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Stimulation of nerves affects bowel motility. Electrical stimulation can be applied across the skin using pad electrodes applied to the belly and back. The authors have tested transcutaneous electrical stimulation (TES) in over 100 children with slow-transit constipation (a form of constipation that is most resistant to existing treatments) with promising results. TES using a special current called interferential current, increases colonic motility, speeds up colonic transit, increases the sensation of the urge to defecate, increases defecation frequency and reduces soiling and bloating. Pilot studies indicate that TES is also effective on anorectal retention (functional fecal retention) in children and slow-transit constipation in adults. TES is not invasive and can be tried before surgical intervention. Good training and close supervision and patient contact allow stimulation by parents/patients at home. TES could affect all of the nerves controlling the bowel and pig studies are being performed to optimize the treatment parameters and determine the mechanism of action.
In some circumstances, chronic constipation is extremely resistant to treatment. When behavior modification, dietary manipulation and laxatives fail, the clinician may be compelled to resort to more aggressive therapies, such as hospital admission for disimpaction. In extreme cases, surgical intervention is required to prevent recurrence of impaction requiring repeat admission. Surgical options include colostomy, colectomy or creation of an appendicostomy/cecostomy as described in Chapters 7 & 8. Even antegrade continence enemas via an appendicostomy require a major commitment in time and effort to achieve regular, complete colonic evacuation.

Colonic motility is controlled by nerves. Motor activity of the gut is determined by both sensory and motor innervation [1]. The intestine contains its own nerve cell network (enteric nervous system) and connections to the CNS [2]. Enteric neurons are located in the myenteric or submucosal plexuses and send processes into the muscle layers, where they release transmitters. Changes in subgroups of enteric nerve fibers occur in association with colonic motility disorders [3]. Nerves also coordinate perception, responses to meals and defecation. The large bowel is connected to the CNS via the vagal, splanchnic and pelvic nerves (Figure 14.1) carrying sympathetic, parasympathetic and sensory nerve fibers [4]. Sympathetic innervation (from spinal cord levels T5–L2, via the splanchnic nerve) inhibits motility, while parasympathetic innervation (via the vagus nerve and pelvic nerves derived from sacral segments S2–S4) activates the colon. Pelvic nerves also carry parasympathetic outflow to the rectum and internal anal sphincter and somatic innervation to the striated anal sphincter muscle [4]. All of these nerves also carry sensory fibers to the CNS.

Spinal cord injuries reveal the importance of connections to the CNS for coordinated muscle contraction in the bowel [4,5]. In patients with thoracic spinal cord lesions, there is stasis in the distal colon and rectum, reduced compliance, loss of postprandial increases in motor activity, and loss of sensation of the need to defecate and voluntary control. Damage to the sacral spinal cord or lower sacral nerves produces atonic bowel that accommodates a large volume without initiating peristalsis, and loss of sensation, while the defecation reflex remains [4,5].

Direct electrical stimulation of spinal nerves (S2–4) in patients with spinal injuries initiates colonic contraction, resulting in movement of feces into the anal canal, followed by reflex pelvic floor relaxation and evacuation of the rectum [6]. Stimulation of S3 initiates high-pressure peristaltic colorectal...
motor activity. S4 stimulation increases colonic and rectal tone and produces sustained contractions of the external anal sphincter [4]. In the last 5 years, neural stimulation using electrodes implanted over the sacral outflow has been developed to treat chronic constipation in adults and children with success (see Chapter 6).

Transcutaneous electrical simulation using interferential current to treat constipation

Electrical stimulation can also be applied across the skin without the need for surgery (Figure 14.2). Transcutaneous electrical simulation (TES) is commonly used by physiotherapists to treat pain and muscle injury. Interferential current (IFC) is a special type of TES using two currents that cross and with varying currents producing a beating effect [7]. While TES-IFC has been successfully used for over 20 years to treat bladder overactivity and urinary incontinence and to strengthen the pelvic floor [8,9], its use has not been noticed outside the urinary specialty. However, when used for urinary incontinence, TES also produced diarrhea [10,11] suggesting to the authors’ continence physiotherapist, Janet Chase that it could be used to treat constipation. Together with pediatrician Susie Gibb, she performed a pilot study of eight children with intractable constipation. To the authors’ pleasure, TES increased defecation in five out of eight of the children, and stopped soiling in seven out of eight of the children [12] with improvement lasting more than 3 months in some children.

The authors then performed a randomized, controlled trial (RCT) on 46 children with slow-transit constipation (STC). Active and placebo stimulation were given three-times/week over a month by physiotherapists. There was a significant improvement in transit as measured by radionuclear transit study [13]. Further analysis showed that half of the patients had abnormal motility in the upper gastrointestinal tract as well as slow colonic transit [14], and there was a greater response to treatment in those with normal upper gastrointestinal motility than those with abnormal upper gastrointestinal motility [15]. A long-term follow-up of the RCT patients showed that two-thirds felt they had improved with TES, and in half of these the effects lasted for more than 2 years, with many of them stopping laxative use [16].

In seven STC patients, 24-h colonic manometry was performed via a catheter through their appendix stoma before and after 1 month of TES. There was a significant increase in the frequency of antegrade propagating contractions 2–7 months after stimulation ceased [17].

Transcutaneous electrical stimulation: applying electrical current across the skin.
Interferential current: current produced by crossing two electrical currents that are slightly out of phase.
Slow-transit constipation: constipation with slow motility in the whole colon, not just in the anorectum.
In the RCT, there was little change in defecation frequency, but analysis showed many children had more than three defecations per week, due to chronic laxative use. Indeed, only a quarter of the patients had less than three defecations/week at the start of the trial. This led us to appreciate that stool frequency was a poor measure of treatment effect because of the multiple laxative therapies, and to separate children in subsequent studies into those with more than or less than three stools/week.

Battery-operated, portable interferential machines (Fuji Dynamics INF-4160) became available in 2008, so we were able to start treating...
Transcutaneous electrical stimulation for constipation

Figure 14.2. Connection of electrodes to create currents that cross.

Connecting the right front to left back and left front to right back creates two currents that cross in the middle of the abdomen. Connecting the left front to left back and right front to right back creates two parallel currents that run along the sides.

children at home and increase the treatments from 20 min, three-times/week to 1 h/day. Eleven of the children who had been in the RCT had daily treatment for 2 months, leading to increased defecation frequency into the normal range [18].

A further 68 children with proven slow colonic transit on radionuclear transit study have just completed a prospective study of home-based

Figure 14.3. Change in defecation, soiling and abdominal pain in children with slow-transit constipation.

Daily TES (A) increased defecation, (B) reduced soiling and (C) decreased abdominal pain. n = 62.

SEM: Standard error of the mean; TES: Transcutaneous electrical stimulation.
TES. Patients were assessed with radionuclear transit study before and after treatment, along with bowel diaries and quality of life assessment. There was a significant increase in defecation frequency, increased conscious urge to defecate and faster colonic transit, reduced soiling and laxative use. Preliminary results on 32 patients have been reported \[19\], with a report on the full study in preparation (Figure 14.3) \[15\]. Proper use of the device took significant training time. The trial was supervised by a clinician with no prior experience with electrical treatment, and it took six patients for him to learn how to teach patients to use the portable machine correctly and to determine optimal data collection. In a separate study involving three children whose treatments were supervised by a physiotherapist (separate patient group from the six above), they were not responding to stimulation and were found to have the electrodes connected incorrectly, and were improved after TES was administered with correctly connected electrodes. There are still many issues to resolve about the optimal use of the device, including current settings, electrode position and treatment frequency. These aspects are under active study in the authors’ laboratory at present.

Children with chronic constipation have bypass soiling where liquid stool oozes past the solid stool. This can be misdiagnosed as diarrhea rather than constipation.

Slow-transit constipation is characterized by frequent small and soft stool rather than large hard fecaloma.
The authors have just completed a pilot study of ten children with anorectal retention, with encouraging results (Figure 14.4). This has led to a RCT on 100 children with anorectal retention, which is just commencing.

What stimulation does to transit through the bowel

Radionuclear transit studies were used to identify where in the bowel slowing occurs. Children take a milk drink containing a radioisotope and then images are taken with a $\gamma$-camera to follow the radioactivity. The authors took images at 0, 30, 60 and 120 min to quantify gastric emptying, then at 6, 24, 30 and 48 h to follow transit through the small bowel and large bowel [20,21]. The authors now have over 950 transit studies performed at their hospital to assess constipation, creating a lot of experience. In general, patients with fecalomas are not sent for transit studies. The authors have found many patients with slow transit through the proximal colon as well as patients who have normal colonic transit with retention of the radiomarker in the anorectum. Surprisingly, the authors found that 30% of the patients with chronic constipation have rapid transit in the proximal colon [22] and this could be related to food allergy or sensitivity.

The authors now use radionuclear transit studies to monitor responses to treatment. The authors showed that if patients had medical treatment and this produced no change in symptoms, there was also no change in their transit rate [23]. As this method shows transit in the stomach and small bowel, the authors have also been able to assess if patients have abnormal upper gastrointestinal motility as well as

Figure 14.5. One month of daily transcutaneous electrical stimulation in adults with anorectal retention decreased laxative use and increased defecation/laxative dose.
colonic transit [14]. It was also found that 30% of the patients with STC have elongated transverse colon and this does not occur in patients with normal colonic transit and anorectal retention [24]. Studies in mice suggest that colonic elongation activates a nerve pathway that stops colonic motility [25], but it is not known if the elongation is a primary or secondary effect.

TES use by other groups

The authors’ colleagues in Adelaide, South Australia have tested if TES is effective in 20 adults with STC (Figure 14.5). Based on the recognition that they start with more than three defecations per week, the outcome measures were: change in laxative use and defecation/laxative dose. After 1 month stimulation (30 min/day), patients noted they developed recognition of the urge to defecate, improved emptying at each defecation, reduced bloating, a significant decrease in laxative use and increase in defecation/laxative dose. Improvement took 2–3 weeks to develop and lasted 2–6 weeks after stimulation stopped [LYNN P ET AL., MANUSCRIPT IN PREPARATION].

TES has also been shown to be effective to improve bowel function in patients with functional dyspepsia [26] and irritable bowel syndrome [27].

Mechanism of action

While it is generally understood that TES is applying an electrical field across the abdomen to produce neuromodulation, the precise mechanism of action of TES is not known. It remains to be determined whether its primary action is via sensory nerves, spinal pathways, direct action on enteric nerves or via the interstitial cells of Cajal. As the effects of TES seem to develop slowly, and clearly persist for months after treatment has ceased, it suggests that cellular or hormonal systems are being altered. The authors are developing an animal model using piglets to investigate the mechanism of action.

Studies on pigs

The authors have developed methods to perform TES-IFC on young, newly weaned pigs. Young pigs are a good model for investigating the mechanism of action as they are omnivores, are nonruminant and have a small/large bowel structure similar.
Transcutaneous electrical stimulation for constipation to humans. The authors have performed studies where pigs are treated with TES-IFC for 30 min/day for between 1 and 2 weeks. In a group of 12 pigs (six given active stimulation, six given sham stimulation over 2 weeks), it was found that stool water content was higher in treated animals compared with sham animals, and water content was higher within the first 5 days. In another group of 20 animals (ten active, ten sham), it was found that the transit rate of plastic markers decreased during 5 days of TES-IFC. The authors are also developing a surgical model to investigate if TES-IFC has immediate effects on bowel activity by using balloon catheters to record bowel contractions in vivo (Figure 14.6).

Financial & competing interests disclosure
JM Hutson, BR Southwell and A Tan hold patents on the method of transcutaneous electrical stimulation to treat constipation. JM Hutson and BR Southwell have received Australian Government National Health and Medical Research (NHMRC) grants to study the effect of transcutaneous electrical stimulation on children with slow-transit constipation and with anorectal retention and to develop an electrical stimulation device specifically to treat constipation. JM Hutson and BR Southwell have received investment from the Medical Research Commercialisation Fund to develop the device and created a startup company – GI Therapies (Melbourne, Australia) – to develop and test a prototype device. The authors have no other relevant affiliations or financial involvement with any organization or entity with

Figure 14.6. Developing a large animal model to study the mechanism of transcutaneous electrical stimulation effects on the bowel.

(A) A piglet receiving transcutaneous electrical stimulation. Electrodes are placed on the back and belly and held in place with surgical netting. Piglets easily train to take the stimulation and handling without stress. (B) Total transit times during transcutaneous electrical stimulation-interferential current. Oral–anus transit time measured using sitz markers and x-rays in ten pairs of pigs given either full stimulation or sham for 30 min/day for 4 days. Mean (standard deviation); p = 0.04.
Summary.

- Transcutaneous electrical stimulation (TES) using interferential current applied across the abdomen:
  - Increases colonic propagating contractions;
  - Speeds up colonic transit;
  - Increases defecation frequency;
  - Decreases soiling;
  - Improves quality of life.
- TES is not invasive and can be tried before surgical intervention.
- Successful TES treatment required close patient contact and teaching.
- Stimulation had to be applied with currents crossing. Stimulation without crossed currents did not improve bowel function.
- Clinician needed six patients to learn how to teach the method and get all parts done correctly.

References

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