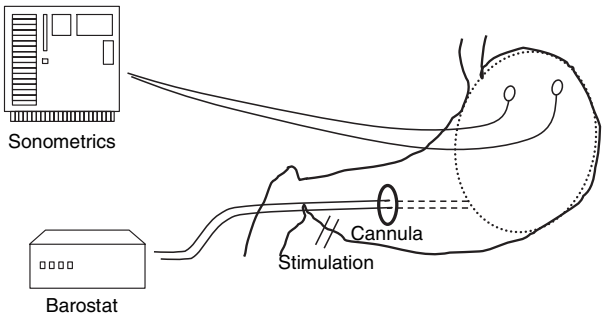

Figure 1 Gastric barostat and sonometric (ultrasound) measurements. Two ultrasound sensors were implanted on the serosa of gastric fundus circumferentially approximately 1 cm apart and 4 cm distal to gastro-oesophageal junction, and one pair of electrodes on the distal stomach 4 cm above pylorus for gastric electrical stimulation. A cannula was implanted in the anterior wall of the stomach, 10 cm above the pylorus, for the insertion of a barostat balloon.

was implanted in the anterior wall of the stomach, 10 cm above the pylorus, for the insertion of a barostat balloon. The dogs were transferred to the recovery cage after receiving medications for postoperative pain control. The study was approved by the Animal Care and Use Committee of the Veterans Affairs Medical Center, Oklahoma City, OK, USA.

Experimental design

This study was composed of four experiments and initiated after the dogs were completely recovered from the surgery, usually 10 days after the surgery. At the beginning of each experiment, there was a 30-min baseline recording for the investigation of the reproducibility and stability of the gastric volume change assessed with the sonometric system.

The first experiment was performed in the fasting state to study the relationship between the distance (or displacement) of the ultrasound sensors and the gastric volume measured by the barostat device (Distender Series IIR, G & J Electronics Inc., Willowdale, ON, Canada). A noncompliant polyethylene balloon connected to the barostat was inserted into the proximal stomach via the gastric cannula (Fig. 1). The balloon was unfolded briefly with 300 mL air and deflated completely afterward. After a 10-min adaptation period without any inflation, the balloon was inflated to 50, 100, 200, 300, 400, 500 mL and the maximal volume up to 800 mL. Each period of inflation was maintained for 5 min with a 5-min deflation period in between. The distance between the two ultrasound sensors was measured by the sonometric system (Sonometrics Corp., London, ON, Canada).

The second and third experiments were designed to assess the validity of sonometry in the assessment of the gastric volume change upon food ingestion or gastric accommodation in comparison with gastric barostat and to study the effect of the intragastric balloon on the postprandial gastric volume change. Gastric responses after a meal were measured on two separate occasions in random order, once with both the barostat and the sonometric systems, and once with the sonometric system alone. A test meal consisting of 237 mL of Boost (250 calories, fat: 6 g, carbohydrate: 33 g and protein: 15 g) was used. In the experiment using the barostat system, the minimal distending pressure was first determined by inflating the balloon in 1-mmHg increments until a pressure at which evident respiratory excursions were recorded and balloon volume was >30 mL. The intra-balloon pressure was then set at minimal distending pressure + 1 mmHg, and the gastric volume and the distance of the two ultrasound sensors were monitored simultaneously for 30 min at baseline and 60 min after the test meal. In the experiment without the barostat and intragastric balloon, the same protocol was followed and the distance of the ultrasound sensors was recorded by the sonometric system.

The fourth experiment was to validate the ability of sonometry to detect the gastric volume change with an intervention without food ingestion. Gastric electrical stimulation is known to increase gastric volume or reduce gastric tone assessed by gastric barostat.[4] This was applied in the fasting state via an adjustable electrical stimulator (Model A310, World Precision Instruments, Sarasota, FL, USA) connected to the gastric serosal electrodes. The electrical stimulus was composed of a series of pulses (square waves) with a frequency of 9 cycles per min, pulse amplitude of 6 mA, and pulse width of 300 ms. The distance between the sonometric sensors was recorded for 30 min at baseline and 30 min with gastric electrical stimulation.

Measurement of sonometric sensor distance

The sonometric system used to measure the distance of the ultrasound sensors in this study was called Digital Ultrasonic Measurement System. The system included two components: a small transceiver unit (TRX Series 4) and a personal computer. It measures the distance within a soft tissue at a rate of many times per sec. In this study, two ultrasound sensors were implanted on the serosa of fundus. They were piezoelectric sensors and an ultrasonic signal was produced by one sensor and received by the other sensor. The sensors were connected to a computer-controlled electronic circuitry, and the time for the ultrasound signal to travel from one

sensor to the other was measured. As the velocity of ultrasound, v, was known, the exact distance between the two sensors was then calculated by the system using the formula $d = v \times t$, where t is the time lag between the transmission and reception of the ultrasonic signal.

Statistical analyses

All data were presented as mean ± SEM. The correlation between the distance of the pair of the ultrasound sensors and the gastric volume measured by the barostat was assessed using the correlation of log barostat volume *vs* linear (distance by sonometry) test. ANOVA for repeated measures was used to compare the data obtained from three recordings periods or more. Paired Student's t-test was applied to compare the data obtained from two recording periods and the data between two sessions with and without the barostat balloon. Results were regarded as significant when the P-value was less than 0.05.

RESULTS

Reproducibility and stability of distance measurement using the sonometric system

Measured using the sonometric system during the baseline recording, there was no difference (ANOVA for repeated measures, $P > 0.05$) in the average, maximum or minimum distance among the three experiments. Similarly, there was no difference (ANOVA, $P > 0.05$) among the average, maximal and minimal distances in each of three experiments.

In Experiment 1, the average distance during the baseline recording was 12.9 ± 1.3 mm, the maximal distance was 14.1 ± 1.4 mm, and the minimal distance was 11.4 ± 1.2 mm. In Experiment 2, there was an average distance of 12.1 ± 0.7 mm with maximal distance of 13.5 ± 0.7 mm and minimal distance of 10.7 ± 0.8 mm. In Experiment 3, the average, maximal and minimal distance was 11.9 ± 0.8, 12.9 ± 0.7 and 10.7 ± 0.5 mm, respectively.

Correlation between the distance of the two ultrasound sensors and the gastric volume measured with the barostat device

Figure 2 shows the data obtained from Experiment 1: the distance of the two ultrasound sensors with various gastric volumes. A significant linear correlation was found between the sensor distance and log of gastric volumes ($r = 0.57$, $P = 0.0015$, Fig. 3).

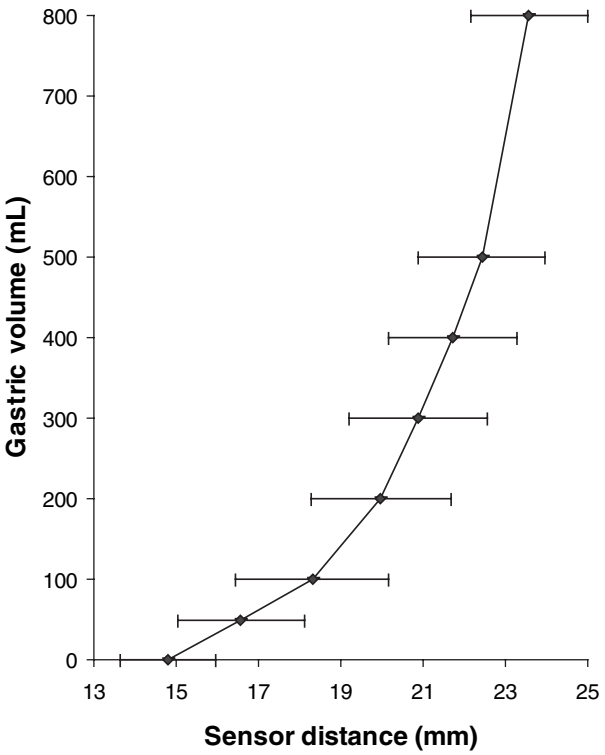

Figure 2 Relation between the distances of the two ultrasound sensors and various gastric volumes. The distance was increased as the balloon was inflated with increased volumes.

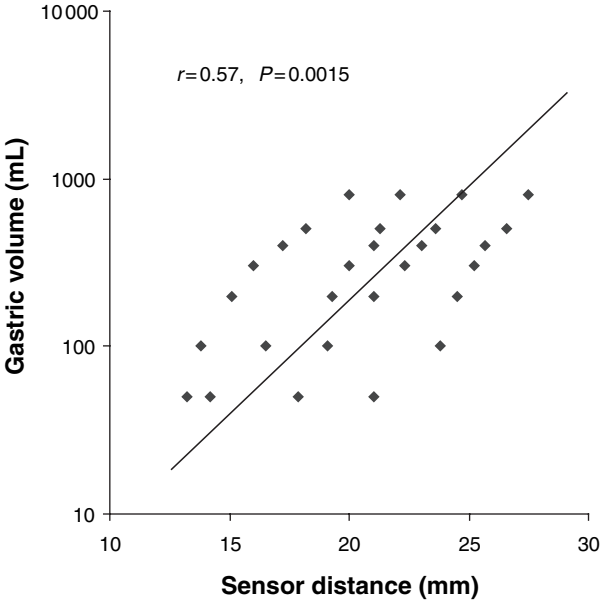

Figure 3 A significant linear correlation was found between the sensor distance and log of gastric volumes ($r = 0.57$, $P = 0.0015$).

Measurement of gastric volume using the sonometric system at the presence of the barostat device

Figure 4A shows the line graph of the gastric volume measured from barostat averaged every 5 min. The barostat was operated under the distending pressure of 4.8 ± 0.4 mmHg. During the 30 min before the meal, the mean gastric volume was 78.3 ± 5.7 mL. The gastric volume was increased immediately after the meal and reached the maximum volume of 439.7 ± 21.7 mL approximately 20 min later and remained significantly elevated (ANOVA, $P < 0.05$) during the next 45 min in comparison with the preprandial value. The postprandial volume averaged during the 60 min after the meal was 394.2 ± 23.6 mL. This reflects an averaged postprandial increase of 315.8 ± 25.8 mL or about a threefold increase from the preprandial volume. Fig. 4B shows the line graph of the distance of the two ultrasound sensors before and after the meal. The sensor distance was quite stable with little variations in the preprandial state and the mean distance was 12.1 ± 0.7 mm. Similar to the gastric volume, the distance was increased immediately after the meal and reached the maximum value about 20 min after the meal and remained significantly increased during the remainder of the postprandial recording (ANOVA, $P < 0.05$ *vs* preprandial). The mean postprandial distance was 21.7 ± 1.9 mm and the postprandial increase was 9.7 ± 1.5 mm. Figure 5 presents typical tracings recorded from one dog.

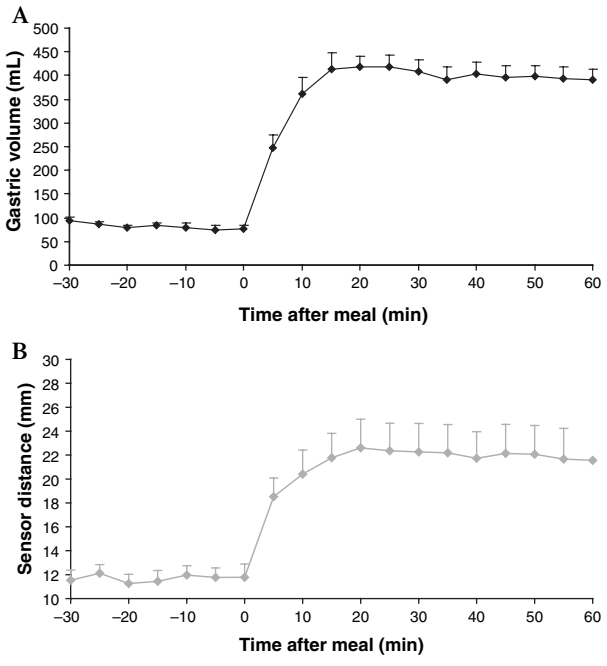

Figure 4 Line graphs of the gastric volume measured by barostat (A) and sensor distance detected by sonometry (B) averaged every 5 min. Both gastric volume and sensor distance were increased immediately after the meal and reached the maximum value approximately 20 min later and remained significantly elevated (ANOVA, $P < 0.05$) during the next 45 min in comparison with the preprandial value.

Measurement of gastric accommodation using the sonometric system in the absence of the barostat device

Figure 6 shows the distance of the two ultrasound sensors measured without the barostat balloon in comparison with that measured with the barostat balloon. The mean postprandial distance during the 60-min after the meal without the balloon was 15.1 ± 0.8 mm, which was significantly shorter than 21.7 ± 1.9 mm ($P = 0.05$) measured with the presence of the balloon.

Measurement of gastric relaxation using the sonometric system without ingestion of food

Figure 7 shows the sensor distance changed with gastric electrical stimulation in the fasting state. The mean distance was 12.9 ± 1.3 mm at the 30-min baseline and increased to 14.8 ± 1.1 mm ($P < 0.02$) during the 30-min period with gastric electrical stimulation.

DISCUSSION

In the present study, we found: (i) The distance measured between two points in the stomach using sonometry was reproducible and stable, and there was a significant correlation between the sensor distance and the gastric volume measured with barostat. (ii) Simultaneous recordings made by sonometry and barostat showed a similar pattern of postprandial response. However, the postprandial increase of the sensor distance was much smaller without the intragastric balloon than that with the balloon. (iii) The sensor distance was increased with gastric electrical stimulation.

Sonometry has been used on the cardiovascular system for years.[5–7] Recently, Adelson *et al.*[3] used this method to monitor the movements of the gut, including the pylorus, antrum, corpus, and lower oesophageal sphincter.

The similar pattern of gastric accommodation (postprandial gastric volume/distance changes measured by barostat/sonometry) observed with simultaneous

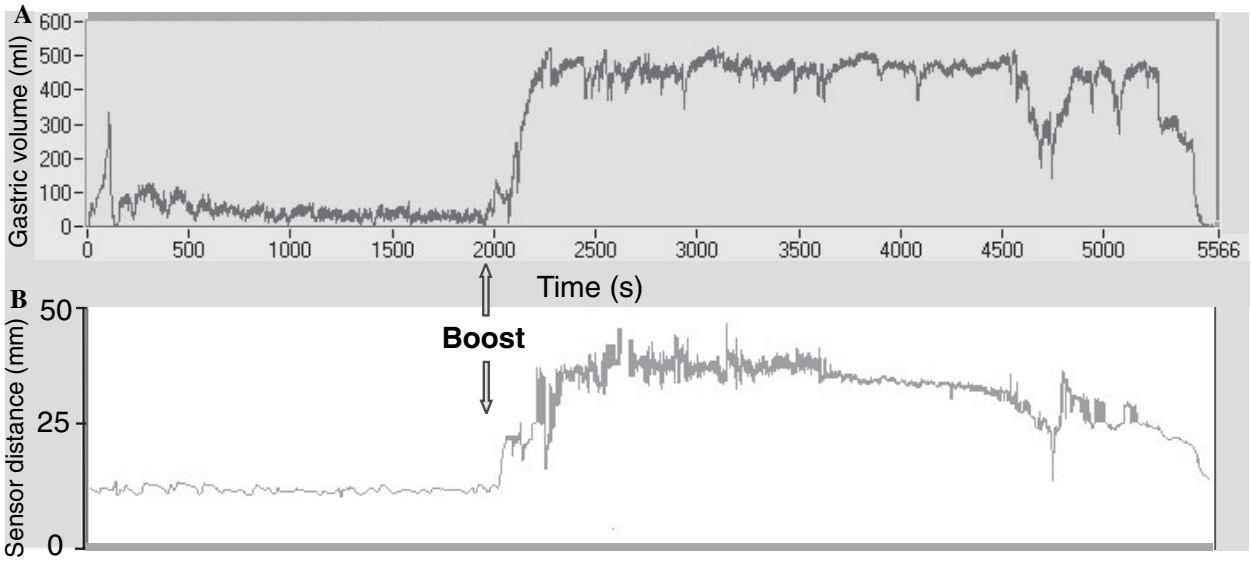

Figure 5 Typical simultaneous recorded tracings of gastric volume measured by barostat device (A) and sensor distance detected by sonometry (B).

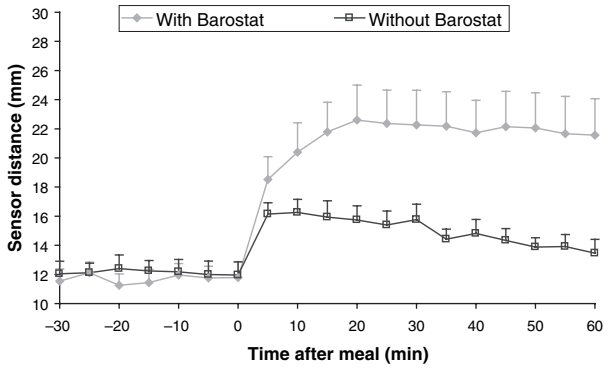

Figure 6 The distance of the two ultrasound sensors measured without the barostat balloon (dark line) in comparison with that measured with the barostat balloon (light line). The sensor distance in the preprandial state was not affected by the barostat balloon. However, in the fed state the distance measured without the barostat balloon was significantly and substantially shorter than that measured with the barostat device.

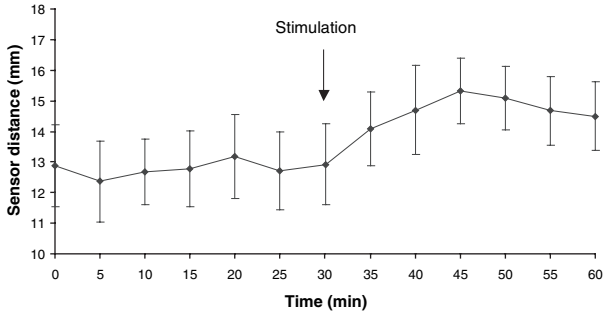

Figure 7 Gastric relaxation with gastric electrical stimulation. The mean sensor distance was increased during 30 min stimulation ($P < 0.02$) when compared with the 30 min baseline.

sonometry and barostat suggests the validity of sonometry in the assessment of gastric volume response. While this method is limited in clinical applications because of its invasiveness, it could be used to assess gastric accommodation in animals. It is also known from this study that the postprandial gastric volume increase assessed with gastric barostat is increased threefold because of the presence of the intragastric balloon. Similar finding was reported by Mundt *et al.*[8] using ultrasound imagine.

Other volume-based methods, including gastric barostat and noninvasive imagining techniques, are commonly used for the assessment of gastric response to a meal.[1]

In conclusion, the volume-based sonometric method is another method able to detect gastric volume responses as validated by barostat with or without gastric food ingestion, and, as currently configured, it has potential application in animal experiments.

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