Original article

The use of flow equation in functional coloproctology: a new theory in anorectal physiology

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Abstract: The flow equation and hybrid law in coloproctology can be used to understand normal anorectal physiology and accordingly explains the controversies experienced due conflicting research data. It can be used equally for incontinence and constipation. According to the flow equation there are four primary mechanical factors maintaining continence and achieving unobstructed defecation, namely intra-rectal pressure (IRP), dynamic viscosity of the bowel contents, anal canal length and diameter. The last 3 factors are responsible for the anal canal resistance (ACR). All other factors are secondary, and working through one or more of the four primary mechanical factors each can be numerically calculated separately. The sensory and reflex components work through the IRP and ACR respectively, and can also be numerically calculated in each individual. This data can be used to plan treatment and predict outcomes. Calculation of the ACR before and after treatment is helpful when making an objective evaluation of different treatment modalities. If different treatments are given to the same patient, e.g. combining constipating agents with sensory biofeedback for the rectum and anal sphincter repair, each modality may affect a different component in the flow equation, such as the dynamic viscosity, IRP, anal canal length or diameter. Calculation of the ACR also gives new insight into the results of modifying existing treatment modalities or creating new ones. Norm-grams and the automated flow calculator were designed to illustrate and avoid tedious calculations and they suggest a final diagnosis for each patient.

Key words: Flow equation; Hybrid law; Intra-rectal pressure; Anal canal resistance; Incontinence; Constipation.

INTRODUCTION

The anorectum is a physiologically highly integrated segment of the bowel. The mechanical factors modified by sensory and reflex components are integrated instantaneously in order to initiate normal defecation within a few seconds and to maintain continence within a fraction of a second. This highly integrated nature may be responsible for the lack of answers to the enigmatic question of how the anal sphincter works. This enigma exists despite the availability of an enormous pool of research data where many different factors have been considered in an unintegrated approach. The use of the flow equation for mathematic integration of anorectal physiology first appeared in the international literature in 1998 when Farag attempted to answer the above-mentioned question and standardize our approach to functional colorectal disorders.[1]

THE RESISTANCE AND FLOW EQUATION IN FUNCTIONAL COLOPROCTOLOGY

The flow equation called the Hagen-Poiseuille law was originally designed to study the flow of newtonian fluids, such as water, in rigid tubes. Poiseuille had used the equation successfully in the study of blood flow (a non-newtonian solution).[2, 3] Newtonian fluids had been defined as those fluids that have a constant dynamic viscosity at different rates of flow.[3] The flow equation for the newtonian fluids can be used for non-newtonian fluids, e.g. stools, if their shear stress equals zero.[2, 3] According to Douglas et al, the Hagen-Poiseuille law can be used for gases and solids, which behave like a very low viscosity, and a very high viscosity fluids respectively.[4] The resistance of the anal canal to flow had been suggested by many authors to be a more important factor in maintaining continence than the ability of the muscles to squeeze around the anal canal. However trials to measure the anal canal resistance mechanically using probes, catheters, small balloons and obturators were unsuccessful.[5, 6, 7, 8] Recently the resistance and flow equations had been applied to the field of functional coloproctology for a mathematically integrated approach of anorectal manometry and defecography.[1] According to the flow equation, constipation can be defined as a low flow state during defecation while anal incontinence (AI) can be defined as abnormal flow of bowel contents through the anal canal during rest or squeeze where (Flow = Pressure/ Resistance). Accordingly the recto-anal interaction is a pressure/resistance interaction rather than pressure/pressure interaction. The anal canal resistance is directly proportionate to dynamic viscosity (DV) or consistency of stools and anal canal length (ACL), and inversely proportionate to anal canal resistance.[4]

Conforming to the flow equation, four primary mechanical factors affect the anal continence and defecation in health and disease, namely:

1. intra-rectal pressure (IRP).
2. dynamic viscosity of the stools (DV)
3. anal canal length (ACL).
4. anal canal diameter (ACD).

$$\text{AC Resistance} = \frac{128 \times \text{Dynamic Viscosity} \times \text{ACL}}{3.14 \times (\text{ACD})4}$$

The flow equation will be finally as follows:

$$\text{Flow} = \text{IRP} \times \frac{3.14 \times (\text{ACD})^4}{128 \times \text{DV} \times \text{ACL}}$$

Other mechanical factors are secondary factors operating through one or more of the above mentioned primary factors. Type of food intake, amount of fluids ingested, rate of gastric emptying, small and large bowel absorption and motility, work through the dynamic viscosity factor. Rate of rectal filling, rectal capacity and rectal compliance work through the factor of IRP, while the pelvic floor muscles, anal sphincters and pelvic supporting connective tissue and fascia work through the factors of ACL and ACD. Sensory and reflex factors are known to intimately interact with the mechanical factors in order to maintain normal continence. Both work through the flow equation by determining which IRP interacts with which anal canal dimensions (length and diameter), at any given time sensory factors principally affects IRP due to delayed sensations (Fig. 1). Reflex factors work mainly by determining which anal canal dimensions (and hence resistance) are challenged by intra-rectal pressure during rest or squeeze for incontinent or during defecation for constipated patients. Each of the sensory or reflex factors can be

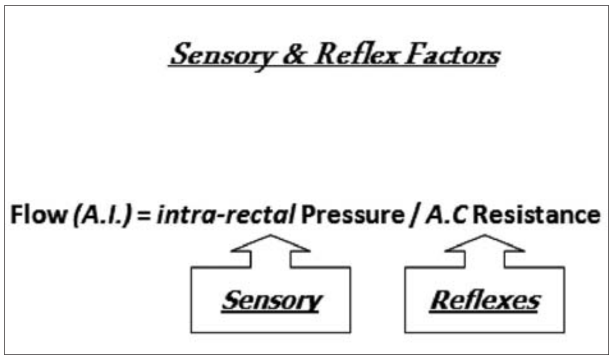


Fig. 1. – The interaction between the Mechanical, Sensory and Reflex Factors in the Anorectal Segment.

numerically quantified individually or in conjunction with other factors.

According to the resistance equation the anal canal resistance increases as the DV (consistency) of the stools increases, and this explains why the anal canal resistance to gas is lower than its resistance to fluid stools which is in turn is lower than its resistance to soft well formed stools.

If we use the DV to air, water and soft well formed barium sulphate paste at normal body temperature as representative to the DV to bowel gas, watery stools and normal well formed stools respectively, the anal canal resistance at any given situation is 1:38:69 respectively for gas, fluid stools and formed stools respectively. This numerically explains why the AI to gases is the easiest to occur and the last to be regained in those patients. It also explains the beneficial effect of constipating agents in patients with AI by increasing the DV (consistency) of the stools which proportionately increase the anal canal resistance.

The above mentioned fact also explains why hard stools are difficult to evacuate even in normally functioning anal canals and can explain the beneficial effect of laxatives in obstructed defecation in any particular patient by decreasing the DV of stools which proportionately decrease the anal canal resistance during defecation.

This beneficial effect of laxatives and constipating agents can also be quantitated numerically using the rotational viscometer and the flow equation in any given patient (Vide infra). Similarly according to the resistance equation the anal canal resistance is directly proportionate to ACL and inversely proportionate to the ACD. The later is the most important determinant of anal canal resistance than ACL and DV of stools being raised to the power four.

This confirms our general knowledge concerning the need of the anal canal to dilate and shorten in order to achieve normal unobstructed defecation. It also explains the findings of other authors that the postoperative ACL was the only statistically significant manometric parameter in predicting the functional outcome of anal sphincters repair for patients suffering from AI using logistic regression analysis.[9]

Measuring the anal canal resistance in an average control subject using lateral defecographic views on regular abdominal films during rest, squeeze, and defecation (Fig. 2), revealed an 8 fold increase in anal canal resistance during squeeze in order to overcome the tendency to increase the flow through the anal canal due to an increase in the intra-rectal pressure during urgency or coughing or Valsalva's maneuver. While during defecation this resistance is voluntarily decreased by 88 times as compared to AC resistance during rest in order to allow for normal unobstructed defecation.

In this control subject the anal canal resistance can be altered over a range of 704 folds (i.e. 8 × 88), from full contraction during maximum squeeze to full relaxation during defecation.

This interesting versatility of the anal canal resistance can only be achieved by muscular tissue which has a resting tone and can actively contract and actively relax maintaining continence during rest and during squeeze while allowing for normal unobstructed rectal evacuation during defecation. This function cannot be achieved by any other natural or synthetic tissue as effectively as the muscular tissue. It can also explain the role played by the anal sphincters being made of a combination of involuntary muscles [longitudinal muscle layer and internal anal sphincter (IAS)] which maintain continence during rest by the basal tone of the IAS, and the voluntary muscles: the external anal sphincter (EAS) maintains the anal canal diameter (primarily) and anal canal length (secondarily) by its basal tone during rest and by its contraction during squeeze, and the puborectalis muscles which work by upwards and forward pull of the ano-rectal junction maintaining anal canal length (primarily) and anal canal diameter (secondarily), by stretching the anal canal during its contraction during squeeze aided by the visco-elastic properties of the anal canal (Tab. 1). A marked decrease in the visco-elastic properties of the anal canal e.g. due to irradiation may attenuate the puborectalis ability to increase the ACL and decrease ACD in addition to the damage to the anal sphincter and the rectum.

The role of the longitudinal muscle can only be appreciated by looking at its unique attachment like strands of a tent passing through the lower part of both IAS and EAS to the perianal skin and to the anoderm anchoring both muscles to the skin and anoderm. If absent, upward recoil of both sphincters can lead to anal canal shortening-widen-

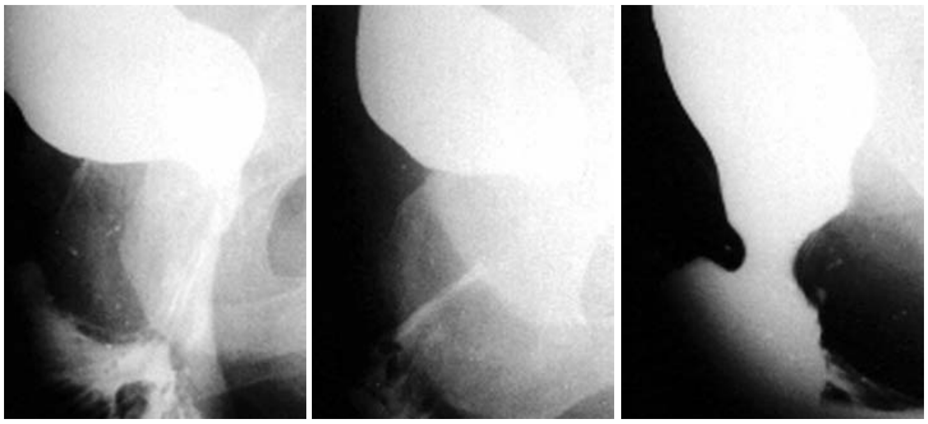


Fig. 2. – The Anal Canal Resistance as they appear on defecography during Rest, Squeeze and Defecation.

TABLE 1. – *Anatomic-function relation-ship according to the flow and resistance equations where the ACL and ACD represent the final common pathway for action of the anal sphincters.*

	Longitudinal muscle	***Internal analsphincter***	***External anal sphincter***	***Puborectalis muscle***
A.C. Length	It forms a supportive framework for the IAS and EAS during rest and squeeze. It decreases the A.C length during defecation	Maintains A.C.L. during rest (+)	Maintains ACL during rest (+) and during Squeeze (+)	Maintains ACL during rest (++) and during squeeze (++) and relaxes to increase ACL during defecation (++)
A.C. Diameter	Forms a supportive framework for the IAS and EAS during rest and squeeze. Opens the A.C. during defecation [10]	Maintains A.C.D. during rest (++) and relaxes to increase ACD during defecation (++)	Maintains ACD during rest (+), decreases ACD during squeeze (++) and relaxes to increase ACD during defecation (++)	Maintains ACD during rest (+) and during squeeze (+) and relaxes to increase ACD during defecation (+)

ing (incontinence) which will not be helped much by contraction of the puborectalis pulling the anorectal junction upwards and forwards, and will lose some of its effect on anal canal dimensions.

This effect theoretically may be responsible for AI after operations for anal fissures or low fistulae if they cut the longitudinal muscle attachments at certain critical points in otherwise previously normal anal canal muscles.

The resting tone of the EAS may be due to its vertical stretch between the pulling puborectalis while its lower part being fixed to the perianal skin by the longitudinal muscle unique attachment. This continuous mechanical stimulation is akin to the theory of dynamic graciloplasty where continuous electric stimulation of any skeletal muscle will increase the percentage of the slow twitch fibers in the muscle from 10-45% which lead to its fatigue resistant properties of the muscle and its resting tone contrary to all other skeletal muscles. In fact the puborectalis also is always mechanically stimulated by the weight of the rectum and its fixation to the presacral fascia in the traditional anatomic theory or by the levator plate and the uterosacral ligament in the musculo-elastic theory.[10] In fact division or loss of function of the puborectalis may also lead to a decrease in the EAS function through the loss of its physiological vertical stretch and hence the loss of some of its resting tone. This may lead to shortening and widening of the EAS and decompensation of the voluntary continence mechanism. On the other-hand division of the EAS will not lead to puborectalis dysfunction. This suggests that the puborectalis is the main muscle of continence while the EAS provides a functional reserve. The role of pelvic fascia for the proper function of the pelvic floor muscles and anal sphincter as was suggested by Petros and Swash,[10] sounds physiologically convincing because muscles has to gain fixed attachment to bones or strong fascia in order to maintain its physiological optimum length for optimum function (Starling's law). Loss of fixed attachment by laxity or injury to the ligaments will reduce the functionality of the muscles.

The upwards and forward pull of the anorectal junction by the puborectalis muscle will keep the longitudinal muscle ani (LMA) over-stretched as it is tethered to the perianal skin by its filamentous attachments, so that it stays in a state of isometric contraction during rest and squeeze. Embryologically the LMA and the IAS are a continuation of the bowel wall telescoped inside the puborectalis and EAS. The action of the LMA and the IAS occurs in two stages:

1. Stage of receptive relaxation: as the stools reaches the lower rectum both muscles relax aided by the relaxation of the puborectalis muscle which allows the relaxed EAS to flip outwards and shorten to facilitate unobstructed defecation;

2. Stage of isotonic contraction: this occurs during the stage of actual flow when the anal canal shortens vertically and becomes everted over the passing stools. According to the musclo-elastic theory [10] the LMA contracts to pull the recto-vaginal septum and perineal body in order to keep the anal canal open during defecation. This action most probably takes place at this stage of actual flow.

The flow equation can suggest answers to many controversial issues in functional coloproctology where the anorectal angle does not show itself as a primary factor in maintaining anal canal resistance. It is most probably an indication of a properly functioning puborectalis muscle which works by increasing the anal canal length and decreasing anal canal diameter through elongation and stretching the anal canal by the upwards and forward pull of the muscle aided by the visco-elastic properties of the anal canal and its surrounding muscles. The reverse action occurs during defecation through relaxation of the puborectalis muscle.

Similarly, perineal descent does not affect the equation directly. However it may represent pelvic floor weakness which yields excessively under straining. In the same way weak abdominal wall muscles form a big belly as a result of increasing intra-abdominal pressure.

THE HYBRID LAW IN COLOPROCTOLOGY

Since two thirds of continent individuals still have normal anal pressures as seen on manometry, and two thirds of patients with AI have low anal pressures, can the anal canal pressure show itself in the flow equation?

As was suggested by other authors, the anal canal pressure measured is the resistance of the anal canal to distension by the measuring probes and is proportionate to the probe diameter.[11]

According to the law of Laplace:

$$\text{Wall Tension (T)} = \frac{\text{Distending Pressure (p)} \times \text{Radius (R)}}{\text{Anal Canal Wall Thickness } (\delta)}$$

R (Inside) = $T\delta/P$ Since the ACD = 2R

Compensating for the ACD in the Flow equation with the Laplace's Law:

$$\text{Flow} = \text{IRP} \times \frac{3.15\,(T\delta)^4}{8 \times \text{DV}\ \ (\text{ACP})^4}$$

This equation suggested by Farag [1] in 1998 was named the Hybrid Law in coloproctology, where: from the Hybrid law, the anal canal pressure is inversely proportionate to flow as is known in the literature and the anal canal wall tension increases as the flow increases i.e. during defecation, where

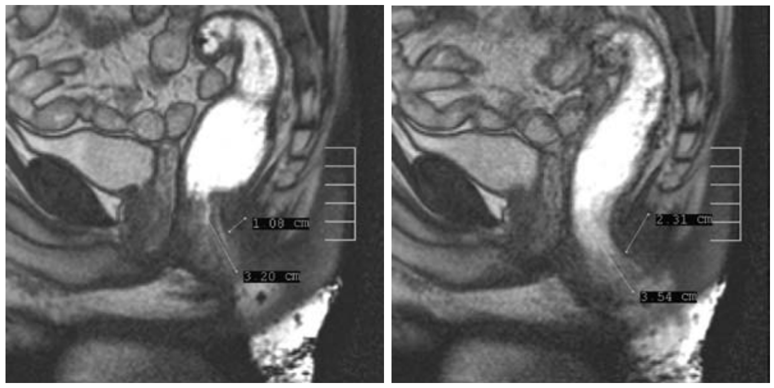
A  B

Fig. 3. – The measurement of the Anal Canal Sphincter Thickness during the beginning = 1.08 cm (A), and at the Zenith of Defecation = 2.31 cm (B).

anal fissure can happen and anal suppurations can start at the anal crypts. According to the equation, contrary to our believes, the anal canal wall thickness has to increase being proportionate to flow in order to protect the anal canal against the increasing wall tension, a physiologic necessity and priority in all the GIT to avoid bowel wall rupture. Our unpublished data in well selected controls proves this (Fig. 3). Failure of the anal sphincters to increase in thickness due to either a congenitally thin sphincter or due to opening of the anal canal by effacement-thinning of the relaxed EAS, (like the cervix uteri during delivery), rather than upwards and outwards recoil of the EAS by puborectalis relaxation and its active relaxation, may be responsible for the development of hemorrhoids in the submucosa in those predisposed to this disease in order to increase anal canal wall thickness in an attempt to minimize the wall tension. Those predisposed to anal fissure will develop cracks while the rest may develop anal suppuration. Anismus may also develop in a desperate attempt to increase the anal sphincter thickness by spasm.

Calculation of resistance and flow in health and disease

$$\text{AC Resistance} = \frac{128 \times DV \times ACL}{3.14 \times (ACD)^4}$$

$$\text{Flow} = IRP \text{ x } \frac{3.14 \times (ACD)^4}{128 \times DV \times ACL}$$

The Intra-rectal pressures are measured manometrically in K Pascal where: 100 mmHg = 13.3 K Pascal. ACL and ACD are measured from the lateral defecographic views in meters. Dynamic viscosity of bowel gas, liquid stools and soft well formed stools were approximated to that of:

air = 0.00001905 Kg m^{-1} s^{-1}, water = 0.000723 Kg m^{-1} s^{-1}

Barium sulphate paste = 0.0013092 Kg m^{-1} s^{-1}, flow index = liter/s. (×1000 = cc/s.) Recently those calculations can be done using an automated calculator available on the following address: http://www.integratedcoloproctology.com/cald.htm

FLOW INDEX IN CONSTIPATION

Using a fixed dynamic viscosity for air, water and barium sulphate, only 3 measurements are done in calculation of flow index in constipated patients:

1. mean IRP during defecation as measured using computerized anorectal manometry (mmHg)
2. ACL (cm)
3. ACD (cm).

Both 2 and 3 are measured from the lateral defecographic views on a standard abdominal film. A flow index of 1cc/sec was taken as well as a cutoff point between obstructed defecation (flow < 1 cc/sec) and unobstructed flow in the absence of anatomical obstruction or excessively hard stools during defecation. The mathematically calculated flow was taken as a flow index rather than an accurate measurement of flow in order to avoid minor corrections on the native equation. Norm grams representing the flow equation during defecation and continence had been plotted in order to facilitate understanding the flow equation and allocation of individual patients as a rough though rapid substitute for suggested mathematical calculations.

Defecation Norm Gram (Fig. 4)

The four primary factors involved in the flow equation could be successfully plotted in order to facilitate understanding the mechanism of normal defecation and continence and to allocate the majority of the patients into normal or abnormal physiology by simply plotting the line connecting the ACL and diameter during attempted defecation against the line connecting the mean IRP during attempted defecation and point M (see the norm gram) where the meeting of the 2 lines allocate the patient in its corresponding functional status. The above mentioned measurements are applied directly to the norm gram as mmHg and cm without conversion to the SI units.

Example:

IRP = 52 mmHg, ACD = 2 cm, ACD = 2,3 cm. Calculated flow index = 1,8 cc. barium sulphate/sec (i.e. zone I).

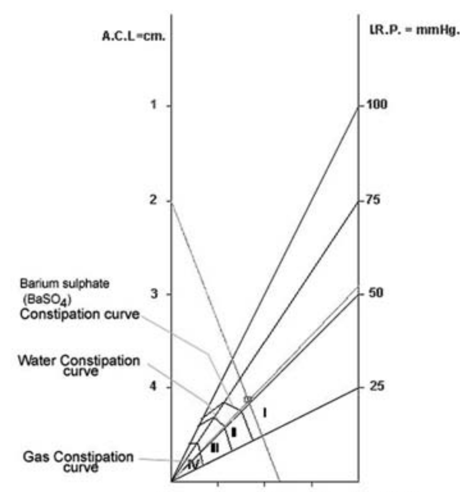


Fig. 4. – Defecation Norm Gram.

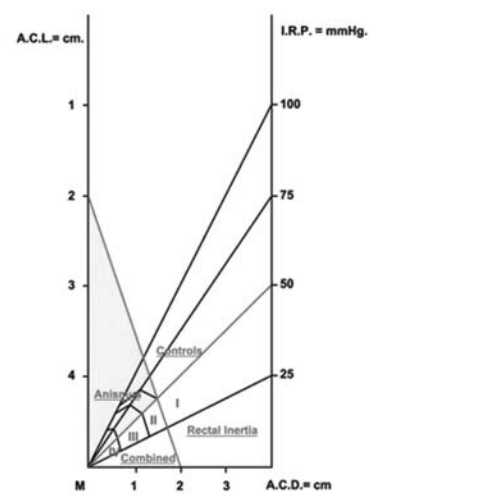


Fig. 5. – Types of patients and controls on Defecation Norm Gram.

Zone I includes: 1. normal unobstructed defecation; 2. patients that have constipation due to hard stools, colonic inertia or mechanical factor such as rectocele or intussusception that is expected to regain normal defecation after correction of the cause.

Zones II, *III* and *IV* include patients with underlying anismus and/or rectal inertia (RI). *Zone II*: obstructed defecation for soft well formed stools. *Zone III*: obstructed defecation for watery stools. *Zone IV*: obstructed defecation for gas.

The minimum normal anal canal resistance was represented by the line connecting ACL = 2 cm and ACD = 2 cm. The minimum normal intra-rectal pressure was represented by ... line connecting IRP = 50 mmHg and point M.

RI can be sub-classified into the following categories according to the IRPs measured during attempted defecation: *mild* from 40 to 50 mmHg; *moderate* from 30 to < 40 mmHg; *severe* from 20 to < 30 mmHg; *rectal atony* < 20 mmHg. The defecation norm gram can define anismus, rectal inertia, combined cases and normal controls (Fig. 5). Some of anismus patients lie in zone I of normal defecation, being compensated for by increased IRP during defecation which had led to the controversies about the role of anismus in constipation. Those cases are compensated anismus patients that should not be recruited as normal controls. In fact normal controls recruited only from the control area above and in front of both lines.

THE FLOW EQUATION IN ANAL INCONTINENCE

According to the flow equation, three main types of AI can be recognized:

– *passive AI* (i.e. during rest), where flow is calculated using maximum intra-rectal pressure during rest and ACL and ACD during rest;

– *stress AI* (i.e. during reflex squeeze e.g. on coughing). Where flow is measured using maximum IRP during cough or Valsalva's maneuver, and ACL and ACD during squeeze;

– *urgency AI* (during voluntary squeeze). Where flow is measured using maximum IRP during sense of urgency and ACL and ACD during squeeze.

Correction for sensory and reflex components

Passive AI: for *delayed first sensation* the flow index is measured using maximum IRP just before the first sensation and AC length and diameter during rest. For *reflex deficit:* if profound RAIR precedes the first sensation causing unconscious profound inhibition of the anal sphincter (*overflow incontinence*) e.g. neurogenic AI, the flow is measured using maximum IRP during rest and ACL and ACD during full relaxation (defecation position).

Stress AI: correction for *defective reflex contraction* of the sphincters where the maximum IRP during coughing challenges the anal sphincter in its resting state instead of its contraction state. Flow is measured using maximum IRP during cough and ACL and ACD during rest.

Urgency AI: when profound RAIR precedes the sense of urgency where flow is measured using maximum IRP during urgency and ACL and ACD during full relaxation (defecation). Quantification of sensory and or reflex deficit can be made easily by the equation: flow index after correction-flow index before correction.

A flow index of 0.1cc/sec was taken as a cutoff point between normal continence and fecal soiling (flow <0.1 cc/sec). A flow index of 1cc/sec was taken as a cutoff point between true incontinence (flow $\geq$ 1 cc/sec) and fecal soiling.

Those corrections can be made much easy by the modern anorectal machines with simultaneous anorectal manometry during contrast defecography. The moments of leak of the contrast can be marked and later on freezed and the measurements done. However knowledge of the above corrections is essential for planning treatment as will be discussed later.

Continence Norm Gram (Fig. 6)

Five curves were calculated and subsequently plotted on the norm gram:

1. barium sulphate continence curve (upper solid curve);
2. water continence curve (middle solid curve);
3. barium sulphate soiling curve (upper dashed curve);
4. water soiling curve (lower dashed curve);
5. air continence curve (lower solid curve).

The above mentioned curves divide the norm gram into six zones forming the basis of a new functional classification of the degree of severity of incontinence.

Grade I: continent, anal staining due to minor anal problem (e.g. hemorrhoids), and incontinence on top of normal anal sphincter (e.g. fecal impaction); *grade II:* gas incontinence; *grade III:* fluid soiling; *grade IV:* solid soiling; *grade V:* fluid incontinence; *grade VI:* solid incontinence. Each grade from II to VI is assigned with letters *P*, *S* or *U* (as an indication for *passive*, *stress* or *urgency* AI) in order to signify which measurements are to be used in calculation of flow index or in

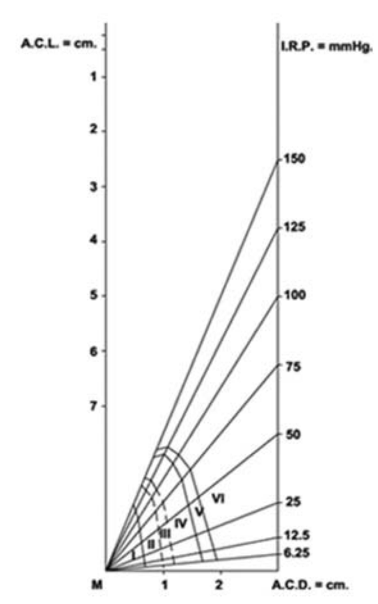


Fig. 6. – Continence Norm Gram.

the norm grams. Allocating each patient on the norm gram is done in the same way as in defecation. An important although difficult clinical tool to discriminate between anal staining due to minor anal problems (grade I) which requires no specific treatment or investigations and fluid or soft stool incontinence (grade III and IV) is by a simple look at the continence norm gram where the later is associated with gas incontinence (grade II). Discrepancies between *mathematical* anal incontinence despite absence of clinical incontinence is considered as sub-clinical sphincter weakness which may be unmasked later. E.g. a patient with sub-clinical gas incontinence may be masked by minimal amount of bowel gas produced in his bowel. Similarly a patient with mathematical stress fluid incontinence my be apparently normal because he will only manifest clinical incontinence when he has watery diarrhea simultaneously with a chest infection.

Frequency of anal incontinence may not correlate with quality of life scores because of different social status and intellectual abilities. The frequency of incontinence does not signify which mechanism is deranged and what can be improved by non specific treatments. As an example a high social rank person with gas incontinence may have a poor quality of life score when compared to a less intellectual person. Similarly a patient with stress gas incontinence may have increased frequency of his AI if he has an attack of bronchitis which can be successfully treated using antibiotics, mucolytics and expectorants.

Individual scores such as such as the flow (physiologic) score are less helpful in planning treatment. Due to the importance of frequency and QoL scores a composite score is suggested as “physiologic/frequency/QoL (PFQ) score” similar to the TNM score local/regional/systemic status of the tumors.

Planning for treatment and predicting outcome in patients with anal incontinence

The calculation of the flow equation and observing its elemental components will help to plan treatment in patients with functional anorectal disorders. Anal sphincter repairs should not be offered to the patients with normal anal canal resistance where the minimum AC dimensions during rest were set as ACL = 3.0 cm and ACD = 0.8 (AC resistance = 5639.6 and tolerating IRP up to 42 mmHg) and the minimum AC resistance during squeeze was taken as ACL = 3.5 cm and ACD = 0.6 cm (AC resistance = 20794.7, tolerating IRP up to 155 cm) as calculated from the flow calculator. Different treatment modalities can be assessed by studying the flow equation in patients suffering from multifactorial causes of AI. The effect of different biofeedback or operations can be followed up by its ability to increase anal canal resistance and decrease the Fl as they appear on the flow equation. Assessment of the anal sphincter function before closure of colostomy can be done preoperatively since the calculations can be done using defecography and anorectal manometry of the defunctionalized anorectal segment as accurately as in normal individuals.

THE USE OF THE FLOW EQUATION IN PLANNING TREATMENT: PREDICTION AND EVALUATION OF OUTCOME IN CONSTIPATED PATIENTS

Patients should be divided into two main groups after exclusion of dietary, hormonal and drug induced causes for constipation.

1. Patients with an apparent cause for constipation such as small bowel inertia, colonic inertia, hard stools, organic stricture, large rectocele or intussusceptions;

2. patients with no apparent cause for constipation.

The patients in the first group are further divided by the result of the flow calculator and the defecation norm gram into:

– patients suffering from apparent cause for constipation and lie in the zone I (normal unobstructed defecation) can be treated medically or surgically with expected normalized defecation after treatment since they have a normal underlying anorectal segment;

– patients with apparent cause of constipation and lying in constipation zones II-IV are expected to have residual obstructed defecation after treatment of the apparent cause of constipation. In fact correction of the underlying rectal inertia and/or anismus is recommended in those patients before correction of their apparent cause for constipation;

– patients suffering from no apparent cause of constipation and who lie in obstructed defecation zones II-IV should be treated for rectal inertia, anismus or both.

Some of the patients who do not have an anatomical abnormality, have a normal flow on the flow calculator and fall in zone I on the norm gram still complain of excessive straining during defecation. These patients have a hidden rectal inertia and have to strain vigorously in order to raise the intra-abdominal pressure for evacuation. These patients can be detected by simultaneously measuring the intravesical pressure or by palpating their abdomen and observing their face during attempted defecation. Repeating the test while asking them to strain gently will unmask their rectal inertia which should be treated by prokinetics.

Treatment of patients who have a normal flow but have a compensated rectal inertia or compensated anismus (Fig. 5), sounds logical if they present for evaluation for other reasons. This group may develop subsequent problems which appear to be due to prolonged periods of compensation by excessive conscious straining.

Normal reflex straining is a natural event during initiation of defecation but it should be reflex, non-laborious and is usually unnoticed by normal individuals. The resistance and flow equation can help in operator independent evaluation of different modalities of treatment for constipation by calculating anal canal resistance and flow equation pre- and postoperatively. A study on the flow equation could predict

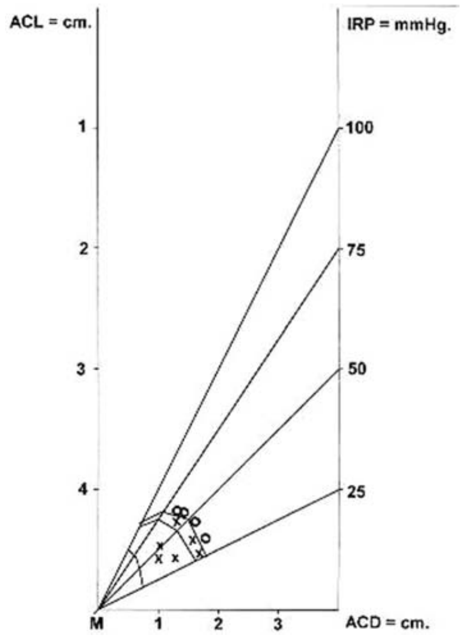


Fig. 7. – The use of Flow equation for predicting outcome in Rectocele Patients (Farag [12]).

the outcome of surgery in 10 female patients suffering from anterior rectocele and obstructed defecation (Farag [12]). The equation was not used to select patients for surgery. The four patients that had successful surgery had a preoperative flow index ≥ 1 cc of barium sulphate/ sec (i.e. abnormal underlying anorectal segment), while the six failures had a preoperative flow index < 1cc barium sulphate/ sec i.e. an abnormal underlying anorectal segment (Fig. 7).

THE FLOW EQUATION AND EXPLANATION OF THE LITERATURE

In a multicenter retrospective analysis of the outcome of artificial anal sphincter implantation for severe fecal incontinence published in the Br J Surg in 2001, Altomare and co-workers concluded that artificial anal sphincter with a diameter 2.9 cm was associated with a high incidence of postoperative obstructed defecation as compared to the cuffs with a 2 cm diameter. Numerical explanation of the authors findings can be given by the flow equation as follows. From the perspective of the flow equation the artificial anal sphincter works by maintaining adequate ACL determined by the diameter of the cuff and minimizes the ACD by the inflation of the balloon. The presence of a pliable anal canal is essential for the action of the artificial anal sphincter in order to reduce the ACD. The procedure should be accompanied by lysis of any fibrosis, which may cause tethering of the AC to the peri-anal structures. The artificial sphincter tries to mimic the normal anal sphincter by its ability to relax in order to achieve normal unobstructed defecation on volition. Use of an artificial inflatable anal sphincter replacement was followed by anismus if the cuff diameter used is 2.9 cm as compared to cuff diameter of 2 cm in this study from Italy. This finding can be explained by the flow equation simply by the fact that the cuff diameter represents the minimal ACL which can be achieved during defecation. For example at any given ACD (e.g. 2 cm), using 2.9 cm cuff would lead to a 45% increase in AC resistance during defecation which needs a proportionate increase in IRP during defecation in order to maintain the same Flow Index achieved with 2 cm diameter cuff during defecation (more straining for the increasing resistance). The use of cuffs with 2.9 cm diameter should be abandoned and the inner diameter of the artificial sphincters with 2 cm diameter cuffs should be tailored according to the mean intrarectal pressures during defecation measured preoperatively and accordingly the expected flow index postoperatively.

IMPROVING THE PRESENT TECHNIQUES AND PLANNING FOR NEW TREATMENT MODALITIES

Failure of the muscle layers that wrap around the anal canal may result from perineal trauma. The rigidity of the anal canal may be fixed by dense perianal adhesions. The muscles are held by the adhesions and cannot contract to decrease the anal canal diameter. An adequate perianal adhesiolysis is an essential step to be added for the success of such operations. Similarly the use of behavioral treatment and biofeedback to teach the patients how to have an urgency defecation is added in my lab as an essential step for the conservative treatment of simple anorectal problems namely, hemorrhoids, anal fissure, anal fistulae, anismus, rectal intussusception, mucosal and complete rectal prolapse.

CONCLUSION

The use of flow equation suggests new definitions for anal incontinence and constipation from the flow point of view, determines the intra-rectal pressure, dynamic viscosity and the anal canal length and diameter as the primary mechanical factors maintaining continence. It also suggests how the sensory and reflex factors interact with the mechanical factors in order to maintain continence in a fraction of a second and initiate normal unobstructed defecation in few seconds. All these factors can be measured numerically in health and disease. This knowledge helps in planning treatment modalities for each individual patient, predicting outcome, and objectively evaluating the outcome postoperatively or after treatment. In cases of combined treatment modalities, the effect of each modality can be evaluated separately. The use of the flow equation can help to anticipate and avoid postoperative constipation after reconstruction of the anal sphincter for the treatment of anal incontinence. It also can be used for improving the present treatment modalities and planning for new treatment options. The hybrid law in coloproctology gives an insight on how the anal sphincters behave during defecation and a new insight on the etiology of haemorrhoids, anal fissure, anal fistulae, anismus, rectal intussusception, mucosal and complete rectal prolapse.

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No grants, pecuniary interest or financial support of the Author.