Gastro-intestinal Pacing: *
A New Concept in the Treatment of Ileus

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PARALYTIC ILEUS is a form of intestinal obstruction characterized by inadequate peristaltic activity affecting the gastro-intestinal system in its entirety or segmentally. Loss of normal peristaltic activity frequently occurs following intra-abdominal surgery, and secondary to a variety of pathological conditions such as peritonitis of various etiologies, retroperitoneal sepsis and hemorrhage, and from trauma, infections, or surgery in areas remote from the abdominal cavity. Spinal injuries, diseases or the genito-urinary tract, and thoracic surgery or trauma are frequently observed causes of paresis of the bowel occurring as a reflex inhibition. Loss of effective peristaltic activity of the gastro-intestinal tract rapidly leads to distention of bowel loops with fluid and gas, which if left untreated is prone to perpetuate itself as a vicious cycle, the more distention occurring the more paralyzed the bowel becomes. Fluid and electrolytes are lost into this third space and distention of the intestine further impairs absorption. In addition, distended inactive loops may twist or kink and a mechanical obstruction thus may be superimposed.

Management of this condition heretofore has been largely passive in nature and has not changed significantly since introduction of nasogastric intubation and suction [12] with administration of intravenous fluids and electrolytes continued until the paretic bowel resumes its tonus and peristaltic activity. Hypertonic saline, multiple enemas, spinal anesthesia, repeated use of hot stupes to the abdomen, and bowel stimulants such as prostigmine, neostigmine, pitressin, and pantothenic acid have all been used with variable and inconsistent success.[14]

The purpose of this presentation is to introduce a new concept in the treatment of paralytic ileus by direct electrical stimulation of the gastro-intestinal system utilizing a specially designed electronic pacemaker (Fig. 1).

Development of the Gastro-intestinal Pacemaker

Open-heart surgery for ventricular septal defects, tetralogy of Fallot, and atrioventricularis communis types of septal defects was introduced in 1954.[8, 15] Postsurgical complete heart block with its slow rate was experienced in some of these patients. It quickly became apparent that the then available methods for treatment by means of drugs or externally applied electric shocks were entirely inadequate for increasing cardiac output and consequently the mortality rate in the blocked patients was very high. Experimental investigation upon

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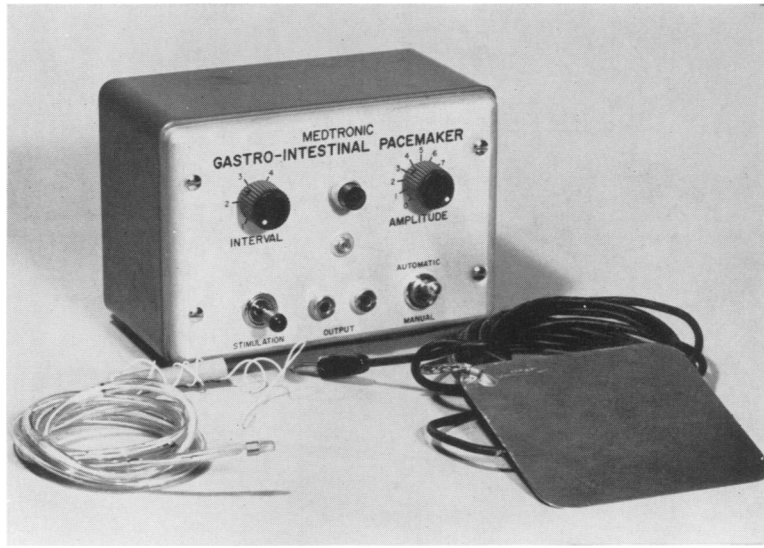

FIG. 1. Equipment for gastro-intestinal pacing. Variable rate and amplitude pacemaker, gastric tube electrode, and indifferent plate electrode.

the feasibility of direct stimulation via a myocardial electrode was begun upon the premise that cardiac muscle forms a true syncytium and that a direct stimulus to a muscle fiber in the ventricle of the heart results in a contraction of the entire organ. This avenue of investigation did prove fruitful and significantly altered treatment and prognosis of complete heart block.[16, 17]

In contrast, in striated muscle only the fiber stimulated will contract. The behavior of the gastro-intestinal muscle, on the other hand, lies midway between that of the myocardium and striated muscle. If one stimulates a point upon the small intestine either mechanically or electrically, a local contraction results which usually is propagated for a short distance from the point of stimulation. Sometimes, however, stimulation at a point will produce a peristaltic rush which will traverse a considerable length of the intestine. Thus, intestinal muscle also behaves as a syncytium but is not *all or none* in its response. Anatomically it is not certain whether the fibers of intestinal muscle communicate with each other or not. They appear to be quite discrete. However, any connections that may exist seem to be unimportant since it is known that conduction does result from the passage of electrical activity directly from active to inactive contiguous smooth muscle cells as well as via the diffuse intrinsic nervous network (plexus of Auerbach and Meissner[9]).

The striking success of electrical cardiac pacemaking via myocardial electrodes in the treatment of complete heart block[16, 17] together with the analogous functional factors just mentioned suggested the possibility of application of a similar concept to the treatment of abdominal distention due to inadequate peristalsis by stimulating gastro-intestinal motility by means of direct pacing.

Exploratory observations upon dogs indicated that this concept was basically sound and worthy of further investigation.

Our initial experiments upon the dogs' gastro-intestinal motility were designed to find optimal current amplitudes, pulse length, frequency, and to determine feasible sites in the gastro-intestinal tract for effective stimulation. Extensive experiments followed with various types of current in regard to wave-shapes, pulse length, and frequency and with regard to their effectiveness in inducing peristaltic activity. These were then tested and modified for human use based on experiments carried out on the authors under fluoroscopy and

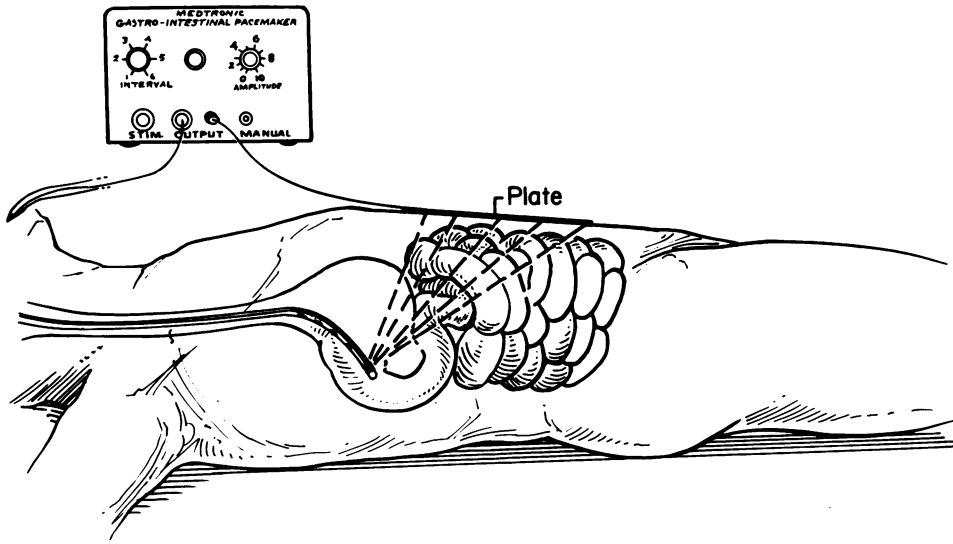

FIG. 2. Technic of gastro-intestinal pacing. Tube electrode is introduced nasogastrically into the stomach and can serve a dual purpose, suction and stimulation. The indifferent plate electrode is applied to the abdominal wall. If operative incisions, colostomies, and dressings do not permit application of the indifferent electrode to the ventral abdominal wall, flanks or dorsal abdominal wall can be utilized. Both electrodes are then connected to the gastro-intestinal pacemaker which is set to deliver impulses at one minute intervals. Other effective routes of stimulation are via a rectal electrode or direct attachment of the electrodes to the bowel.

FIG. 3 A, B, C. Demonstration of induced peristaltic waves in a normal stomach taken in films exposed in rapid sequence. Note the pacemaker electrode in the stomach. The progression of a peristaltic wave can be readily followed in the series.

FIGURE 3B.

later in the operating room by direct observation upon patients undergoing laparotomy (Fig. 3).

It was found from these studies that a current of 7.0 to 10 MA (milli-amperes) output and a frequency of 50 cycles/sec. given for five to 10 seconds duration would be sufficient to induce effective peristaltic activity and was not perceptible to the patient. Hence, a pacemaker was designed with variable output (1–10 MA) equipped with a timer to give impulses of 50 cycles/second of pulsating current of five seconds duration at adjustable intervals from one to five minutes (Fig. 1).

Along with these studies, determination of sites for effective stimulation was also the stomach, pylorus, and first, second, and carried out. Fundus, corpus, and antrum of third portions of the duodenum were stimulated with different types of current. While responses were obtained from all these areas, most effective peristaltic waves appeared when the antrum and first and second parts of the duodenum were stimulated.

FIGURE 3C.

Stimulation was tried by unipolar and bipolar electrodes, intraluminally, transluminally, intramurally, and via the serosa. Unipolar, transluminal stimulation was favored and accepted for clinical application because of convenience and because it was reasoned that the electrical field created by the use of unipolar electrodes would traverse the whole thickness of the bowel wall and stimulate both Meissner's and Auerbach's plexus and the smooth muscle layers over a larger area (Fig. 2).

Technic

The following method was developed for clinical gastro-intestinal pacing. A specially designed brass tip electrode was incorporated onto a standard plastic disposable nasogastric tube (Fig. 1) and passed into the stomach transnasally and advanced to lie in the antral region. The indifferent electrode in the form of a 5 × 5-inch plate (Fig. 1) is taped on either the ventral or dorsal abdominal wall. Both electrodes are then connected to the gastro-intestinal pacemaker which is set to deliver impulses at set intervals (Fig. 2). As the gastric activity is greatest normally in the antrum where trituration, mixing, and emptying are effected, we prefer to stimulate this more active area. In patients with ileus, pacing is continued until gas and the first stool is passed.

The rectal route wherein an electrode probe is passed into the rectum has also been used clinically for stimulation. This method was initially tried to evacuate the large bowel (electrical enemas), but has been found feasible for inducing peristalsis to paretic bowel postoperatively. Intramural implantation or serosal attachment of bipolar electrodes to the stomach wall by catgut stitches at the time of surgery with the lead wires brought out through a tiny stab wound in the abdominal wall

has been utilized effectively for stimulation in experiments.

Clinical Application

To date, gastro-intestinal pacing has been utilized in over 40 patients with paralytic ileus of differing etiologies. Reports of representative patients treated follows:

Case Reports

Postoperative Use

Case 1 (E. M., U. H. 995834). This 62-year-old white woman was admitted to the University of Minnesota Hospitals with complaints of pyrosis and dysphagia. She had been a chronic alcoholic for 27 years. Her esophagogram showed an esophageal stricture near the cardia with a large hiatus hernia. Esophagoscopy revealed a peptic ulcer at the strictured area. She had 60-degree free acid upon histamine stimulation. On December 10, 1962, she underwent laparotomy for repair of the hiatus hernia with coincidental vagotomy and pyloroplasty. Postoperatively, transgastric gastro-intestinal pacing was started utilizing a current of 10 MA with impulses of five seconds duration delivered every minute. Active bowel sounds could be auscultated during stimulation. Sixteen hours after pacing started, she passed gas and had a bowel movement at which time pacing was discontinued and oral intake started.

Comment. In this case and in five other patients who had had either Billroth II or segmental gastrectomy with pyloroplasty and bilateral vagotomy, transgastric, rectal or gastro-intestinal pacing was effective in inducing and maintaining bowel motility. In these cases it required an average of 16 hours of pacing before the first stool was passed, following which pacing was routinely discontinued. These patients have demonstrated that peristaltic activity could be induced and maintained by pacing and the period of recovery of function for the paretic bowel could be shortened after gastric resections with vagotomy and pyloroplasty.

Case 2 (B. C., U. H. 920898). This 8-year-old white girl had biliary cirrhosis, portal hypertension, and repeated episodes of hemorrhage from esophageal varices since the age of one month. She was admitted at this time because of another episode of massive bleeding. Following attempted nonoperative management she underwent laparotomy on December 12, 1962. A splenectomy, splenorenal shunt, and liver biopsy were performed. Twelve hours postoperatively it was noticed that she had developed a severe thrombophlebitis at her cutdown site in the leg. Other cutdown sites in the legs and arms had been utilized on previous admissions for the episodes of bleeding. In order to permit starting her on oral fluids early, gastro-intestinal pacing was started transrectally utilizing a current output of 10 MA of five seconds duration with impulses every minute. This route was chose as it was not deemed feasible to pass the electrode into the stomach for fear that her varices might be further traumatized. Oral intake was well tolerated. Nasogastric suction was discontinued. Within 16 hours after initiation of gastric pacing she had five stools and was therefore advanced on oral intake and pacing was discontinued.

Comment. This case illustrates the feasibility and advantages of rectal stimulation in certain patients, and also the early commencement of oral intake facilitated recovery in this patient with a complicated surgical problem and in a debilitated condition preoperatively.

Case 3 (E. E., U. H. 870212). This 44-year-old white woman with rheumatic heart disease (mitral insufficiency, mitral stenosis, aortic insufficiency, aortic stenosis) was admitted with complaints of severe right lower quadrant pain, anorexia, and vomiting. She was initially treated nonoperatively, but during the next 48 hours an increase in intensity of the right lower quadrant pain, development of rebound tenderness, and a rise in her white blood count occurred, and therefore she was explored on December 9, 1962. At laparotomy she was found to have acute oophoritis. Cholecystectomy and appendectomy were also performed after careful exploration of the small bowel. Six hours postoperatively, transgastric gastro-intestinal stimulation was started. A current output of 9 MA for five seconds duration was delivered every minute for gastro-intestinal pacing. Nasogastric suction was discontinued and oral fluids were allowed. She experienced no nausea or vomiting. During stimulation, she volunteered the information, "my stomach is rumbling." She started to pass gas and had a bowel movement in 12 hours upon which pacing was discontinued.

Comment. In this patient, no nasogastric suction was employed and there was no

need to replace fluids or electrolytes which would have been lost by suction. Oral intake was allowed and recovery was shortened without prolonged requirement for intravenous administration of fluid and electrolytes. Moreover, the dangers of electrolyte imbalance in a patient with low cardiac reserve and on digitalis therapy were obviated. Return of spontaneous peristaltic activity has been achieved in similarly short times following other abdominal operations including colectomies and resection of abdominal aneurysms.

Case 4, F. G. This 66-year-old white man was admitted to the University of Minnesota Hospitals with constant right upper quadrant pains of five days duration. He had had a cholecystostomy 18 years ago. However, since then he had belching, flatulance, and fatty fried food intolerance. At the present admission, he had jaundice with a bilirubin of 4.0 mg.%. On February 8, 1963 a common bile duct exploration was carried out. A duodenotomy, sphincteroplasty, and cholecystectomy were also performed. His early postoperative recovery was smooth. He was started on a regular diet on February 16, 1963. The next day he started vomiting and belching with recurrence of epigrastric distress and abdominal distention. This situation continued until February 21, 1963 when an upper gastro-intestinal series was obtained and a hugely dilated stomach with near total obstruction of the gastric outlet was revealed (upper gastro-intestinal series 2 weeks prior to this was normal). Intramural hemorrhage incident to duodenetomy and sphincteroplasty, an acute ulcer with spasm, and a right upper quadrant abscess with ileus were some of the conditions entertained as possible mechanisms to explain the gastric outlet obstruction. On February 23, 1963, a milk drip of 150 cc./hour with 10-minute aspirations every hour was started. On this regimen return of gastric aspirates varied between 120 and 280 cc. every hour. Exploration was considered, but in reviewing the x-rays the possibility of a gastric atony and dilatation were considered as possibly a primary condition rather than being secondary to obstruction. Gastro-intestinal pacing therefore was started. Fluoroscopic and cinegraphic study of the stomach was also carried out. While the stomach stayed atonic and dilated for one-half hour during observations under fluoroscopy, it readily exhibited peristaltic activity upon pacing and emptied into the duodenum. Pacing was continued over the next day with the same amount of milk drop hourly. The gastric aspirations decreased in amount to 45 to 12 cc. every hour. Pacing was discontinued on March 2, 1962 and the patient was discharged without resort to exploration.

Comment. This case illustrates the use of gastro-intestinal pacing both diagnostically and therapeutically. Its use here undoubtedly eliminated re-exploration. The use of gastro-intestinal pacing in diagnostic radiology to detect abnormal areas of rigidity, fixation, or displacement may not only help with the evaluation, but also shorten the time of exposure to radiation.

Ileus Secondary to Renal Colic

Case 5 (K. E., U. H. 999764). This 33-year-old white man was admitted to the University of Minnesota Hospitals on March 4, 1963 with a three-day history of colicky left flank pain and hematuria for two days. He had not been able to pass stools and had been nauseated, vomiting, and not eating for the prior three days. Past history revealed that he had had renal stones diagnosed six years ago, and he had been having intermittent attacks of renal colic from time to time. On admission, his abdomen was distended and silent. A flat film of the abdomen revealed a kidney stone in the left kidney pelvis and ileus. The entire gastro-intestinal system was dilated with gas. Transgastric pacing was started on March 5, 1963 at 3:00 p.m. with immediate return of bowel sounds. Oral fluids were allowed. After a few hours the patient stated he felt more comfortable. The nausea, vomiting, and crampy abdominal pain had disappeared. He started passing gas 12 hours later and then had a bowel movement. The next day he was operated upon for removal of his kidney stone (Fig. 4).

Comment. This case illustrates effective management of reflex ileus secondary to kidney stone by gastro-intestinal pacing. Reflex inhibition of peristaltic activity in the dilated bowel can be counteracted by pacemaker stimulation.

Discussion

Wangensteen[14] has emphasized that *paralytic ileus* is an ill-chosen name for the meteorism and motor inactivity of the bowel frequently observed in the numerous clinical situations in which this condition is evident.

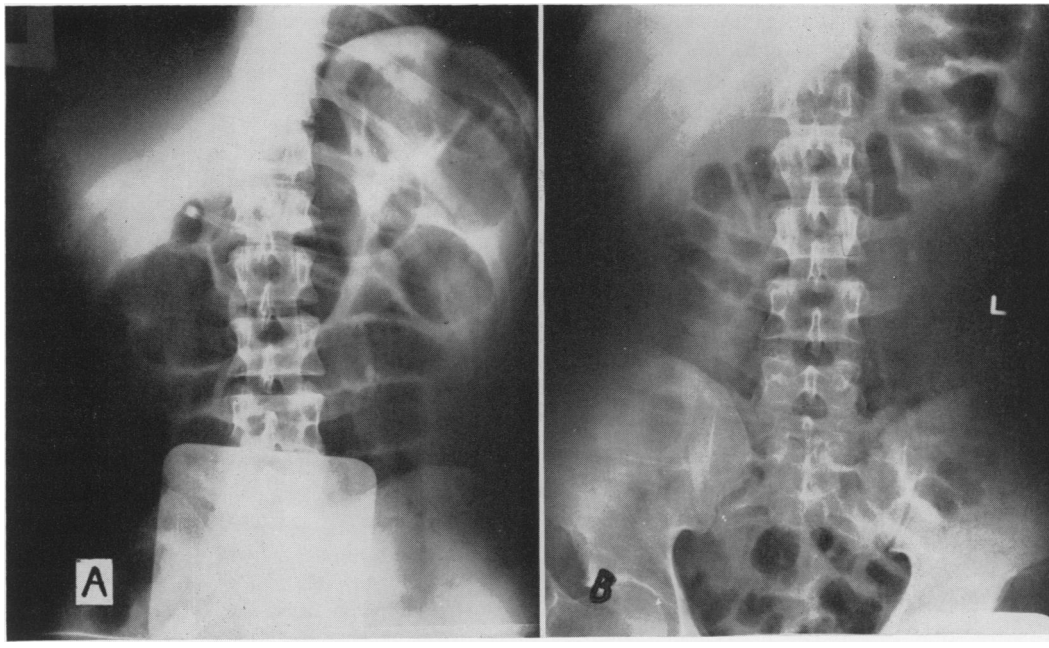

FIG. 4. Abdominal x-rays of Patient K. E. with reflex ileus secondary to renal stone and colic. A. X-ray taken upon starting gastro-intestinal pacing. Note distended bowel and position of the electrodes. No suction was utilized. Oral intake was allowed. Left renal calculus is shown. B. Twelve hours later. Patient passed flatus and feces. Film shows decreased gas and distention.

Numerous observers have provided evidence that the intestine is not paralyzed, rather its activity appears to be inhibited and restrained but it does remain responsive.

In chemical iodine peritonitis, Frey[2] observed the intestinal activity through a celluloid window and found that dilated and contracted segments responded similarly to stimulation with choline given subcutaneously. In the intestines distended with gas for several hours, Hotz[6] found that the rhythmic contractions of the segment ceased. The gaseous distention of the loop and not the toxins of peritonitis, Hotz concluded, were responsible for the disappearance of intestinal contractions. Distention of the intestine impairs absorption and the gas in the intestine which is normally carried away as fast as it is formed, continues to accumulate and a vicious cycle ensues.[11, 13]

The degree of intestinal distention and fluid accumulation in paralytic ileus varies greatly; but when extreme or protracted may be a fatal complication.

We have observed in these studies that the gastro-intestinal system remains responsive to pacemaker stimulation in dogs subjected to the effects of atropine, bilateral vagotomy, after gastrectomies (Billroth I, II, segmental), after pyloroplasties, after induced bile or septic peritonitis, and in mechanical obstructions. Hotz[6] showed, many years ago, that loops of intestinal musculature from animals suffering from peritonitis exhibited a fairly normal contractile power and the reaction to stimulation with drugs was normal.

In our patients, we have also observed that electrical pacemaking was successful in stimulating peristalsis in postoperative ileus following intra-abdominal operations including vagotomies, pyloroplasties, gastrectomies, procedures requiring wide retroperitoneal dissection, and also in reflex ileus. Clinically, it has usually required six to 20 hours (an average of 16 hours) of

stimulation before pacing could be discontinued in these conditions.

We have not yet completed a controlled clinical study * to determine and compare the time interval required before return of spontaneous peristaltic activity postoperatively wtih that observed when gastro-intestinal pacing has been utilized; however, this is less significant than the clear-cut observation that the function of the bowel can be promptly induced and maintained by pacing in a previously distended inactive intestinal tract.

The earlier return of bowel activity achieved when using gastro-intestinal pacing is utilized has reduced the time interval required for intravenous administration of fluids and electrolytes and the period of intubation has also been shortened or even eliminated. Oral intake is resumed sooner. As gastro-intestinal motility can be induced and maintained by pacing, swallowed gas or gas formed in the intestines is carried away by peristalsis.

However, a combination of nasogastric suction and pacing may usually be desirable at the start of therapy in cases with a full-blown picture of ileus. For this reason, we have incorporated the electrode for stimulation at the tip of an ordinary plastic disposable nasogastric tube to serve a dual purpose.

Clinicians are often troubled on occasion in making a differential diagnosis between a strangulating mechanical obstruction and paralytic ileus. Heretofore, in some patients differentiation has been impossible and operation of necessity carried out. Gastro-intestinal pacing offers promise in resolving some of these difficult problems. It is also interesting to speculate as to whether earlier return of motility in ileus associated with peritonitis might reduce the formation of adhesions.

Distention impairs absorption. Induced peristalsis is effective in carrying the intestinal gas away thus correcting or preventing distention which is a major factor responsible for impaired absorption. These circumstances may permit early oral intake in patients postoperatively. We have tried this in a number of our patients with success, by allowing oral fluids while they were being paced instead of resorting to intravenous fluids and nasogastric suction. Wider exploration of the feasibility of this method is under way.

Our experiments on dogs showed more forceful peristaltic activity in response to pacing when the stomachs were filled with liquids as judged both by direct observation and balloon pressure studies. Hunt and Spurrell [7] showed gastric emptying to be exponential in form and fundamentally dependent on the volume of gastric contents. Our findings support their observations. Not every peristaltic wave induced by pacing at the antrum crosses the pylorus. This simulates normal gastric motility and is explainable by enterogastric reflexes (neural or hormonal) which regulate gastric emptying.[4] It appears that the normal mechanism of gastric emptying is not altered by pacing. This is advantageous, as otherwise diarrhea might follow each meal or occur with pacing were each peristaltic wave conducted across the pylorus and traversed the entire bowel.

Morphine [3, 18] has a marked effect on lessening gastric motility and increasing the tonus of the pylorus interfering with the normal gastric emptying rate. With pacing peristalsis can be induced under the effect of morphine but gastric emptying is similarly retarded. Demerol (pethidine) has been reported to have virtually no effect on normal tone and peristalsis even in a fully effective dose.[18]

In the clinical studies reported, we have been following response to pacing by aus-

* To date, in this study of patients postoperative from all types of major surgical procedures, paced patients have shown return of peristaltic activity (passage of flatus) in an average of 20 hours as compared to an average of 55 hours in the non-paced group.

cultation of the abdomen for bowel sounds, and marking the time when patients would pass flatus and feces. When pacing is started immediately postoperatively, depending on the type of anesthesia and sedatives used and perhaps due to a decompressed stomach, bowel sounds may not be readily audible in the first few hours. However, as soon as patients are completely awake from anesthesia and intragastric contents are pushed into the duodenum by peristaltic waves that cross the pylorus and travel down the duodenum, typical peristaltic sounds are heard. When patients are allowed oral intake, this is more remarkable.

A pacemaker area has been described [5, 10] as being located in the second portion of the duodenum and controlling the activity of the small intestine somewhat similar to the sinus node in the heart. We have not, as yet, fully investigated the comparative efficacy of stimulation in this area, but have arbitrarily chosen the area of most marked activity in the stomach for stimulation of motility; namely, the antrum. As peristaltic waves are induced here and cross the pylorus and are carried down the duodenum, they will of necessity activate the duodenum which in turn, having a pacemaker area, thus stimulated, may control the rest of the intestinal tract. We have not proved whether gastrocolic reflex may be aroused by pacing via the stomach but return of peristaltic activity in the upper gastrointestinal tract has been achieved by stimulation from the rectum.

Summary

Gastro-intestinal pacing has been introduced as a new concept for the active treatment of paralytic ileus.

Experimental development of a gastrointestinal pacemaker and its clinical application has been described.

Indications, technic and advantages of gastro-intestinal pacing, both diagnostically and therapeutically, are illustrated in representative case histories.

Gastro-intestinal pacemaking shortens recovery from paralytic ileus, reduces or eliminates in some patients the need for nasogastric suction, intravenous fluids, and the dangers of induced electrolyte imbalances.

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Discussion

Dr. Clarence Dennis (Brooklyn): My associate, Dr. Adrian Kantrowitz, has been working in this same field and is equally gratified with the experimental and clinical results which have been obtained. He has, however, embarked on some basic studies, to begin with, on the type of stimulus which is to be employed, whether it is a direct current stimulus or an alternating current stimulus; whether, if it is an alternating current stimulus, the frequency of cycles should be rapid or slow, or whether the shape of the wave of stimulus should be square wave, sine wave, or of what shape; and finally, the studies on the importance of the frequency of bursts of stimulation which take place.

Inasmuch as Dr. Bilgutay did not mention such basic studies in his presentation, I am very curious what his basic studies show in this regard.

Dr. C. Walton Lillehei (closing): There are relatively few cherished institutions left at Minnesota, but one that did seem almost invulnerable was use of the nasogastric tube with siphon drainage.

Nonetheless, I can emphasize, from our clinical experience to date, that this method of gastro-intestinal pacing is very effective. Exactly how far the method can go in eliminating the need for nasogastric intubation is not completely definable at this time. However, of the 45 patients treated to date referred to by Dr. Bilgutay in his presentation, a number required no gastric suction whatsoever during their postoperative interval. Others had suction with stimulation beginning immediately postoperatively for a period of time until they passed their first stool. In these postsurgical patients, this interval ranged from six to 24 hours with an average of 16 hours. At the time that they passed their first stool, pacing and intravenous fluids were discontinued and oral intake instituted.

The current that has been used for pacing in the clinical cases is provided by this small ($9 \times 6.25 \times 2.5$ cm.), self-contained battery powered unit called the Peri-Start which I am holding up. The large unit which you saw in the motion picture was our experimental stimulating unit which permitted us to vary the strength, type, and duration of the stimulating current. Extensive investigation has been done in our animal laboratory, and in humans under fluoroscopy and at operation with the abdomen open upon the types of current optimal for bowel stimulation. The results of those studies have allowed us to simplify this clinical unit (Peri-Start) because it does not need to be variable. The Peri-Start provides a current of 10 milliamperes at 50 cycles per second. The duration of the stimulus is 5 to 10 seconds, and it seems best if the stimulus occurs once a minute. A disposable nasogastric catheter electrode of polyvinyl plastic is provided for clinical usage.

In the motion picture just presented you were able to see the very prompt response of the gastro-intestinal tract to pacemaker stimulation in the dog with bile peritonitis. In fact, the induced contractions were identical to those occurring in the normal animal. It is interesting that in a paper in 1909 upon gastro-intestinal function, Hotz mentioned the fact that in his animal studies the bowel even though covered with pus from peritonitis was responsive to mechanical stimuli in virtually a normal manner, and that there was no real impairment in contractility unless distention took place. Distention is, of course, the most potent inhibitor of bowel motility. Therefore, often in ileus we do have a vicious circle of bowel distention due to swallowed and bacterial gas together with accumulation of the intestinal secretions further distending the bowel, this distention in turn increases the severity of the paresis and the entire cycle of bowel paralysis is kept in motion. Gastro-intestinal pacing, combined with a period of suction when