Gastric Pacing Improves Emptying and Symptoms in Patients With Gastroparesis

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Background & Aims: No effective treatment is available for patients with gastroparesis refractory to standard medical therapy. The aim of this study was to investigate the effects of gastric pacing on gastric electrical activity, gastric emptying, and symptoms in patients with gastroparesis. Methods: Nine patients with gastroparesis participated in this study. Four pairs of cardiac pacing wires were implanted on the serosa of the stomach. The protocol consisted of two portions: a temporary inpatient study period and an outpatient study for a period of 1 month or more. Results: Gastric pacing entrained the gastric slow wave in all subjects and converted tachygastria in 2 patients into regular 3-cpm slow waves. Gastric emptying was significantly improved after the outpatient treatment with gastric pacing. The gastric retention at 2 hours was reduced from 77.0% ± 3.3% to 56.6% ± 8.6% (P < 0.05). Symptoms of gastroparesis were substantially reduced at the end of the outpatient treatment (1.51 ± 0.46 vs. 2.84 ± 0.61; P < 0.04). Eight of 9 patients no longer relied on jejunostomy tube feeding, and no adverse events were noted related to the pacing unit. Conclusions: Gastric pacing seems to be able to improve symptoms of gastroparesis and to accelerate gastric emptying in patients with gastroparesis. More controlled studies are necessary to further investigate the role of gastric pacing in clinical practice.

Gastroparesis is a chronic disorder of gastric motility, defined as delayed gastric emptying of a solid meal. Symptoms of gastroparesis range from early satiety and nausea in mild cases to chronic vomiting, dehydration, and nutritional compromise in severe cases. It is known that gastric motility is regulated by gastric myoelectrical activity. Therefore, it is conceivable that abnormalities in gastric myoelectrical activity may lead to impaired gastric motility, and in turn to delayed gastric emptying. Gastric myoelectrical abnormalities include abnormal frequency of the gastric slow wave (gastric dysrhythmia), abnormally low amplitude of the gastric slow wave, which may be below the necessary threshold for contractions, and uncoupling of the gastric slow wave, which may result in a lack of propagated gastric contractions.

The commonly used medical therapy for gastroparesis is prokinetic agents. These agents were developed to stimulate gastric motility, i.e., contractility of smooth muscles of the stomach, and coordinate gastric-duodenal motor activity. Those who are refractory to the prokinetic agents may require placement of a feeding jejunostomy tube (J-tube) to sustain nutritional support, although that procedure will not affect gastroparesis.

Recently, gastric pacing (electrical stimulation of gastric smooth muscles) has received increasing attention among researchers and clinicians. A number of studies have been performed to investigate the acute effects of gastric pacing on gastric myoelectrical activity, gastric motility, and gastric emptying. The majority of studies in both humans and dogs have indicated that gastric pacing with appropriate parameters is able to entrain gastric slow waves and normalize gastric dysrhythmias. This has led some to propose the use of gastric pacing to treat patients with gastroparesis. However, studies to this point have produced conflicting results. Although gastric pacing improved gastric emptying in the dog model with gastroparesis, it did not: accelerate gastric emptying in patients after surgery. Very few studies have assessed the effect of gastric pacing in patients with gastroparesis. The aim of this study was to investigate systematically the effect of gastric pacing on gastric myoelectrical activity, gastric emptying, and gastrointestinal symptoms in patients with gastroparesis.

Abbreviation used in this paper: J-tube, jejunostomy tube.
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Materials and Methods

Subjects

Nine patients (3 men and 6 women; mean age, 37 years; range, 19–48 years) with severe gastroparesis participated in the study. All patients had documented delayed gastric emptying of an isotope-labeled solid meal before enrollment. Five patients were diagnosed as having diabetic gastroparesis, 3 were idiopathic, and 1 was postsurgical. The common symptoms of these patients included nausea, vomiting, bloating, abdominal pain, weight loss, and anorexia. All patients had been receiving a full regimen of standard medical therapy but still required an abdominal surgery (laparoscopic approach) for the placement of a J-tube for nutritional support. The study protocol was approved by the Human Investigation Committee at University of Virginia Health Science Center, and written consent forms were obtained from all subjects before the study.

Placement of Serosal Electrodes

During the scheduled surgery for the placement of the feeding J-tube, four pairs of temporary 28-gauge cardiac pacing wires (A & E Medical, Farmingdale, NJ) were implanted on the serosal surface of the stomach. They were arranged in an arching line along the greater curvature from the corpus to pylorus (Figure 1). The distance between two electrodes in the pair was 1 cm, and the distance between two adjacent pairs of electrodes was 4 cm. The most distal pair of electrodes were 2–4 cm above the pylorus. The pacing electrodes were affixed to the gastric serosa by partially embedding the wire in the seromuscular layer of the stomach. The electrode wires were brought out through the abdominal wall percutaneously and placed under a sterile dressing. The most proximal electrodes were used to deliver electrical stimulation, and the remaining pairs were used for recording gastric myoelectrical activity.

Figure 1. Location of serosal electrodes. The most proximal pair (S1) was used for pacing, whereas the rest were used for recording gastric myoelectrical activity.

Experimental Protocol

The study protocol consisted of (1) temporary inpatient gastric pacing to determine its effect on gastric myoelectrical activity, (2) baseline gastric emptying study without gastric pacing, (3) outpatient electrical stimulation for a period of 1 month or more, and (4) gastric emptying study with gastric pacing at the end of the study protocol. Patients remained on their individual prokinetic drug regimens during the baseline and throughout the outpatient protocol. All patients were taking cisapride (20 mg, four times daily) before and during the study. Metoclopramide was used intermittently in 4 patients with a dose of up to 60 mg/day. The study was initiated in November 1994 and completed in September 1996.

The temporary inpatient gastric electrical stimulation was performed in the laboratory 1 week or more after the patient had recovered from surgery and, particularly, was off all narcotic medications. On the day of the study, the patient fasted for 6 hours or more and was given no medications with known effects on gastrointestinal motility. A 30-minute baseline serosal recording was made in the fasting state via all the pacing wires to assess the intrinsic frequency of the gastric slow wave. Then a 30-minute recording was made from the three distal pairs of electrodes while the most proximal pair of electrodes was sham stimulated (the patient was told that electrical stimulation was performed, but no electrical current was actually delivered to the electrodes). This was followed with another 30-minute recording with real electrical stimulation. The stimulator used was a commercial product from World Precision Instruments (Sarasota, FL). It delivered a series of constant electrical current with an amplitude of 4 mA, width of 300 milliseconds, and frequency of 10% higher than the intrinsic frequency of the gastric slow wave measured in the baseline recording. These parameters had been determined in our laboratory by previous experiments on these patients and others with gastroparesis to be the appropriate combination for achieving entrainment of the gastric slow wave.

The baseline gastric emptying was performed when the patient was completely recovered from the surgery before being discharged from the hospital. A portable pacemaker unit was developed in collaboration with the Department of Electrical Engineering at the University of Virginia. This system delivered constant electrical current with the same parameters as used in the initial laboratory setting. It was operated by batteries and was the size of a Walkman. Before being sent home with the pacemaker, the patient was trained in its use, and written instructions were given. During the following month or more when the patient was at home, electrical stimulation was performed for up to 1 hour before the meal and for up to 3 hours after the meal. The patient was asked to turn on the device for at least two meals every day during the entire outpatient study period. Patients used the J-tube at night from 8 PM to 7 AM initially and ate at 9 AM, 1 PM, and 5 PM if possible. Meals began as liquids and were slowly advanced to soft and semisolid depending on symptom tolerance. Patients were
instructed to never use the J-tube during the day and to
decrease the rate of J-tube feeding at night as the oral intake
increased with improved symptom control. Their goal was to
have no J-tube feeding at night and rely only on their ingested
calories. The patient was also given a daily symptom score form
and was asked to complete it daily for the entire study period.
The duration of this outpatient study in individual patients
ranged from 35 to 90 days with a mean value of 49 days. At the
end of the outpatient treatment, the patient returned for
another gastric emptying test. The procedure for this second
gastric emptying was the same as for the baseline test, except
that electrical stimulation was performed via the most proximal
pair of electrodes using the portable pacemaker during the
entire gastric emptying testing period. Also at that time, the
patient’s clinical status was assessed by reviewing the symptom
grading in the diary, current oral nutritional intake, and J-tube
needs. The patient was also asked to comment on the need for
medical encounters including emergency room visits and, in
the case of diabetics, their day-to-day glucose control and an
overall global view of the change in quality of life.

Recording and Analysis of Gastric
Myoelectrical Activity

The recording of gastric myoelectrical activity from the
implanted serosal electrodes was made using a Hewlett Packard
model 7758B Stripchart Recorder (Palo Alto, CA) chart
recorder. The signals were displayed on the chart and simulta-
nuously recorded on a tape recorder. The low and high cutoff
frequencies of the recording device were 0.02 and 30 Hz,
respectively. At the end of the study, all signals were played
back from the tape recorder, digitized by a 12-bit analog-
digital converter (DATAQ Instruments Inc., Akron, OH), and
stored in ASCII files on a 486 personal computer. The sampling
frequency was 60 Hz. To reduce the volume of data, the
digitized recording was filtered by a digital low-pass filter with
a cutoff frequency of 0.5 Hz and sampled again at 2 Hz. The
smoothed power spectral analysis, called periodogram meth-
ods,19 was applied to compute the power spectrum of the
recording. The frequency and amplitude of the gastric slow
wave were assessed from the power spectrum. Figure 2 shows a
portion of the serosal recording of the gastric slow wave from
a patient and its smoothed power spectrum. Slow waves (3 cpm)
can be appreciated from both the tracing and the spectrum.

Gastric Emptying Test

The meal used in the gastric emptying test consisted of
7.5 oz of commercial beef stew mixed with 30 g of chicken
livers. The chicken livers were microwaved to a firm consist-
cency and cut into 1-cm cubes. The cubes were then evenly
injected with 18.5 MBq of 99mTc-sulfur colloid. The liver
cubes were mixed into beef stew, which was heated in a
microwave oven. On the day of the gastric emptying test, the
patient fasted over 6 hours. After the intake of this isotope-
labeled solid meal, the patient was asked to lie supine under a
gamma camera for 2 hours. Continuous anterior images were

![Figure 2](image)

**Figure 2.** (A) A portion of serosal recording of the gastric slow wave in
a patient and (B) its smoothed power spectrum. The peak at 3 cpm in
the spectrum represents the frequency of the slow wave. The peaks at the
multiples of 3 cpm are harmonics of the 3-cpm slow wave.

obtained at 1-minute intervals for 120 minutes. The gastric
region of interest was outlined by hand on the initial images by
a nuclear medicine technologist who had no interest in the
outcome of the study. The counts were decay corrected and
normalized to give percent of solid food retained in the stomach
over time. Greater than 70% retention at 2 hours represents
two standard deviations above the mean for the normal subjects
established in our laboratory.

Assessment of Symptoms

A daily symptom score form was developed. Each
subject was asked to report symptoms of nausea, vomiting,
bloating, and abdominal pain. Each symptom was rated as 0
(none), 1 (mild), 2 (moderate), or 3 (severe). The mean total
symptom score was calculated based on the completed form,
and a comparison was made between the mean total symptom
scores from the first week to the last week of the study. Patients
were also asked to assess their overall quality of life, J-tube
feeding requirement, and emergency room visits and hospital-
izations and, in the diabetics, their impression of glucose
control.

Statistical Analysis

Analysis of variance (ANOVA) and paired Student’s t
test were used to investigate the effect of electrical stimulation
on gastric myoelectrical activity, gastric emptying, and gastro-
testinal symptoms. All data were represented as mean ±
SEM. Results were considered significant when P values were
<0.05.
Results

Effect on Gastric Myoelectrical Activity

Gastric slow waves (2-4 cpm) were observed in 7 of the 9 patients in the baseline recordings. The mean frequency of the gastric slow wave in these patients was 2.9 ± 0.1 cpm (range, 2.6-3.2 cpm). Gastric dysrhythmias were identified in the other 2 patients. Electrical stimulation with a frequency of 10% higher than the intrinsic slow-wave frequency completely entrained the gastric slow wave in all 9 patients. The time required for the entrainment ranged from 1 to 10 minutes in individual subjects with a mean value of 5 minutes. A typical example illustrating the entrainment of the gastric slow wave is presented in Figure 3. Gastric dysrhythmias observed in the 2 patients were converted into 3-cpm slow waves with electrical stimulation within 10 minutes of the onset of stimulation. In comparison with sham stimulation, the amplitude of the gastric slow wave during electrical stimulation was significantly increased in the distal antrum (13.00 ± 1.83 vs. 10.71 ± 1.43 mV; P < 0.05), and in the proximal antrum (5.64 ± 0.73 vs. 4.79 ± 0.60 mV; P = 0.07).

Effect on Gastric Emptying

A significant acceleration in gastric emptying was observed at the end of the study. Before the study, the mean gastric retention at 2 hours was 77.0% ± 3.3% with the upper limit of normal being <70% at 2 hours for our test meal. All patients had a gastric retention >60% at 2 hours. After the outpatient treatment with electrical stimulation, a significant improvement in gastric retention was observed at 90 minutes (68.6% ± 7.1% vs. 86.1% ± 3.1%; P < 0.05, paired t test) and at 2 hours (56.6% ± 8.6% vs. 77.0% ± 3.3%; P < 0.04, paired t test) (Figure 4). Gastric retention at 2 hours was <70% in 6 of the 9 patients (67%) at the end of the study.

Effect on Gastroparesis Symptoms

Figure 5 presents serial symptom scores over the outpatient study period. A significant reduction in the symptoms was observed (P < 0.005, ANOVA). The average total symptom scores during weeks 4 (1.3 ± 0.4) and 5 (1.6 ± 0.4) were significantly lower than that during week 1 (2.8 ± 0.4) (P < 0.05, ANOVA). No patient required admission for symptom control during the study. The most consistent observation was not only the reduction in symptom severity but also the stability, lack of extreme symptom fluctuation, and no symptom...
breakthroughs, which was prevalent with prokinetics alone. The diabetic patients also reported less fluctuation in blood glucose and better day-to-day control.

At the end of the study (between 2 and 3 months of gastric pacing), 8 of the 9 patients no longer required J-tube feeding. These patients had returned to adequate oral intake and were able to take their medications orally. One patient who still required continued nutritional J-tube support was a patient with vagotomy and Billroth II who had initially fully responded to the electrical stimulation, but the electrodes connections broke and gastric pacing was not possible. The J-tube feeding then had to be continued. She subsequently underwent a total gastrectomy as the only remaining option.

The electrodes and pacing stimulus were well tolerated, and there were no infections with pacing wires. Some electrodes did become displaced and fell out during the trial, or the connection tips snapped off. Within 4 months in all cases, all electrodes were finally removed. This was easily achieved by gently tugging and pulling on the external wires, freeing the electrodes from their serosal site.

Discussion

In this study, we have systematically investigated the effect of gastric pacing on gastric myoelectrical activity, gastric emptying, and clinical profiles in patients with gastroparesis. The experimental data showed that gastric electrical stimulation was able to entrain the gastric slow wave and improve gastric emptying and clinical symptoms. Previous studies have associated delayed gastric emptying in patients with gastroparesis with impaired gastric motility and/or abnormal gastric myoelectrical activity. Our data seem to indicate that the improvement of the gastric emptying and clinical symptoms might be attributed to the entrainment and improvement of the gastric slow wave with gastric pacing. It is unknown, however, whether gastric contractility was increased with gastric pacing due to the fact that gastric motility was not simultaneously recorded in this study.

Only a few studies have previously investigated the effect of gastric pacing on gastric emptying, and their results were conflicting. Experiments in dogs with healthy stomachs showed that gastric emptying was not accelerated by gastric pacing. On the other hand, the study of a canine model of gastroparesis indicated an acceleration of gastric emptying with electrical stimulation. This model of gastroparesis was implemented in 5 dogs with truncal vagotomy and combined with an injection of glucagon, which induced gastric myoelectrical dysrhythmias. Studies in human subjects reported similar conflicting findings. A very limited number of patients with gastroparesis were previously studied. Gastric emptying was improved in a few patients but not in others. Hocking et al. investigated the effect of gastric pacing on gastric emptying in patients after gastric surgery. Eighty-eight percent of the patients had delayed gastric emptying at the baseline. Two gastric emptying studies of a solid test meal were performed in a random order on consecutive days with and without gastric pacing, and no difference was observed in the gastric emptying rates. In this current study, however, gastric emptying was significantly accelerated. It should be noted that the current study differed from previous studies reported in the literature in the following three factors: (1) the patients in the present study were all referred to one of the investigators for the treatment of severe gastroparesis, and all were refractory to standard medical therapy; (2) the parameters used for gastric pacing were optimized by careful laboratory trials to establish that the entrainment of the gastric slow wave was achieved; that is, the gastric slow wave was always entrained even with an initial dysrhythmia present; and (3) a gastric emptying test was performed at the end of outpatient gastric pacing with a duration of 1 month or longer.

It is conceivable that the degree of entrainment of the gastric slow wave may be associated with the improvement of gastric emptying. Previous studies have shown that there is a higher prevalence of gastric myoelectrical abnormalities in patients with gastroparesis. The abnormalities may include gastric dysrhythmias (the frequency of gastric slow wave is abnormally higher or lower than the normal value or irregular) and low amplitude of the gastric slow wave. Using the optimized parameters obtained from our previous study, full entrainment of the gastric slow wave was achieved in all subjects. Ectopic gastric dysrhythmia were observed in 2 of the patients and normalized to regular 3-cpm slow wave with gastric pacing. This normalization was achieved within 10 minutes of starting gastric pacing. The amplitude of the gastric slow wave present in patients with gastroparesis was significantly increased during gastric pacing. It is not known whether this amplitude increase achieved the same level as could be expected in a normal subject because no data on normal subjects in a gastric pacing setting were available. Our data suggest that the mechanism that led to the improvement of gastric emptying may result from the entrainment of the gastric slow wave, normalization of gastric dysrhythmia, and enhancement of slow wave amplitude. We hypothesize that this in turn would result in the presence of stronger and better
coordinated gastric contractions and hence accelerated gastric emptying.

The effect of electrical stimulation on symptoms of gastroparesis has not been clearly known. Our current study has indicated an improvement in the symptoms. This is in agreement with another recent study, in which a dramatic improvement in the symptoms of nausea and vomiting in patients with gastroparesis was revealed after 1–4 weeks of gastric pacing. However, the parameters used in their study were different from our current study (pacing frequency, 12 cpp; pulse width, 300 microseconds). The electrodes used were also different, and they were implanted deeper in the gastric muscles than in our study. The effects of gastric pacing on gastric myoelectrical activity and gastric emptying were not reported in that previous study.

It should also be noted that the patients in our study experienced a greater stability in their quality of life, with no admissions required during the period of the study. The diabetic patients, in particular, reported less fluctuation of blood glucose levels and no "peaks and valleys" in their symptom levels with no subsequent breakthrough vomiting leading to admission. Most importantly, 90% of the patients were able to return to oral intake to sustain all nutritional needs. In these patients, all medications were able to be administered orally, whereas in the past the medication was given via the J-tube.

Although this study provided promising data with gastric pacing, it should be completely pointed out that a possible placebo effect could not be ruled out due to the fact that data with sham stimulation was not available.

In conclusion, gastric pacing seems to be able to improve symptoms of gastroparesis and to accelerate gastric emptying in patients with severe gastroparesis. Gastric pacing may have a future as a therapeutic option in the treatment of gastroparesis. However, further controlled studies are required to investigate the role of gastric pacing in clinical practice.

References

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