Int J Colorect Dis (1986) 1:231–237

International Journal of Colorectal Disease

An analysis of anal sphincter pressure and anal compliance in normal subjects

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Abstract. To investigate anal sphincter mechanics, anal pressure was measured in 14 normal males and 11 normal females using probes of 0.4 to 3 cm in diameter. Resting pressure profiles on insertion and withdrawal did not differ significantly. Antero-posterior pressure differences could be explained by leverage of rigid probes against the anterior rectal wall. A maximal voluntary squeeze increased pressure throughout the anus, whereas the recto-anal inhibitory reflex resulted in a greater reduction in pressure in the upper part of the anal canal. Resting pressure, squeeze pressure and minimum residual pressure (during rectal distension) rose with increasing anal diameter. Estimated sphincter tension was linearly related to anal diameter and the slope of this relationship was increased by sphincter contraction and reduced by sphincter relaxation. The deviation from linearity of this relationship at low anal diameters may be due to swelling of the anal cushions to maintain anal pressure when muscular tension approaches zero.

Measurements of anal sphincter pressure with narrow continuously perfused catheters or balloon probe systems [1–4] may be relevant only to the resting state and do not necessarily reflect the anal pressures prevailing during defaecation.

Alterations in anal pressure during the expulsion of solid stool depend primarily on the distensibility of the anus which is determined by its intrinsic mechanical properties. During normal defaecation these properties may be modified by the reflex inhibition of the internal and external anal sphincters, inferred from electromyographic (EMG) recordings [4].

Previous studies have shown that sphincter pressures recorded with balloon probes exceed those with narrow continuously perfused catheters [5–7]. However, the association between pressure and probe diameter is inconclusive. Gutierrez et al. [8] found that anal pressures recorded by continuously perfused catheters mounted in the wall of a hollow tube increased with the diameter of the recording assembly up to 1.5 cm, but Duthie et al. [9] found anal pressures to be independent of the probe diameter provided sufficient time was allowed for adaptation to occur.

The present study was undertaken to define more accurately the compliance characteristics of the anal canal in normal subjects in the resting state and to assess the effects on these characteristics of voluntary external sphincter contraction and internal sphincter relaxation.

Patients and methods

Patients

Measurements of anal pressure were performed on one occasion in 14 healthy male subjects (mean age 38.0 ± 20.2 years SD) and 11 healthy female subjects (mean age 42.2 ± 15.3 years SD). All subjects had a normal bowel habit with a defaecation frequency per week of 9.6 ± 5.2 (SD) for the males and 6.8 ± 1.9 (SD) for the females. No subject had perineal descent or any other ano-rectal abnormality. Small asymptomatic first degree haemorrhoids were considered normal.

Recording methods

A series of cylindrical rigid plastic probes, 12 cm long, 1–3.5 cm in diameter and tapered at one end was used (Fig. 1). Each probe carried four polyvinyl tubes of 1.14 mm internal diameter arranged radially at 90° around the circumference of the probe and inset into the barrel to maintain a smooth profile. Each tube ended blindly but possessed a side opening 4 cm from the tip of the probe. In addition, a 0.4-cm diameter probe was constructed by embedding four identical tubes, arranged radially at 90°, in epoxy resin with identical side holes 1.5 cm from the tip. This probe was semi-rigid to avoid the risk of penetrating the anterior rectal wall.

Each tube was continuously perfused with degassed water at 1 ml/min by a low compliance perfusion apparatus (Mui PIP2, Mississauga, Toronto, Canada). A pressure transducer (Statham 230B, Oxnard, Calif, USA), was incorporated into the infusion line and the output of the transducer was connected to an amplifier and chart recorder (Hewlett Packard Co, Waltham, Mass, USA).

No bowel preparation was used but the subjects were invited to defaecate prior to the test if they felt the desire to do so.

Prior to recording, an inflatable balloon, connected to a narrow catheter (inside diameter 1.14 mm, outside diameter 1.5 mm) was inserted into the lower rectum via a proctoscope with the subject in the left lateral position. (Pilot experiments showed that the presence of this catheter did not significantly affect the recorded pressure.) The 0.4-cm recording probe was well lubricated and introduced into the anal canal so that the side holes remained in the anterior, posterior and left and right lateral positions. After a period of 30 s to allow pressures to stabilise, recordings were made at 1-cm stations on insertion and withdrawal, allowing at least 15 s at each station for a plateau to be reached. Resting pressure profiles on insertion and withdrawal were thereby attained. Following this, a maximum squeeze pressure profile was constructed on insertion using the average peak pressure attained during two 10-s maximum voluntary sphincter contractions at each station, allowing 15 s for stabilisation between contractions.

In 7 male and 3 female subjects pressure profiles were then constructed using the minimum residual pressure achieved during reflex internal sphincter relaxation induced by the inflation of the rectal balloon with 100 ml air for 1 min at each station. (This volume was selected because it caused maximal internal sphincter relaxation with minimal external sphincter contraction.) One minute was allowed for stabilisation between inflations. In the remaining subjects reflex internal sphincter inhibition was tested by inflating the rectal balloon at the station of maximum resting pressure only. The whole procedure was repeated using the 1- and 2-cm probes, in that order. Subsequent progression to the 2.5- or 3-cm probes depended on subject tolerance. Seven of 14 males and 10 to 11 females tolerated the 3-cm probe. Of the remaining 7 males, 6 tolerated the 2.5-cm probe.

In 18 subjects the adaptation of the anal canal was assessed by recording with the 0.4- and 2-cm probes in random sequence for 10 min at the point of maximum resting pressure.

In 1 subject electromyography of the external anal sphincter was performed using a bipolar electrode as described by Read et al. [10].

The studies were approved by the Ethical Committee of the Royal Hallamshire Hospital on 3 October 1983.

Treatment of results

Resting pressures at each quadrant (anterior, posterior and right and left lateral) were compared at each station. The average pressure at each station was calculated and used to construct longitudinal pressure profiles during insertion and withdrawal. The mean of maximum resting pressures achieved on insertion and withdrawal of each probe was plotted against probe diameter to obtain the anal compliance curve at rest. Similar compliance curves were constructed using the maximum squeeze pressures and the minimum residual pressures (during inflation of the rectal balloon). Sphincter tension was calculated using Laplace's law. Assuming that the sphincter behaves as a thin walled elastic tube, $T' = Pd/2$, where T' = estimated sphincter tension per unit length, P = recorded pressure, d = diameter or probe. Maximum sphincter tension for each probe was then plotted against the diameter of the anus at rest, during maximum squeeze and during reflex inhibition of the internal anal sphincter. The slope and intercept of the resulting line for each subject was calculated by the method of least squares and the mean ± SEM calculated for each of these indices in males and females. Comparisons were made between different slopes or intercepts using Dunnett's t-test [11] or Student's t-test where appropriate.

Results

On insertion of a probe there was an immediate peak in pressure in all patients which decayed to a plateau value within 15 s (Fig. 2). Movement of a probe within the anus also caused a brief rise in pressure which again returned to a stable level within 10 s. In 1 patient in whom the external

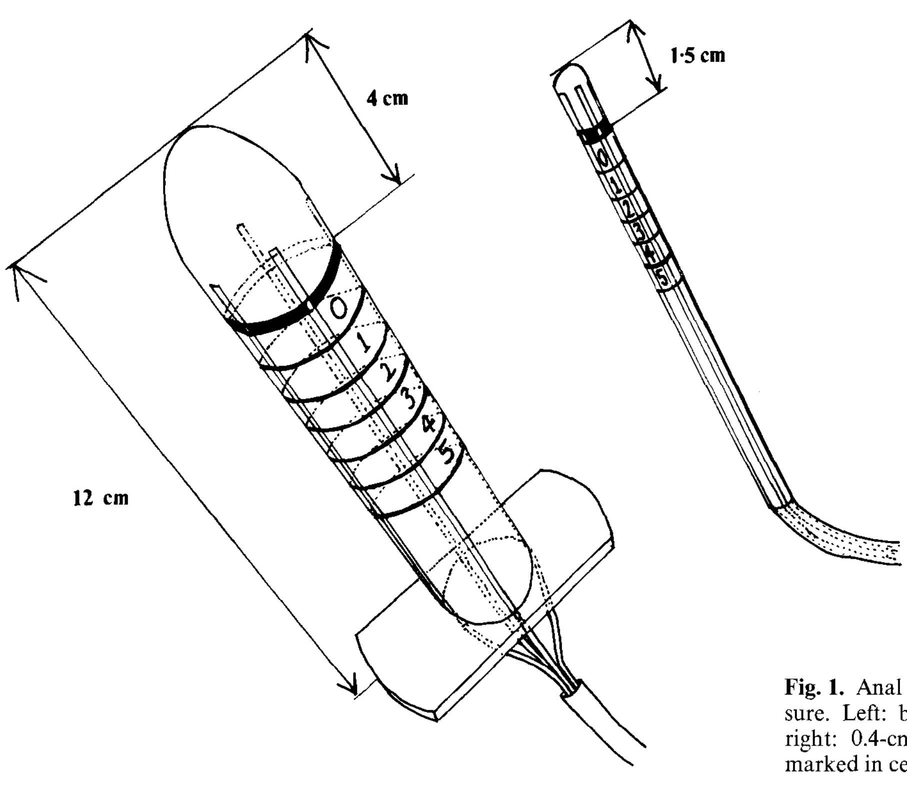

Fig. 1. Anal probes used for measurement of anal pressure. Left: basic design of 1- to 3-cm diameter probes; right: 0.4-cm-diameter probe. In each case distance is marked in centimetres from site of open ports

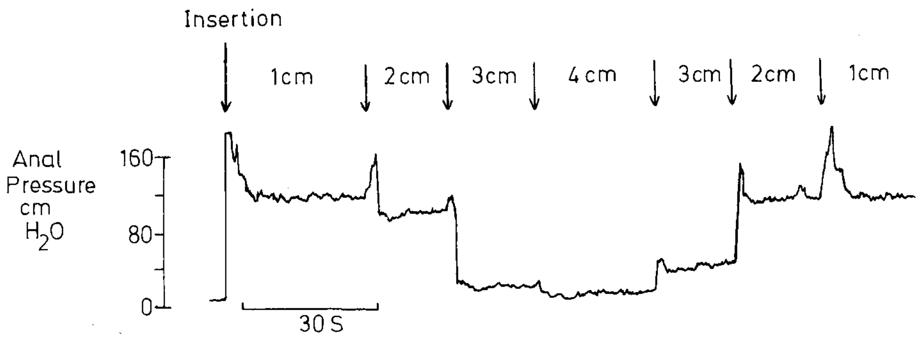

Fig. 2. Pressure recording at four consecutive stations using 2-cm probe in a normal female

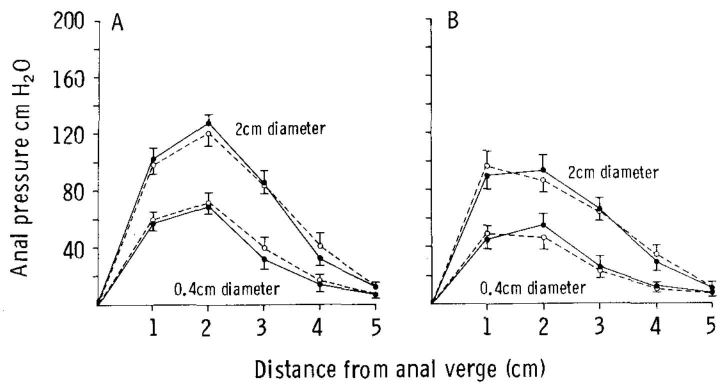

Fig. 3A and B. Comparison of insertion and withdrawal pressure profiles using 0.4-cm and 2-cm probes in **A** 14 normal males and **B** 11 normal females. Each point represents mean ± SEM. ●—● insertion; ○---○ withdrawal

sphincter EMG was simultaneously recorded, a peak in electrical activity was found to accompany the anal pressure rise on insertion or movement of a probe within the anus and this also decayed to baseline values within 30 s whilst the anus remained distended. No further change in pressure occurred over 10 min during continuous recording at the point of maximum resting pressure. In 8 males the ratio of the pressures measured at 10 min and at 30 s was 1.023 ± 0.223 (SD) and 0.988 ± 0.190 (SD) using the 0.4-cm and 2-cm probes respectively (not significant by paired *t*-test). The equivalent values for 10 females were 1.022 ± 0.214 (SD) and 0.960 ± 0.104 (SD) respectively (not significant).

Ultra slow waves (regular pressure fluctuations with a frequency less than 2 cycles/min and an amplitude of at least 25 cm H_2O) were found in 2/14 (14%) males and 3/11 (26%) females using the 0.4-cm probe and in 2/14 (14%) males and 2/11 (18%) females with the 2-cm probe.

Longitudinal pressure profiles

Longitudinal pressure profiles (taking the mean of 4 radial pressures) on insertion and withdrawal were similar (Fig. 3). The average of pressures recorded at each station during insertion and withdrawal were used in subsequent calculations. In women, distension of the anal canal altered the shape of the pressure profile, the maximum pressure occurring at the 1-cm station instead of the 2-cm station (Fig. 4). In men, the maximum pressure was recorded at the 2-cm station with each probe.

When subjects contracted their anal sphincter maximally, anal pressures rose approximately fourfold in men and threefold in women throughout the anus.

In seven males subjects profiles were constructed for the minimum residual pressure during inflation of the rectal balloon. These were compared with the resting and squeeze pressure profiles of the same subjects in Figure 5. Inflation of the rectal balloon tended to cause a proportionately greater fall in pressure at the 2-cm (66%) or 3-cm (50%) stations than at 1 cm (33%) from the anal margin, altering the shape of the pressure profile so that the greatest pressure was recorded at 1 cm.

Radial differences in pressure profile

Resting pressure profiles recorded via the anterior port were not significantly different from those recorded via the posterior port using the 0.4-cm probe. For all other probes the pressures recorded from the caudad part of the anus were lower posteriorly than anteriorly, while those recorded from the orad part were lower anteriorly than

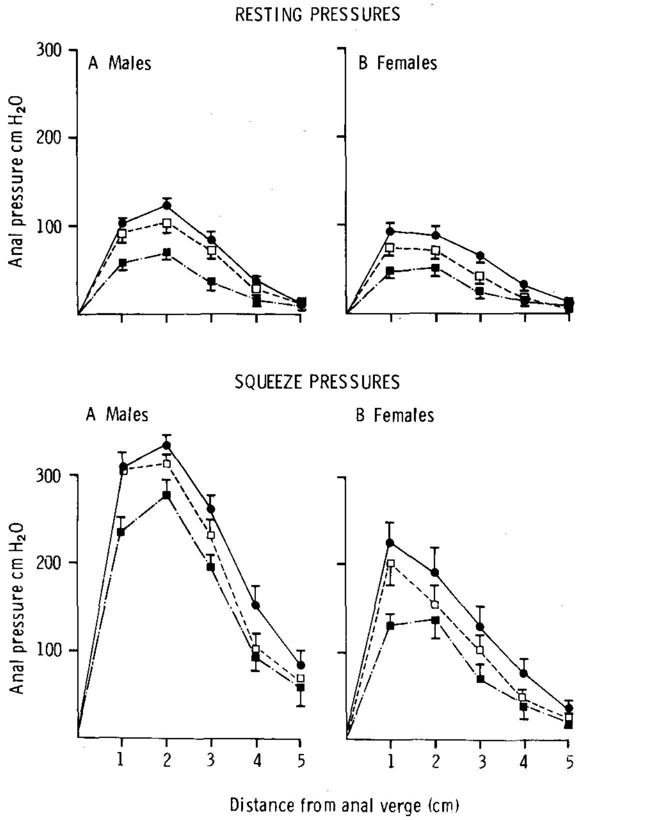

Fig. 4. Resting and squeeze pressure profiles using 0.4 cm, 1 and 2-cm probes. Each point represents mean ± SEM. ●—● 2 cm; □---□ 1 cm; ■·—·—■ 0.4 cm

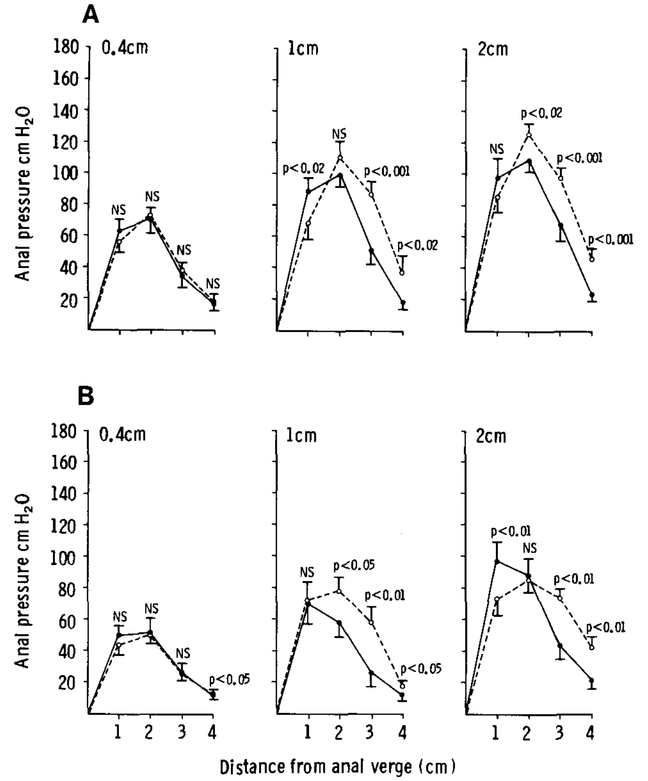

Fig. 6A and B. Pressure profiles recorded via anterior and posterior ports (shown in top left hand corner of each graph) using probes of increasing diameter in **A** 14 males and **B** 11 females. Each point represents mean ± SEM. Comparisons by paired *t*-tests. ●—● anterior; ○---○ posterior

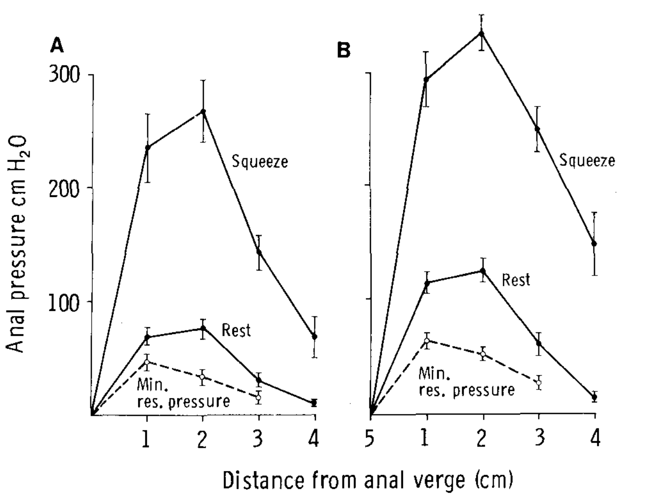

Fig. 5A and B. Resting, squeeze and minimum residual pressure (during inflation of 100-ml rectal balloon) profiles in 7 normal male subjects, using **A** 0.4- and **B** 2-cm diameter probes. Each point represents mean ± SEM

posteriorly (Fig. 6). Right and left lateral pressure profiles were, however, not significantly different.

Pressure-diameter relationships

Maximum resting, maximum squeeze and minimum residual pressures (at the station of maximum resting pressure) were recorded in all 25 subjects. In both males and females maximum squeeze pressures were significantly ($p < 0.001$) more than resting pressures at all diameters. Compliance curves were constructed from the available data (Fig. 7). Pressures rose consistently with anal diameter from 0.4 cm to 2 cm but reached a plateau thereafter. Analyses of variance for resting, squeeze and minimum residual pressures at 0.4 cm and 2 cm showed the increases in pressure with diameter to be highly significant in both men and women ($p < 0.001$). Resting and squeeze pressures were significantly higher in males than females ($p < 0.001$). However, there was no significant difference between minimum residual pressures in men and women. Qualitatively similar results were obtained when integrated resting or squeeze pressures (the sum of pressures recorded at 1-cm stations throughout the anal canal) were substituted for maximum resting or squeeze pressures.

Tension-diameter relationships

Figure 8 shows the observed variation of estimated sphincter tension ($T' = Pd/2$) with diameter for maximum squeeze, resting and minimum residual pres-

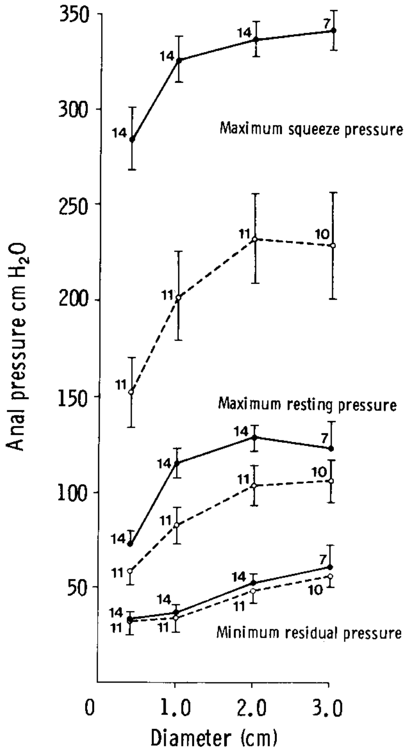

Fig. 7. Anal compliance curves during rest, maximum squeeze and at minimum residual pressure during inflation of a 100-ml rectal balloon in 14 normal males and 11 normal females. Each point represents mean ± SEM. (Number of observations adjacent to one point). ●—● males; ---○ females

sures in men and women. The relationships are linear for diameters between 0.4 and 3 cm. The slope and intercept values for these are shown in Table 1. Enhancing anal 'tone' by squeezing increases the slope ($p < 0.01$ by Dunnett's t-test) and reducing anal 'tone' by the recto-anal inhibitory reflex decreases it ($p < 0.01$). The slopes for maximum squeeze and resting pressures, but not for minimum residual pressure, were significantly greater for men than for women ($p < 0.01$ by Student's t-test). There was no significant difference between the intercept values for squeeze, resting or minimum residual tension-diameter relationships or between equivalent values in men and women.

Discussion

Our results show that the recorded value of anal pressure is dependent upon the diameter of the recording probe, confirming and extending the preliminary report of Gutierrez et al. [8]. The effect explains the differences between pressures recorded with large and small balloons or balloons and narrow open tipped catheters [5–7]. The suggestion of Duthie et al. [9] that anal pressure recorded after a 5- to 10-min period of adaptation is independent of the diameter of the recording apparatus is not confirmed.

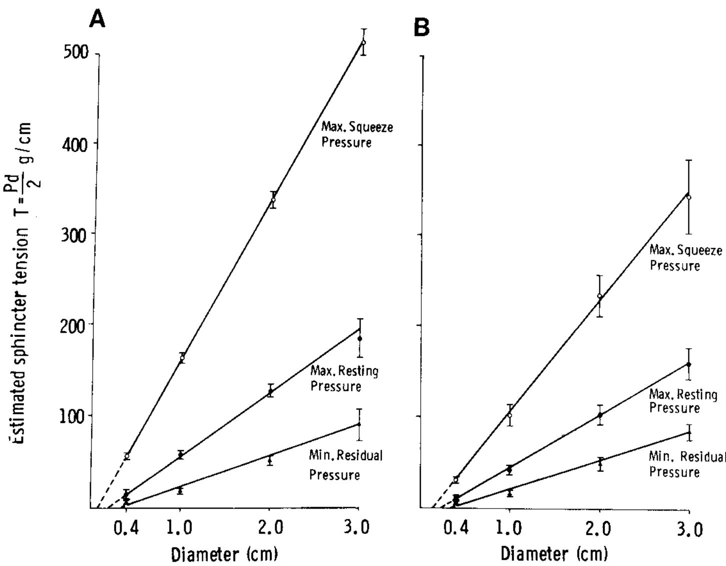

Fig. 8 A and B. The relationship of estimated sphincter tension and diameter for **A** 14 normal males and **B** 11 normal females under conditions of maximum squeeze, at rest and at the minimum residual pressure during inflation of a restal balloon with 100 ml air. Each point represents mean ± SEM. Each line represents the mean of lines calculated for each subject by the method of least squares (including 2.5-cm-diameter values where available)

Table 1. Slope and tension intercept values for the relationship between estimated sphincter tension and anal diameter in normal male and normal female subjects

Conditions of measurement	Male		Female	
	Slope[a] g cm^{-2}	Intercept[a] g cm^{-1}	Slope[a] g cm^{-2}	Intercept[a] g cm^{-1}
Max resting pressure	70.5 ± 4.4	−12.92 ± 2.57	57.5 ± 4.2	−12.66 ± 1.37
Max squeeze pressure	177.1 ± 3.6	−13.95 ± 4.37	126.3 ± 12.6	−18.48 ± 4.51
Min residual pressure	32.8 ± 3.5	−10.33 ± 2.87	31.0 ± 2.8	−10.84 ± 2.84

[a] Mean ± SEM

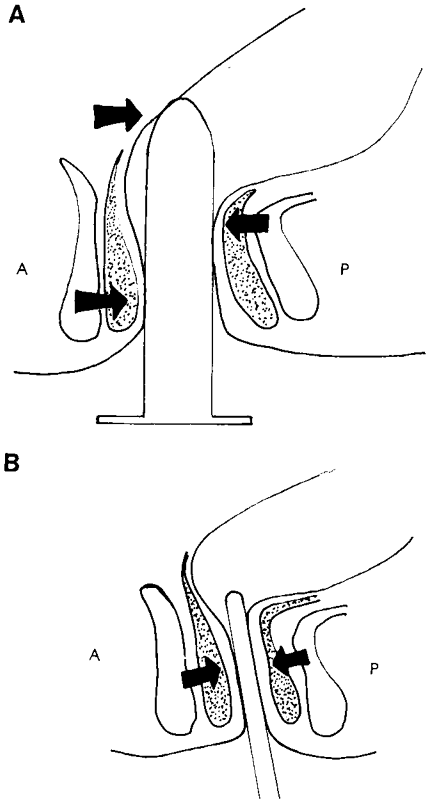

Fig. 9A and B. Diagrammatic representation of the forces acting on **A** a rigid probe and **B** a semi-flexible 0.4-cm probe in the anal canal

Under the conditions of the present study, an immediate pressure increase occurred on insertion of a probe, but this decayed to baseline within 15 s with no significant further adaptation occurring over a 10-min period. This initial rise and subsequent decay may be partly explained by the mechanical properties of collagenous tissues, which, after impulsive loading, relax immediately in a logarithmic fashion, reaching a relatively stable plateau within a few seconds [12, 13]. In addition, introduction or movement of a probe within the anus appears to stimulate receptors in the lower anus, probably within the anoderm, thereby evoking reflex external sphincter activity.

Steady-state pressure profiles on insertion and withdrawal were similar, demonstrating that little movement of the anal verge occurred in relation to the sphincter. The proportional increase in resting anal pressure with increasing probe diameter was of the same order of magnitude throughout the anal canal, implying that no part of the anus reached its elastic limit. Contraction of the external anal sphincter increased the pressure throughout the anal canal, but the absolute rise was greater distally, as would be predicted from the anatomy of the external sphincter. Distension of the rectum with a balloon relaxes the internal anal sphincter [3, 4, 14] and causes a proportionately greater reduction in pressure at 2 cm and 3 cm from the anal verge than at 1 cm. The internal sphincter is therefore responsible for a greater proportion of the resting pressure in the upper part of the anal canal and may open like a funnel on relaxation [15].

When rigid probes were used, the resting pressures in the upper part of the sphincter were higher posteriorly than anteriorly, whereas they were higher anteriorly in the lower sphincter. Taylor et al. [16] ascribed this phenomenon to the direction of pull of the muscular slings which constitute the puborectalis and external anal sphincter [17]. This cannot be the complete explanation, however, since these forces would create a turning moment which would rotate the probe to remove the radial asymmetry unless it was balanced by an opposing moment. The opposing force was not provided by the observer since the effect was seen with a 1-cm probe, left free in the anus at each station. (A steadying hand was usually required to prevent the extrusion of larger probes.) More probably, it originated from pressure on the anterior rectal wall as the probe negotiated the ano-rectal angle. Support for this interpretation is provided by the similarity of anterior and posterior profiles with the 0.4-cm probe, which was semi-flexible and possessed side holes closer to the tip (Fig. 9). This artefact was eliminated from other calculations by taking the mean of the four radial pressures at each station.

Anal pressures were significantly lower in women than men and there was a tendency towards a shorter high pressure zone in females, as noted by others [16, 18]. The slight difference between men and women in the effect of anal distension on the shape of the pressure profile may be related to the relative shortness of the female anal canal.

The changes in pressure with increasing diameter of the recording assembly are believed to reflect the predominant mechanical properties of the anal canal. The linearity of relationship between estimated sphincter tension and anal diameter may be related to the elasticity of the sphincter [19], and the change in the slope of this relationship with changes in the contractile state of the sphincter may be due to alterations in elasticity. Extrapolation of the linear relationship between tension and anal diameter indicates that tension (and therefore pressure) tends to zero at a positive internal anal diameter. In other words, the anus should not close. In practice this is not the case since none of the subjects was incontinent of faeces and, as can be seen in Figure 8, this linear relationship begins to break down at the lowest probe diameter during rectal distension. Possible causes for this include an increase in the thickness of the sphincter as it passively contracts or an increase in the thickness of the anal lining as it bunches at small diameters, or the inherent non-linearity of the stress-strain relationship in biological tissues.

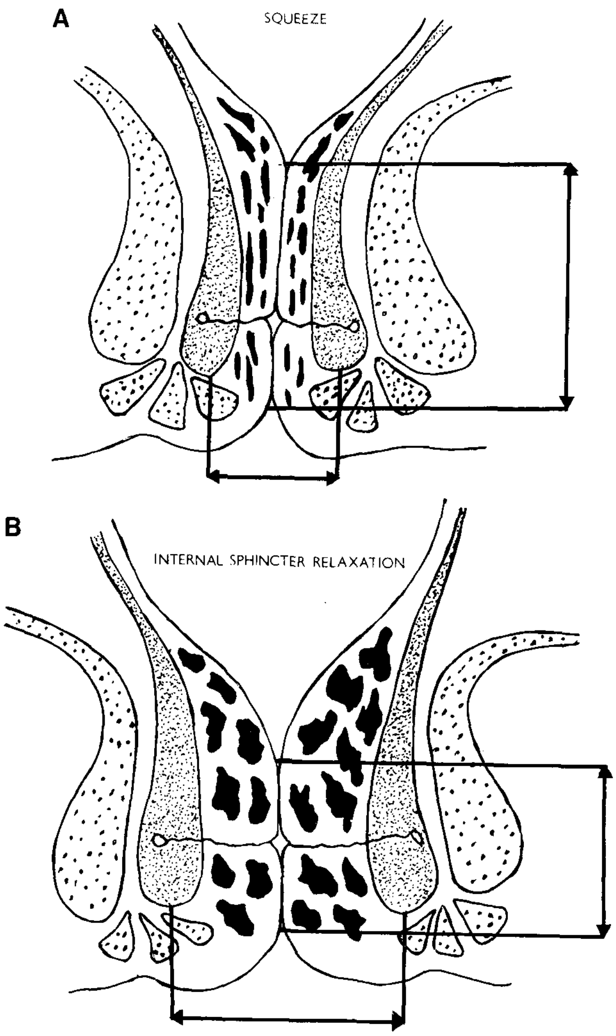

Fig. 10 A and B. Proposed mechanism for the maintenance of continence by the anal cushions. During a maximal squeeze the anal cushions are compressed, expelling blood from the vascular spaces (upper) which fill during internal sphincter relaxation (lower). Vertical lines show the effective length of the anal sphincter. Transverse lines show the diameter of the internal anal sphincter

However, there is a further possible mechanism: the anal lining is specialised to form three anal cushions containing vascular spaces [20]. Because they are directly supplied by arterio-venous communications, the hydrostatic pressure within the vascular spaces must lie somewhere in between venous and arterial pressures. Should the anal pressure fall beneath this value, blood will enter and distend the anal cushions, whereas at higher pressures they would be compressed (Fig. 10). This mechanism could provide some degree of autoregulation, ensuring the maintenance of anal pressure at rest and preventing the anus gaping during sphincter relaxation. It would also explain the importance of preserving the anal lining (in particular the anoderm lining the zone of maximum pressure) in haemorrhoidectomy and in sphincter saving resections of the rectum to maintain continence [21]. In the present study, distension of the anus by the larger recording probes would have compressed the anal cushions, reducing the thickness of the anal lining, and so give rise to the anomalous intercept values.

References

1. Dickinson VA (1978) Maintenance of anal continence: a review of pelvic floor physiology. Gut 19:1163–1174
2. Schuster MM (1975) The riddle of the sphincters. Gastroenterology 69:249–262
3. Ihre T (1974) Studies on anal function in continent and incontinent patients. Scand J Gastroenterol [Suppl] 25:1–64
4. Kerremans R (1969) Morphological and physiological aspects of anal continence and defaecation. Editions Arsica SA, Brussels
5. Hill JR, Kelley ML, Schlegel JF, Code CF (1960) Pressure profile of the rectum and anus of healthy persons. Dis Colon Rectum 3:203–209
6. Duthie HL, Watts JM (1965) Contribution of the external anal sphincter to the pressure zone in the anal canal. Gut 6:64–68
7. Hancock BD (1976) Measurement of anal pressure and motility. Gut 17:645–657
8. Gutierrez JG, Oliai A, Chey WY (1975) Manometric profile of the internal anal sphincter in man. Gastroenterology 68:907 (Abstract)
9. Duthie HL, Kwong NK, Brown B (1970) Adaptability of the anal canal to distension. Br J Surg 57:388 (Abstract)
10. Read NW, Haynes WG, Bartolo DCC, Hall J, Read MG, Donnelly TC, Johnson AG (1983) Use of anorectal manometry during rectal infusion of saline to investigate sphincter function in incontinent patients. Gastroenterology 85:105–113
11. Dunnett CW (1964) New tables for multiple comparisons with a control. Biometrics 20:482–491
12. Haut RC, Little RW (1972) A constitutive equation for collagen fibres. J Biomech 5:423–430
13. Trowbridge EA, Black MM, Daniel CL (1985) The mechanical response of glutaraldehyde fixed bovine pericardium to uniaxial load. J Mat Sci 20:114–140
14. Schuster MM, Hookman P, Hendrix TR, Mendeloff AI (1965) Simultaneous recording of internal and external anal sphincter reflexes. Bull Johns Hopkins Hosp 116:79–88
15. Phillips SF, Edwards DAW (1965) Some aspects of anal continence and defaecation. Gut 6:396–406
16. Taylor BM, Beart RW, Phillips SF (1984) Longitudinal and radial variations in pressure in the human anal sphincter. Gastroenterology 86:693–697
17. Shafiq A (1975) A new concept of the anatomy of the anal sphincter mechanism and the physiology of defaecation. The external sphincter: a triple loop system. Invest Urol 12: 412–419
18. Read NW, Bannister JJ (1985) Anorectal manometry: techniques in health and anorectal disease. In: Henry MM, Swash M (eds) Coloproctology and the pelvic floor: pathophysiology and management, Ch 4. Butterworths, London, pp 65–87
19. Gibbons CP, Trowbridge EA, Bannister JJ, Read NW (1986) Role of anal cushions in maintaining continence. Lancet 1:886–887
20. Thompson WHF (1975) The nature of haemorrhoids. Br J Surg 62:542–552
21. Goligher JC (1980) Surgery of the anus, rectum and colon, 4th edn. Balliere Tindall, London

Accepted 7 July 1986

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