LECTURES 14-15: ARTIFICIAL BOWEL

14.1 Introduction

The bowel (or intestine) is part of the gastrointestinal tract which is a long muscular tube of approximately nine meters in length and completes the process of digestion. It can be broadly divided into two different parts: the small bowel and large bowel.

The small bowel begins at the pyloric sphincter at the bottom of the stomach and coils its way through the central and lower aspects of the abdominal cavity and joins the caecum at the ileocecal valve. The small bowel is divided into three separate segments: the duodenum, jejunum, and ileum.

The function of the small bowel is the digestion and absorption of nutrients, and the transportation of chyme by peristaltic movement. Digestion is completed in the small bowel with the aid of enzymes secreted from the liver and the pancreas. The chyme is transported to the large bowel for further digestion and disposal. The large bowel extends from the ileocecal valve of the terminal ileum to the anus. It comprises of the caecum, colon, rectum, and the anal canal.

The main functions of the large bowel are the absorption of water and ions, the degradation of short-chain fatty acids, and the transport and storage of luminal contents. Although the small bowel absorbs some water, this process is intensified in the large bowel until the familiar consistency of fasces is achieved. The large bowel also houses a variety of bacteria crucial for the synthesis of vitamins, such as vitamin K and some B vitamins.

In addition, these bacteria ferment carbohydrates and thus play part in the digestion. The content of the colon is moved down to the terminal part of the colon, known as rectum, by peristaltic waves. The anal canal is the terminal section of the rectum. The main functions of the anorectum are to preserve fasces continence, distinguish between solid, semi-solid fasces or flatus (gas), and act as a conduit from the colon to the anal canal and as a reservoir so that defecation can be accomplished when it is deemed convenient.

The wall of the bowel consists of four layers. the adventitia, muscularis, submucosa, and mucosa. The adventitia consists of a serous membrane composed of connective tissue and epithelium. The muscularis mostly consists of smooth muscle layers, and the nerve supply is called myenteric or Auerbach's plexus.

14.2 The Artificial Bowel

Recent developments in sacral nerve stimulation, artificial bowel sphincter procedures, and dynamic graciloplasty are considered to be promising. Enthusiasm for any new technique often leads to overemphasis on the outcomes, and early reports are usually good. Outcomes can deteriorate with time and long-term results do not correspond to initial encouraging data such as for instance in the case of the artificial bowel sphincter or dynamic graciloplasty. Both methods are technically demanding, with considerable morbidity, and substantial learning curve. Despite these obvious disadvantages, both artificial bowel sphincter and dynamic graciloplasty remain attractive to colorectal surgeons because once successful, they provide outstanding and long-lasting improvement of bowel function and quality of life.

Unfortunately, these procedures require special equipment and their utility is limited because there is high morbidity to consider, which discourages coverage by health care insurers.

Tissue engineering approaches to create novel bowel tissue are currently still at the stage of proof-of-concept in small experimental animals. Promising research is going on for both small and large intestines. However, no clinical studies are expected shortly.

14.3 Bowel function: peristalsis, defecations, and continence

The intestinal tract consists of longitudinal and circular smooth muscle layers. Contractions of these two layers in the small intestine assist in mixing the chyme with digestive secretions. In the large bowel, the coordinated contraction and relaxation of the longitudinal and circular muscle layers supports colonic propulsion. This action is referred to as peristalsis.

Defecation is the evacuation of feces from the rectum through the anus. It is a complex process involving the temporal coordination of a variety of muscles, nerves and reflex arcs. As the filling of the rectum continues, sensory information ascending to the brain leads to the sensation of rectal fullness and the urge to defecate.

There are two major muscles the fasces have to pass through to exit the body. These muscles are the internal anal sphincter muscle (smooth muscle) and external anal sphincter muscle (skeletal muscle) which encircle the anal canal. The external sphincter muscle assists in retaining the fasces in the rectum until defecation is needed. Squeezing the external sphincter muscle eliminates the fasces out of the canal and the rectum relaxes.

The ability to retain and evacuate fasces is also dependent on the muscles of the pelvic floor, which are under voluntary control. Two major muscles are the levator ani muscle and the puborectalis muscle, which need to coordinate properly in order to evacuate fasces from the anal canal.

Factors such as feces consistency, rectal and colonic storage capacity, perception of rectal sensation, and cognitive and behavioral function also play important roles. The current understanding of the neural control of bowel function in humans is still limited.

The complex system of the neural supply to the bowel is both autonomic (sympathetic and parasympathetic) and somatic. Although the enteric nervous system can function independently of the central nervous system, the latter has an important role in coordinating the diverse functions of the enteric nervous system.

1.4 Bowel dysfunction

A variety of diseases result in the loss of large sections of the bowel, often leading to dysfunction. Short bowel syndrome is a form of intestinal failure resulting from the loss of more than two-thirds of the jejunal part of the intestine. This results in diarrhea, dehydration, malabsorption, and progressive malnutrition. Colon resection can be required in diseases like cancer, ischemic injury, dysmotility, inflammatory bowel disease, and trauma. It leads to problematic changes in the enterohepatic circulation, microbiology, and changes in water and sodium absorption. Also, in complete bowel functional disorders may occur.

Intestinal dysmotility may lead to severe propulsive dysfunction. For instance, hyperactivity of colonic muscles generates abnormal bowel movements, abdominal pain, and disordered defalcation. When intestinal muscles are hypoactive, displacement of luminal contents is too slow resulting in obstruction of the intestine and eventually in delayed colonic emptying.

15.5 State of Development

The medical device-based approach in intestinal failure is not aimed at the replacement of (parts of) the bowel but at the support or recovery of bowel function. In this section, an overview will be given of the state of development concerning electrical medical devices for restoring intestinal motor functions either through activation or inhibition of luminal transit along the intestinal tract. In subsequent paragraphs, an overview of hydraulic and mechanical medical devices will be given. Hydraulic medical devices are used to restore fecal continence. Mechanical medical devices, such as stents, can be used in intestinal obstruction due to malignancy. Approaches, devices, and some surgical techniques that are likely to affect the field in the future are also described.

14.5.1 Electrical medical devices for neurostimulation

Sacral nerve root stimulation

Stimulation of sacral anterior nerve roots S2-S3-S4 can be used for the treatment of patients with neurogenic bowel dysfunction, e.g. the initiation of defaecation in spinal cord injury patients. Parasympathetic and somatic nerves that supply the distal colon, rectum, and anal sphincters are all derived from the same sacral spinal roots that are stimulated for bladder micturition using the Fintech-Brindley sacral root stimulator. Together with clinical observations, it seemed likely that the Fintech-Brindley Bladder System could also be used to induce colorectal motility.

Sacral nerve stimulation

Sacral nerve stimulation in humans was first used in 1981 for the treatment of urinary incontinence. In urology, it is commonly referred to as sacral nerve neuromodulation. In 1994 it was first used for the treatment of anorectal dysfunctions in patients with idiopathic fecal incontinence, i.e. patients with deficient function of the external anal sphincter and levator ani, but with no structural defect [Matzel et al., 1995].

Since then, sacral nerve stimulation has undergone continuous development. The spectrum of indication has expanded to include for example patients suffering from idiopathic constipation, slow-transit constipation, fecal incontinence due to systemic sclerosis, patients with rectal resection for cancer, muscular dystrophy, rectal prolapsed repair, and neurologic dysfunction. Although these latter results are also encouraging, current data are too sparse, and further investigations are required.

14.5.2 Hydraulic medical devices

Artificial bowel sphincter

The artificial bowel sphincter was adapted from the artificial urinary sphincter AMS 800®, which was introduced. The first experiences of the use of the AMS 800® artificial urinary sphincter for fecal incontinence were published in 1987. In 1996, it was modified for fecal incontinence, creating a specific artificial bowel sphincter.

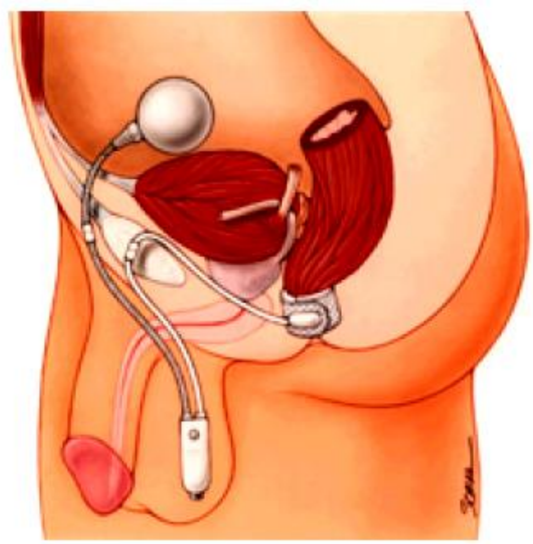

Figure 1: Acticon® Neosphincter. The artificial bowel sphincter (on the left) consists of an inflatable cuff (left side), a pressure-regulating balloon (middle), and a control pump (right side). The artificial bowel sphincter was implanted in a male patient (on the right).

It is an implantable, fluid-filled, solid silicone elastomer medical device. It consists of an inflatable cuff (mimicking the function of the anal sphincter) placed at the level of the anorectal junction, a pressure-regulating balloon implanted in the suprapubic prevesical space or extra peritoneally in the left iliac fossa, and a subcutaneously positioned control pump in either the soft tissue of the scrotum or the labium major (see Figure 1). The three components are connected with kink-resistant tubing. The device remains deactivated until healing is completed, usually within 6-8 weeks.

The device is not without complications and safety issues remain a cause of concern, but its success rate is high. Infection, skin erosion, device malfunction, and pain are common adverse events and many patients require revisional procedures.

Another difficulty is independent of surgical excellence is related to the complex pathophysiology of fecal incontinence and the technical limitation characteristic of artificial bowel sphincter implantation. An artificial bowel sphincter causes ischemia of the gastrointestinal tract at operating pressures required to maintain continence, because of the circular design of its inflatable cuff. Faucal incontinence is far from being just a mechanical problem.

14.5.3 Mechanical medical devices

Enteral stents

Enteral stents are being used for palliative treatment and as a bridge to surgery in (acute) obstructive colorectal and duodenal cancers. A variety of self-expanding metal stents have been used effectively.

Injectable bulking agents

The use of injectable bulking agents is an evolving treatment for faecal incontinence. Although bulking agents have been used to treat urinary incontinence for many years, their use in colorectal surgery has so far been limited and reports are confined to a small number of pilot studies. The intention is to facilitate closure of the anal canal by creating a better seal. The agent is injected submucosally to create a bulking effect. It is injected either circumferentially if the internal sphincter muscle is degenerated or fragmented, or at the site where the muscle is deficient to augment the deficient internal sphincter.

14.6 Recent research efforts and future devices

Specific areas of interest are the following:

- Selective activation of sacral ventral nerve roots: leading to greater efficiency of defecation using electrical stimulation techniques.
- ® PC Neuromodulation System is under cl- Intestinal electrical stimulation: modulation of peristalsis via electrical stimulation in case of intestinal motor dysfunctions.
- Percutaneous tibial nerve stimulation: an alternative method of neuromodulation in the treatment of fecal incontinence in patients with incomplete spinal cord injury; the Urgent initial investigation.
- German Artificial Sphincter System (GASS): micro-pump driven artificial sphincter for the treatment of major faecalis incontinence (proof of principle in vitro).
- Prosthetic anal sphincter: alternative to the artificial bowel sphincter which may overcome the major problem of ischemic injury at operating pressures required to maintain continence.

- Artificial sphincter using shape memory alloy material: two Ni-Ti shape memory alloy ribbons revealing reversible deformation between flat and arc shape during a temperature cycle induced by foil heaters attached to the ribbons and powered by a transcutaneous energy transmission system.
- Anal neo sphincter construction: surgical technique where the gracilize muscle is transposed from the inner thigh to construct an autologous neo sphincter in conjunction with electrical stimulation.
- Perineal puborectalis sling operation: recent technique to treat idiopathic faecalis incontinence using a specially designed polyester mesh sling.
- Pudendal nerve anastomosis: new approach to treat faecalis incontinence by surgical reconstruction of a neo-anus with pudendal nerve anastomosis.

14.7 Cell/tissue-based approach for function recovery

Solutions with living cells to create artificial bowel segments are all following the classic tissue engineering approach using an extracellular matrix seeded with living cells, mostly accompanied by biomolecules such as growth factors or cell differentiation factors. Tissue engineering of intestinal tissues is considered an emerging field, where significant progress can be expected in the not-too-distant future.

Research in bowel tissue engineering is making use of a variety of different scaffold materials serving as the extracellular matrix. Both synthetic biodegradable materials such as poly-lactic acid (PLLA) and polyglycolic acid (PGA) and natural materials such as collagen, fibrin, and decellularized small intestinal submucosa (SIS) are being employed. The use of both autologous and allogeneic cell sources is being pursued.

14.7.1 State of Development

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Although interesting research results have been reported, bowel tissue engineering is still at an early stage where proof-of-concept studies are being performed mostly in rats. Large animal studies are expected shortly.

The most promising studies make use of the transplantation of organoid units on polymer scaffolds. Organoid units are multicellular units derived from neonatal rat intestine, containing a mesenchymal core surrounded by a polarized intestinal epithelium, and contain all of the cell types of a full-thickness intestinal section.

Small intestine constructs lined with neo mucosa and surrounded by smooth muscle cells, which resembled native intestine were developed by Choi et al. [1998]. Other studies where similar constructs were placed in rats having received 75% small intestine resection showed growing (length and diameter) neo intestine closely resembling native tissue with a neo mucosa that was continuous between native and engineered bowel.