Compliance and capacity of the normal human rectum – physical considerations and measurement pitfalls

A. P. ZBAR
Department of Surgery, University of the West Indies Queen Elizabeth Hospital, Barbados

The assessment of parameters which adequately represent rectal and neorectal compliance is complex. Biological properties of the rectum during distension and relaxation show significant departures from in vitro physical compliance measurements; as much dependent upon the viscoelastic characteristics of hollow organ deformation as upon the technique of compliance calculation. This review discusses the pressure/volume characteristics of importance in the rectum during distension from a bioengineering perspective and outlines the disparities of such measurements in living biological systems. Techniques and pitfalls of newer methods to assess rectal wall stiffness (impedance planimetry and barostat measurement) are discussed.

Key words: rectum, biological, continence

INTRODUCTION:

The factors involved in continence and coordinated evacuation are complex. Although much has been written concerning sphincter function and morphology, assessment of normal rectal reservoir function is somewhat in its infancy, with considerable disagreement concerning how rectal distensibility both in health and disease should be measured. The simplest functional assessment in the laboratory of this parameter is rectal compliance, (a progressive change in pressure for a change in volume; $\Delta P/\Delta V$) which is an inadequate physical representation of the biomechanical properties of the human rectum. In its most basic form, compliance is detected with a distensible highly compliant rectal balloon in which a pressure-volume curve (a proctometrogram) is generated with the compliance measure defined as the slope of the curve. Since the rectal compliance curve is non-linear, values depend upon the site of the curve where the slope is measured. Given the assumptions made in the estimation of rectal compliance and its relevance in intestinal biomechanics in vivo, it is not surprising that consistency in the derivation of "normal" values has been lacking.

Some of these assumptions are that the rectum represents a closed cylinder where compliance measurements, (which are incorrectly assumed to be equivalent to distensibility or inversely related to rectal wall stiffness), are independent of rectal size or wall thickness and that there is no effect on rectal distensibility of less compliant extrarectal tissues. These simple compliance measurements do not take into account the complex geometry and structure of the rectum and they neglect inherent viscus tone. All of these assumptions are wrong and their aspects are highlighted in this review. We attempt to show the flaws in the reliance on rectal compliance measures in the normal and diseased rectum as practiced by many anorectal laboratories and discuss the nature of rectal biomechanics in vivo as well as new methodology which more suits its clinical assessment in health and disease.

THE PHYSICS OF RECTAL DISTENSION - WHAT IS WRONG WITH SIMPLE COMPLIANCE MEASUREMENT

The rectum as a distensible organ can in part be understood by revisiting basic bioengineering principles, although there are specific complex problems posed by the gut which require the development and utilization of more advanced methodologies. When measured, compliance is in fact a single artificial averaged value of the effects of changes in luminal volume with incremental pressure steps and it does not take into account the effect of organ stretch under varying loading conditions or rectums with differential wall thickness. An intraluminal distending bag inserted into the rectum aims to assess the force-deformation relationship of the viscus, although within a living system, there is little account taken of the intrinsic rectal tone or the response to balloon distension of mechanosensitive intra- and extramural receptors. Despite these limitations, fundamental differences in rectal compliance-measure-
ment have been shown in acute ulcerative colitis and radiation proctitis, which loosely correlate with disease activity. In a research context, hollow viscus distension both in vitro and in vivo, can be objectively assessed with equilibrated pressure measurements and with volume determinations being made by rectal imaging. The latter may be performed using B-mode ultrasonography or magnetic resonance imaging. Here, geometric data is obtained concerning the luminal cross-sectional area (CSA) of the viscus, where wall thickness is assumed to be negligible (or constant) and cannot effectively be measured in vivo.

Bioengineering principles apply for isobaric (constant pressure) or isovolumetric (constant volume) distension protocols, where distension may be performed in incremental stepwise (phasic or staircase) or ramp distension modes; the latter providing continuous inflation with variable inflation rates. Although there is fundamentally little to choose between these techniques in the assessment of compliance or rectal capacity in different ages and in males or females, comparative visual analog scoring of rectal compliance or rectal capacity indicating rectal capacity or asymptotic compliance. These two compliance parameters do not correlate with one another.

mations tend to be higher in age-matched normal males. Each of these techniques, (no matter how it is controlled), fails to provide a uniform or reproducible stimulus (or constant) and cannot effectively be measured in vivo. Bioengineering principles apply for isobaric (constant pressure) or isovolumetric (constant volume) distension protocols, where distension may be performed in incremental stepwise (phasic or staircase) or ramp distension modes; the latter providing continuous inflation with variable inflation rates. Although there is fundamentally little to choose between these techniques in the assessment of compliance or rectal capacity in different ages and in males or females, comparative visual analog scoring of rectal sensitivity (first perception, desire to defecate or maximum tolerable volume with pain) shows that males tend to experience larger volumes at the same pressures with females showing greater differences during inflation/deflation cycles (so-called hysteresis) with a differentially larger hysteresis in women of advancing age. In normal patients, the calculated basic and maximal dynamic compliances tend to be higher in age-matched normal males. Each of these techniques, (no matter how it is controlled), fails to provide a uniform or reproducible stimulus on the rectal wall, although there is some intra-case reproducibility between measurements. This reproducibility requires accommodation and stabilization of the procedure through repeated and equilibrated distensions; a phenomenon called tissue preconditioning. Moreover, the nature of the distension load relies on stable rectal viscoelastic properties where the soft-tissues are suddenly stressed. The advantage of the ramp distension mode is that the results reflect the elastic properties without the viscous properties significantly coming into play. The early part of distension reflects a rapid rise in rectal volume at low pressures where there is receptive rectal relaxation; in effect a marker of intrinsic rectal compliance, where at higher volumes as the P/V curve plateaus, resistance to distension during this linear phase is a measure of the inherent rectal connective tissue indicating rectal capacity or asymptotic compliance. These two compliance parameters do not correlate with one another.

Such a model makes the assumption that the geometry of the rectum is essentially irrelevant. Moreover, in many studies, it is assumed that the organ is isotropic; namely, that all components, (mucosa, submucosa, muscularis mucosae, muscularis propria and serosa), have similar mechanical properties which are not reliant upon the direction of the stress. In the gastrointestinal tract, this assumption is patently false, where the tissue is by definition anisotropic. Here, the entire surface area of a distensible bag must be in complete contact with the distended organ; a factor not attained in the intestine where the bag must be of sufficient size so that its elastic properties do not contribute to the measurements themselves and where hysteresis of the bag is also negligible. The mechanics and size of the bag are no small matters in this debate, where shorter bags provide localized distension mimicking a rectal faecal bolus. Larger bags, (or small but very compliant bags), may provide substantial volume changes due to elongation without any discernable effect on pressure despite the fact that there may be substantial shape variation. This implies that volume measurement, (a hallmark of rectal compliance calculation), may be less worthwhile as a parameter than CSA determination. In this case, the CSA will be less affected by balloon movement as it distends or by linear extrusion of the inflating balloon, where there will be both axial effects on the rectal wall but where there will typically be movement of bag components during inflation and deflation. This emphasizes the physical characteristics of the component material of the bag as well as the importance of the basic bag dimensions.

Put simply, these factors will result in false estimations, (usually overestimates), of compliance at the extremes of inflation or deflation where substantial volume changes may occur with minimal pressure variation. Interpretation of the biomechanical properties of a distensible hollow viscus is therefore dependent upon the geometric factors (of the vescus and the distending balloon) and upon assumptions which ignore this complex geometry and the anisotropic nature and wall thickness of the gut. In addition, the size of the rectum will influence the compliance and stiffness measurements where in megarectum, for example, compliance may be reported as high as a consequence of rectal size even though the rectal wall may be abnormally thickened.

THE PHYSICS OF RECTAL DISTENSION - CONCEPTS OF STRESS AND STRAIN

It would seem reasonable to apply valid bioengineering principles and mechanical measures as suggested in the extensive work by Gregersen and colleagues. These include strain (a measure of deformation), stress and tension (measures of normalized force) and stiffness (elastic moduli based on constitutive equations) to the gut since it is in theory valuable to equate these parameters with specific rectal diseases likely to affect rectal wall stiffness such as proctitis. This approximation may be applicable in a defined stress/strain relationship where stress is the force per unit CSA and where the weight of the luminal contents can effectively be neglected. Force may be applied perpendicularly to the surface by a bolus (normal stress) or exerted upon the wall parallel to the surface (shear stress). These stresses can be either compressive or tensile and can be defined in radial, circumferential and longitudinal directions in a biological tube such as the rectum. The major tensile normal stress occurs circumferentially.

Here, the assumptions are made as outlined in part above, that the rectum is a cylinder and where the main (circumferential) stress is such that: $\tau = \Delta P r / h$ where $\tau$, $P$, $r$, and $h$ are...
and $h$ are the stress, transmural pressure, internal radius and wall thickness, respectively). The parameter $h$ can either be the undeformed wall thickness (providing an engineering stress) as opposed to the deformed wall thickness (so-called true stress). This equation often called Laplace’s law providing a stress measure for a homogeneous material with simple geometry and is an expression so lauded in colorectal surgery. Laplace’s Law also assumes that the wall tension is the same at all points, that the change in pressure within the rectum is equilibrated with the pressure outside the rectum and that the rectal length-to-radius ratio is high. In living systems, the law also takes no account of the inherent rectal geometry which differs for stereotypical cylinders, ellipses and spheres and assumes that provided that the rectal wall is thin there should be no bending rigidity during the distension process. Clearly since there is no anatomical barrier within the rectum, a further assumption is made regarding the proximal extent of what is defined as "rectum" when there is neither an anatomical nor a physiological limit of the balloon even though the expectation in standard rectal compliance measurement is that axial rectal distension will conclude at the rectosigmoid junction. Such a situation may result in a very stiff megarectum accommodating the balloon with recorded high compliance values and a normal but angulated rectum recording low compliance as there is a shift in pressure for small volumes near a luminal rectal kink. In both circumstances variation in the rectal wall stiffness, rectal capacity and wall thickness for very different rectal states (or diseases) could conceivably provide equivalent compliance measurements.

A further problem with this simplistic view in the living gastrointestinal tract is that it is subject to intrinsic mechanoreceptor tone which varies from moment to moment.

Here too, Laplace’s law is based on the wall thickness-to-radius ratio being relatively small so that circumferential stresses across the wall are equivalent and where these stresses are equally distributed. Such is certainly not the case in the gastrointestinal tract, where large bolus transport will provide an "evened out" stress as a protective mechanism against plastic deformation or rupture. As Laplace’s Law is really only valid for cylindrical systems, the diameter of the distended gut will be variable in the axial direction with differential circumferential and longitudinal effects and computation of the membrane stress resultants should be based on this intestinal profile. In in vivo work on porcine intestine, the tension in the $z$-axis lies about 25% away from the middle of the balloon with a higher circumferential as opposed to a longitudinal stress so that the shape of the distended intestine will more accurately define the circumferential and longitudinal tensions developed.

Strain within a hollow organ is also a complex mechanical issue, referring to deformation of a viscous as a fraction of its initial length (so-called Lagrangian strain). This effect refers to a continuum between an initial (undeformed) configuration and an end (deformed) state. The stiffer the material, the simpler the relationship between the basal and the stretched length and the easier strain is to quantify, where most biological materials are of such a nature that large deformations commonly occur without the risk of rupture. Hence, equations taking large deformations into account must be used and both the deformed and the undeformed states need to be assessed. With most in vivo methods nowadays, this is not possible and the true zero-stress state (where the undeformed configuration is ideally determined) obviously cannot be assessed in vivo because the tissues need to be transected into segmented pieces. In vitro, the reference length ($L_0$) is measured at zero stress with pressure loading whereas in vivo there is collapse of the viscus at zero pressure loading as well as the effects of tonic agents. Despite this, strain is a useful, (although dimensionless), parameter, however, advanced methodology must be used to determine the strain distribution in the various layers and directions of the gastrointestinal system. In effect, the rectal compliance measurement typically measured is but one of many compliances occurring in series, incorporating the compliances of the extrarectal fat, vascular and neural structures, genitourinary organs and the bony pelvis summed with the compliance of the rectum itself.

As stresses and strains occur in all directions, the gut as it expands is subject to a load (distension) which causes an increase in circumferential length (tensile circumferential strain), a reduction in wall thickness (compressive radial strain) and an elongation which is dependent upon the material properties of the rectal wall. In this case, deformation, (both negative and positive strains), will have three-dimensional components in both normal and shear directions providing a normal proportionality constant between stress ($s$) and strain ($e$). This constant is the elastic (Young’s) modulus, a bioengineering parameter expressing the rate of change of $s$ with $e$, being derived from Hooke’s law as applied to deformable springs for “Hookean” materials where the $s/e$ relationship is linear. The modulus would then be represented by the equation:

$$E = \frac{\sigma}{\beta} = F/A_0 = \frac{F L_0}{A_0 \Delta L}$$

where $E$ is the Young’s modulus of elasticity, $F$ is the force applied to the rectum, $A_0$ is the original CSA of the rectum through which the force is applied, $\Delta L$ is the length change during deformation and $L_0$ is the original length prior to deformation. As already stated some of these parameters are unmeasurable in vivo. The non-linearity of this relationship in living tissues, however, is related to their anisotropy, which less readily defines their compressibility (lateral contraction-to-axial compression). This non-linearity actually facilitates stretch, with increasing pressure ranges which are encountered in normal physiology preventing irreversible distortion of the rectum during bolus transport.

In order to determine this non-linear relationship in the human rectum, an incremental elastic modulus (IEM) needs to be calculated between measured points of strain for any given stress, defining the effective stiffness of a
hollow organ, where constitutive equations must be developed to provide a more accurate mathematical description of the mechanical properties of the rectum. Each of these moduli is subject to both preconditioning and hysteresis in biological materials and added to this complexity, the stresses and strains imposed on biological tissues such as the rectum are time-dependent since they cannot be applied or removed instantaneously. This latter effect results in stress relaxation, (reduction in stress with time after sudden distension) and creep, (an ongoing deformation after rapid stress application). Each of these phenomena occurring in biological tissues (stress relaxation, creep and hysteresis) are inherent features of tissue viscoelasticity\textsuperscript{22,46} which have been described for the rectum in both health and disease but which are not considered in compliance measurement\textsuperscript{47}.

### Alternatives to Compliance Measurement: Impedance Planimetry and the Electromechanical Barostat in Clinical Practice

Given the constraints of rectal compliance measurement and its lack of reproducibility, other techniques have been sought to objectively assess rectal stiffness and capacity. Impedance planimetry (IP) is a technique for the measurement of the luminal CSA in a hollow viscus which utilizes electrical impedance between recording electrodes after controlled distension of a compliant balloon with a conductive fluid\textsuperscript{48}. This system works on the simple principle of Ohm’s Law, (the field-gradient principle), originally employed by Harris and colleagues for assessment of flow in the ureter,\textsuperscript{49} whereby the CSA was measured using linear array electrodes passed into the ureter and applying a current between these electrodes so that the potential voltage difference bore an inverse relationship to the luminal CSA. Later on Mortensen and coworkers applied a balloon54 for application to all parts of the gastrointestinal tract\textsuperscript{55}. Pressure within this system is measured in the standard manner using a low compliance perfused system.

In IP measurement, Ohm’s Law applies where the electrodes are mounted on a catheter assembly and an AC current is induced in a volume conductor so that $V = I Z$ (where $V =$ voltage, $I =$ current and $Z =$ fluid impedance). A uniform electrical field is created around the detection electrodes so that:

$$Z = d \delta^{-1} \text{CSA}^{-1} \quad \text{or} \quad V = I d \delta^{-1} \text{CSA}^{-1}$$

where $d =$ distance between the detection electrodes and $\delta =$ fluid conductivity. Such a formula in this system is of advantage since it has validity for CSA measurements in both circular and non-circular geometries. Since all these parameters can be kept constant, in effect, $V = k \text{CSA}^{-1}$ where the voltage measured in the IP system is inversely proportional to the CSA. This system can be modified for multi-electrode detection of different CSA values within a 3-dimensional geometric bag with computerized analysis through a signal processing unit using potential difference amplification and digital conversion\textsuperscript{56}.

This new system makes several significant assumptions about low impedance of the distension fluid, the constancy of current magnitude and the location of the tube where the probe is presumed to adopt a central (non-eccentric) axial position. It also makes basic assumptions about the balloon characteristics which should be large, thin, non-stretchable, non-conducting and have low bending rigidity with minimal linear extrusion during distension. Using IP, (given these limitations), the complex rectal geometry does, however, appear to be less critical in measurement than it would otherwise be were rectal compliance relied upon as the cardinal measure of rectal stiffness and capacity.

The data provided by IP can be plotted using a least-squares method so that an exponential (polynomial) relationship is derived where the slope of the curve, $E$ (elasticity) represents the $\sigma/\varepsilon$ relationship during incremental rectal distension,\textsuperscript{58} providing a potential mathematical model for rectal distension and for describing the viscoelastic properties of the rectum\textsuperscript{59-61}. This model is, however, affected by rectal tone which is not able to be determined and where broadly, tone represents a sustained stress which is capable of reducing the measurable CSA. This parameter could in theory be inferred by any $\Delta \varepsilon$ for a change in the slope of a conventional compliance curve during distension\textsuperscript{62,63}. Impedance planimetry is still experimental and in clinical practice, rectal pressures obtained during rectal compliance measurement tend to be lower than those obtained with IP methodology. This probably reflects
the different distension protocols used in these techniques as well as variations in the maximal CSA achievable and its relationship to the rectal sensation of maximal tolerable volume (MTV) during rectal inflation. The electromechanical barostat is an alternative approach which has been used in a more practical setting to correlate the P/V characteristics during equilibrated rectal distension with sensory rectal perceptions in an attempt to define both rectal wall stiffness and capacity. In this technique, a large, thin-walled polyethylene rectal bag is distended electronically up to a desired maximal volume with minimal elongation over 0–40 mmHg. The bag is presumed to have infinite compliance where distension may be created by either a ramp (continuous) or staircase (phasic) method and where the barostat maintains a constant pressure by a feedback mechanism which measures the P/V characteristics of the distension cycle. The device functions as an isotropic volumetric instrument with pressure equilibration at each step, normally producing a sigmoidal curve which has been correlated directly with the recognizable rectal sensations of first perception, earliest urge to defecate and painful maximal tolerable volume on a visual analog scale of pressure, sense of gas, urgency and pain. The components of the curve initially represent the muscular contraction activity in response to distension which will diminish as distension increases and which latterly will reflect the passive tension elements of the connective tissue gut components. At these distending volumes, the recorded barostat bag volume will be defined by the structural limits of rectal capacity where barostat volume at any pressure is expressed as a normalized rectal volume (rectal capacity – measured rectal volume/rectal volume at any pressure) expressed as a normalized rectal volume (rectal capacity – measured rectal volume/rectal volume at any pressure) expressed as a normalized rectal volume (rectal capacity – measured rectal volume/rectal capacity). This parameter will be somewhat analogous to the strain measured by IP methodology and would represent a more useful parameter than spot rectal compliance readings.

In normal circumstances, the P/V curve generated by the barostat shows no association with gender, BMI or age. At pressures of 40 mmHg, both rectal capacity and compliance show a direct correlation with corrections for variations in capacity resulting in reduced standard deviations for measured rectal compliance, suggesting that it is a more reliable and reproducible parameter. In normal patients, the barostat measurements of rectal capacity are unaffected by the sequence, rate or type of barostat distension. Experimental work has shown standardized reduction in rectal bag volumes in response to meals and a predictable range of tonic pharmacological agents with reductions in bag volume and increases in phasic contractions to neostigmine, the reverse effects with glucagon and a differential reduction on the upper and lower anal canal with atropine.

Barostat assessment of rectal disorders is still poorly characterized, where in fecal incontinence the contractile responses during inflation appear less rate-dependent, there is an increased duration of distension perception at lower sensory thresholds and there is more typically reduced rectal capacity and compliance values when compared with controls. Some recent data using the barostat after sacral neuromodulation shows a relative decrease in volume thresholds for first sensation, earliest urge to defecate and maximal tolerable volume during isobaric phasic distension along with lower pressure thresholds and tensions for all filling sensations without any demonstrable effect on compliance suggesting an important role in determination of sensory perception for the barostat with this intervention. In severe constipation the barostat has shown impairments in rectal sensation which correlate with altered measurable compliance, however, this is not a universal finding. This approach may be of value in categorization of such patients where most patients with idiopathic slow-transit constipation have shown alterations in rectal sensation and compliance but where rectal sensitivity is greater in patients with paradoxical puborectalis contraction in the absence of compliance changes.

Early assessments of rectal capacity using the barostat following total mesorectal excision and neorectal reconstruction show a progressive adaptation of compliance over the first year following surgery which appears to loosely correlate with reported episodes of urgency and incontinence. Late development of incontinence appears to be associated with a reduced neorectal capacity and occurs with poor recovery of the rectoanl inhibitory reflex (RAIR) usually ahead of a weakened anal sphincter. Interestingly, barostat assessments of patients undergoing transanal endoscopic microsurgery (TEMS) show an altered rectal compliance which persists even when the RAIR, rectal sensitivity and resting anal pressures have recovered, and this may better correlate with the fact that only three-quarters of patients remain fully continent after such procedures. Factors which more readily predict for post-TEMS incontinence include the preoperative presence of internal anal sphincter defects, low preoperative resting pressure, full-thickness TEMS resections and 50% circumferential resections although it is unknown at present whether preoperative barostat assessment may be predictive for post-TEMS incontinence.

There is currently no data comparing the clinical use of the barostat with that of IP methodology. Hans Gregersen, the father of IP has suggested that rather than the volume, pressure or tension within the recording system being of prime importance, what may be most critical in our interpretation of rectal wall biomechanics is the degree of deformation or strain which measures either elongation or compression in any given direction and which is most likely to stimulate mechanical wall receptors. IP is less affected by bag compliances and distension protocols than the barostat although both methods rely on different volume measurement technology in the face of a presumed minimal (or attenuated) muscle wall activity which is assumed to be independent of rectal geometry.

CONCLUSIONS

The biomechanical properties of living tissues are as important in the rectum as they have proven to be in the assessment of cardiovascular and urinary function. These hollow organs are subject to similar physiologic changes in wall stresses and strains and in the rectum an
improved understanding of viscoelastic properties as they pertain to markers of rectal sensibility and bolus transport mechanics which define disease states and activity is required. This article outlines the reasons why the use in anorectal physiology laboratories of rectal compliance as a clinical parameter is too simplistic and why there is great variation in the reported normal results. Spot compliance measures poorly reflect the nature of rectal distensibility and stiffness, being both technique- and operator-dependent. Compliance as a marker of rectal capacity is flawed, ignoring intrinsic rectal characteristics such as rectal size and geometry or wall thickness as well as extrarectal factors.

The physics of rectal distension in vivo is discussed in this review showing that standard inflation dynamics take no account of tissue anisotropy, viscoelastic properties such as stress relaxation, creep and hysteresis or inherent resting muscular tone. Newer methods of assessment of rectal compliance and capacity are discussed in this review, including impedance planimetry (IP) and the electromechanical barostat. Both of these methods use differing techniques during isobaric pressure equilibration to determine rectal volume; in one case by CSA determination and in the other by computerized volume measurement, but both methods make assumptions which are less reliant on the complexity of hollow organ geometry. Impedance planimetry has in this regard been successfully validated for use in the ureter and bladder \(^{49,50,84}\), the aorta \(^{35,55,86}\), the duodenum \(^{35,55,86}\), the oesophagus \(^{49,50,84}\), small intestine \(^{35,55,86}\) and the rectum \(^{54,55,86}\). Barostat recordings have been extensively used in the rectum and colon \(^{22,51,82}\) as well as in the oesophagus \(^{54,55,86}\) correlating in the former situation both with visual analog recordings of rectal sensitivity to distension and in response to pharmacodynamic modulation. This latter methodology appears to provide some evidence for the value of rectal capacity measurement in clinical and experimental practice showing less intra- and inter-personal variation than compliance calculation. Its role in the diseased rectum and in the quantitative parameter assessment of neorectal reservoirs and its function/symp-ton correlation where there is small capacitance, urgency, sepsis or evacuatory difficulty remains to be established.

**SUMMARY**

Procena parametara koji adekvatno reprezentuju rek-talnu i neorektalnu komplijansi je kompleksan. Biološke osobine rektuma tokom distenzije i relaksacije pokazuju značajno odstupanje od in vitro fizičkih merenja komplijanse. Biološke osobine rektuma tokom distenzije zavise od visoko elastičnih karakteristika deformacije šupljeg organa i od računanja komplijanse. Ovaj rad razmatra osobo-bine pritisak/volumena u rektumu za vreme distenzije iz perspektive bio-inženjeringa i naglašava disparitet izmeđju merenja kod živih bioloških sistema. Tehnike i zamke novijih metoda da se proceni čvrstina zida rektuma (planimetrija impedancije i merenje barostatom) razmatrane su u ovom radu.

**BIBLIOGRAPHY**

1. Outcome measures for fecal incontinence: anorectal structure and function. Gastroenterology 2004;126(1 Suppl 1):S90-8
5. Preston DM, Barnes PRH, Lennard-Jones JE. Proctometerogram: does it have a role in the evaluation of patients with constipation? Gut 1983; 24:86A


27. Rectal compliance as a routine measurement: extreme volumes have direct clinical impact and normal volumes exclude rectum as a problem. Dis Colon Rectum 2000; 43:1732-8


34. Dobrin PB. Mechanical properties of arteries. Physiol Rev 1978;58:397-460


63. Gregersen H, Orvar KB, Christensen J. Biomechanical properties of the duodenal wall and tone during phase I and phase II of the MMC. Am J Physiol 1992; 263: G795-G801


76. Sloots CE, Felt-Bersma RF. Rectal sensorimotor characteristics in female patients with idiopathic constipation with or without paradoxical sphincter contraction. Neurogastroenterol Motil 2003; 15: 187-93


92. Transient lower esophageal sphincter relaxations do not result from passive opening of the cardia by gastric distention. Gastroenterology 2006; 130:89-95

Acknowledgement: The author wishes to thank Professor Hans Gregersen for his critical review of this manuscript.