Application of Anal Manometry in the Planning for Anal Fistula Surgery

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Abstract: Anal fistula does not heal spontaneously without surgery, and anal function should be preserved after muscle dissection, which is a challenge even to the most experienced surgeon. In order to develop a planner for anal fistula surgery, anal manometry used in the measurement of pressures in the anal canal to investigate the anal function is reviewed. In this review paper, current techniques are described and compared with each other, and technical and clinical challenges are discussed. There are four types of catheters used to measure anal sphincter pressure: water-perfused, solid-state, air-coupled, and fiber optic catheter. Parameters acquired by anal manometry and their relationship with fecal incontinence after anal fistula surgery are discussed. Vectormanometry can provide the pressure profile along the anal canal in three dimensional space, pressure vectorgram, and cross-sectional radial asymmetry, which have more advantages than the conventional method. Understanding the technology and development of anal manometry is critical for the anal fistula surgical planning. A novel design is highly desired for 3D pressure profile measurement along the entire anal canal simultaneously without pulling the catheter.

Keywords: Anal fistula, Anal manometry, Surgical planning, Anal incontinence.

INTRODUCTION

Anal fistula, or fistula-in-ano, is an abnormal connection between the epithelialized surface of the anal canal and the perianal skin (see Figure **1**). The formation of anal fistulas may be explained by the cryptoglandular theory. Anal fistulae originate from the secretory anal glands, which are located between the two layers of the anal sphincters and drain into the anal canal. If the outlet of these glands becomes blocked, an abscess will develop and track along the path of least resistance. A perianal or ischiorectal abscess presents and an anal fistula occurs after erupting at the surface. Abscesses can recur if the fistula seals over, allowing the accumulation of pus. Anal fistulas release watery pus or mucus from the external opening, which is continuous or intermittent and blood stained. Recurrent abscesses lead to significant short-term morbidity from pain, create a nidus for systemic spread of infection, and make the patient's life a misery. If the abscess is infected, the symptoms may include fever and an unwell feeling. It is widely accepted that anal gland infection is the principal cause of anal fistula, but may also be due to Crohn's disease (CD), trauma and neoplasm [1]. The prevalence of anal fistulas in the general population is approximately 0.02% [1, 2]. The total median (range) cost per patient for the fistula cohort, $10,863, mainly by high hospital and surgery costs [3].

As wound healing in CD patients with active proctitis tends to be slow and prolonged, the therapeutic approach is mainly medical [1, 4]. Anal fistula does not heal spontaneously without surgery, the infection anal glands and ducts must be removed to allow healing of the tract. Surgery is considered essential in the decompression of acute abscesses, and repair of the fistula itself is undertaken by many patients due to the discomfort and inconvenience associated with a draining tract.

Complex anal fistulas involve large portions of the sphincter muscle, making their surgical treatment challenging because of consequent incontinence. A number of surgical approaches to treat complex perianal fistulas are available, including the cutting or tight seton technique, loose seton, chemical seton and advancement flap repair, but with conflicting results. Permanent loose seton is in the management of high anal fistulas in CD patients while two-stage seton

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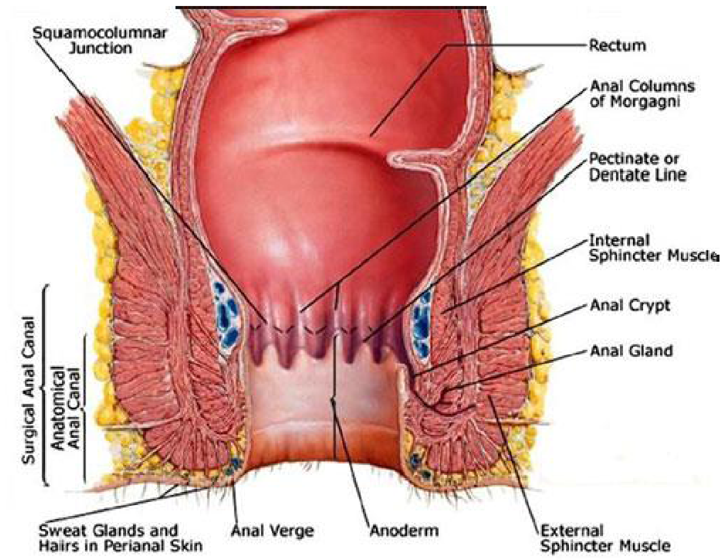

Figure 1: Anatomical structure of the anal canal with fistula.

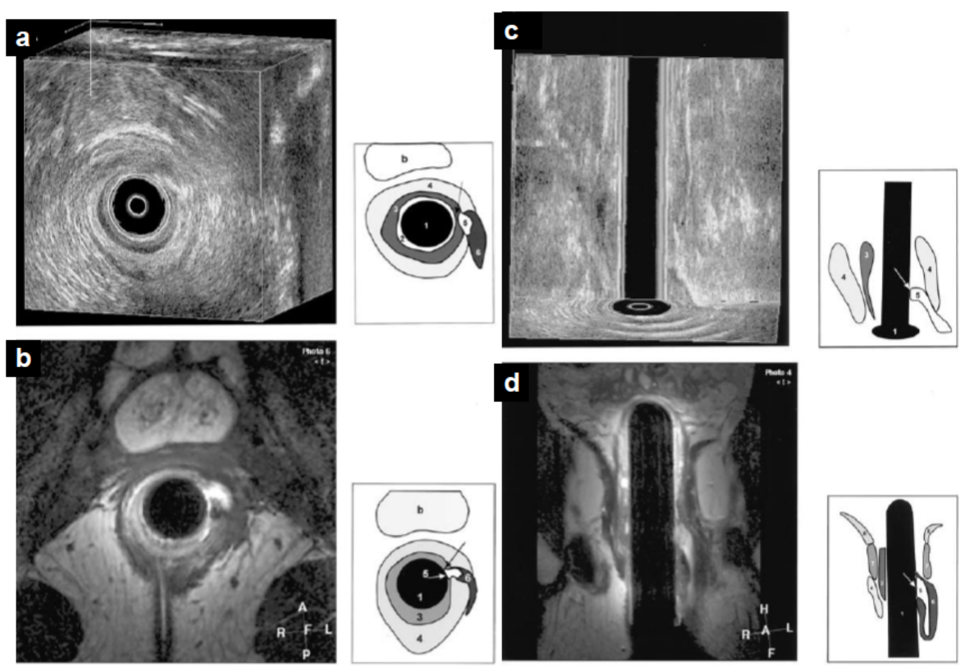

Figure 2: Transsphincteric fistula and the internal opening. (**a**) Axial and (**c**) coronal images of hydrogen peroxide–enhanced three-dimensional endoanal ultrasonography, and (**b**) axial and (**d**) coronal images of endoanal magnetic resonance imaging (T2-weighted, gradient echo). 1: the endoprobe or anal coil; 2: submucosa; 3: the internal anal sphincter; 4: the external anal sphincter; 5: the fistula and the internal opening; 6: fibrosis; 7: puborectal muscle; 8: levator ani muscle; b: the bulbocavernous muscle. A: anterior; R: right; F: feet; L: left; P: posterior; H: head; F: feet (used with permission [6]).

fistulotomy is for patients without CD. Peri-operative, mainly local sepsis or bleeding, and early postoperative complications, were recorded in about 10% patients. In CD patients, use of permanent loose seton was effective in controlling local sepsis in about half of patients and had low rates of subsequent incontinence. However, the fistula recurrence rates were 40% and 47% in patients with and without CD in a median 24-month follow-up, respectively [5].

There are two main problems associated with current fistula surgery for the successful cure: accurate identification of the target and appropriately complete excision for anal function preservation. For evaluation of perianal fistulas, hydrogen peroxide–enhanced 3D endoanal ultrasonography (EAUS) and endoanal magnetic resonance imaging (MRI) have a good agreement, especially for classification of the primary fistula tract and the location of an internal opening, which show a good agreement compared with surgical findings. Thus, these imaging modalities are reliable methods for preoperative evaluation of perianal fistulas [6]. However, complete excision or laying open of the tract would compromise sphincter integrity or function because of the significant amount of anal sphincter muscles involved in some situations. Appropriate treatment planning with the guarantee of cure and maintenance of anal function is a challenge even to the most experienced surgeons.

Anal manometry is a technique used to measure contractility in the anus and rectum for the anal function or stool leakage, using a balloon in the rectum to distend the rectum and a pressure sensor at the internal anal sphincter to determine the presence or absence of the rectosphincteric reflex. Its first application to the recto-anal inhibitory dates back from 1877. Since the 1960s, anal manometry has played a major role in the physiological investigation of anal function by measuring the strength of the anal sphincter muscles, the sensation of stooling in the rectum, reflexes that govern bowel, and movements of the rectal and anal muscles [7]. It is a simple and noninvasive procedure with mild discomfort, but allows surgeons to obtain peculiar information of continence and defecation. Despite the widespread use of anal manometry, there has been no universal standard nor normal values in agreement, which has great variations according to the techniques used [8].

APPARATUS

Anal manometric apparatus consists of three essential components: a catheter (or a probe) with pressure sensor(s), a pressure recording device (amplifier/recorder, pneumo-hydraulic pump, and transducer) that detects the pressure in the anal canal, and a computer that is used to analyze and display the pressure profiles. Presently, there are four types of pressure sensor and transducer of a manometric assembly used in the clinics: water-perfused catheter, solid-state catheter with incorporated strain gauge transducers, air-coupled catheter, and fiber optic catheter [1, 8].

The operation principle of the water-perfused catheter follows Bernoulli's theory. A pneumo-hydraulic pump is used to generate a water flow at the flow rate of 0.2-0.4 ml/min. The water flows through the channel inside the catheter and exit from the side holes as shown in Figure **3b**. Perfusion must be constant throughout the entire examination. As water is incompressible, the pressures at the anal canal are measured and converted to electrical signals by a series of pressure transducers, which are located at the pneumo-hydraulic pump. There are several different configurations of side holes (two commercial types shown in Figure **3b**). For example, 8 holes can be located collinearly in the longitudinal configuration to measure pressures at different anal canal levels simultaneously along the same side of the anal canal circumference. They can also be radially for pressure measurements at the same anal canal level around the anal canal circumference.

Solid-state manometer catheter has almost the same structure as that of the water-perfused catheter, consists of a balloon catheter attached to the

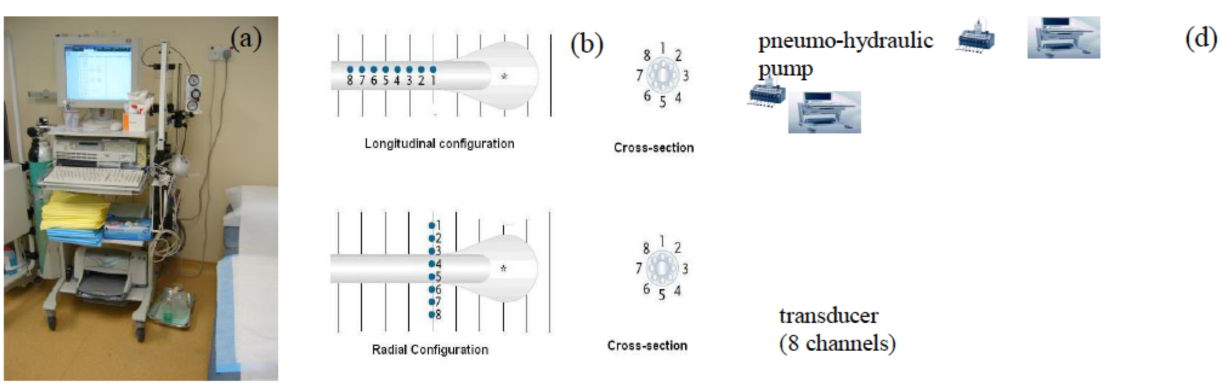

Figure 3: (**a**) Water-perfused manometry system and its components: (**b**) water-perfused catheter, (**c**) penumohydraulic pump with pressure transducer, and (**d**) computer system (used with permission [13, 41]).

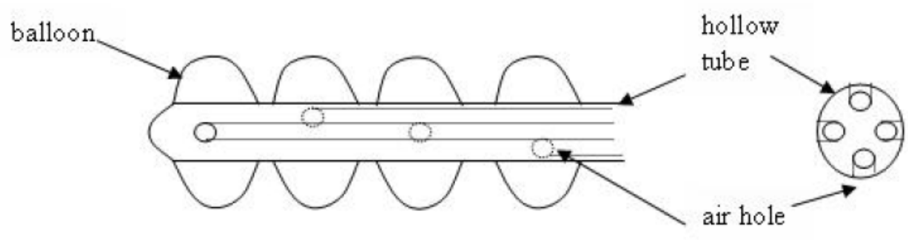

Figure 4: Configuration of air-coupled catheter.

transducer port except the side holes being replaced with piezoresistive strain gauge microtransducers, with the most distal sensor having a circumferential transducer. The measured electrical resistance is proportional to pressure.

The working principle of the air-coupled catheter is that the pressure-sensing membranes (or balloons) are located at each segment along the length of the catheter (Figure **4**). When pressure is exerted on the membrane, it is transmitted (air coupled) through a hollow tube to the reusable connector with a pressure transducer.

Two fiber optic techniques have been reported for the measurement of intra-luminal pressure, both using Poisson ratio effects due to compression of a compliant outer coating. The first technique uses group delay measurements in a chirped fiber Bragg grating [9] while the second uses spectrally separated grating elements [10]. However, they haven't been applied in clinics. A fibre Bragg grating based manometry catheter has been used for *in vivo* diagnostics. Its array was spectrally separated which allowed simultaneous interrogation of the whole sensors using wavelength division multiplexing techniques [11]. The distortion of the fiber due to external variations in pressure causes the shift of the reflected peak wavelengths as a function of pressure. The minimum wavelength spacing between gratings is approximately 2 nm, which is determined by the required dynamic range of each sensor.

A novel probe of the following configuration was proposed [12] (see Figure **5**). The pressure sensor, either solid-state transducer or side holes, was arranged radially and spaced at position 1, 2, 3, 4, 5, 6. Sensors located at 2, 3, 4, 5 were arrayed at 90° to each other. This design avoided the pull-through manoeuvre in order to estimate the length of the high-pressure zone. However, this design still cannot cover the entire anal. It suggests that the best way to measure the anal pressure is to measure the entire anal canal simultaneously by employing a 3D manometry probe without any relative motion. But there is no wide application of this probe.

Water-perfused manometer has a limited frequency response, requires considerable effort in setting up and use, and it is difficult to use and read and prone to artifacts due to movement of the connecting tubing or air bubbles in the system. From the patient's perspective, its complex appearance is much more daunting than the solid-state manometer. Advantages of solid-state manometers are good high-frequency response, application in ambulatory subjects and ease

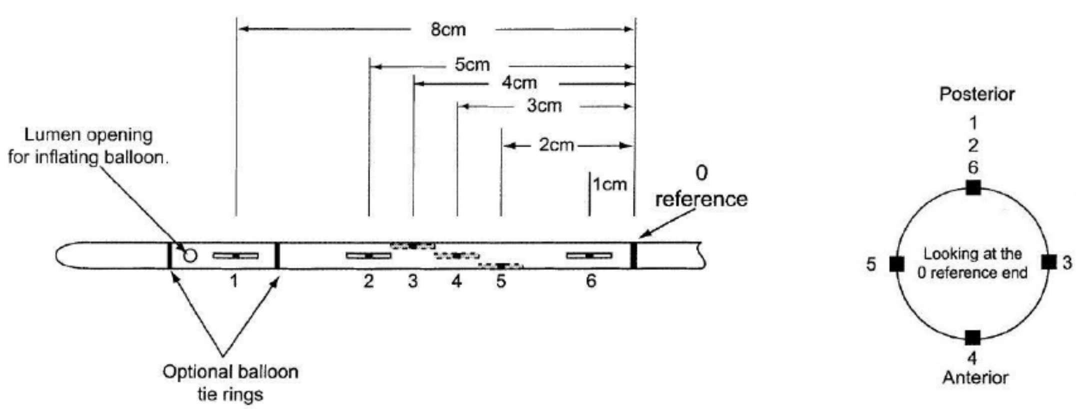

Figure 5: Configuration of anaorectal manometry (used with permission [12]).

of use [13]. The output of solid-state manometer is 8.1 mmHg higher on average than that of the water-perfused manometer, which is not significantly different from a clinical standpoint and will not affect decisions on patient management. The consistently lower readings obtained using the water-perfused system may be explained by the different methods of measuring the high-pressure zone. In the solid-state manometer, the balloon is manipulated until it is positioned in the high-pressure zone for a single reading, whereas the water-perfused catheter is positioned at 1-cm intervals and the pressures from the four quadrants at the high pressure zone are averaged. If the highest anal canal pressure is not exactly at the locations of water-perfused catheter's pressure transducers, a lower reading will be obtained. Therefore, solid-state manometer provides accurate measurements. However, its accuracy at pressures over 150 mmHg needs further studies. There was a marked difference in the repeatabilities of two manometers with the solid-state device being more precise. Caution is required in interpreting results of the solid-state manometer in the very hypertonic sphincter. A solid-state catheter correlates well with a water-perfused system if a continuous pull-through technique is used for the solid-state manometer or when the radial variation is taken into account. On the other hand, the solid-state manometer is simpler and more convenient to use. In addition, the solid-state catheters have no fluid-filled parts, which eliminates artifacts related to side-hole sensor migration within or out of the anal sphincter [14]. The water-perfused and solid-state catheters were applied in an artificial sphincter model, and coefficient of variation for the solid-state catheter (2.8%) was better than for the water-perfused catheter (8.3%) [15]. Although air-coupled catheters were thought to be too inaccurate and insensitive to rapid changes, recent development leads to reliable measurements of intrauterine and urodynamic pressures. The water-perfused catheter is recommended to use the balloon probe to measure the resting tone of the anal canal [16]. The balloon probe could accurately measure the resting tone and the water-perfused catheter may be uncomfortable and embarrassing for the patient since the perfused water escapes from the rectum and anus onto the patient's buttocks and bed. The measured pressure is the highest pressure over the length and circumference of the balloon area, representing an advantage over the point-sensing pressure of the solid-state and water-perfused catheters. This may reduce artifactual relaxation of the sphincter due to orad sphincter movement relative to point-sensing pressure sensors. Another problem is that the compressible air may affect the accuracy of results. The air-coupled balloon catheter was compared with the solid-state and water-perfused catheter, and there was no significant difference among them for all variables measured [8, 13]. Till now, fiber optic manometer has not been evaluated completely and compared with the others. In summary, considering the accuracy and reliability, the solid-state catheter is superior to another two for anorectal physiology assessments in the setting of the pelvic floor clinic [13, 17] and is an ideal method to measure anal rectal manometry [18].

Water-perfused catheters require an expensive pneumohydraulic perfusion pump ($3,000–$5,000), experienced personnel for equipment maintenance, cleaning, and sterilization after each use. Solid-state catheters are expensive ($6,000–$10,000) and somewhat fragile. All catheters are not disposable, requiring disinfection, due to the high cost of solid-state systems and even for extruded polyvinyl (water-perfused) catheters relative to reimbursements. Disposable manometric catheters eliminate the space, time, and resources needed for reprocessing. Using disposable manometry catheters avoids the phenomenon of stretching of the silicone covering of solid-state catheters over time.

MEASUREMENT PROTOCOL

Although the anal manometry has been used for more than one century, there has been no universal standardization of the anal mamometry measurement. Bowel preparation is essential for anal manometry measurement. The patients are required to empty their bowels before the examination. After bowel preparation, the patient is placed in the left lateral position with knee and hips bent to 90° to form an "L" shape. The surgeon usually explains the procedure before the performance of a digital rectal examination using a lubricated gloved finger. The presence of tenderness, stool or blood on the finger glove should be noted. The lubricated probe is gently inserted into the rectum. If the patient reports any pain or discomfort during the probe insertion, it should be pulled back or removed. After the probe placement, a resting (run-in) period should be allowed (about 5 min), which allows the patient to relax and the sphincter to return to basal levels. The patient is then asked to squeeze the anus for as long as possible, maximum 30 seconds. This manoeuvre allows the anal sphincter pressure to be assessed in a voluntary manner.

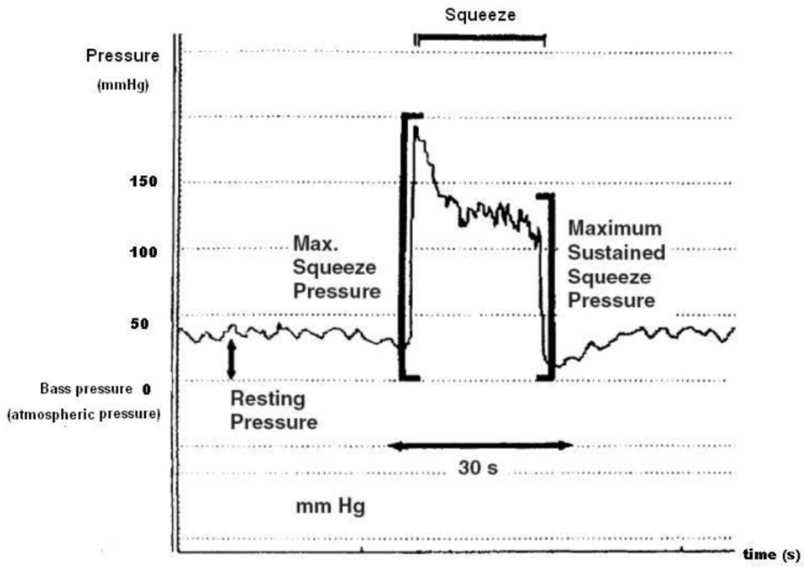

Figure 6: Resting pressure, maximum squeeze pressure and squeeze duration (used with permission [42]).

DATA ANALYSIS

The anal manometry can measure many parameters, and only related parameters with anal fistula surgical planner are introduced here (see Figure **6**). Resting sphincter pressure is defined as the difference between the baseline atmospheric pressure and the maximum anal sphincter pressure at rest. Maximum squeeze pressure is defined as the difference between the baseline pressure and the highest one recorded at any level within the anal canal during the squeeze. Squeeze duration is defined as the longest time interval, in seconds, between the onset of increase in anal sphincter pressure and its return to the baseline. High-pressure zone (HPZ) is defined as the length of the internal sphincter where pressures are greater than half of the maximum pressure at rest as shown in Figure **7**.

The study of rectoanal inhibitory reflex (RAIR) is usually performed with the catheter within the high pressure of the anal canal (measuring anal canal pressures during reflex) [12]. When the rectal balloon is inflated with air at a constant rate to increase the intra-rectal pressure, the pressure change at the anal canal in the RAIR will be recorded as shown in Figure **8**. The functional purpose of RAIR can be explained using the concept of a coordinated “sampling mechanism” discriminating between flatus and feces when they arrive at the rectum [19, 20]. The anal pressure drops because the internal sphincter relaxation is controlled by involuntarily nerve system, which allows the content inside the rectum to enter the upper anal canal. There are rich receptors at the upper anal canal to sense gas and liquid from solid inside the rectum.

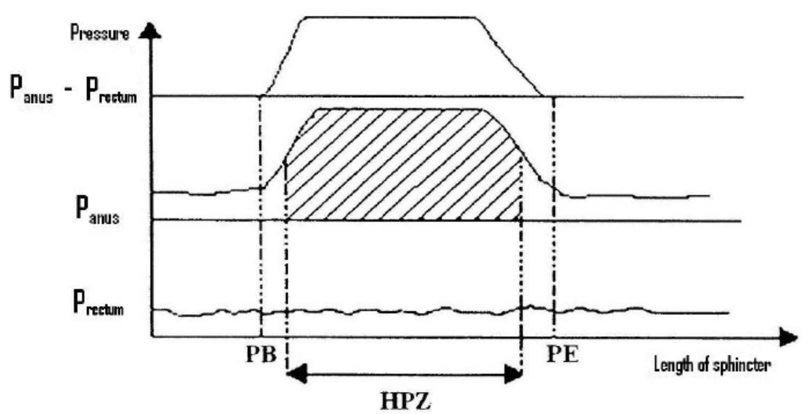

Figure 7: Measurement of resting pressure and high pressure zone (used with permission [7]). PB: pressure begin; PE: pressure end.

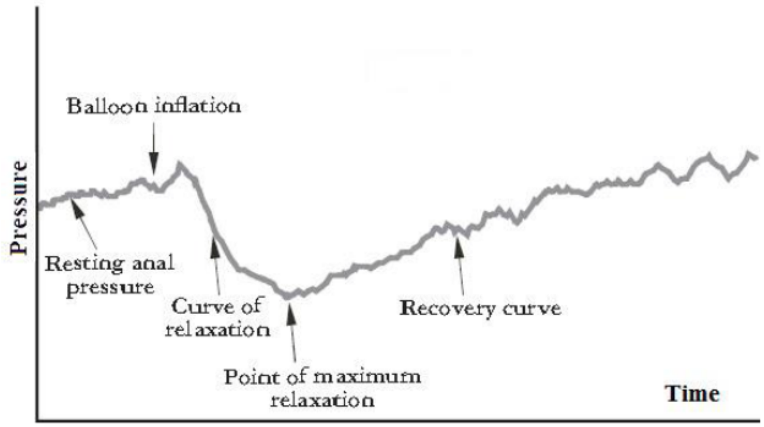

Figure 8: Rectal inhibitory relaxation (used with permission [19]).

Vectormanometry is a computer graphic method to generate 3D pressure profile along the anal canal. The anal pressure profile which revolves radially around a central zero axis, represents the baseline pressure as shown in Figure **9** [21, 22]. Vectormanometry can provide resting and squeezing pressures as the conventional method. Furthermore, it offers an additional advantage of displaying 3D anal pressure vectorgram and cross-sectional radial asymmetry which may reflect the defect of anal sphincters. Since the anal canal is anatomically asymmetrical, some degree of functional asymmetry is expected (see Figure **9c**). The parameter, sphincter asymmetric index (SAI), can be defined as

$$SAI = \left(1 - \frac{P_{mean}}{P_{\max}}\right) \times 100\% \quad (1)$$

where $P_{mean} = (P_1 + P_2 + \cdots + P_8)/8$, $P_{\max} = \max(P_1, P_2, \cdots, P_8)$. In general, how to interpret the measured results mentioned above depends on the type of catheter in use and the experience of each surgeon, and there is no established standard.

MEASUREMENT OF ANAL SPHINCTER PRESSURE

There are three types of techniques in the measurement of the anal sphincter pressure. The stationary technique is used to measure the highest sphincter pressure at any level in the anal without withdrawing the catheter. The recorded pressure is taken as the resting pressure. The stationary pull-through technique is used to measure the sphincter pressure at different levels in the anal canal by withdrawing the catheter manually or automatically. A resting period (5 min) should be given for each level in the canal before recording the pressure. The average pressure of all recorded pressures is taken as the resting pressure. The slow pull-through technique is used to measure the sphincter pressure along the entire anal canal by continually withdrawing the catheter manually or automatically at a constant speed

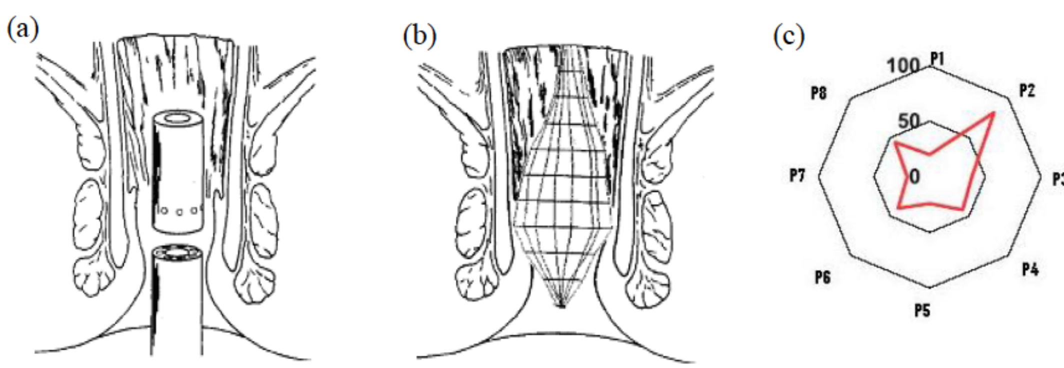

Figure 9: Diagram of vectormanometry. (**a**) An 8-channel water-perfused catheter and its position in the anal canal. Continuous pull-through technique is used to scan the entire anal canal. (**b**) 3D radial pressure vectorgram topographically related to the anatomic structure of the anal canal. (**c**) One cross-section of the 3D pressure profile. P1-P8 refer to the 8 channels of the water-perfused system. The numbers refer to pressure in cmH_2O. The red line is the pressure profile.

(5 mm/s). The average value of all recorded pressures is taken as the resting pressure.

The pull-through techniques involve a manoeuvre due to two reasons, localizing the high-pressure zone and determining the length of the high-pressure zone. Since the anal sphincter is richly innervated by sensory neurons and surrounded by striated muscle, a pull-through manoeuvre excites the anal sphincter by the catheter movement and may cause a false high sphincter pressure. The stationary technique is likely to provide more accurate and repeatable information regardless of the operator and patient and is the most time-efficient comparing to pull-through techniques. Therefore, it is the preferred method to measure the resting sphincter pressure [12, 23, 24].

UUSE OF ANAL MANOMETRY IN ANAL FISTULA SURGERY

Both anal manometry and diagnosis, either EAUS or MRI, play an important role in the anal fistula surgery. Anal manometry measures the pressure profile of the anal canal to assess the function of the anal sphincters while anal diagnosis determines the anal sphincters anatomy [25]. Many research showed that EAUS, especially the hydrogen peroxide-enhanced 3D EAUS, is a reliable method for defining the anatomy of the anal canal and is well comparable to body-coil MRI in classifying and describing the topography of an anal fistula [22, 23, 27].

The performance of pre-operative anal manometry in patients with anal fistula is very important in deciding the choice of the proper surgical procedure as well as predicting the chance of anal incontinence [28, 29]. Some anal manometry parameters may be responsible for anal incontinence, such as resting pressure, squeezing pressure, the high-pressure zone, and the rectoanal inhibitory reflex [30]. When the manometrical finding shows poor resting and squeezing pressures, a division of more than 1 cm of both internal and external sphincter should be avoided in order to prevent anal incontinence. It is reported that the RAIR may be the reason to cause the fecal incontinence [20, 31, 32]. Investigation of the causes of post-operative soiling in male patients with intact sphincters showed that the difference of maximal rectal sensation threshold between continence and incontinence patients was significant, and the patients who suffered from postoperative soiling could feel the urgency stimulus at the larger volume than normal pre-operatively [33]. There was no difference between the continent and incontinent patients as far as pre-operative anal pressure was concerned. It was concluded that the maximal rectal sensation was the only pre-operative parameter which seemed to have prognostic value and surgery rather than anal manometry may predict the fecal incontinence and rectal sensation may play a role which needed further investigation. Therefore, the RAIR may not change significantly after fistula surgery.

Although the anal manometry is performed before anal fistula surgery to assess the anal function, there is no gold standard for treatment planning and the surgery guidance. Instead of “lay open”, a conservative method (*i.e.*, seton fistulotomy) should be chosen to treat the fistula, which is accepted by most surgeons. After the laying open operation for the intersphincteral type anal fistula patients, there was a significant decrease in maximal resting anal pressure and the maximal contractile pressure after the operation was similar to pre-operation [34]. The maximum resting pressure difference is not predictive of the severity of continence change because the correlation between the maximum resting pressure and the increase in the continence score is poor. Thus, the laying open of the fistula tract should be more conservative in the patients with low resting anal pressure, especially in women. Patients suffering from fecal incontinence have normal anal resting pressure and rectal sensation, [35] and a decrease in rectal adaptation could be involved in fecal leakage with no anal manometric weakness.

Although there is no clear conclusion which preoperative parameter can be used to predict postoperative fecal incontinence after fistula surgery, the resting pressure, SAI, and anal canal length (ACL) are three promising parameters which seem to correlate with fecal incontinence caused by anal fistula surgery. The most commonly accepted explanation of anal incontinence is that the higher pressure zone in the anal canal at rest cannot provide an effective barrier against pressure in the rectum [30]. ACL is defined as the length of the anal canal in which the resting pressure is equal to or exceeds a certain level, *i.e*. 20 mmHg, in all quadrants. The high-pressure zone increases the resistance to the passage of enteric contents from the rectum through the anal canal to the exterior. The postoperative ACL showed significant correlation with improved continence scores, which are grading system to quantify the severity of fecal incontinence, and the postoperative ACL was the best factor to indicate the fecal continence [36]. It suggested that ACL has a role in assessing patients with fecal incontinence [37]. Incontinence patients with a previous history of sphincter trauma had higher SAI than patients without prior trauma and concluded that the SAI could be a valuable tool in the evaluation of fecal incontinence and the determination of traumatic causes of incontinence [38]. Since fecal incontinence caused by fistula surgery is most likely the traumatic incontinence, SAI may play an important role to predict the outcome of anal fistula surgery.

Currently, all parts of the anal sphincter are considered contributing to the fecal continence equally with no correction factor for the collected data. The position of highest mean resting pressure segment was significantly more proximal in the continent patients than incontinent ones, which means not only the absolute value of the highest mean resting pressure but also its location play an important role in the anal function [39]. Therefore, certain portions of the anal canal are crucial areas that are more indicative of fecal continence. In the data analysis, a correction factor or weight should be given to these crucial areas to make the data meaningful. However, how to define the crucial area and sign a correction factor to the crucial area is a big challenge. Artificial intelligence can be applied to decide the correction factor for the crucial area for the iterative learning.

The conventional manometry system could register only a single localized pressure peak which cannot represent the whole circumference. However, sphincter injuries are restricted to a single quadrant of the whole circumference of the anal canal in most cases. Vectormanometry can provide the resting and squeeze pressure just as the traditional manometry. In addition, it offers the advantage of displaying a three-dimensional anal pressure profile and cross-sectional radial asymmetry. Vectormanometry has used to diagnose fecal incontinence. SAI in patients with sphincter defects (identified by EAUS or MRI) is significantly higher fecal continence than in their control group using three-dimensional vectormanometry [21]. Anal sphincter asymmetry, determined by the coefficient of variation = standard deviation / mean ×100%, is an important parameter in the assessment of anorectal function and appears to be pivotal in understanding the mechanisms of continence [40]. Vectormanometry is superior to the conventional method in the pressure measurement along the whole anal canal, because it offers the additional advantage of displaying three-dimensional anal pressure vectorgram and cross-sectional radial asymmetry. Therefore, vectormanometry will be applied in this project instead of conventional manometry later.

The water-perfused catheter is less reliable than the solid-state catheter, and the excitation on the anal sphincter by a pull-through manouvre in the stationary pull-through may cause a false high sphincter pressure. Therefore, the exact relationship between the anal canal pressure profile and the fecal continence cannot be determined. A novel anal manometry system should be designed and built for 3D pressure profile measurement along the entire anal canal simultaneously without pulling the catheter.

CONCLUSION

In conclusion, anal fistulae require surgical treatment with a focus on preserving anal function, a challenge for even the most skilled surgeons. This review examines anal manometry, which measures anal canal pressures and is crucial for assessing anal function in relation to fecal incontinence post-surgery. Different catheter types—water-perfused, solid-state, air-coupled, and fiber optic—are compared and discussed for their clinical implications. Vectormanometry stands out for its detailed three-dimensional pressure profiles and advantages over conventional methods. There is a clear need for innovative technology that can provide comprehensive 3D pressure measurements along the entire anal canal without the need for catheter dragging, to enhance surgical planning and outcomes for anal fistula patients.

CONFLICTS OF INTEREST

The authors declared that they have no conflicts of interest.

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