OBSERVATIONS ON SOME MOTILITY DISTURBANCES OF THE HUMAN DISTAL BOWEL AND PELVIC FLOOR

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CONTENTS

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Formal approval was obtained from the Ethical Committee of the North Lothian District, Lothian Health Board, Edinburgh, Scotland, on the 16th of June 1983 to perform the investigations described in this thesis. In addition, informed consent was obtained from all the participants.

ABBREVIATIONS AND UNITS OF MEASUREMENT

A	Amperes
cGy	CentiGrays
cm	Centimetres
CSA	Coloanal sleeve anastomosis
CSP	Pressure (rectal) at constant sensation (cm H2O)
CSV	Volume (rectal) at constant sensation (ml H2O)
DN	Dorsal nerve (of penis or clitoris)
EAS	External anal sphincter muscle
EMG	Electromyography
FI	Faecal incontinence
H&E	Haematoxylin and eosin
H2O	Water
HPZ	High pressure zone or functional sphincter length (cm)
Hz	Hertz
IAS	Internal anal sphincter muscle
MRP	Maximum resting or basal (anal canal) pressure (cm H2O)
mA	Milliamperes
MI	Motility index
ml	Millilitres
mm	Millimetres
ms	Milliseconds
MTP	Maximal tolerable (rectal) pressure (cm H2O)
MTV	Maximal tolerable (rectal) volume (ml H2O)
MUPD	Mean motor unit potential duration (ms)

MVC	Maximal voluntary contraction pressure (cm H2O)
n	Numbers (of subjects) studied
NS	Not statistically significant ($p>0.05$)
p	Probability (statistical significance value)
P	Pressure (ml H2O)
PAR	Pudendo-anal reflex
PR	Puborectalis muscle
r	Correlation coefficient
RC	Rectal compliance
RSR	Rectosphincteric reflex (relaxation of IAS)
s	Seconds
S2,S3,S4	Sacral segments 2,3 and 4
SD	Standard deviation
SEM	Standard error of the mean
SP	Squeeze pressure (cm H2O)
STP	Pressure at (rectal) sensory threshold (cm H2O)
STV	Volume at (rectal) sensory threshold (ml H2O or air)
UM	Urethral mucosa
US	Urethral sphincter
V	Volts, or Volume (ml H2O or air)
μV	Microvolts

ABSTRACT

Three new methods of anorectal manometry and electrophysiology are described and evaluated. These are the microtransducer, the proctometrogram and the pudendo-anal reflex. With the aid of these and other techniques the pathophysiology of colorectal and pelvic floor dysfunction has been investigated in incontinence, some forms of constipation and after chronic radiation anorectal injury. The three methods are demonstrated to be highly reproducible. The proctometrogram provides useful information on rectal volume, compliance and sensory function. The latency of the pudendo-anal reflex in health is 38.5±5.8 ms (mean±SD). It does not appear to vary with age or sex in health but is significantly prolonged in neurogenic faecal and stress urinary incontinence and is shown to provide a useful index of neuropathy in these disorders.
Following symptomatic chronic radiation anorectal injury, there are significant manometric abnormalities of internal anal sphincter function. The striated external sphincter remains manometrically normal but concentric needle EMG abnormalities are demonstrable. Rectal function is severely compromised with loss of volume and compliance. The latter correlates significantly to symptomatic and sigmoidoscopic parameters. Histological evidence suggests that myenteric plexus damage and smooth muscle hypertrophy are contributory. Some of the manometric abnormalities persist and are responsible for the functional results following colo-anal anastomosis for radiation injury, although the longterm clinical results are acceptable.
The differential influence of segmental sacral outflow on colorectal motility were investigated by a study on spinally injured patients with sacral anterior root stimulators implanted for electromicturition. There is a major contribution from S3 to colorectal contractility, this response being frequency-dependent. S2 stimulation resulted in minor low-pressure contractions. S4 appears to be dedicated to innervation of the pelvic floor musculature.
Studies in constipation in the elderly demonstrate two predominant types of disorder: a megarectum syndrome and a hypertonic distal bowel. Deficits of rectal sensory perception are present in both groups. In many patients delays in transit occur due to rectal stasis. In 2 out of 17 patients intraluminal bisacodyl failed to elicit a sigmoid colon motor response. Abnormalities of the pudendo-anal reflex suggest that sacral spinal cord function may be compromised in this group and contribute to the observed functional disturbances.
There is evidence from preliminary neurophysiological studies in young women with chronic idiopathic constipation that neurogenic abnormalities of the conus medullaris may exist in the absence of sphincteric denervation.

SECTION 1

INTRODUCTION

Fired by the challenge to understand the functional abnormalities that result from disease states, the motility of the gastrointestinal tract has intrigued investigators since the beginning of this century. In the quest for knowledge and cure, many a reknowned treatise was written by the giants of gastrointestinal physiology of the earlier years, often establishing principles that have stood the test of decades. The works of Pavlov, Cannon, Schafer, Bayliss, Hurst, and Alvarez will be familiar to most in this field.

Nevertheless, many of the physiological mechanisms of colonic propulsion, defaecation and continence remained elusive. For many years the anorectum has been a forbidden area for both the physiologist and clinical scientist. Few ventured near, and as a consequence the region has been slow to reveal its secrets. The early pioneers spent much time inserting pressure probes of various designs into the anal orifice. Arguments raged over whether balloons, perfused tubes or strain gauges were the optimum instruments for measurement. The technical problems were further compounded by the difficulties of interpretation of the vast amount of data on pressure events often recorded in unphysiological states. As the intrepid pioneers became bolder the advent of crude electromyography saw some further advances but the investigation remained confined to a handful of committed, yet often outstanding, enthusiasts (Kerremans, 1969).

Dr. Walter C. Alvarez wrote in the preface to the second edition of his 'Introduction to Gastroenterology' in 1940:

'I have an idea that gastroenterology is some day going to forge ahead spectacularly much as cardiology did at the beginning of this century'

Over the last ten years the situation has indeed changed dramatically. The impact of new technology and the enthusiasm with which many investigators have tackled basic physiological questions has been rewarded with with an explosion of information related to the anorectum and its pathophysiology (Henry and Swash, 1985). The crude manometric and EMG measurements have led the way to more sophisticated techniques which utilize microtransducers, telemetry capsules, and hair-like wire electrodes. There has been greater emphasis on dynamic and simultaneous measurement rather than the static, isolated investigation. It is now possible to measure anorectal pressure and electromyographic sphincter activity while simultaneosly visualising the anorectum by radiology (Womack et al, 1985). The pressure-volume relationships and sensitivity of the rectum to distension can be monitored continuously in the same useful way as cystometry (Varma and Smith, 1986). The precise measurement of several polysynaptic reflex latencies involving the perineal musculature (Smith and Varma 1984; Fidas et al, 1985; Varma et al, 1986, 1987) has enabled a more physiological evaluation of entire neural pathways rather than techniques that measure the integrity of motor pathways only. Newer techniques have emerged to assess the perineal sensory deficits in

functional anorectal and urological disorders which have for so long been ignored (Powell and Feneley, 1982; Fidas et al,1985; Roe et al, 1986; Varma et al, 1987; Miller et al, 1987). These methods of measurement of anorectal and pelvic floor function are rapidly emerging from being research tools into a service requirement (Smith and Varma, 1986). The number of patients requiring such investigations will continue to rise as longevity increases and the range of sphincter-saving surgery extends.

Much of the information generated has real practical value. The studies of the late Sir Alan Parks and his colleagues from St. Mark's Hospital, London, have made outstanding contributions in establishing the aetiology of so-called 'idiopathic' faecal incontinence and some forms of rectal prolapse. The earlier histological studies on operative muscle biopsies suggested a denervation disorder (Parks et al, 1977, 1979; Beersiek et al, 1979). With the aid of single fibre EMG of the anal sphincter musculature, this hypothesis was able to be confirmed (Neill et al, 1981). Further studies using sophisticated nerve conduction techniques suggested an injury to the terminal portion of the pudendal nerve as the causative factor (Kiff and Swash, 1984). The puborectalis was shown to have a separate innervation from the external anal sphincter (Percy et al, 1981) but this too was affected in 'neurogenic' incontinence (Bartolo et al, 1983; Snooks et al, 1985). Chronic straining at stool is one factor that can result in a stretch injury to the sphincter musculature resulting in incontinence (Kiff et al, 1984). Various obstetric factors are now also recognised to predispose women to this hazard (Snooks et al, 1985).

Proctography has shown widening of the anorectal angle in many but not all incontinent patients with sphincter denervation (Hardcastle and Parks, 1970; Read et al, 1984). This angle is normally maintained by the forward pull of the puborectalis sling which is in a state of tonic contraction. Return of continence can be promoted by Parks' post-anal repair which mecanically butresses the sphincter complex posterior to the anal canal (Parks, 1975). The precise mechanism for the success of Parks' operation, however, remains unclear (Hardcastle and Parks, 1970; Preston et al, 1984; Womack et al, 1986) probably due to our lack of complete understanding of the sophisticated mechanisms responsible for anal continence (Bartolo et al, 1986). Genuine stress incontinence of urine, for long thought to be a purely mechanical disorder, is likewise beginning to be better understood. It is now recognised to have an important neurogenic element to it, both motor and sensory deficits being able to be defined by the same new techniques as for anorectal incontinence (Varma et al, 1987).
The understanding of various forms of chronic constipation has also been considerably aided by the new technolology. Studies with sacral anterior root stimulators have been able to define the differential influences of the sacral outflow on colorectal and pelvic floor motility (Varma et al, 1986). There is evidence of autonomic nerve damage in the small proportion of women who develop intractable constipation following hysterectomy (Varma et al, 1985, 1986). In the chronic idiopathic constipation of young women (Arbuthnot Lane's disease, 1901) combined proctography and EMG measurements have confirmed the initial suspicion (Preston and Lennard-Jones, 1981; Barnes and Lennard-Jones, 1984, 1985) that an important functional

disturbance lies in an inappropriate contraction (and/or failure of relaxation) of the puborectalis muscle during attempted defaecation (Womack et al, 1985). Our own electrophysiological studies appear to suggest that at least some of these women may have occult neurogenic deficits in the sacral spinal cord (Varma and Smith, 1984) associated with a high incidence of lumbosacral dysraphism similar to that seen in some functional urological disorders (Galloway and Tainsh, 1985; Fidas et al, 1987). Somewhat similar disturbances have also been described in elderly patients with chronic constipation (Varma and Smith, 1985) and faecal impaction (Read et al, 1985).

It seems important to identify the group of patients with paradoxical puborectalis spasm ('anismus') so that appropriate treatment can be instituted. At present the treatment for many such women is total colectomy with ileorectal anastomosis. The rationale for this operation under such conditions is difficult to defend, but until modification of the anorectal abnormalities can be achieved by other means, colectomy may offer the only successful means of treatment. Whether biofeedback will be successful remains to be determined. Other radiological abnormalities are often seen in such patients with constipation (Bartolo et al, 1986), their precise importance being uncertain. Attempts to correct them surgically have infrequently relieved the constipation (Roe et al, 1986). Proctography has also aided our understanding of the solitary rectal ulcer syndrome (Womack et al, 1986), confirming a 'dyskinetic' contraction of the pelvic floor, sometimes with rectal intussusception.

As improvements in technology continue so will our understanding of the basic concepts of colorectal and pelvic floor function. Such basic

information will help to explain problems encountered after the increasing number of sphincter-preserving procedures that are now being performed, e.g. low anterior resections, pelvic pouch procedures (Naysmith et al, 1986; Martin et al, 1986; Deasey et al, 1987) and colo-anal pullthrough procedures such as those done for complicated radiation injury to the rectum (Varma and Smith, 1986). A better understanding and appreciation of post-operative functional problems will undoubtedly lead to further improvements in surgical technique and 'quality control'. In Ivan P. Pavlov's own words:

'I am convinced that it is by frequent interchange of opinion between the physiologist and the physician that the common goal of physiological science and medical art will be most quickly and safely reached.'

Increased co-operation between various disciplines also brings patients into contact with other specialists. Patients under the care of geriatricians, urologists, gynaecologists and radiation oncologists may, for example, require joint management of faecal and urinary incontinence, procidentia, constipation, radiation intestinal injury and other seemingly intractable bowel and pelvic floor disorders. The contribution of methodology and measurement to the understanding of some of these problems is described in the following Sections.

SECTION 2

METHODOLOGY

2.1 THE MICROTRANSDUCER

SUMMARY

The reproducibility of anal sphincter manometry was evaluated in 17 patients with a continuous pull-through technique using a miniature transducer mounted on a 2 mm diameter Dacron catheter. Comparison was made with a conventional station pull-through technique using a 4 mm diameter waterfilled microballoon connected to an external transducer. Parameters measured with the microtransducer (maximum resting pressure, squeeze pressure, functional sphincter length, area under high-pressure zone and amplitude of rectosphincteric reflex) showed mean coefficients of variation from 3.2 to 5.7 per cent. Pressures measured with the microballoon were uniformly higher than those obtained with the microtransducer. The functional sphincter length was significantly shorter when measured with the microballoon ($p < 0.001$). The microtransducer can provide a highly accurate and reproducible method of anorectal profilometry that avoids many of the drawbacks associated with fluid-filled systems.

INTRODUCTION

The two most common methods of measuring anorectal pressure utilize either open-tipped tubes (Phillips and Edwards, 1965; Duthie and Watts, 1965; Meunier and Mollard, 1977; Bennett and Duthie, 1964; Harris and Pope, 1964; Kuypers, 1982) or closed balloon systems (Phillips and Edwards, 1965; Duthie and Watts, 1965; Kerremans, 1969; Ihre, 1974; Frenckner and Von Euler, 1975; Henry and Parks, 1980; Wunderlich and Parks, 1982; Neill et al, 1981), connected via fine tubes to strain-gauge transducers outwith the anal canal. Although these systems have provided us with much of the information on which our basic concepts of anorectal physiology are based, they possess disadvantages that are often the cause of conflicting results (Dickinson, 1978). Strain gauges that can be used inside the anal canal have been difficult to construct and prone to mechanical failure. They have hence not been adequately evaluated.

The availability of reliable miniature transducers mounted on fine catheters (Vela and Rosenberg, 1982; Schoulen and Van Vroonhonen, 1983; Blessing, 1984, 1985) has enabled many of the disadvantages associated with water-filled systems to be overcome. The aim of this study was to evaluate the reproducibility of a new continuous pull-throgh technique of anorectal manometry with such a microtransducer, and to compare the results with those obtained with a conventional microballoon technique.

PATIENTS AND METHODS

Anorectal manometry was performed in 17 patients. They comprised six hospital patients with no anorectal symptoms, six patients with chronic constipation and five patients with faecal incontinence. None of the patients had undergone previous anorectal surgery. All patients gave informed consent. No bowel preparation was used but patients were given the opportunity to empty their bowel before manometry, which was performed in the left lateral position.

The microballoon station pull-through technique was performed first (Method 1) followed by profilometry with the microtransducer (Method 2).

Method 1

A 4 mm diameter soft rubber microballoon (HSC4, Precision Dippings Ltd., Bristol, UK) mounted onto a 6FG ureteric catheter (Figure 1) and connected to an external transducer (4-442, Bell & Howell Ltd) was used. The entire system was water-filled and free of leakage and air bubbles. The transducer was calibrated to a full-scale deflection of 200 cm H20 pressure which was recorded on a multichannel chart recorder (Devices Ltd). The microballoon was inserted into the rectum to 7 cm from the anal verge and rectal pressure recorded. Withdrawal was then performed in 1 cm steps, the pressure at each station being recorded for approximately 1 minute. Maximum voluntary contraction pressure (MVC) was measured by placing the microballoon at

FIGURE 1

Photograph comparing the relative sizes of the microballoon and microtransducer

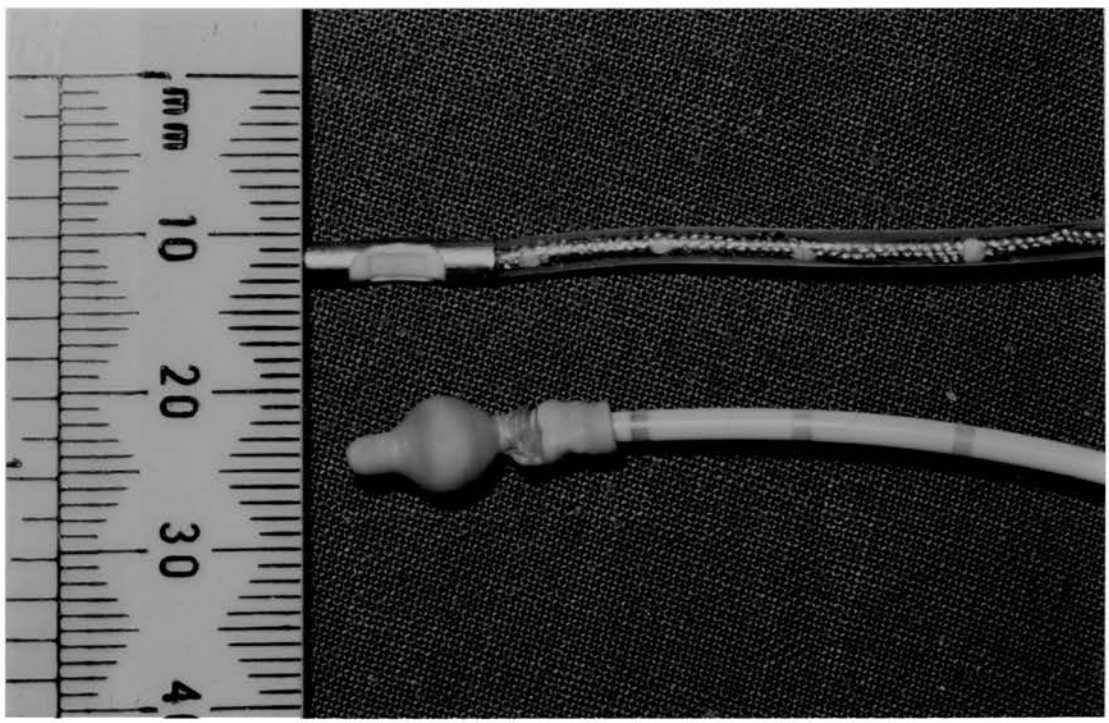
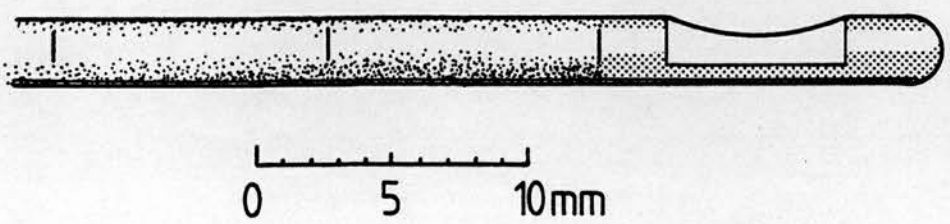


FIGURE 2

Illustration of a microtransducer mounted at the tip of a 3 mm diameter dacron catheter



the site of maximum resting pressure (MRP) and instructing the patient to contract the anal shincter as strongly as possible. The rectosphincteric reflex (RSR) was elicited by inflating a 2 x 1 cm soft rubber rectal balloon (HSC1, Precision dippings Ltd, Bristol, UK), placed at 10 cm from the anal verge, with 50 ml of air, and measuring the fall in resting anal canal pressure with the microballoon placed at the site of MRP. The functional sphincter length was measured as the length of the high-pressure zone in the anal canal (zone of pressure above the resting rectal pressure).

Method 2

A catheter-mounted microtransducer (16CT, Gaeltec Ltd, Dunvegan, Isle of Skye, UK; Figures 1 and 2) directly connected to a second channel on the chart recorder was introduced 7 cm into the rectum after calibration from 0 to 200 cm H2O. Continuous controlled withdrawal of the catheter at a speed of 1 mm/s was performed with a profilometer (21 HO5, DISA, Bristol, UK), thus obtaining a continuous pressure-profile of the HPZ. This procedure was repeated three times with the transducer orientated randomly (Figure 3). The MVC and amplitude of the RSR were measured as in method 1. In addition the area under the HPZ curve was accurately measured by computer (Hewlett Packard 85 with Summagraphics attachment). The mean coefficient of variation was calculated for all parameters measured, taking into account all three consecutive measurements.

RESULTS

Reproducibility of Method 2

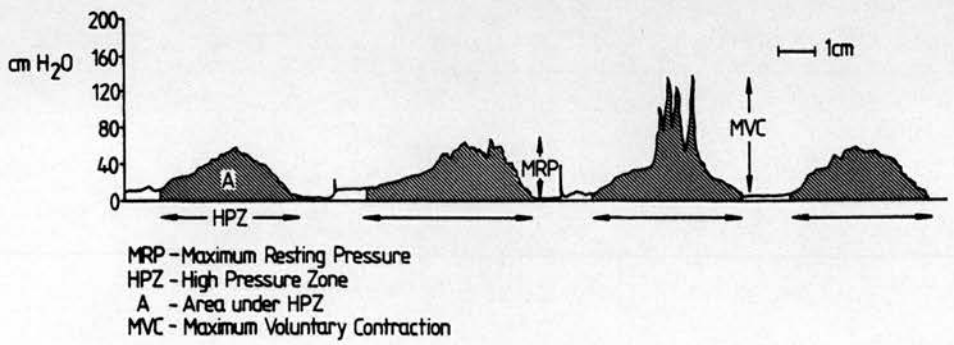
Figure 4 shows the reproducibility of the MRP using transducer profilometry (the first two values are plotted but the mean coefficient of variation was calculated for all three values). All plots lie close to the 100 per cent reproducibility line with slightly higher variation at the peak values (mean coefficient of variation 4.4 per cent). Table 1 shows the mean coefficients of variation for the other parameters measured (range 3.2 to 5.7 per cent). Figure 5 shows the reproducibility of the area under the high-pressure zone. The movement of the catheter during withdrawal did not affect the magnitude of the pressures recorded; for example the MRP value recorded was unchanged whether the catheter was stationary or being withdrawn. most patients were unaware of any sensation of movement within the anal canal during profilometry.

Comparison of methods

Figure 6 shows comparison of the absolute MRP values for the two techniques. Similar results were obtained for the MVC and RSR amplitude measurements. The microballoon measured all pressures uniformly higher compared to the microtransducer. However, there was a high degree of correlation between the two techniques in pressure measurements of each parameter (r=0.96, 0.98,0.95; MRP, MVC,RSR

FIGURE 3

Continuous pull-through sphincter profiliometry with the microtransducer (redrawn). Four profiles are shown, with the patient 'squeezing' during the third pull-through



MRP - Maximum Resting Pressure
HPZ - High Pressure Zone
A - Area under HPZ
MVC - Maximum Voluntary Contraction

FIGURE 4

Reproducibility of the maximum basal anal canal pressure using the microtransducer. Two plots are shown although the mean coefficient of variation has been calculated for three pull-throughs

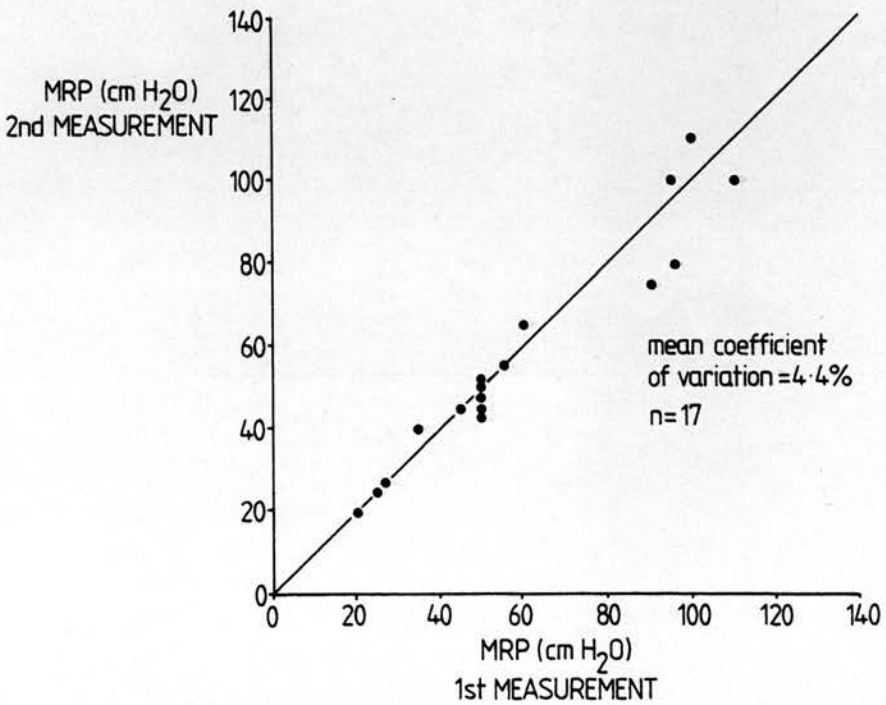


FIGURE 5

Reproducibility of the area under the high-pressure zone using the microtransducer. Two plots are shown although the mean coefficient of variation has been calculated for three pull-throughs

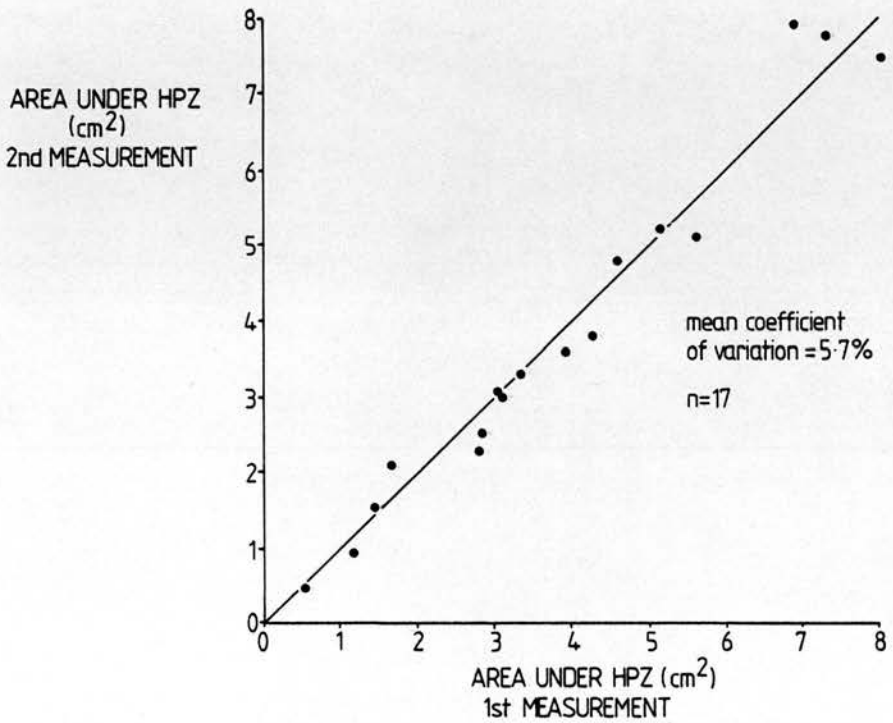


TABLE 1

Reproducibility of parameters measured with the microtransducer

Parameter	Mean coefficient of variation (%)
MRP	4.4
MVC	4.0
Amplitude RSR	3.2
Length HPZ	3.6
Area under HPZ	5.7

FIGURE 6

Comparison of the maximum basal anal canal pressure values obtained by the two techniques.

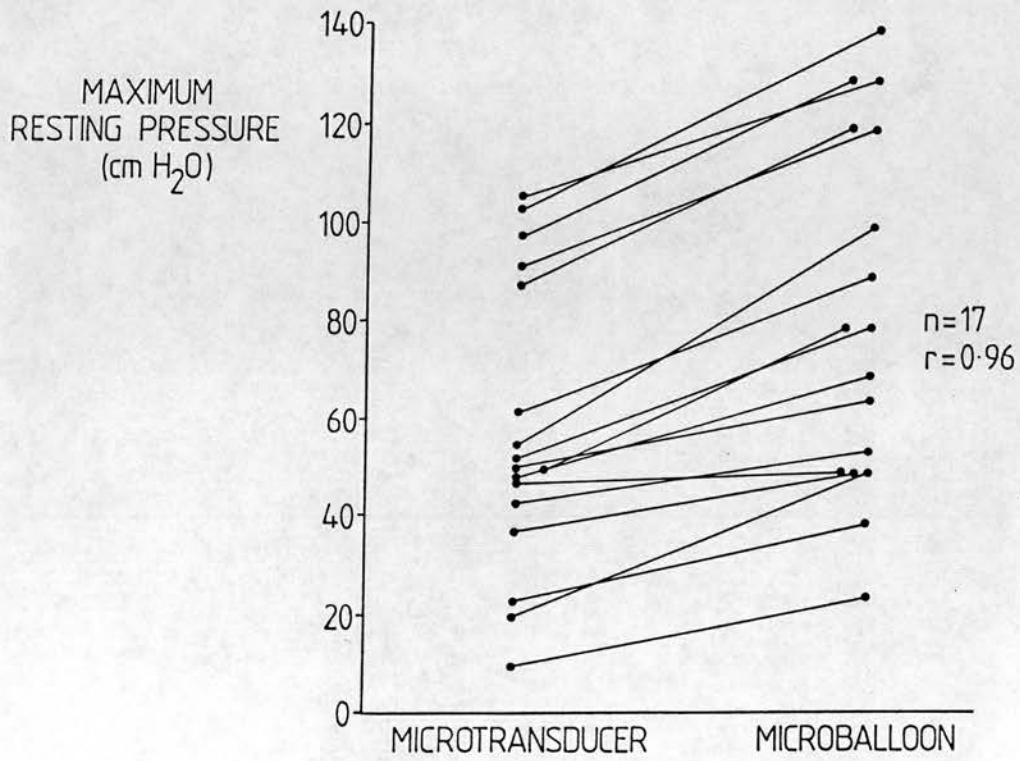
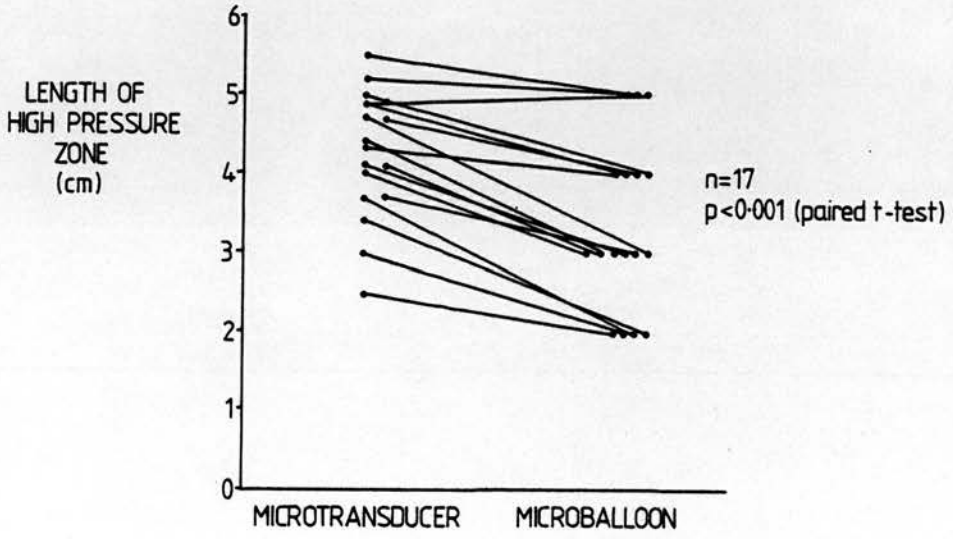


FIGURE 7

Comparison of the length of the high-pressure zone obtained by the two techniques



amplitude respectively). The length of the HPZ was significantly greater when measured with the microtransducer (Figure 7, $p < 0.001$, paired t test).

DISCUSSION

Pressure measurements within the anal canal are a common and useful means of assessment of sphincteric function and provide valuable information (Henry and Parks, 1980; Wunderlich and Parks, 1982; Henry and Swash, 1985). Until recently, fluid-filled closed balloon systems or open-tipped perfused tubes have been in standard use (Phillips and Edwards, 1965; Duthie and Watts, 1965; Meunier and Mollard, 1977; Bennett and Duthie, 1964; Harris and Pope, 1964; Kuypers, 1982; Kerremans, 1969; Ihre, 1974; Frenckner and Von Euler, 1975; Henry and Parks, 1980; Wunderlich and Parks, 1982; Neill et al, 1981; Henry and Swash, 1985). Dickinson (1978) has reviewed the disadvantages and conflicting results obtained with such systems. Assembling the balloons can be tedious and time-consuming and must be done correctly to ensure accurate results (Linke and Schuster, 1980). Variation due to the presence of air bubbles and leaks can be particularly troublesome. Calibration of the absolute zero value in relation to the height of the anal canal is imprecise. Movements of the connecting tubes can introduce artefacts that are difficult to damp. The size of the microballoon influences the pressures recorded (Duthie and Watts, 1965; Hill et al, 1960). With continuously perfused systems the pressure profile varies with the diameter of the tube (Gutierrez et al, 1975), the location of the openings (Harris and Pope, 1964) and

the perfusion rate (Hancock, 1976). In addition, continuous perfusion may reflexly stimulate the sphincters by causing irritation of the perianal skin (Kerremans, 1969). These differences in methods may account for many of the conflicting results.

Modern microtransducers, such as the one described in this study, are 'solid-state' systems that can be directly connected to chart recorders thereby obviating the need for fluid-filled tubes and external transducer relays. Furthermore, they permit the use of a continuous pull-through technique described above. This is not possible using a microballoon because of artefacts produced by balloon distortion. Continuously perfused systems likewise present the problem of stimulation of the sphincers by irritation of the sensitive perianal skin, hence introducing inaccuracies in the recorded pressure profile (Kerremans, 1969; Gutierrez et al, 1975). The small diameter of microtransducers now available (Vela and Rosenberg, 1982; Schoulen and Van Vroonhonen, 1983; Blessing, 1983, 1985) minimizes reflex stimulation by perceived movement within the anal canal. The resultant pressures recorded which are lower compared with the microballoon and the high correlation obtained suggests that diameter of the recording device may be an important factor. This has been observed in other studies in which the size of the measuring probes has been varied (Duthie and Watts, 1965; Harris and Pope, 1964; Hill et al, 1960; Gutierrez et al, 1975). The transducer may therefore give a more accurate indication of anal canal pressures when compared with larger devices. In addition, all the parameters measured by this technique were found to be highly reproducible. The area under the HPZ curve gives an integral index of the function of the internal anal sphincter

(Kuypers, 1982; Blessing 1984) which is primarily responsible for maintaining resting anal canal pressure (Frenckner and Von Euler, 1975). It is not possible to assess this with station pull-through techniques. Studies with several microtransducers mounted on the same catheter may enable the assessment of radial forces within the anal canal and the elucidation of the mechanisms that normally maintain faecal continence (Collins et al, 1967, 1969; Taylor et al, 1984). By recording the entire high-pressure zone by means of the continuous pull-through technique, a very accurate indication of the functional sphincter length is obtained. It is not surprising that the microballoon underestimates sphincter length when a 1 cm station technique is used. As the balloon is withdrawn from the rectum it can move from the station immediately outside the HPZ by up to 1 cm to the first high pressure station. This would result in underestimation of the location of the upper end of the HPZ by between 0 and 1 cm. This error can be reduced by using a 0.5 cm station pull-through technique which is therefore recommended when the microballoon is used, although this can be tedious. A continuous pull-through evaluation with the microballoon was abandoned because of the numerous artefacts produced due to balloon distortion.

Sphincter manometry in the studies described in the following Sections was performed using a conventional fluid-filled microballoon system connected to an external transducer to enable comparison with other workers. Nevertheless, evaluation of the microtransducer as described in this Section was felt necessary prior to its use for the proctometrogram (Section 2.2).

2.2 THE PROCTOMETROGRAM

SUMMARY

The reproducibility of a method of measuring rectal distensibility by continuous controlled fluid inflation with a balloon has been evaluated in health and disease in fifteen patients. The volume at sensation threshold , constant sensation and maximal tolerance , the pressures at these volumes and rectal compliance were measured. The mean coefficients of variation of the seven parameters measured ranged from 4.7 per cent to 7.9 per cent. The expected correlation between rectal compliance and maximal tolerable volume was confirmed ($r=0.85$, $p < 0.001$). The high reproducibility makes this investigation reliable for use in clinical and research practice. The pressure-volume characteristics of the proctometrogram in seventeen asymptomatic subjects are described.

INTRODUCTION

In 1927 Rose described a method of recording pressure responses within the urinary bladder in response to filling. Since then the cystometrogram has become accepted as a useful aid in studying the bladder in health and disease. Joltrain and his colleagues proposed a method of measuring the filling pressure of the large intestine in 1919. They described a few observations but drew no important conclusions. White , Verlot and Ehrentheil independently rediscovered the method in 1940. They noted abnormalities in patients with neurological disease by filling the entire colon with water. Their technique of performing the colonmetrogram was difficult , messy and hazardous and was therefore not accepted in clinical practice. Scott and Cantrell used a similar technique to study the effects of section of the parasympathetic nerve supply of the colon in the anaesthetised dog (1969). Lipkin et al (1962) were probably the first to use balloon distension of the sigmoid colon to measure its pressure-volume relationships and to describe alterations with pharmacological agents. Godec et al (1980) and Bubrick et al (1980) used balloon distension of the rectal ampulla with air as an adjunct to the evaluation of bladder dysfunction and postulated its use for the study of neurogenic bowel dysfunction. Preston et al described a method of evaluating rectal pressure and volume in constipation using fluid distension (1983). However, none of these techniques have been subjected to reproducibility studies.

We have used a method of continuous controlled balloon rectal

distension modified from Bubrick et al (1980) to measure rectal sensation , volume and compliance. This study reports on its technique and reproducibility and describes the normal measurements in seventeen asymptomatic subjects.

PATIENTS AND METHODS

Fifteen patients (5 male, 10 female, age range 16-85 years, mean 48.4 years) were evaluated in the reproducibility study. Their details are shown in Table 2. Seven patients underwent repeat proctometrograms on the same day at an interval of 2-4 hours, whilst the remaining eight patients were recalled for a repeat test approximately ten days later. In addition to the reproducibility study seventeen 'control' hospital patients underwent single proctometrograms in an attempt to define a normal range. These patients had been admitted for minor conditions not involving the anorectum and were asymptomatic from this point of view. They comprised 9 males and 8 females (age range 35-85 years, mean 52.4 years).

All the subjects were requested to fast from the night before and to empty their bowel on the morning of the study but no laxatives were used. Immediately before the proctometrogram a digital rectal examination and limited sigmoidoscopy with a paediatric instrument and without air insufflation were performed to ensure that the rectum was empty.

The apparatus used is shown in Figure 8. The patient lies in the left lateral position. A high-compliance balloon (condom type, deflated dimensions 19 cm X 5 cm) bound onto non-distensible polyvinylchloride

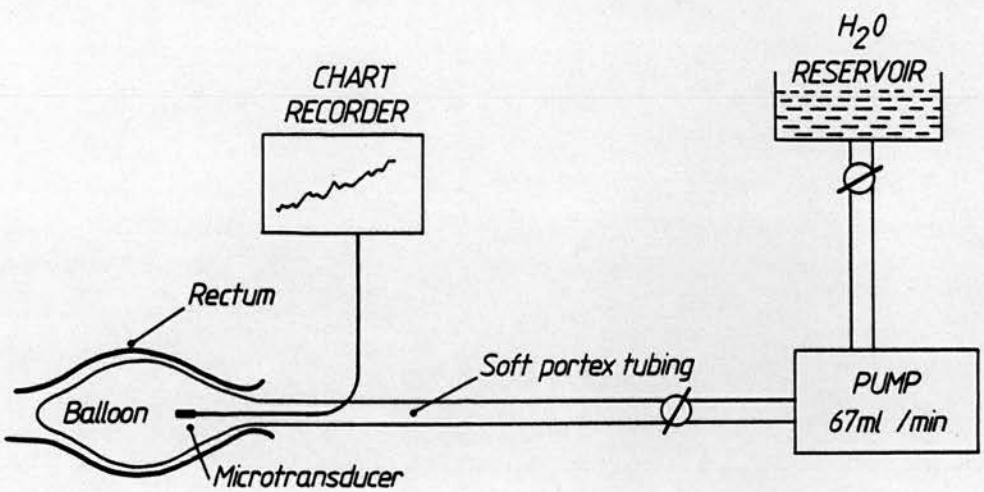
TABLE 2

Details of 15 patients evaluated in the proctometrogram reproducibility study

Condition	No. of patients
No anorectal pathology	2
Acquired megacolon	3
Chronic constipation	3
Radiation proctitis	3
Irritable bowel syndrome	2
Solitary rectal ulcer	1
Colo-anal anastomosis (radiation injury)	1

FIGURE 8

Apparatus for the proctometrogram

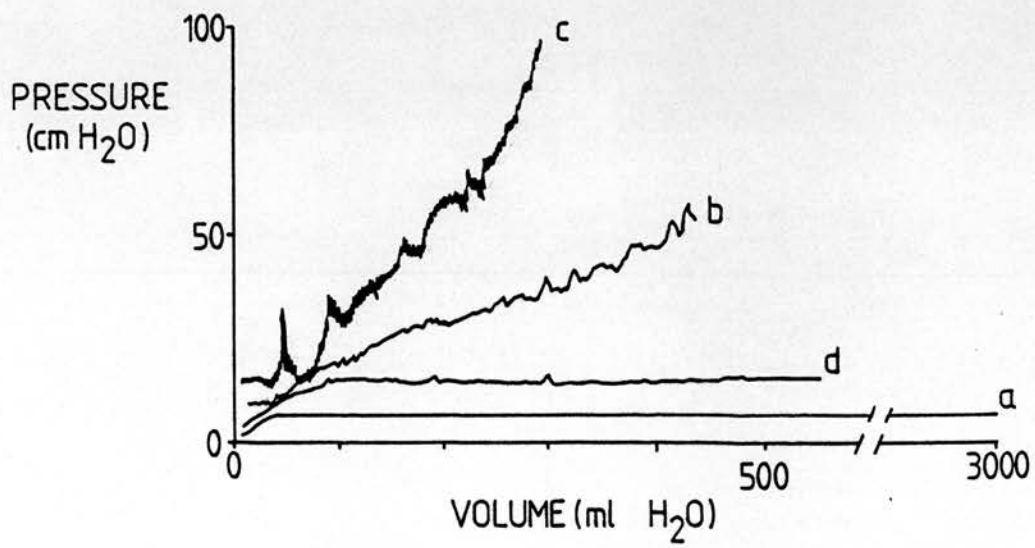


tubing (internal diameter 5 mm, reference number 800/002/067 Portex Limited, Kent, U.K.) is introduced into the empty rectum. A microtransducer (type 16 CT silicone, Gaeltec Limited, Dunvegan, Isle of Skye, U.K; Varma and Smith, 1984) within the rectal balloon monitors pressure continuously and is connected to a chart recorder (Devices Limited, U.K.).The microtransducer is precalibrated to record pressures from 0 to 100 cm H20, the chart speed being 10 mm per minute. It is possible to use a water-filled microballoon (internal diameter 4mm, HSC4, Precision Dippings Ltd., Bristol, U.K.) connected via fine non-distensible tubing to an external transducer to record pressure instead of the microtransducer (Varma and Smith, 1984). It is important to exclude air from the system prior to inflation and to place the balloon in the rectal ampulla where the lowest rectal pressure is recorded (approximately 15 cm H20). Continuous balloon inflation is performed at a rate of 67 ml per minute (4 litres per hour) by means of a peristaltic pump (Nouvag SP40, Plastic Pumps Limited, Middlesex, U.K.).

Bench testing of the system was performed to measure the pressure-volume characteristics of the distending balloon itself (Figure 9a). Several balloons of the same make tested showed identical characteristics. There is an initial rise in intraballoon pressure of approximately 10 cm H20 with infusion of the first approximately 50 ml of water into the balloon. With further infusion there is no further rise in pressure upto a capacity of more than three litres. This system is therefore ideal for the measurement of rectal distensibility as the slope of the rectal pressure (P, cm H20) - volume (V, ml H20) graph following the first 50 ml infusion

FIGURE 9

Diagrammatic representation of the pressure-volume (proctometrogram) characteristics of (a) the proctometrogram balloon, (b) a normal patient, (c) a patient with radiation proctitis, (d) a patient with acquired megacolon



accurately reflects true rectal compliance ($\Delta V/\Delta P$, ml/cm H2O). True intrarectal pressures can also be easily calculated from the graph by subtracting the 10 cm H2O contribution from the balloon at volumes in excess of 50 ml. In the megacolon type of curve (Figure 9d) the compliance is more easily calculated by dividing the maximal tolerable volume by the rectal pressure increment achieved on instillation of this volume although the slope of the graph can also be measured. The patient is asked to report the first perception of rectal filling and this is recorded as the sensation threshold. This is followed by a sensation of constant rectal distension andthe volume at this sensation is also recorded. In some patients these initial sensations may be indistinguishable. Inflation is continued until the patient has a strong desire to evacuate the balloon and will not tolerate further distension - this is the maximal tolerable volume. This sensation is usually not painful. The balloon is then emptied via the tubing. The parameters recorded in the reproducibility study were the volumes and pressures at the threshold, constant and maximal tolerable sensations and the rectal compliance measured on the linear portion of the graph. Figure 9 shows some typical proctometrograms from patients in this study. In a normal subject there is a slow and steady rise in intrarectal pressure with distension in an approximately linear fashion. In sharp contrast to this is the proctometrogram from a patient with symptoms of urgency and frequency of defaecation following mild chronic radiation rectal injury from radiotherapy for prostatic carcinoma (Figure 9c). The graph is shifted to the left with a relatively steep rise in pressure and there was marked reduction in sensation threshold, maximal tolerable volume and rectal

compliance in this patient. In chronic idiopathic constipation and acquired megacolon the pressure-volume relationship is shifted to the right (Figure 9d) and there is a relative increase in sensation threshold , maximal tolerable volume and rectal compliance.

RESULTS

Figure 10 shows a reproducibility plot for the maximal tolerable volume in the fifteen patients studied. The straight line represents a 100% reproducibility graph. The mean coefficient of variation for this parameter was 7.9%. Figure 11 shows a similar plot for rectal compliance. There is more variation at the higher compliance values such as those found in acquired megacolon but the mean coefficient of variation is only 6.5%. Table 3 lists the reproducibility values of the other parameters of the protometrogram. The mean coefficients of variation ranged from 4.7% to 7.9%. No significant differences in reproducibility could be demonstrated between the group of patients who had the investigation performed on the same day compared to the group in whom it was performed on different days.

Figure 12 demonstrates the significant correlation of the maximal tolerable volume with rectal compliance in the fifteen patients comprising this study.

Table 4 defines the normal pressure-volume parameters of rectal distensibility as measured in the seventeen asymptomatic subjects studied.

FIGURE 10

Reproducibility of the maximal tolerable volume (n=15). The straight line represents 100% reproducibility

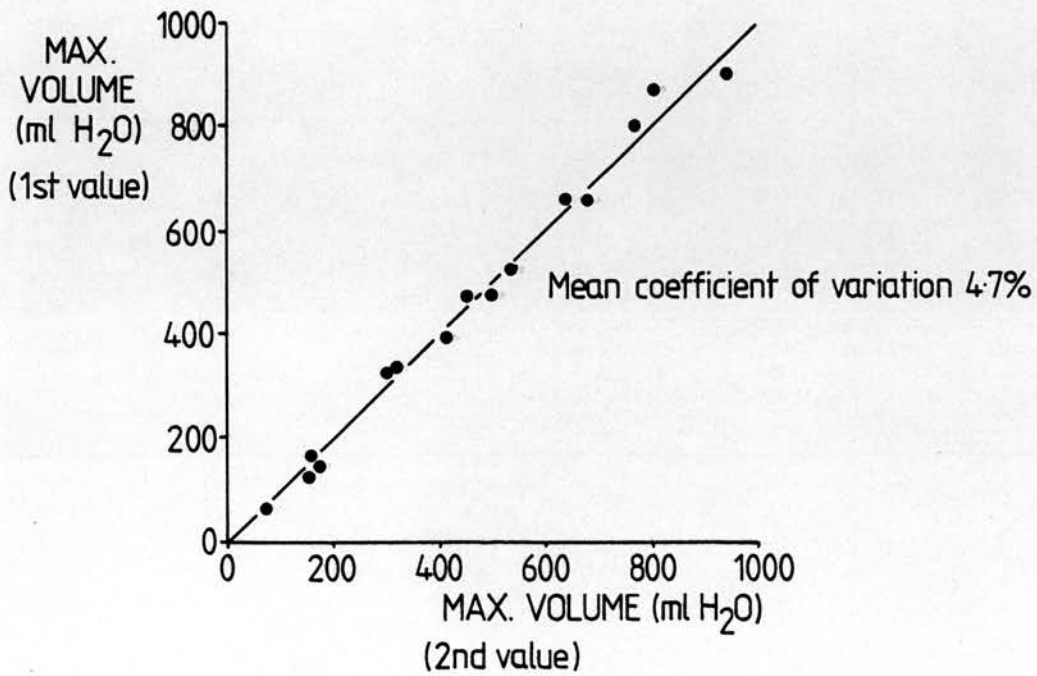


FIGURE 11

Reproducibility of rectal compliance (n=15). The straight line represents 100% reproducibility

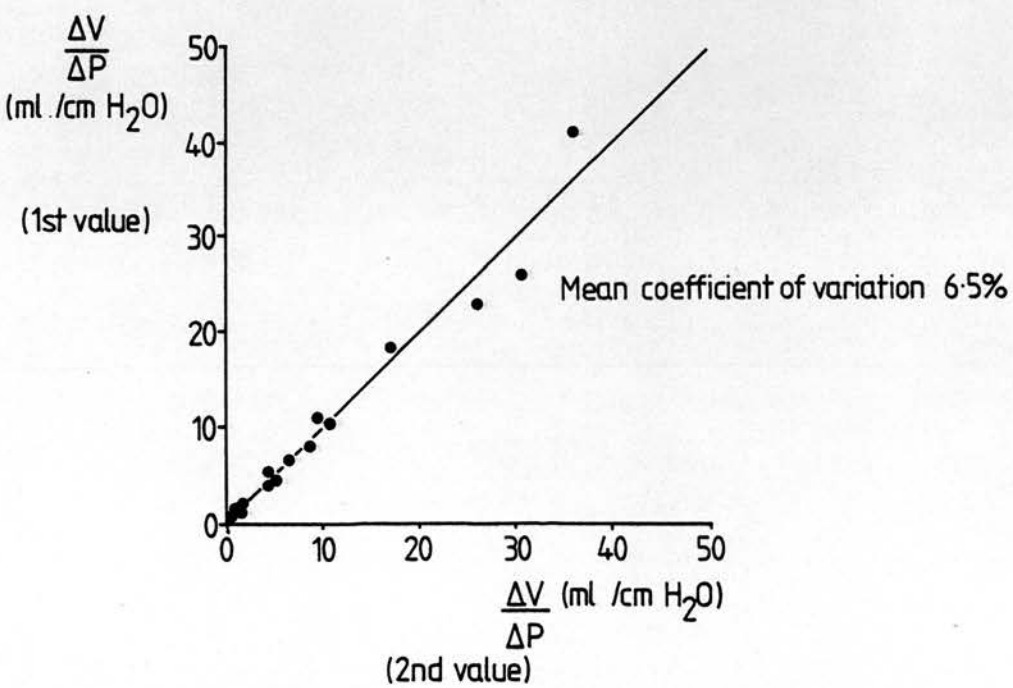


TABLE 3

Reproducibility of the proctometrogram

Parameter	Mean coefficient of variation (%)
Volume at sensation threshold	7.9
Volume at constant sensation	6.7
Maximal tolerable volume	4.7
Pressure at sensation threshold	7.6
Pressure at constant sensation	6.2
Pressure at MTV	5.1
Rectal compliance	6.5

FIGURE 12

Correlation between rectal compliance and maximal tolerable volume (n=15)

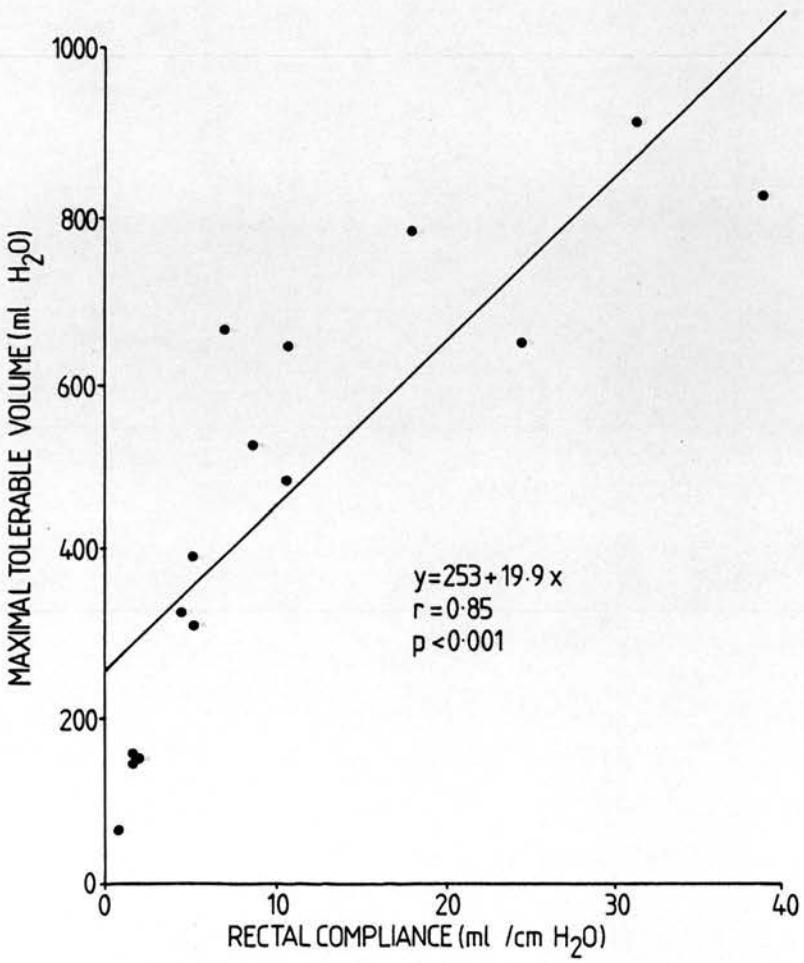


TABLE 4

Normal values for the proctometrogram (n=17)

Parameter	Sensation threshold	Constant sensation	Maximal tolerance
Volume (ml H2O)	229 ± 23.8	286 ± 20.5	509 ± 19.4
Pressure (cm H2O)	29 ± 2.5	34 ± 2.8	65 ± 3.1
Rectal compliance (ml/cm H2O)		8.7±0.4	

All measurements Mean±SEM

DISCUSSION

An important function of the rectum is its ability to act as a dynamic reservoir for faeces. Like the urinary bladder, this function is dependent on its functional capacity, perception of filling and contractile properties. The measurement of rectal volume, sensory perception and distensibility is therefore of undoubted value in the physiological investigation of anorectal function (Suzuki et al, 1980; Farthing and Lennard-Jones, 1978). The information obtained helps to explain the basis of many symptoms such as that described after radiation rectal injury, and may help to decide the logical course of treatment (Keighley et al, 1982). The technique of the proctometrogram described offers a relatively simple , cheap and practical method of evaluating the physiology of rectal function in health and disease. The use of water as the distending agent eliminates the necessity of correction for pressure and temperature in calculating the distending volume when gas is used (Ihre, 1974). The continuous infusion pump makes the tedious calculation involved in stepwise inflation methods (Suzuki et al, 1980; Ihre, 1974) unnecessary. The bench properties of the high-compliance rectal balloon (Figure 9a) were found to be consistently identical for the type used in this study. However, the characteristics of individual types of balloon should be ascertained before use in vivo. The use of the microtransducer to measure rectal pressure avoids the drawbacks associated with fluid-filled transducer systems (Varma and Smith,

1984). The calculation of intrarectal pressure and compliance is made much simpler compared to other methods (Ihre, 1974) due to the lack of any significant pressure contribution by the balloon. The relatively low rate of infusion (67ml/minute) was employed because it corresponds to an intermediate rate (10-100 ml per minute) used in medium fill cystometry (International Continence Society, Committee on standardisation of terminology, 1984) and hence probably represents a more physiological rate of filling. It has also been observed that the sharp increase in pressure when the maximal tolerable volume is reached is seen less often compared to other workers (Bubrick et al, 1980; Preston et al, 1983), partly because of the lower infusion rate - for example Preston et al who used a similar balloon with similar rates of infusion - and partly to the larger size and capacity the balloon used in this study (for example compared to Bubrick et al who used a balloon of only 405 ml capacity). These factors may also explain the the relatively higher maximal tolerable volumes observed in normal subjects in this study. Lipkin and Sleisenger (1958) found, not unexpectedly, that the onset of pain on distension of either the rectum or sigmoid colon was inversely proportional to the level of water pressure exerted by the balloon. Although they did not report differences in the rate of inflow, these certainly existed. There is more variation in measuring threshold sensation and pressure compared to the other parameters. This is not surprising in view of the transient and intermittent nature of this sensation which is also more difficult to explain to the patient. The reproducibility at higher volumes (Figure 10) and compliance (Figure 11) is also reduced although overall reproducibility remains

high and the measurements therefore reliable. Such a reproducibility has not been previously demonstrated with other methods. The functional reservoir capacity of the rectum might be expected to be dependent on its compliance. We have been able to confirm this in practice (Figure 12) and shown a high correlation between these parameters. The compliance and accomodation properties of the rectum may also play a role in determining the characteristics of the rectosphincteric reflex as suggested by the studies of Arhan et al (1976).

The values listed in Table 4 represent measurements of both sexes over a wide age range. They can only be usefully interpreted as a guide to comparison with similar measurements in other groups of symptomatic patients (Varma et al, 1985; Varma and Smith 1984, 1985, 1986). Absolute normal values, however, can only be safely defined in much larger groups with prevailing experimental conditions delineated. In order to obtain consistent and reliable results care must be taken to ensure that the rectum is empty , that there is no air within the system and in the placement of the balloon. Drugs can alter the pressure-volume characteristics of the colon (Lipkin et al, 1962) and their effects should therefore be considered.

The effects of variation with age of the proctometrogram is discussed in Section 4.2.

2.3 THE HUMAN PUDENDO-ANAL REFLEX

SUMMARY

An electrophysiological technique is described to determine the latency of reflex contraction of the external anal sphincter in response to stimulation of the dorsal genital nerve: the pudendo-anal reflex (PAR). This was studied in 38 asymptomatic control subjects (25 female, 13 male).

The stimulus sensory threshold was 33±13 Volts and the stimulation voltage 110±31 Volts (mean±SD). Reproducible responses were obtained in all subjects. The reflex latency in this group ranged from 27.2 to 46.8 ms (mean 38.5±5.8 SD ms) and appeared to be independent of age or sex. Its amplitude was 4.9±3.2 μV with a duration of 16±7 ms.

This technique of recording the pudendo-anal reflex is shown to provide a useful method of investigating the neurophysiological integrity of the sacral spinal cord and pelvic floor in Section 5.

INTRODUCTION

There has recently been much interest and controversy about the electrically evoked reflex activity of the external anal sphincter, particularly in relation to faecal incontinence of neurogenic origin (Pedersen et al, 1978; Henry and Swash, 1978; Swash, 1982; Pedersen et al, 1982; Bartolo et al, 1983; Wright et al, 1983,1985). Swash et al suggested that the latency of the classical anal reflex measured electrophysiologically was significantly increased in idiopathic faecal incontinence (Henry and Swash, 1978; Swash, 1982; Neill et al 1981). However, studies by other workers did not confirm the usefulness of the latency of this reflex as an index of pelvic floor neuropathy (Bartolo et al, 1983; Wright et al, 1983,1985), and raised doubts about the interpretation of the earlier latency measurements. It has since become clear that electrical stimulation of the perianal skin results in direct stimulation of the terminal innervation of the external anal sphincter. This produces the 'early' or short-latency responses (Pedersen et al, 1982; Swash, 1982; Bartolo et al, 1983; Wright et al, 1983,1985; Vodusek et al, 1983) that had previously been erroneously interpreted as spinal cord reflexes (Henry and Swash, 1978; Neill et al, 1981; Swash, 1982). These inconsistencies have limited the usefulness of the classical anal reflex for studying the clinical neurophysiology of the pelvic floor.

Electrical stimulation of the dorsal nerve of the glans penis or clitoris evokes a reflex contraction of the external anal sphincter mediated via the sacral spinal cord segments 2,3 and 4 - a

modification of the bulbocavernosus reflex described by Bors and Blinn in 1959 (Figure 13). The availability of modern electrophysiological equipment has enabled more precise studies on the latency of the pudendo-anal reflex (Smith and Varma, 1984). This section describes a reproducible method of measuring the latency of this reflex and investigates its variation with age and sex in 38 normal subjects.

PATIENTS AND METHODS

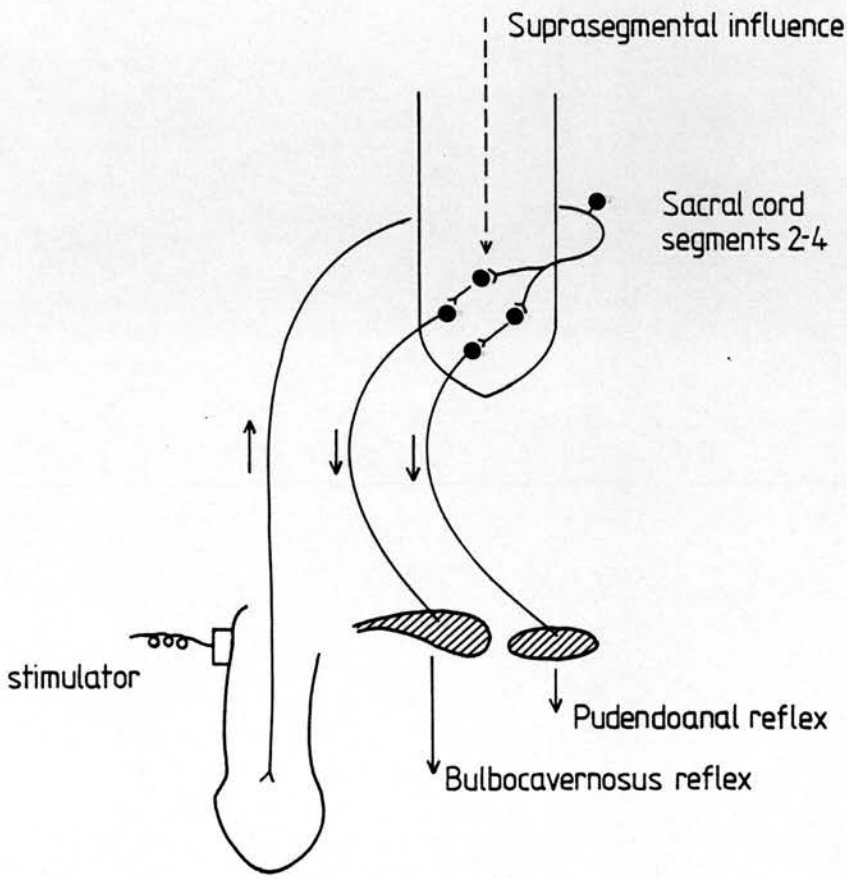
The control group consisted of 25 female and 13 male subjects (age range 23 - 75 years, mean 45 years). They were hospital patients who had been admitted for minor surgery outwith the alimentary tract and none had any anorectal symptoms.

The pudendo-anal reflex

Figure 13 illustrates the anatomical basis of the PAR (Smith and Varma, 1984). It was elicited by electrical stimulation of the dorsal nerve of the glans or clitoris with a felt bipolar surface stimulating electrode (type LBS 53051, Medelec, U.K.). The reflex contraction of the external anal sphincter was recorded with a bipolar surface stainless-steel anal plug electrode (type 13K78, DISA, Copenhagen) using the Medelec MS92a evoked response unit. Electrode jelly was used to improve electrical contact between the plug electrode and the sphincter. A saline-soaked felt strap wrapped around the right thigh was used as the ground electrode. More than 100 square-wave stimuli (

FIGURE 13

Diagrammatic representation of the anatomical basis of the bulbocavernosus and pudendo-anal reflexes (modified from Ertekin and Reel, 1976)



duration 0.1ms, frequency 2Hz) were applied and the digitally averaged response displayed on the oscilloscope at a sweep speed of 10 ms/cm with the gain at 10 or 20μV/cm and filter settings of 2Hz - 10kHz. The stimulation voltage was approximately three times the voltage at sensation threshold, typical threshold and stimulation voltages being 30V and 90V respectively. In no case was the stimulation reported to be painful by the patient. The procedure was repeated in each subject to ensure reproducibility. The latency of the PAR was measured from the onset of the sweep (triggered by the stimulus) to the onset of the clearly defined reflex response at the external anal sphincter (Figure 14).

Statistics

Differences in the electrophysiological measurements between the various groups were analysed by the Wilcoxon rank sum test.

RESULTS

Completely reproducible reflex responses were confirmed in all subjects. Reversal of the polarity of the stimulating electrode simply resulted in reversal of the stimulus artefact without altering the shape or latency of the evoked response. 'Bifid' responses were observed in some subjects, i.e. responses with late components. In these cases the latency of the PAR was taken from the onset of the first response because this represents the shortest measurement. Table 5 lists the latencies of the PAR in the control group of 38 subjects.

FIGURE 14

Typical trace of the electrophysiological pudendo-anal reflex from a normal subject with a latency of 34.0 ms. Note the stimulus artefact at the start

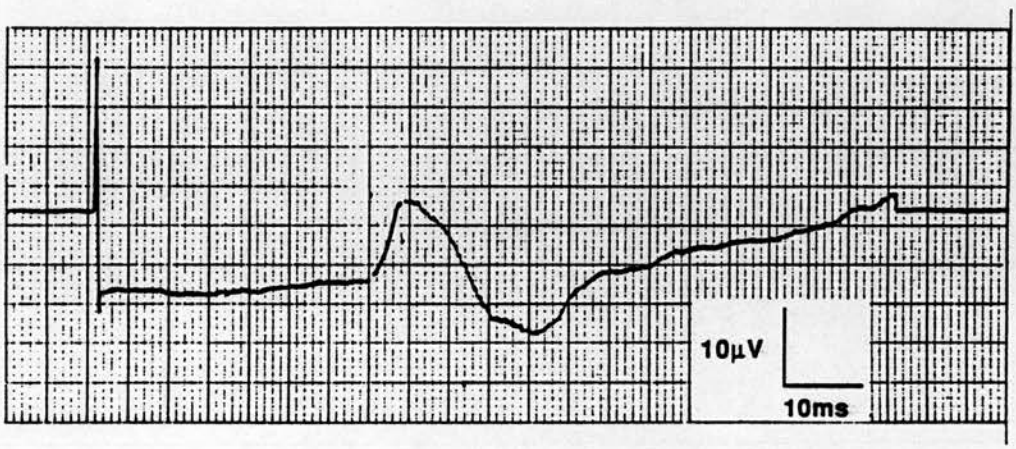


TABLE 5

Normal range and variations with age and sex of the latency of the pudendo-anal reflex

Subjects	Age (Range, Mean±SD, years)	Latency (Range, Mean±SD, ms)	p
25 female, 13 male	23 - 75 (45±14.6)	27.2 - 46.8 (38.5±5.8)	—
10 female	28 - 57 (46.4±12.6)	33 - 46 (40.7±4.4)	} >0.1
10 male	28 - 59 (47±12.7)	27.2 - 46.8 (38.5±6.6)	
10 female ('young')	23 - 49 (33.6±9.2)	33 - 44.8 (39.6±4.3)	} >0.1
10 female ('old')	55 - 75 (62±6)	29.2 - 46 (36.6±6.6)	

These were further subdivided into age-matched male and female groups (n=10) and 'young' and 'old' female groups (n=10). No differences in the latency of the reflex were demonstrable with either sex or age. The stimulus sensory threshold in the 38 patients was 33±13 SD Volts with the stimulation for reflex elicitation being performed at 110±31 Volts. The pudendo-anal reflex had an amplitude of 4.9±3.2 SD μV with a duration of 16+7 SD ms. These parameters did not appear to vary with sex.

DISCUSSION

Reflexes involving the perineal muscles have stimulated much interest in the neurological evaluation of the conus medullaris and its afferent and efferent connections. These studies are considered to be of particular value in disorders of the genito-urinary system and the pelvic floor musculature (Rossolimo, 1891; Lapides and Bobbitt, 1956; Bors and Blinn, 1959; Ertekin and Reel, 1976, 1979; Pedersen et al, 1978, 1982; Henry and Swash, 1978; Siroky et al, 1979; Krane and Siroky, 1980; Neill et al, 1981; Swash, 1982; Marsden et al, 1982; Vereecken et al, 1982; Haldeman et al, 1982; Bartolo et al, 1983; Vodusek et al, 1982,1983; Bilkey et al, 1983; Smith and Varma, 1984; Wright et al, 1983,1985; Galloway and Tainsh, 1985; Fidas et al, 1985, 1987). Since the description of the classical anal reflex by Rossolimo in 1891 using mechanical stimulation of the perianal skin, the reflex has been extensively investigated by more sophisticated electrophysiological methods (Pedersen et al, 1978; Swash, 1982; Bartolo et al, 1983; Wright et al, 1985; Vodusek et al, 1983;

Vereecken et al, 1982). Henry and Swash described a latency for this reflex of 8.3±1.7 SD ms in 13 normal subjects (1978) and suggested that it was prolonged in faecal incontinence and rectal prolapse (Neill et al, 1981; Swash, 1982). The presence of these short-latency responses has been observed by other workers who also noted later responses of longer duration (Pedersen et al, 1982; Vodusek et al, 1983; Haldeman et al, 1982). The early reactions have a uniform electrical pattern and show no sign of fatigue. They are not abolished by spinal anaesthesia (Pedersen et al, 1982; Wright et al, 1985) and their latencies are too short for a spinal reflex (Pedersen et al, 1982; Swash, 1982; Marsden et al, 1982). They have therefore been attributed to direct activation of the terminal innervation of the anal sphincter (Wright et al, 1985, Vodusek et al, 1983). Some of the intermediate responses may be due to antidromic stimulation with interaction between neighbouring α-motoneurones in Onuf's nucleus (Onuf, 1901) hence resulting in 'oligosynaptic' latencies (Pedersen et al, 1982). The 'classical' polysynaptic anal reflex is now recognised to have a latency of 50±10.5 SD ms (Pedersen et al, 1978). These variable factors have made the precise determination of the latency of the anal reflex difficult and its interpretation controversial (Pedersen, 1985).

Reflex reaction of the external anal sphincter can also be provoked by stimulating the glans penis, clitoris, the mucosa of the rectum, urethra and bladder and even the posterior tibial nerve (Pedersen, 1954). Stimulation of the dorsal nerve of the penis or clitoris evokes a reflex contraction of the bulbocavernosus muscle - the classical bulbocavernosus reflex (Bors and Blinn, 1959; Lapides and

Bobbitt, 1956; Figure 1). Bors and Blinn also described a simultaneous reflex contraction of the anal sphincter in response to this stimulus. This was variously termed the sacral evoked potential (Krane and Siroky, 1980), sacral evoked response (Galloway et al, 1985) sacral reflex (Bilkey et al, 1983; Fidas et al, 1985), pudendal evoked response (Haldeman et al, 1982) and pudendal sexual reflex (Dick et al, 1974). However, at a meeting of the Physiological Society the more accurate terminology of 'pudendo-anal reflex' was adopted (Smith and Varma, 1984).

The latency of this response appears to be dependent on the intensity of stimulation and it shows little or no signs of habituation (Pedersen, 1985). Hence, the most appropriate electrophysiological method for investigating this reflex is to use a train of high-voltage stimulus impulses and to digitally average the anal sphincter response (Pedersen, 1985; Torring et al, 1981) as described in this study. The averaging technique helps to obtain a clearly defined response by reducing background activity. The relatively greater distance between recording and stimulating electrodes diminishes the stimulus artefact and , more importantly, eliminates the 'direct' short-latency responses such as those observed in the elicitation of the classical anal reflex. The use of a surface anal plug electrode is preferable to concentric needle electrodes because a much larger area of muscle is sampled thus giving a more accurate indication of its function.

Voltage was used to measure sensory threshold and stimulation parameters in this study as have many other previous reports, although current probably constitutes a better measurement.

Haldeman et al (1982) were able to demonstrate a conduction time of

approximately 8 ms in the afferent limb of the pudendo-anal reflex by recording evoked potentials over the sacral conus. Marsden et al (1982), using percutaneous spinal cord stimulation, measured a latency of approximately 8 ms in the efferent limb of the reflex in normal subjects. This observation was confirmed by Snooks et al (1985) who also showed prolongation of this latency in neurogenic incontinence, thus demonstrating a lesion in the efferent pathway. Hence, assuming a normal latency range of 30-48 ms, the central conduction time for the PAR has a range of 15-33 ms, thus confirming its polysynaptic nature. This characteristic of the pudendo-anal reflex and its reproducibility also render it a suitable tool for the electrophysiological exploration of the sacral spinal cord in the absence of neuropathic changes in the external anal sphincter. Hence, it has been used in the investigation of patients with neurogenic disorders of the urinary bladder and of sexual function (Ertekin and Reel, 1976; Galloway et al, 1985; Fidas et al, 1985). Many of these patients often have radiological evidence of lumbo-sacral spinal dysraphism (Galloway and Tainsh, 1985; Fidas et al, 1987). Similar observations have been made in some patients with intractable constipation of idiopathic origin (Varma and Smith, 1984; Section 4).

The usefulness of the pudendo-anal and other similar polysynaptic reflexes in the investigation of constipation and neurogenic incontinence is described in Sections 4 and 5 respectively.

SECTION 3

CHRONIC RADIATION ANORECTAL INJURY

3.1 RECTAL FUNCTION FOLLOWING CHRONIC RADIATION INJURY

SUMMARY

Continuous fluid-inflation proctometrograms were performed in men with the symptoms of chronic radiation proctitis and in age and sex-matched control subjects (n=10). Rectal volumes and compliance were measured. There was a significant reduction in the rectal volumes at sensory threshold, constant sensation and maximal tolerance and in rectal compliance ($p < 0.01$). Comparable pressure measurements did not demonstrate significant differences. The maximum tolerable volume, symptomatic and sigmoidoscopic scoring correlated to rectal compliance ($r = 0.77, -0.8, -0.73$; $p < 0.01, < 0.01, < 0.02$, respectively). Reduction in volume and compliance is often not obvious radiologically. Histological evidence suggests that smooth muscle hypertrophy and myenteric plexus damage are contributory.

INTRODUCTION

Radiotherapy is being used increasingly for the treatment of malignancy arising in the pelvic viscera (Hatcher et al, 1985). The incidence of associated radiation injury to healthy surrounding tissue with its sequelae has increased, sometimes necessitating surgical intervention (Morganstern et al, 1977; Schmitt and Symmonds, 1981; Hatcher et al, 1985; Cooke and Moor, 1981; Varma and Smith, 1986). The rectum is the commonest site of injury after pelvic irradiation with more than 70% of patients with radiation-induced gastrointestinal injury suffering from rectal involvement, sometimes in conjunction with other organs (Hatcher et al, 1985; Anseline et al, 1981). The fixed anatomical position of the rectum in the pelvis makes it more susceptible to the injurious effects of radiation compared to the more 'mobile' organs such as the small bowel.

A very common symptom of radiation rectal injury is urgency and increased frequency of defaecation with occasional faecal incontinence, often chronic in nature (Hatcher et al, 1985). Some of these symptoms are explainable by the accompanying dysfunction of the internal anal sphincter (Varma and Smith, 1984, Varma et al, 1986). However, it is conceivable that the reservoir function of the rectum is also compromised as a result of the radiation injury, thus aggravating the severity of the faecal incontinence.

In an attempt to elucidate these observations , the function of the rectum was evaluated manometrically in patients with symptomatic chronic radiation rectal injury and compared to a matched control

group of asymptomatic subjects. The manometric results were correlated to the patients' symptoms and sigmoidoscopic findings. Specimens from another group of patients who had undergone excisional sphincter-saving rectal surgery for radiation injury (Section 3.3) were also examined histologically.

PATIENTS AND METHODS

The symptomatic irradiated group comprised ten men (age range 63-80 years, mean 74 years) who received radiotherapy for prostatic carcinoma and had subsequently developed chronic symptoms of faecal incontinence, increased frequency, urgency and occasional loose bowel motions. Identical small field external beam radiotherapy (5000 cGy in twenty treatments over four weeks) had been given to this group of men from 2 to 5.5 years prior to the study (mean 3.5 years). The control group consisted of ten approximately age-matched male hospital patients who had been admitted for minor surgery not involving the gastrointestinal tract and who had no anorectal symptoms.
All the patients in the radiation group had double contrast barium enemas performed during the course of investigation of their symptoms. These were reviewed by one person prior to manometry to assess rectal capacity which was graded as normal or diminished (Keighley et al, 1982).

Manometry

Patients were fasted from the night before the study and requested to

empty their bowel on the morning of the study. This was assisted by means of a saline washout if necessary but no laxatives were used. Immediately before the proctometrogram a digital rectal examination and limited sigmoidoscopy using a paediatric instrument but without air insufflation were performed to ensure that the rectum was empty. Proctometrograms (Varma and Smith, 1986; Section 2.2) were obtained with the patient in the left lateral position.

The patient was asked to report the first perception of rectal filling and this was recorded as the sensory threshold. This is followed by a sensation of constant rectal distension and the volume at this sensation was also recorded. In some subjects these initial sensations were indistinguishable. Inflation was continued until the patient had a strong desire to evacuate the balloon and could not tolerate further distension - the maximal tolerable volume. The balloon was then emptied via the tubing. The manometric parameters measured were the volumes and pressures at the threshold, constant and maximal tolerable sensations and rectal compliance.

Scoring of symptomatology and sigmoidoscopic findings

Table 6 lists the symptoms and sigmoidoscopic appearances in the irradiation group that were considered important correlates to the physiological measurements with the proctometrogram. A scoring system was utilised in which one point was allocated to each positive finding. The respective scores were added and correlated to the proctometrographic measurements. Sigmoidoscopic scoring was performed several days before proctometrography by one observer. An adult

TABLE 6

Parameters used for the scoring system

Symptomatic	Sigmoidoscopic
Frequency	Mucosal pallor/atrophy
Urgency	Telangiectasia
Incontinence	Contact bleeding
Loose bowel motions	Ulceration
Rectal bleeding	Loss of distensibility

instrument with a distal light source was used to a distance of 15 cm. from the anal verge.

Histology

Histological material was obtained from eight other patients who had undergone anterior resection of the rectum with coloanal sleeve anastomosis for complications of radiation injury (Section 3.3). Two of these patients had been treated for prostatic cancer and six for bladder tumours. The total radiation dosage that these patients had received (3000 to 5000 cGy) was similar to that used in the study group of symptomatic but unoperated patients (5000 cGy). Following fixation with formalin, paraffin embedded sections were examined by conventional techniques using light microscopy and Haematoxylin and Eosin staining.

Statistics

The manometric measurements between the two groups were analysed by the Wilcoxon rank sum test. Correlation between manometric and clinical findings were performed by Pearson's correlation coefficient and a regression line thus computed.

RESULTS

Manometry, clinical and radiological findings

Table 7 lists the values for all the manometric parameters measured. There is a marked and significant reduction in the maximal tolerable volume after radiotherapy ($p < 0.01$). Rectal compliance is also severely reduced following irradiation ($p < 0.01$; see also Figure 9c, Section 2.2). A significant correlation exists between these two parameters ($r = 0.77$, $p < 0.01$; Figure 15). The volumes at threshold and constant perception of rectal distension are also significantly reduced after irradiation. Comparison of rectal pressures at the three volumes do not show significant differences. Figures 16 an 17 show the correlation of rectal compliance with symptomatic and sigmoidoscopic scores respectively. Figure 18 demonstrates the high correlation between rectal compliance and the added scores from sigmoidoscopic and symptomatic evaluation ($r = -0.89$, $p < 0.001$).

Double-contrast barium enemas failed to demonstrate any abnormalities of function or capacity in eight patients. In two patients rectal capacity appeared reduced and in three patients mucosal abnormalities consistent with proctitis were identified.

Histopathology

Microscopic examination of the sections taken from all the eight

TABLE 7

Pressure-volume characteristics of the rectum in radiation proctitis

	Sensory threshold		Constant sensation		Maximal tolerance		RC
	P	V	P	V	P	V	
Control (n=10)	31 ± 3.5	224 ± 31.4	38 ± 3.7	303 ± 22.6	71 ± 2.7	493 ± 25.3	9 ± 0.5
Radiation (n=10)	31 ± 4.4	99 ± 25.3	36 ± 36.4	122 ± 26.5	72 ± 2.9	224 ± 29.6	2.5 ± 0.4
Significance (p)	NS	<0.01	NS	<0.01	NS	<0.01	<0.01

P: pressure, cm H2O

V: volume, ml H2O

All values Mean±SEM

FIGURE 15

Regression line showing positive correlation between rectal compliance and maximal tolerable volume in chronic radiation injury (n=10)

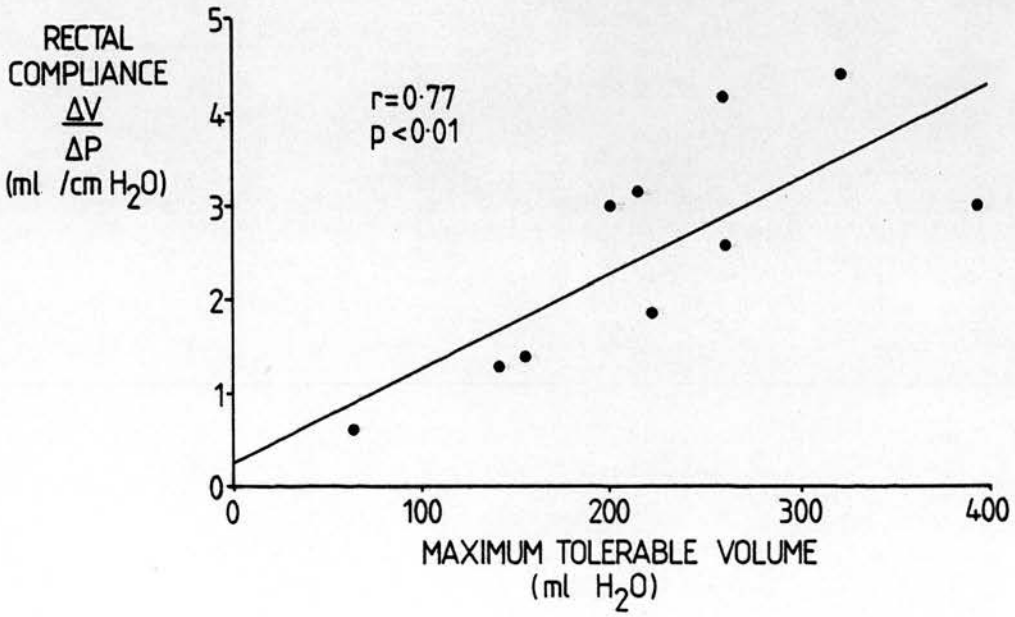


FIGURE 16

Regression line showing positive correlation between rectal compliance and symptomatic score in chronic radiation injury ($n=10$)

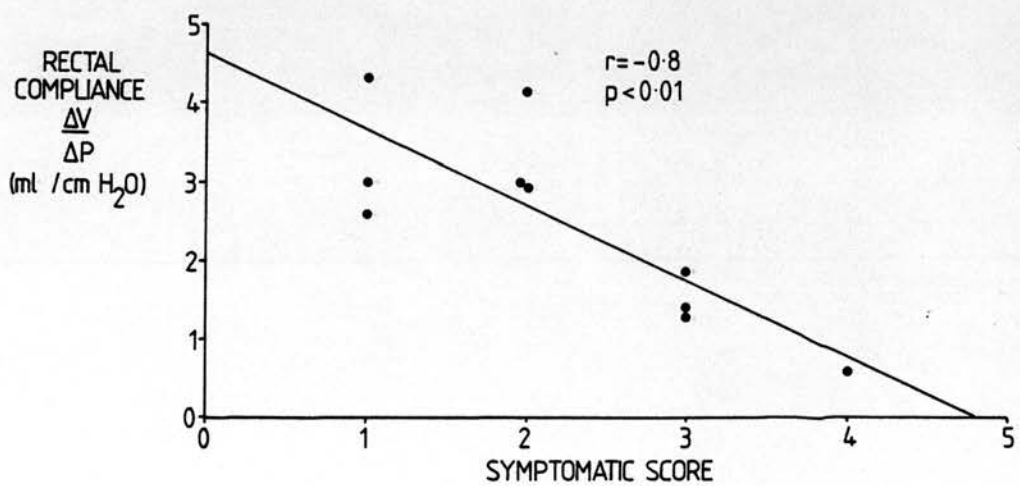


FIGURE 17

Regression line showing positive correlation between rectal compliance and sigmoidoscopic score in chronic radiation injury (n=10)

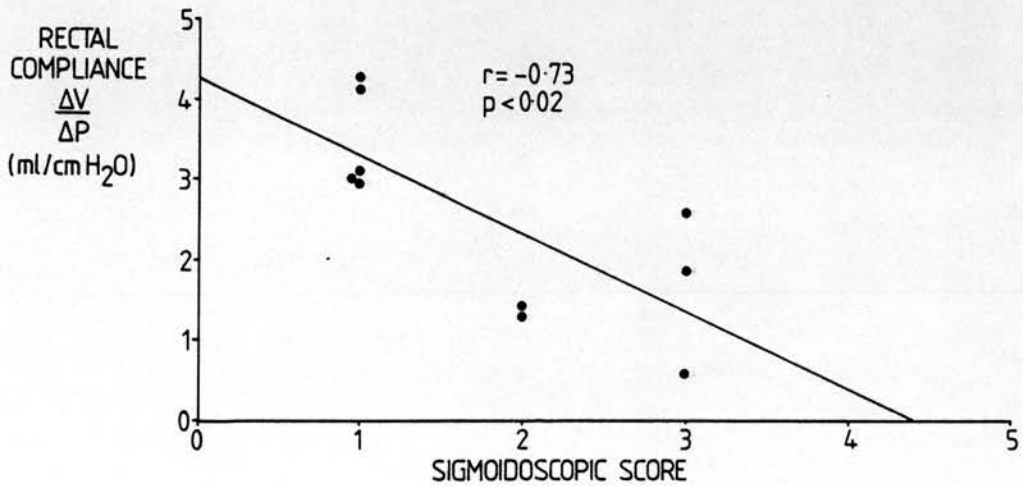
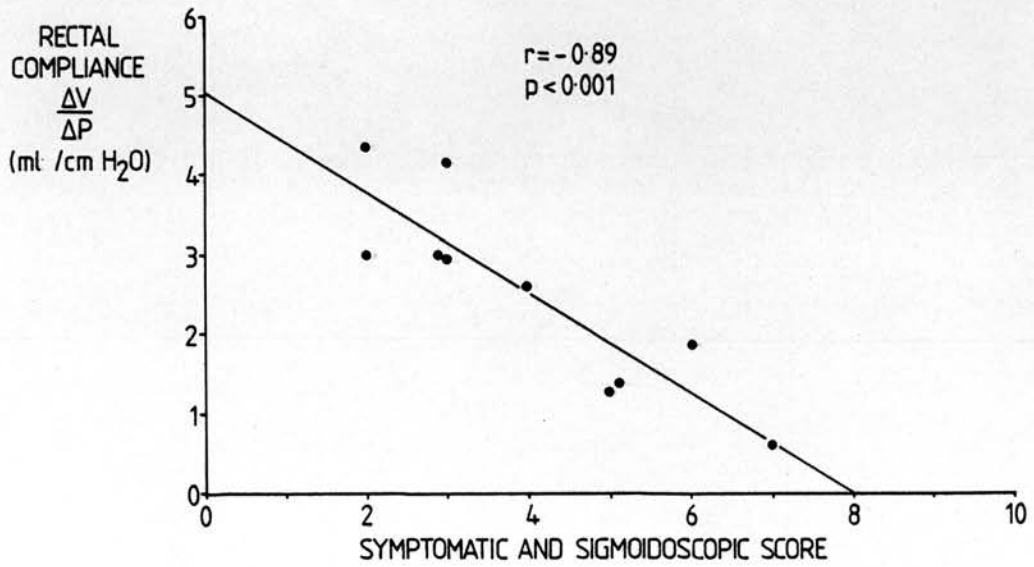


FIGURE 18

Regression line showing negative correlation between rectal compliance and cumulative symptomatic and sigmoidoscopic score in chronic radiation rectal injury (n=10)



resected specimens showed identical histopathological changes. An excess of round cells with no evidence of active inflammation was present in the lamina propria; no glandular abnormalities were noted. Hypertrophy of the muscle of both the muscularis mucosae and muscularis propria with some enlargement of the myocytic nuclei are prominent features. In the submucosal nerve plexus (Meissner's) ganglion cells are sparse but hypertrophy of the nerve fibres is not present. The residual ganglion cells are degenerate and their nuclei pyknotic. In the muscular plexus (Auerbach's) there is marked hypertrophy of the nerve fibres with vacuolation of the nerve sheaths giving the plexus a laciform pattern (Figure 19). The ganglion cells are diminished in number and show cytoplasmic vacuolation and degranulation. Their nuclei are eccentrically placed. The chromatin pattern is altered with increase in density, loss of outline of the nuclear membrane and diminution of nucleolar prominence (Figure 21). For comparison purposes the features of normal myenteric plexus are demonstrated in Figures 20 and 22.

DISCUSSION

The rectum has the ability to act as a dynamic reservoir for faeces. Like the urinary bladder, this role is dependent on its functional capacity, perception of filling and contractile properties. The measurement of rectal volume, sensory perception and distensibility is therefore of value in the physiological investigation of anorectal function (Keighley et al, 1982; Farthing and Lennard-Jones, 1978; Suzuki et al, 1980).

FIGURE 19

Photomicrograph of myenteric plexus from excised, radiation-injured rectum (H&E x 150). The ganglion cells (g) show marked degenerative changes with pyknosis of nuclei. There is proliferation of perineural tissue (t) with vacuolation.

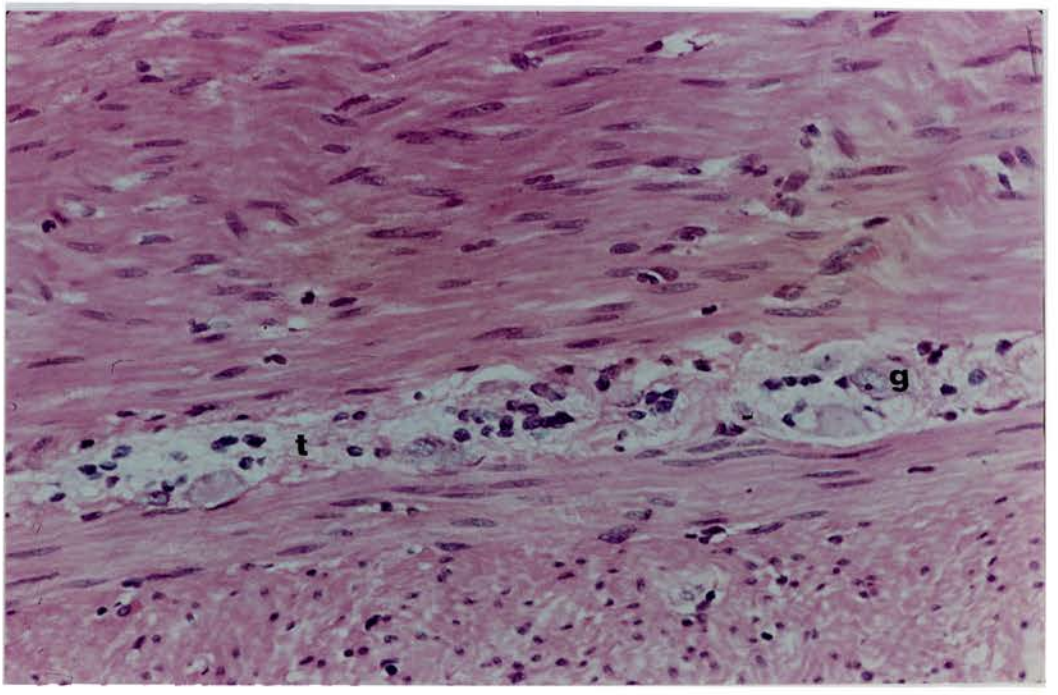


FIGURE 20

Photomicrograph of normal myenteric plexus (H&E x 150) showing ganglion cells (g) and perineural tissue (t).

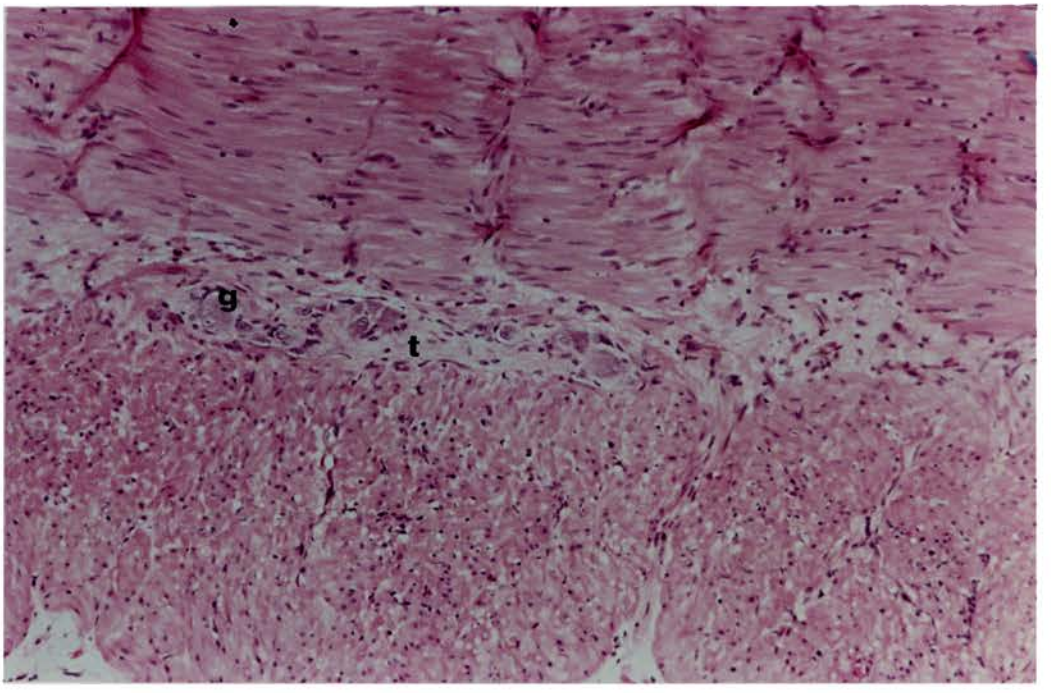


FIGURE 21

Photomicrograph of radiation-injured Auerbach's plexus (H&E x 250). There is diminution in the number of ganglion cells (g) which show degenerative changes. There is hypertrophy and vacuolation of nerve fibres (n).

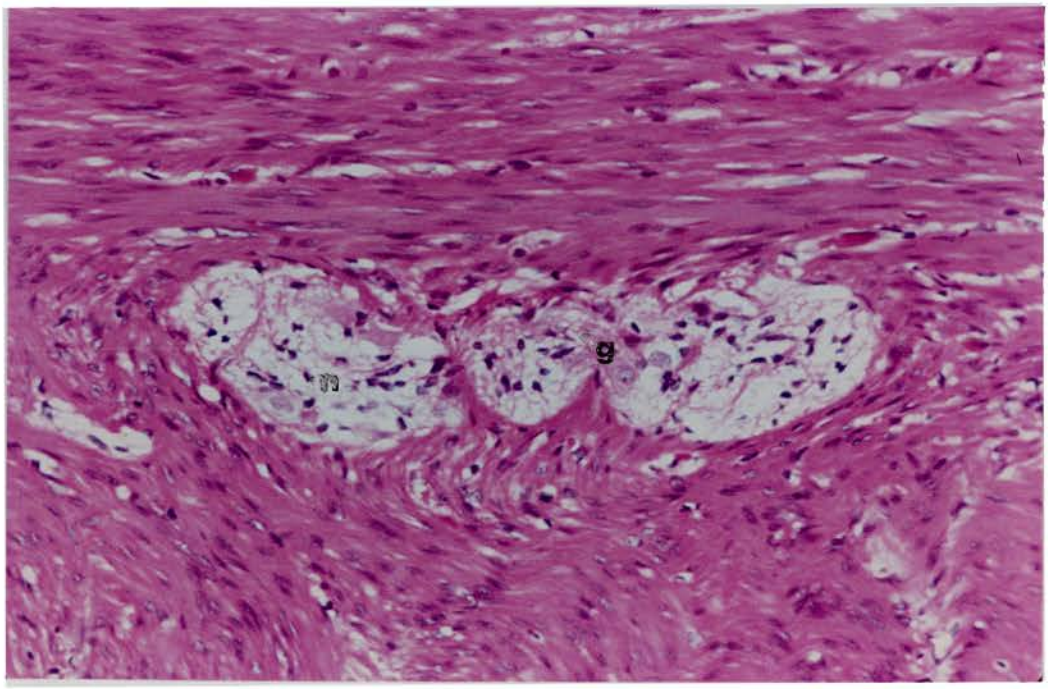
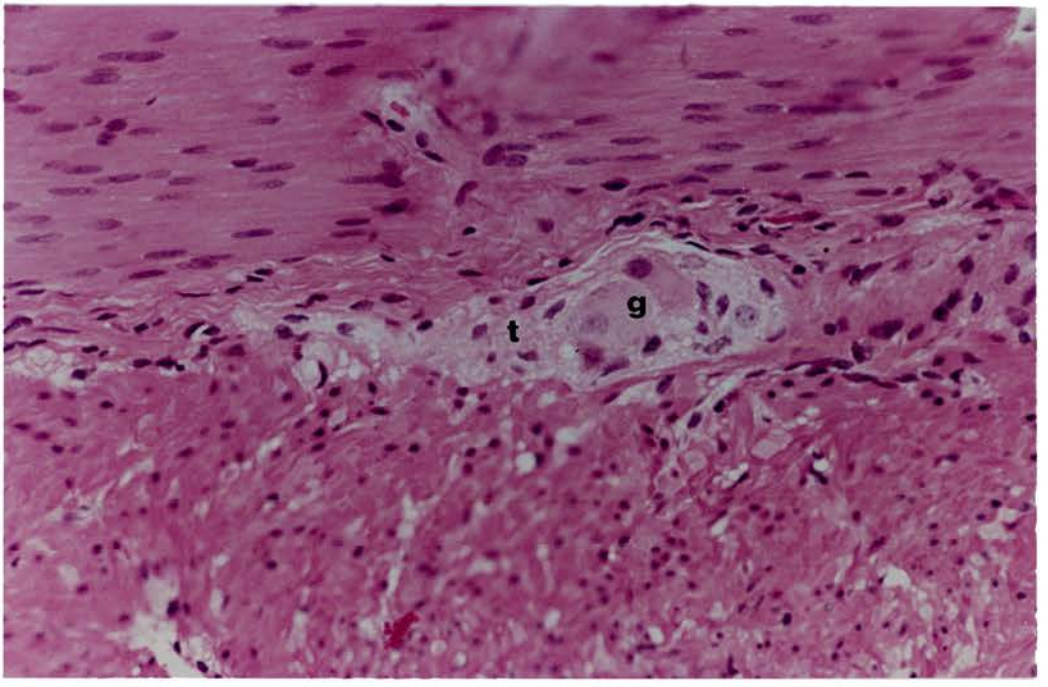


FIGURE 22

Photomicrograph of normal Auerbach's plexus (H&E x 250) showing typical ganglion cells (g) with scanty perineural tissue (t).



Previous clinical and pathological studies have distinguished two types of irradiation intestinal injury (Rubin and Casarett, 1968; Carr et al, 1984; Hatcher et al, 1985). Early symptoms occur during treatment and are due to a reversible direct injury to the intestinal mucosa. Up to 75 per cent of patients may be affected, usually by a transient mild proctocolitis which subsides following cessation of radiotherapy. In contrast delayed abnormalities appear after a latent interval of 6 months to 30 years and are believed to be due to progressive ischaemia from radiation-induced changes affecting the intestinal vasculature. Only 2 to 5 per cent of patients are affected but the pathological changes can be severe and irreversible, and may require surgical treatment (Section 3.3).

Urgency, increased frequency of defaecation and incontinence of faeces are common symptoms in patients with chronic radiation-induced anorectal injury (Hatcher et al, 1985). There is evidence that dysfunction of the internal anal sphincter is partly responsible for these symptoms (Varma et al, 1984,1986). The rectum is particularly susceptible to the effects of radiation directed at the primary pelvic pathology due to its fixed anatomical position. Damage to the rectum may therefore further compromise the continence of faeces. The purpose of this study was to define alterations in the motor function of the rectum in patients with the symptoms of chronic radiation rectal injury and to attempt to correlate these with clinical parameters. Male patients were chosen for the study to eliminate the effects of pelvic floor abnormalities predominantly found in females (Snooks et al, 1984; Kiff et al, 1984) with their possible resultant effects on rectal function (Womack et al, 1985).

None of the patients had anorectal symptoms prior to radiotherapy. Patients with severe symptoms often refuse permission to be studied because of the discomfort of rectal examination. The patients in this study, therefore, may represent lesser degrees of symptomatic radiation injury. Digital rectal examination of the prostate had been performed at six-monthly intervals following radiotherapy and was not presumed to have had any adverse effects on rectal function.

The maximal tolerable volume and hence the reservoir capacity of the rectum appears to be dependent on its compliance (Figure 15). On distension of the rectum, intrarectal pressures appear to play an important part in its proprioceptive ability (Table 7) probably mediated by sensory receptors in the levator ani muscles or perirectal tissues (Lane and Parks, 1977). The highly significant correlations between the manometric and clinical parameters (Figures 16-18) suggest that the reduction in rectal volumes and compliance are responsible for the frequency, urgency and urge type of faecal incontinence that are common symptoms in this group. Similar symptoms are encountered in other forms of inflammatory bowel disease. Farthing and Lennard-Jones were able to demonstrate changes in rectal volumes in ulcerative colitis and correlate them to clinical features (1978). Similar observations were confirmed by other workers (Colin et al, 1979; Suzuki and Fujioka, 1982). Keighley et al (1982) demonstrated abnormalities of rectal volume in Crohn's disease and used it as a prognostic indicator for the results of anterior resection and ileorectal anastomosis in this group. A maximum rectal capacity of less than 150 ml before surgery was associated with poor postoperative anorectal function. The correlation of manometric and sigmoidoscopic

parameters in this study may be taken to implicate mucosal damage as the direct cause of the patients' symptoms. However, the sigmoidoscopic scoring system takes into account the distensibility of the rectum, a feature that is also related to smooth muscle function. The sigmoidoscopic scores, therefore, may also reflect chronic damage to the underlying muscle and neuronal plexuses, although alteration of the sensory modalities in inflamed mucosa may influence symptoms as suggested in the colitis study (Farthing and Lennard-Jones, 1978). Myenteric plexus or smooth muscle damage are not histological features of ulcerative colitis and therefore mucosal changes alone correlate well with the severity of symptoms and experimental findings. Not surprisingly, the best correlation to manometric evaluation after radiotherapy was obtained with the added symptomatic and sigmoidoscopic scores (Figure 18).

Although the histological preparations were taken from different patients to those studied manometrically, the total therapeutic pelvic radiation dosage delivered to the two groups was identical. The marked damage to the myenteric plexus seen histologically may be responsible for the abnormalities of distensibility or non-relaxation as suggested by the absence or reduction in amplitude of the rectal distension reflex in such patients (Varma and Smith, 1984, 1986). The hypertrophy of the smooth muscle seen in the histological preparations is further evidence of damage to the myenteric plexus as there is some evidence that denervated smooth muscle hypertrophies (Alvarez, 1949).

We were unable to demonstrate radiological changes in rectal capacity or function in most patients but this may be because the patients

chosen for this study represented milder degrees of radiation injury. We also did not evaluate rectal capacity on true lateral pelvic radiographs which appear to be more accurate (Farthing and Lennard-Jones, 1978). Keighley et al (1982), using standard radiographs to assess rectal capacity, found poor correlation between this and the maximal tolerable volume.

This study demonstrates and helps to explain the physiological abnormalities of rectal function in symptomatic radiation anorectal injury. The manometric and histopathological evidence suggests thatradiation damage to the relatively radiosensitive myenteric plexus and hypertrophy of smooth muscle may be important factors in the pathophysiology of this disorder, although mucosal damage is contributory. The treatment of mucosal inflammation in chronic radiation injury is hence important but resolution of symptoms may be disappointing due to the underlying myenteric plexus and muscle abnormalities. These also contribute to dysfunction of the internal anal sphincter (Varma and Smith, 1984, 1986).

Longitudinal studies of rectal function in patients with radiation injury would further help to clarify the pathophysiology and clinical course of this disorder and assist in their management.

3.2 FUNCTION OF THE ANAL SPHINCTERS FOLLOWING CHRONIC RADIATION INJURY

SUMMARY

Anorectal manometry and electrophysiology was performed in ten men with chronic radiation proctitis. All had symptoms of urgency, frequency and occasional incontinence of faeces. They were compared to ten asymptomatic approximately age and sex-matched controls. The maximum resting anal canal pressure and the physiological sphincter length were significantly reduced ($p < 0.01$) in the irradiated group. The rectosphincteric reflex was absent in one patient and showed abnormalities of recovery in four others who had received radiotherapy. The squeeze pressure of the external sphincter was not significantly different ($p > 0.05$). Mean motor unit potential duration of the EAS was significantly prolonged in the radiation group ($p < 0.01$), although the electrophysiological latency of the pudendo-anal reflex appeared unaffected.

These results indicate that dysfunction of the internal anal sphincter may contribute to patients' anorectal symptoms after pelvic radiotherapy. Histological evidence suggests that damage to the myenteric plexus may be responsible. Although the manometric function of the external sphincter remains relatively unaffected, an early electromyographic abnormality is detectable.

INTRODUCTION

Radiotherapy is being increasingly used for the treatment of malignancy arising in the pelvic viscera (Hatcher et al, 1985). Inevitably, the incidence of associated radiation injury to healthy surrounding tissue with its sequelae has increased , sometimes necessitating surgical intervention (Morganstern et al, 1977; Schmitt et al, 1981; Hatcher et al, 1985; Cooke and Moor, 1981; Varma and Smith, 1986). The rectum is the commonest site of injury after pelvic irradiation, more than 70% of patients with radiation gastrointestinal injury having this site involved, sometimes in conjunction with other organs (Hatcher et al, 1985; Anseline et al, 1981). The fixed anatomical position of the anorectum in the pelvis makes it more susceptible to the injurious effects of radiation compared to the more 'mobile' organs such as the small bowel.

A very common symptom of radiation anorectal injury is loose bowel motions with faecal incontinence, often chronic in nature (Hatcher et al, 1985). Some of this symptomatology may be explainable by the accompanying proctitis and changes in rectal physiology (Varma et al, 1985; Section 3.1). However, it is conceivable that the continence function of the pelvic floor is also compromised as a result of the radiation injury, thus aggravating the severity of the faecal incontinence.

This Section studies the function of the internal and external anal sphincters in patients with symptomatic chronic radiation rectal injury.

PATIENTS AND METHODS

The symptomatic irradiated group comprised ten men (age range 63-80 years, mean 74 years) who received radiotherapy for prostatic carcinoma and all had subsequently developed the symptoms of faecal incontinence, increased frequency, urgency and occasional loose bowel motions. Identical small field external beam radiotherapy (5000 centiGrays in twenty treatments over four weeks) had been given to this group of men from 2 to 5.5 years prior to the study (mean 3.5 years). The control group consisted of ten approximately age-matched male hospital patients who had been admitted for minor surgery not involving the gastrointestinal tract and who had no anorectal symptoms.

Manometry

All subjects were requested to empty their bowel prior to the pressure studies (Varma and Smith, 1984). Anorectal manometry was performed with the patient in the left lateral position. A water-filled system consisting of a microballoon (internal diameter 4 mm HSC4, Precision Dippings Limited, Bristol, U.K.) mounted onto a 6 FG ureteric catheter and connected via an external transducer (4-442, Bell & Howell Ltd., U.K.) to a chart-recorder (Devices Limited, U.K.) was used to measure anal canal pressure. The system was precalibrated and the balloon introduced into the rectum 6 cm from the anal verge and rectal pressure measured.

The balloon was then withdrawn in steps of 0.5 cm and the resting pressure at each 'station' measured until a stable value was obtained. The subject was also asked to contract the external sphincter and the maximum voluntary contraction pressure recorded. The 'squeeze' pressure or the external sphincter contribution to this pressure was calculated as the difference between the maximum voluntary contraction pressure and maximum resting pressure. The rectosphincteric reflex was elicited by placing the microballoon at the site of maximum resting pressure and quickly distending the rectum by inflating a 2cm by 1cm soft rubber balloon (HSC1, Precision Dippings Ltd., Bristol, U.K.) with 50 ml of air. The rectal balloon was placed at 10 cm from the anal verge. The decrease in the resting anal canal pressure on rectal distension was recorded as the amplitude of the rectosphincteric reflex.

Electrophysiology

A modification of the method described by Bartolo et al (1983) was used. A standard concentric needle EMG electrode (surface area 0.07 mm^2,type 13L49 DISA, Copenhagen) was inserted into the external anal sphincter without anaesthetic via a puncture site 1cm. lateral to the anal orifice to a depth of approximately 250 mm. This was connected via preamplifiers to an oscilloscope (Medelec MS92a, Woking, Surrey, U.K.). The tonic electrical activity of the sphincter was monitored using a time base of 10 ms/cm with the gain at 100μV/cm and filter settings of 20Hz - 10kHz). Single motor units firing at a steady rate were identified using the delay and trigger facilities incorporated in

the apparatus. A saline-soaked felt strap wrapped around the right thigh was used as the ground electrode. Approximately 100 consecutive action potentials of the same motor unit were digitally averaged on one channel of the oscilloscope and the process repeated on the second channel. When two identical traces were obtained on both channels, the action potential duration for that motor unit was measured from the first deflection from the baseline to the return of the action potential to the baseline. Stable late components were thus easily identified (Bartolo et al, 1983). Permanent recordings were obtained of at least twenty action potentials from the external anal sphincter representing approximately ten recordings from each side of the sphincter. This was made possible by minor movements of the tip of the needle electrode in the sphincter. The arithmetic mean of the twenty recorded potential durations was calculated and represented the mean motor unit potential duration for that sphincter.

The electrophysiological latency of the pudendo-anal reflex was determined by the method described in Section 2.3. These two measurements were used as indices of neuropathy of the external anal sphincter (Varma et al, 1986; Buchtal and Pinelli, 1953).

Statistics

All the data was analysed by means of the Wilcoxon rank sum test.

Histopathological material

The same material as has been described in Section 3.1 was used for

this study. It was obtained from eight other patients who had undergone excisional surgery for complications of radiation rectal injury (Varma and Smith, 1986; Section 3.3). At least three sections were examined from each specimen.

RESULTS

Table 8 lists the manometric and electrophysiological results in the two groups.

Manometry

Figure 23 shows a comparison of the maximum resting anal canal pressures between the two groups. There is a significant reduction in this pressure in the radiation group ($p < 0.01$). Figure 24 compares the length of the manometrically determined high-pressure zone in the two groups as measured with the station pullthrough technique. This is also significantly reduced in the radiation group ($p < 0.01$). Table 8 shows the values for the other parameters measured and their statistical sagnificance. The presence and recovery of the rectosphincteric reflex was affected by radiation. The amplitude was significantly reduced after radiation and in one patient the reflex was absent. All control subjects showed restoration of the maximum resting pressure to baseline levels within 30 seconds on inflation of the rectal balloon and immediately on deflation of the balloon. In contrast, four patients in the radiation group showed no recovery of this reflex as long as the balloon remained inflated, and time to

TABLE 8

Manometric and electrophysiological anal sphincter data in chronic radiation injury

Parameter	Control (n=10)	Radiation (n=10)	p
MRP (ml H2O)	99±6.7	66±7.6	<0.01
HPZ (cm)	4.25±0.2	2.65±0.2	<0.01
Amplitude RSR (cm H2O)	46±2.7	25±4.8 (1 absent)	<0.02
MVC (cm H2O)	219±10.5	151±16.9	<0.05
SP (cm H2O)	120±10.9	86±27	>0.5
Latency PAR (ms)	36.3±1.9	41.5±3.2	>0.1
Amplitude PAR (μV)	3.7±0.66	2.9±0.71	>0.1
Duration PAR (ms)	16+1.64	17+2.66	>0.1
Sensory threshold (Volts)	30.5±3.2	34±2.5	>0.1
Stimulation voltage (Volts)	100±8.2	102±6.2	>0.01
MUPD EAS (ms)	8.4±0.5	11.6±1	<0.01

All measurements Mean±SEM

FIGURE 23

Effect of radiation on maximum basal anal canal pressure. Bars represent Mean±SEM

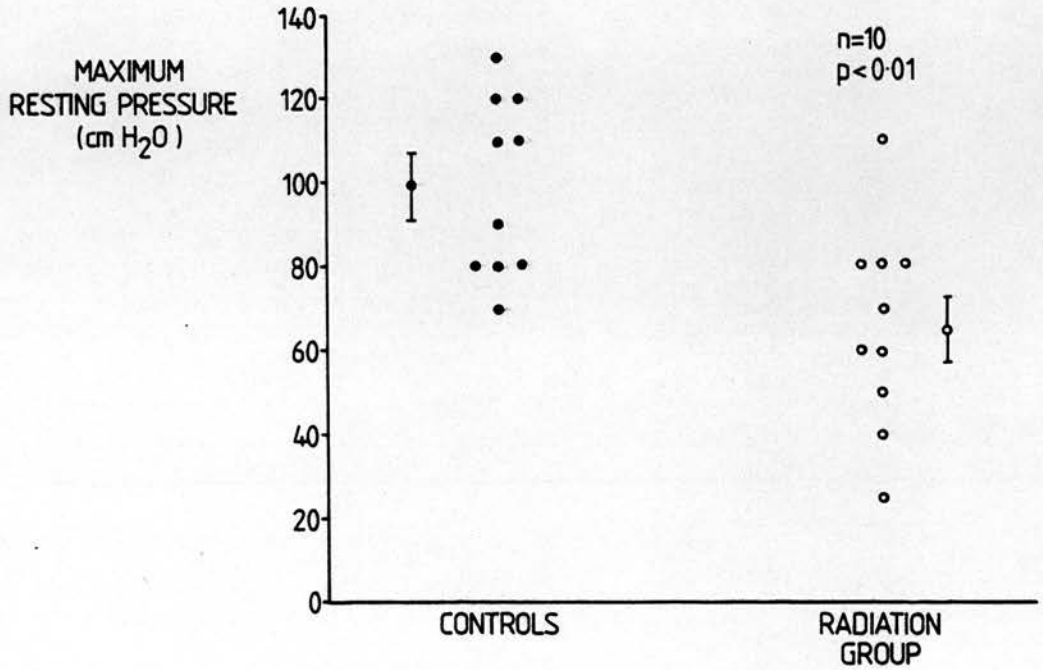
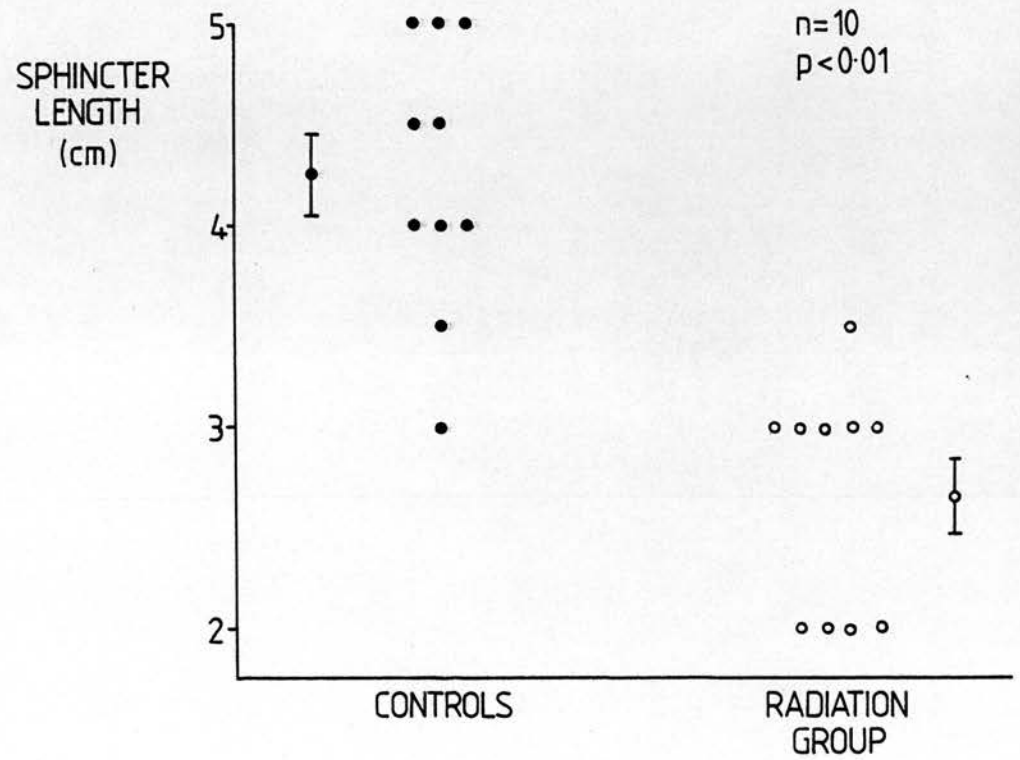


FIGURE 24

Effect of radiation on the length of the manometric high-pressure zone in the anal canal. Bars represent Mean±SEM



recovery of resting pressure was prolonged to more than 60 seconds on deflation of the balloon. The remaining five patients showed normal recovery of the reflex. Maximum voluntary contraction pressure was reduced in the radiated group but this is probably attributable to the reduced maximum resting pressure because no difference in the 'squeeze' pressure (i.e. maximum voluntary contraction pressure minus maximum resting pressure) could be demonstrated ($p > 0.05$).

Electrophysiology

Mean motor unit potential duration was significantly prolonged in the radiation group (Table 8). However, The latency or amplitude of the pudendo-anal reflex were not significantly affected.

Histopathology

Microscopic examination of the sections taken from all the eight resected specimens showed identical histopathological changes. These have been described in Section 3.1 showing abnormalities of the myenteric plexus and smooth muscle hyperrophy (Figures 19-22).

DISCUSSION

Urgency, increased frequency of defaecation and incontinence of faeces are common symptoms in patients with chronic radiation anorectal injury (Hatcher et al, 1985). There is evidence that reduction in

rectal compliance and volume is partly responsible for these symptoms (Varma et al, 1985; Section 3.1). The pelvic floor - in particular the anal canal and sphincters - is also susceptible to the effects of radiation directed at the primary pelvic pathology. Damage to the sphincteric mechanasms may therefore further compromise continence. The purpose of this study was to determine whether anal sphincter function is affected in patients with the symptoms of chronic radiation rectal injury. All the irradiated patients had identical symptoms of faecal incontinence with urgency and frequency of defaecation. Male patients were chosen for the study to eliminate the effects of parturition (Snooks et al, 1984) and chronic straining at stool (Kiff et al, 1984) predominantly found in females with resultant effects on sphincter function. None of the patients had anorectal symptoms prior to radiotherapy. Digital rectal examination of the prostate had been performed only at six-monthly intervals following radiotherapy and was therefore not presumed to have had any adverse effects on anal sphincter function. Although the histological preparations were taken from different patients to those studied manometrically, the total therapeutic dosage of pelvic irradiation delivered to the two groups and the time since radiation was identical.

The internal anal sphincter is responsible for upto 85% of the maximum resting pressure in the anal canal (Dickinson, 1978) and therefore also for the length of it's manometric high-pressure zone. The significant reduction in the maximum resting pressure and physiological sphincter length in the irradiated group suggests dysfunction of this muscle. Relaxation of the internal anal sphincter

on distension of the rectum is a smooth muscle reflex partly mediated via the myenteric plexus (Nixon, 1964) although receptors in the pelvic floor may share in this (Lane and Parks, 1977). The abnormalities in the elicitation, amplitude and recovery of this reflex after pelvic radiotherapy point to a possible functional abnormality of the autonomic ganglion cells or axons constituting this neuronal network. The reduction in the amplitude of the rectosphincteric reflex in the irradiated group is partly due to the lower resting anal canal pressures but can also be influenced by other variables (e.g. the radius of the rectal lumen and compressibility of the air filling the rectal balloon). Nevertheless, it has been used as an index of internal sphincter function by other workers (Iwai et al, 1979; Taylor et al, 1980; Lanfranchi et al, 1984; Callaghan and Nixon, 1964) and complements the results obtained from measurement of the other parameters in this study. Furthermore, there is some evidence that the presence and amplitude of the rectosphincteric reflex is inversely related to the compliance and accomodation properties of the rectum (Iwai et al, 1979; Lanfranchi et al, 1984; Callaghan and Nixon, 1964; Arhan et al, 1976). The observation that this reflex is reduced after radiation injury (i.e. in the presence of severe reduction in rectal compliance) is therefore good evidence of internal anal sphincter malfunction in this disorder. It is relevant that similar abnormalities of the rectosphincteric reflex may be seen in Hirschprung's disease where the significant pathology is an absence of the ganglion cells (Nixon, 1964; Barnes et al, 1986) and in other forms of neuronal intestinal dysplasia (Scharli and Meier-Luge, 1981). The hypertrophy of the smooth muscle seen in the histological

preparations is further evidence of damage to the myenteric plexus as there is some evidence that denervated smooth muscle hypertrophies (Alvarez, 1949).

The function of the striated external sphincter as evaluated manometrically appears relatively less prone to the effects of pelvic irradiation. This is perhaps not surprising as somatic nerve axons and muscle are considered relatively resistant to radiation effects (Rubin and Casarett, 1968) with resultant 'sparing' of the manometric function of this sphincter. It remains possible, however, that late effects occur with microvascular involvement (Rubin and Casarett, 1968; Carr et al, 1984). This may be reflected in the findings of a prolonged MUPD in the radiation group in this study. It was, however, not supplemented by abnormalities of the pudendo-anal reflex as observed in neurogenic faecal incontinence (Varma et al, 1986; Section 5.1). It is of interest that in polymyositis MUPD is usually decreased (Buchtal and Pinelli, 1953). Our findings may, therefore, reflect an early neuropathy of the terminal innervation of the external sphincter induced by radiotherapy. With higher doses of local irradiation such as that used for the treatment of cervical cancer, dysfunction of the external sphincter may become more evident.

This study demonstrates physiological dysfunction of the internal anal sphincter in symptomatic radiation anorectal injury. This may contribute to and therefore aggravate symptoms caused by abnormalities of rectal function (Varma et al, 1985). The manometric and histopathological evidence suggests that radiation damage to the relatively radiosensitive myenteric plexus is an important factor in the pathophysiology of this disorder, although a degree of direct

damage to smooth muscle may also occur. There is also some electrophysiological evidence from this study to support an early neuropathy of the external anal sphincter which remains manometrically normal.

Awareness of the pathophysiological effects of radiation on pelvic floor function may lead radiation oncologists to study the feasibility of less injurious techniques and gastroenterologists to search for better therapeutic measures.

3.3 ANORECTAL FUNCTION FOLLOWING COLO-ANAL SLEEVE ANASTOMOSIS FOR CHRONIC RADIATION INJURY TO THE RECTUM

SUMMARY

Anorectal manometry and electrophysiological studies of the pelvic floor were performed in eight patients who had undergone anterior resection of the rectum with mucosal proctectomy and colo-anal sleeve anastomosis for radiation rectal injury.

There is a severe reduction in the compliance of the neo-rectum and in the maximal tolerable volume. Maximum basal anal canal pressure and physiological sphincter length are also significantly reduced although the 'squeeze' pressure of the external anal sphincter and the latency of the pudendo-anal reflex were unaffected. Four patients had an absent rectosphincteric reflex, 4 patients involuntarily expelled the test balloon at the maximal tolerable volume during a proctometrogram, and 4 patients demonstrated paradoxically increased EMG activity of the pelvic floor on straining and on rectal distension with 200 ml air.

These physiological findings help to explain many of the patients' symptoms. Histological abnormalities of the myenteric plexus were a prominent feature in all the excised specimens and may be responsible for some of the functional abnormalities because a significant length of rectal muscle sleeve is left in situ.

INTRODUCTION

With greater use of radiotherapy for the treatment of pelvic malignancy (Hatcher et al, 1985) the incidence of chronic radiation intestinal injury, particularly to the rectum, has also increased (Morganstern et al, 1977; Schmitt and Symmonds, 1981; Editorial, Lancet, 1983). The symptomatic sequelae are often extremely distressing (Varma et al, 1985) and the organic complications such as haemorrhagic proctitis may be life-threatening, sometimes necessitating surgical intervention (Schmitt and Symmonds, 1981; Anseline et al, 1981; Hatcher et al, 1985; Cooke and De Moor, 1981; Browning et al, 1987). Parks' operation of anterior resection of the rectum with mucosal proctectomy of the rectal stump and an endoanal pullthrough anastomosis (Parks, 1966, 1972) has been used to treat these complications with acceptable surgical results (Jeffrey and Parks, 1983; Gazet, 1985; Varma and Smith, 1986; Browning et al, 1987). However, urgency and frequency of defaecation, occassionally accompanied by anorectal incontinence, often persist following these measures and can be most troublesome for the patient. To explain the physiological basis of these symptoms, the function of the neo-rectum and anal sphincters were evaluated by manometric and electrophysiological techniques. In addition, the excised rectal specimens were examined histologically.

PATIENTS AND METHODS

The symptomatic operated group comprised six female and two male patients (age range 61-84 years, mean 71 years). Six patients had received external beam radiotherapy for carcinoma of the urinary bladder and two for carcinoma of the cervix. The bladder carcinoma patients had received small field (10cm X 10cm) external beam radiotherapy (5500 cGy in twenty treatments over four weeks); the cervical cancer patients had been given whole pelvis, external beam radiotherapy supplemented by a single Caesium implant (cumulative dosage of 9500 cGy to the vaginal vault, equivalent to 7500 cGy to point A). The interval from radiotherapy to physiological study ranged from 2.8 to 5.5 years (mean 3.5 years). All patients had subsequently developed chronic haemorrhagic proctitis, two with a rectal stricture and were treated by a Parks' colo-anal procedure (Parks, 1966, 1972; Jeffrey and Parks, 1983) after exclusion of recurrent malignancy. There were no major complications. All patients had been followed up for more than 2.5 years since operation. There was no evidence of proctitis, haemorrhage or stricture at the time of the study but all had varying degrees of troublesome urgency and frequency of defaecation by day and night; three patients had to wear an incontinence pad for occasional faecal leakage. Table 9 lists some the important clinical features. The control group consisted of eight sex-matched and approximately age-matched hospital patients who had been admitted for minor surgery not involving the gastrointestinal tract and who had no anorectal symptoms.

TABLE 9

Details of some clinical and physiological features of the eight patients with colo-anal sleeve anastomosis for radiation injury

Cont grade	Pad	Freq D	Freq N	Urg	RSR	RC	BE	EAS EMG 50 ml	EAS EMG 200ml	EAS EMG Strain
B	-	4	6	+++	-	1.5	-	+	-	-
C	+	5	3	++	+	1.4	+	+	+	-
B	-	2	1	++	-	2.2	-	+	-	+
B	-	2	1	++	+	1	-	+	+	+
B	-	4	3	+	+	0.34	+	+	+	+
D	+	5	1	+	+	3.5	+	+	-	-
C	+	7	1	++	-	1.6	+	+	+	+
A	-	3	2	-	+	2.8	-	+	-	-

Continence grades: A, fully continent; B, incontinent of flatus only; C, incontinent of liquid stool ± flatus; D, incontinent of solid and liquid stool

Freq=frequency by day and night

Urg=urgency

RSR=presence or absence of the rectosphincteric reflex

RC=compliance of the neorectum

BE=expulsion of the proctometrogram balloon

EAS EMG=Increase or decrease of EMG activity in the external anal sphincter on distension of the neorectum with 50 or 200 ml air, or on defaecation straining

Manometry (Figure 25)

Fasted patients were requested to empty their bowel on the morning of the study, assisted by means of a saline washout if necessary but laxatives were not used. Digital rectal examination and limited sigmoidoscopy using a paediatric instrument were performed to ensure that the rectum was empty and for tube placement in the left lateral position.

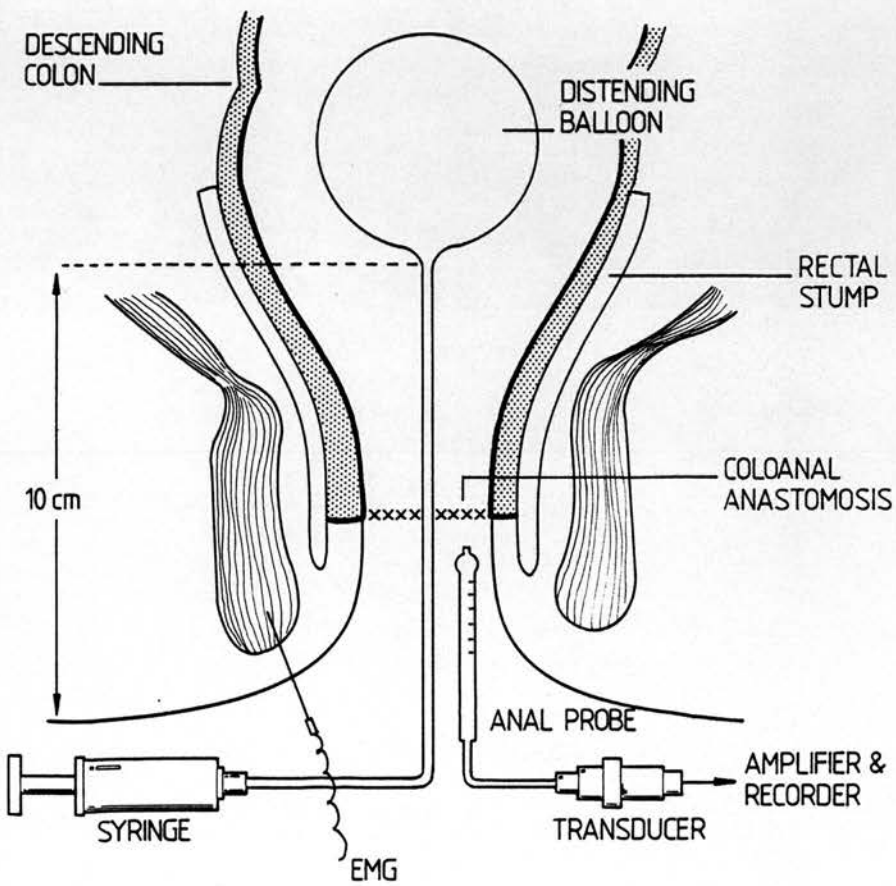
Basal and squeeze sphincter pressures, sphincter length and rectosphincteric reflex were measured with a conventional water-filled microballoon and external transducer using a 0.5 cm. station-pullthrough technique (Varma and Smith, 1984; Section 2.1). The larger soft rubber balloon was inflated slowly with air (above the anastomosis) to obtain a value for the sensory threshold of rectal distension and an average of three measurements calculated. Proctometrograms (Varma and Smith, 1986; Section 2.2) were performed to measure rectal compliance and the maximal tolerable volume. The manometric parameters measured with this technique were the volumes and pressures at the maximal tolerable volume and rectal compliance.

Electrophysiology

A standard concentric needle EMG electode (type 13L49 DISA, Copenhagen) was inserted into the external anal sphincter (Figure 25) without anaesthetic via a puncture site 1 cm posterior to the anal orifice to a depth of approximately 2.5 cm. This was connected via

FIGURE 25

Diagrammatic representation of the methodology in the physiological evaluation of the anorectum following colo-anal sleeve anastomosis (modified from Williams et al, 1980)



preamplifiers to an oscilloscope (Medelec MS92a, Woking, Surrey, U.K.). Electrical activity of the sphincter was continuously monitored using a time base of 100 ms/cm with the gain at 100uV/cm and filter settings of 20Hz - 10kHz). Permanent recordings were obtained of electrical activity at rest, on voluntary contraction, on defaecation straining and on distension of the rectal balloon with 50 ml and 200 ml of air. The tip of the needle was moved to at least three different sites to ensure reproducibility of the recordings. The electrical activity was also heard as amplified sound via a loudspeaker incorporated in the equipment.

The pudendo-anal reflex (Varma et al, 1986) was elicited by electrical stimulation of the dorsal nerve of the penis or clitoris with a felt bipolar surface stimulating electrode (type LBS 53051, Medelec, U.K.) and recording the reflex contraction of the external anal sphincter with a bipolar surface stainless-steel anal plug electrode (type 13K78, DISA, Copenhagen) using the Medelec MS92a evoked response unit. Details of the methodology are described in Section 2.3. In no case was the stimulation reported to be painful by the patient. The procedure was repeated in each subject to ensure reproducibility. The latency of the pudendoanal reflex was measured from the onset of the sweep (triggered by the stimulus) to the onset of the clearly defined evoked response (Figure 14).

Histopathology

Histological material was obtained from the eight patients who had undergone a colo-anal procedure. Following fixation with formalin, paraffin-embedded sections of the rectum were examined by conventional techniques. Sections were taken from various sites in each specimen.

Statistics

The manometric and electrophysiological measurements between the two groups were analysed by the Wilcoxon rank sum test.

RESULTS

Manometry

Table 10 compares the manometric parameters measured in the two groups. There is a significant reduction in the physiological sphincter length, maximum resting pressure and the amplitude of the 'recto-sphincteric reflex in the colo-anal group. The squeeze pressure of the external anal sphincter appears to be reduced in the colo-anal group but this difference does not reach statistical significance. In 4 patients the 'recto-sphincteric reflex could not be elicited despite several attempts, its amplitude being reduced in the remainder. Figure 9c represents the type of proctometrogram obtained from a colo-anal patient and Figure 9b a control subject. In the control

TABLE 10

Anorectal manometry following colo-anal sleeve anastomosis

Parameter	Control (n=10)	CSA (n=10)	p
MRP (cm H2O)	104±5.3	54±7.7	<0.01
SP (cm H2O)	159±5.9	120±17.9	>0.1
HPZ (cm)	3.5±0.25	2.4±0.21	<0.02
Amplitude RSR (cm H2O)	47.5±3.1	12.5±5.6	<0.02
STV (ml H2O)	58±10.2	29±3.8	<0.05
MTV (ml H2O)	504±29	120±25	<0.01
MTP (ml H2O)	73±2.8	86±6.5	>0.01

All measurements Mean±SEM

subject there is a slow and steady rise in rectal pressure with inflation until no further distension can be tolerated to the maximal tolerable volume of approximately 450 ml H2O. In contrast to this the patient with colo-anal sleeve anastomosis shows a rapid and steep rise in rectal pressure with infusion of only 250 ml H2O, prominent rectal contractions occuring during this distension. There is a severe and significant reduction in the rectal compliance in the operated group (Figure 26). The volumes at the sensory threshold of rectal distension and at maximal tolerance are also significantly reduced (Table 9). Comparison of rectal pressures at the maximal tolerable volume did not show a significant difference. In addition to these abnormalities, in 4 patients in the colo-anal group the proctometrogram balloon was expelled involuntarily at the maximal tolerable volume, although this phenomenon was not seen in any of the control subjects. Table 9 lists some of the clinical, manometric and electromyographic findings in the colo-anal group.

Electrophysiology

There appeared to be no difference in the resting and 'squeeze' external sphincter electrical activity between the two groups. However, on defaecation straining, 4 patients demonstrated a paradoxical increase in EMG activity of the external sphincter whereas all the control subjects showed reduction in activity (Figure 27). In addition, on balloon distension of the rectum with 200 ml of air, another 4 patients had increased electrical activity of the external sphincter in contrast to the control subjects all of whom showed

FIGURE 26

Scattergram of rectal compliance values showing the severe reduction in the CSA group. Bars represent Mean±SEM

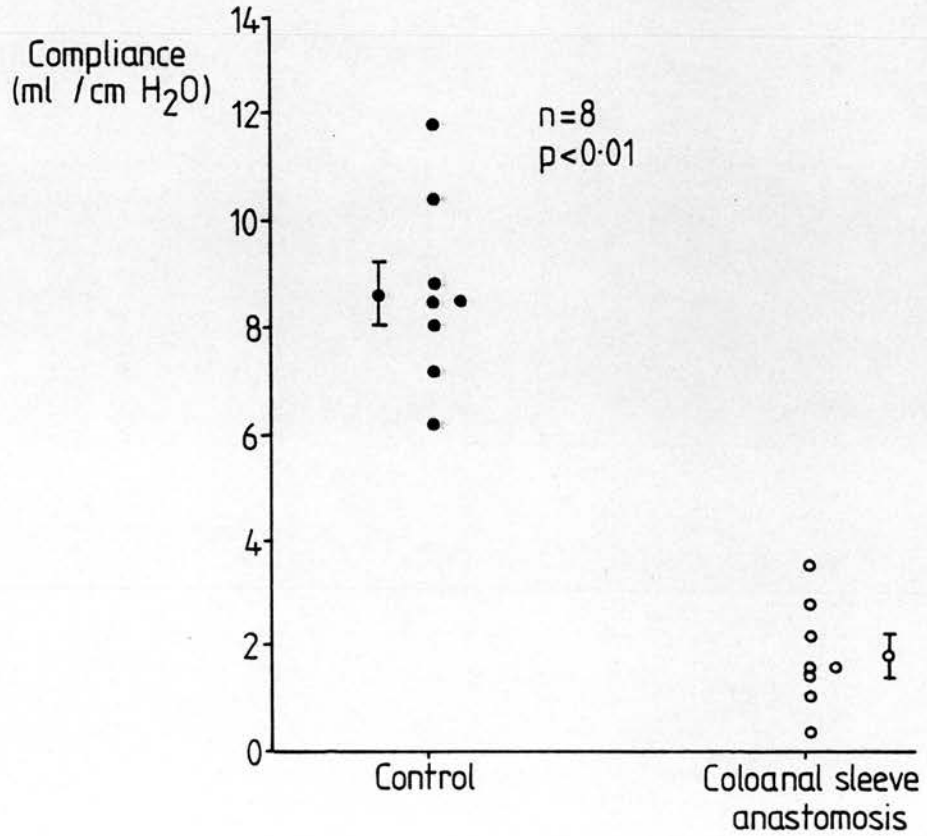
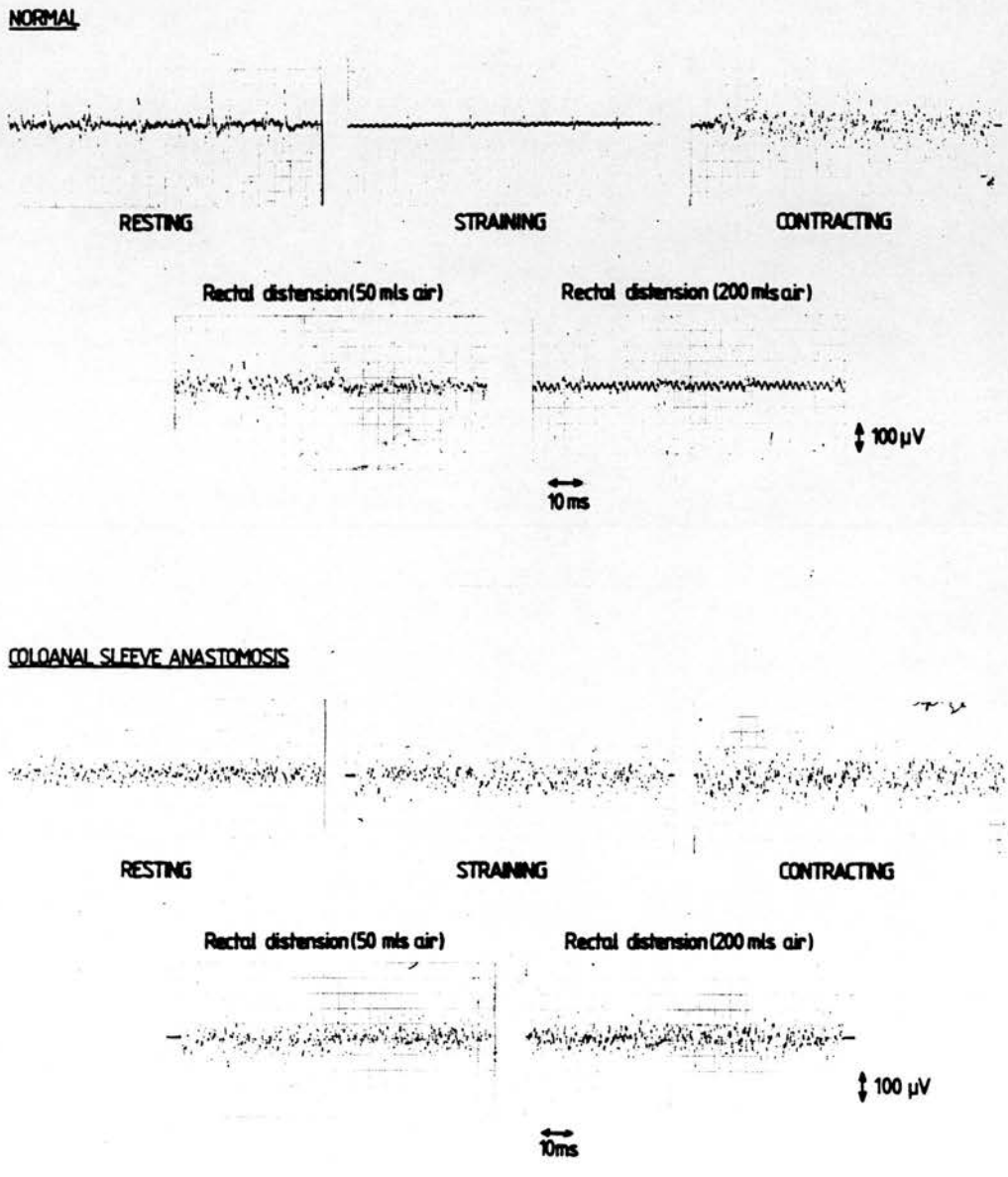


FIGURE 27

Concentric needle EMG of the external anal sphincter in health and following colo-anal sleeve anastomosis. Note the paradoxical increase in activity during defaecation straining and on rectal distension with 200 ml air after CSA



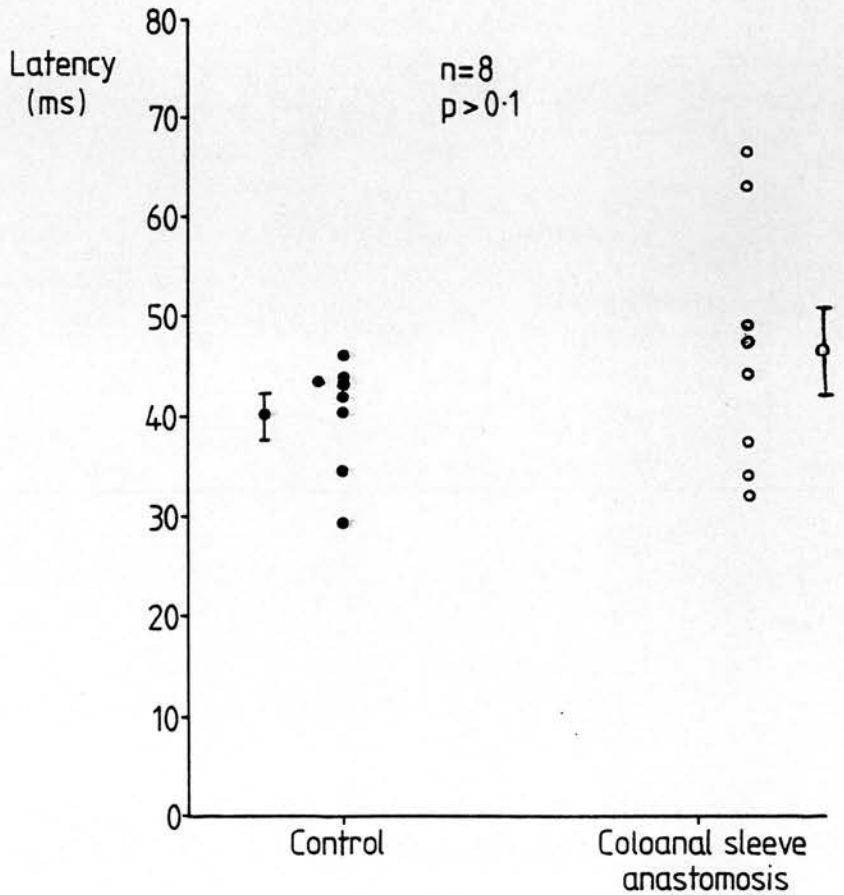
reflex reduction in the EMG activity of the sphincter (Table 9). The latency of the pudendo-anal reflex appeared to be prolonged in the operated group although the difference was not statistically significant (Figure 28).

Histopathology

Proximal sections taken from the eight resected specimens showed identical histopathological changes (Figures 19, 21). Mild non-specific chronic inflammatory changes were present in the lamina propria; the glandular epithelium appeared normal. The muscle of both the muscularis propria and muscularis mucosae was hypertrophied and showed some enlargement of the nuclei of the muscle cells. In the submucosal nerve plexus (Meissner's) ganglion cells were sparse but the nerve fibres were not hypertrophied. The residual ganglion cells demonstrated degenerative changes with pyknosis of their nuclei. In the muscular plexus (Auerbach's) the nerve fibres were hypertrophied and the nerve sheaths vacuolated producing a lace-like appearance. There were few ganglion cells and these showed cytoplasmic vacuolation and degranulation. The chromatin pattern of their nuclei showed an increase in density and there is loss of outline of the nuclear membrane and absence of the nucleolar detail. These striking abnormalities are in contrast to the histological appearances of the myenteric plexus from normal rectum illustrated in Figures 20 and 22. Sections from the proximal resection line showed similar normal appearances.

FIGURE 28

Scattergram of electrophysiologically determined latency measurements of the pudendo-anal reflex in the two groups. Bars represent Mean±SEM



DISCUSSION

Parks' operation of colo-anal sleeve anastomosis after anterior resection of the rectum with mucosal proctectomy of the stump (Parks, 1966, 1972; Jeffrey and Parks, 1983) appears to deal with the organic complications of severe radiation injury to the rectum (Jeffrey and Parks, 1983; Gazet, 1985; Varma and Smith, 1986; Browning et al, 1987), at the same time restoring intestinal continuity with preservation of the anal sphincters. The long-term functional results after colo-anal sleeve anastomosis for the treatment of low rectal cancer appear to be satisfactory (Lane, 1983). However, following this operation for radiation rectal injury many patients experience some degree of troublesome urgency and frequency of defaecation which may be associated with occasional incontinence. No previous physiological studies have been reported on patients treated by this operation for radiation injury. As the operation is rarely performed for carcinoma of the rectum, the ideal comparison of such patients with the radiation group was precluded. The reduction in the maximum resting sphincter pressure, physiological sphincter length and the abnormalities of the rectosphincteric reflex suggest a dysfunction of the internal anal sphincter. It has been shown that a similar dysfunction of the internal sphincter may occur in patients with chronic radiation proctitis who have not had surgery performed (Varma et al, 1986). The anal stretch necessary for the mucosal proctectomy and colo-anal anastomosis may contribute to the decrease in anal canal pressure (Browning et al, 1982). The more

extreme anal dilatation involved in Lord's operation for haemorrhoids can produce a similar permanent decrease in resting anal canal pressure (Hancock and Smith, 1975). Mucosal proctectomy includes excision of the lower rectal mucosa and submucosa along with the submucosal plexus of Meissner which may already have been compromised by radiation effects (Varma et al, 1985, 1986). The presence and function of normal intramural ganglion cells and nerve fibres is of paramount importance to the dynamic functional properties of the internal anal sphincter (Gowers, 1877; Denny-Brown and Robertson, 1935; Gaston, 1948; Callaghan and Nixon, 1964; Schuster et al, 1963). The abnormalities of the 'recto-sphincteric reflex seen in the patients in this study may therefore, at least in part, be explicable by the excision of Meissner's plexus. Decrease in anal canal pressure and loss of inhibition of the internal sphincter has been noted in other studies of patients after sphincter-saving excision of the rectum without preoperative radiotherapy (Lane and Parks, 1977; Williams et al, 1980; Nicholls et al, 1981; Neal et al, 1982). The radiation-induced damage to the myenteric plexus must further compromise the function of the internal sphincter. This is supported by the manonometric evidence. Although the histological sections were taken from the lower rectum, it is likely that similar abnormalities are present at the sphincteric level.

The external anal sphincter appears to be relatively 'spared' as assessed by its squeeze pressure and the electrophysiological latency of the pudendo-anal reflex. Although both these parameters appear to be altered in the colo-anal group suggesting some weakness of the external sphincter, the differences do not achieve statistical

significance (Figure 28 and Table 10). It is possible, however, that more sensitive techniques such as single fibre electromyography (Stalberg and Trontelj, 1979) could detect subtle abnormalities in this sphincter following radiation. The increase in activity of the external sphincter on distension of the rectum with 50 ml air is a normal reflex (Parks et al, 1962) and was present in all the patients and controls. The paradoxical increase in external sphincter EMG activity on distension of the rectum with 200 ml air is abnormal and may be due to voluntary sphincter contraction by the patient. Rectal distension with this volume of air tended to be a painful procedure, in contrast to patients with a normal rectum. This is probably due to higher rectal pressures being produced with smaller rectal volumes compared to controls (Figure 9); there is also less contribution by the internal sphincter in maintaining continence, thereby calling into play the external sphincter. This phenomenon has been observed by other workers (Lane and Parks, 1977; Williams et al, 1980). The physiological interpretation of the paradoxical increase in external sphincter activity on defaecation straining is difficult. It may be due to inadvertent voluntary activity by the patient who is under constant threat of incontinence from rectal and internal sphincter dysfunction. A similar phenomenon has been observed in some patients with the solitary rectal ulcer syndrome who have anatomical and functional abnormalities at the anorectal angle (Snooks et al, 1985). An abnormality of the sampling response (Duthie and Gairns, 1960; Duthie, 1975) developing in the lower rectum and anal canal following mucosal proctectomy could also be responsible, secondary to damage or excision of the nerve-rich anal transition zone (Martin et

al, 1986; Deasy et al, 1987; Primrose et al, 1987; Keighley and Winslet, 1987).

This study confirms the findings of other workers of intact rectal proprioception after low sphincter-saving surgery (Lane and Parks, 1977; Williams et al, 1980; Nicholls et al, 1981; Neal et al, 1982). On distension of the rectum, intrarectal pressure appears to play an important part in its proprioceptive ability - the intrarectal pressures attained at the maximal tolerable volume in both groups do not differ (Table 10); indeed it appears that intrarectal pressure may also determine its sensory threshold (Varma et al, 1985), thus explaining the lower threshold values seen with loss of rectal compliance. There is now evidence that this function is mediated by sensory receptors in the levator ani muscles or extrarectal tissues (Lane and Parks, 1977; Williams et al, 1980; Winckler, 1958; Walls, 1959; Duthie and Gairns, 1960; Scharli and Kieswetter, 1970) rather than in the rectal wall as was suggested by earlier workers (Parks et al, 1962; Hertz, 1911). The very severe reduction in rectal compliance and volumes following colo-anal sleeve anastomosis for radiation injury is somewhat surprising because relatively healthy, compliant sigmoid or lower descending colon was anastomosed to form the neo-rectum. Rectal compliance is markedly reduced before operation in these patients (Varma et al, 1985) and would be expected to be improved, even if not to normal values, following surgery. These findings suggest that the neo-rectum is unable to 'expand' in the pelvis. This may be due to 'intermural' fibrosis between the layers of the neo-rectum or extramural fibrosis in the pelvis and/or loss of compliance in the 'sleeve' of remaining rectal stump which also

remains susceptible to the late effects of radiation injury (Rubin and Casarett, 1968; Carr et al, 1984). Minor degrees of anastomotic dehiscence and 'cuff' sepsis may be contributory. Other factors may be implicated in the motility disturbances involved. Browning, for example, demonstrated hypermotility of the mobilised sigmoid colon following colo-anal anastomosis in some patients (Browning, 1982). The marked damage to the myenteric plexus seen histologically may also contribute to the abnormalities of distensibility or non-relaxation as suggested by the absence or reduction in amplitude of the rectal distension reflex in such patients. The hypertrophy of the smooth muscle seen in the histological preparations is further evidence of damage to the myenteric plexus as there is some evidence that denervated smooth muscle hypertrophies (Alvarez, 1949). The loss of compliance of the neorectum together with internal sphincter dysfunction further explains the expulsion of the proctometrogram balloon at low maximal tolerable volumes in four patients.

A clear correlation between clinical and physiological features is difficult to demonstrate due to the relatively small number of patients in this study, and the complex interaction of rectal and pelvic floor function in determining syptomatology (Table 9). However, involuntary balloon expulsion appears to occur in those patients with the poorest continence and the need to wear a pad occasionally. Frequency of defaecation appeared to be more related to internal sphincter dysfunction; abnormalities of external sphincter relaxation occured more often in patients with severe reduction in rectal compliance.

This study helps to explain the physiological basis of the

abnormalities of anorectal function which follow colo-anal sleeve anastomosis for severe radiation rectal injury. Increased knowledge of the pathophysiology of this disorder may help to achieve better functional results. For example, it may be possible to improve anorectal function by leaving a very short rectal stump and/or performing a full-thickness myotomy of the stump prior to the sleeved anastomosis. Dilatation of the neorectum might increase its compliance and capacity (Telander and Perault, 1981) and improve functional results in although conclusive results with this technique are not yet available. Repair operations of the pelvic floor musculature (Parks, 1977) are unlikely to confer much symptomatic benefit in view of the normal function of the external sphincter. The development of radiotherapeutic techniques to reduce injurious effects to the anorectum is also of paramount importance.

The late clinical results of colo-anal anastomosis for severe complicated radiation rectal injury have recently been described by Browning et al (1987).

SECTION 4

CHRONIC CONSTIPATION

4.1 DIFFERENTIAL INFLUENCE OF THE CONUS MEDULLARIS ON COLORECTAL AND PELVIC FLOOR MOTILITY

SUMMARY

The motility responses of the sigmoid colon, rectum and external anal sphincter to sequential electrical stimulation of the sacral anterior roots (S2, S3 and S4) were studied in five patients with constipation following traumatic spinal cord injury. These patients had sacral neuroprostheses implanted for electromicturition, hence offering a unique physiological opportunity for this study.

Identical and reproducible results were obtained. S2 stimulation provoked isolated low-pressure phasic colorectal contractions. S3 stimulation initiated high-pressure phasic colorectal motor activity which appeared peristaltic and was enhanced with repetitive stimuli. This response appeared to be frequency-dependent. S4 stimulation resulted in tonic increases in colonic and rectal pressures. External sphincter activity was stimulated in increasing order from S2 to S4. This study examines directly the central control of colorectal motility and may have implications in the treatment of severe constipation following spinal injury.

INTRODUCTION

Electromicturition by neuroprosthetic stimulation of the sacral anterior roots has proved effective in facilitating bladder emptying and continence following spinal cord injury (Brindley et al, 1982; Cardozo et al, 1984). However, faecal stasis sometimes with colonic dilatation remains a distressing problem in these patients and is usually managed empirically. The distal colon, rectum and anal sphincters are innervated by the parasympathetic and somatic outflow via the same sacral spinal roots that are used for electromicturition. Patients with these implants therefore present a unique physiological opportunity to study directly the neurogenic influence of the conus medullaris and its outflow on distal bowel motility in conscious man. This Section reports the results of such a manometric and electrophysiological study in five patients.

PATIENTS AND METHODS

Patients

Five men were studied (Table 11), their mean age being 38.2 years. All had traumatic cord lesions resulting in complete spinal cord injury in four and incomplete tetraplegia in one. Sacral anterior root stimulators had been implanted for recurrent or persistent urinary tract infections and had proved effective in emptying the bladder (

TABLE 11

Details of the five patients with spinal injury

No	Age	Sex	Segmental level of injury	Duration of implant (years)	Duration of implant (months)
1	35	M	T3, complete	19	36
2	37	M	C6, complete	15	18
3	48	M	C7, complete	1	6
4	30	M	C6, complete	2	6
5	46	M	C6, complete	1.5	6

Brindley et al, 1982; Cardozo et al, 1984).

All the patients required digital evacuation of the rectum approximately every third day. In addition, some needed the aid of suppositories or enemas. At the time of the study most of the patients were observed to be faecally impacted. It was also apparent that these patients had abnormal perineal descent and rectal mucosal prolapse. None of the patients had observed any significant improvement in bowel function with use of the stimulator for bladder control. However, three of them admitted improvement in the rectal mucosal prolapse since implant surgery.

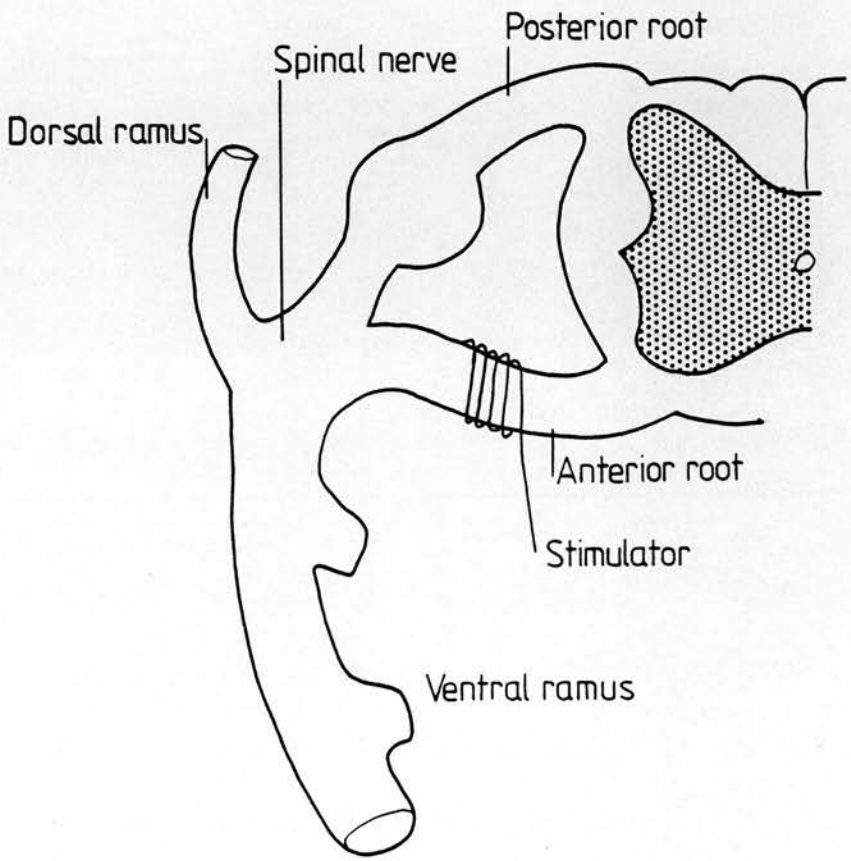
Implants, surgery and stimulation technique

Figure 29 illustrates the anatomical principle of sacral anterior root stimulation. The type of stimulator and surgical procedure to implant it was similar to that described by Brindley et al (1977, 1982). Patient 2 had S3 and S4 implants only. The remaining patients had all three implants (S2-S4). In one patient cerebrospinal fluid tracked along the cables and formed a swelling over the receiver block. However, this leak stopped spontaneously. There were no other operative complications.

Stimulation was performed by radiofrequency activation of the subcutaneous receiver block via the transmitter placed over it (Brindley et al, 1982). Bilateral stimulation of the S2, S3 and S4 roots was performed in succession and the motility responses of the colon, rectum and anal sphincters recorded simultaneously. Train stimulation was performed at 'low' and 'high' frequencies ranging from

FIGURE 29

Diagrammatic representation of sacral anterior root stimulation. The parasympathetic outflow is via the anterior root



10-40 Hz for upto 10 seconds and repeated subsequently. These were the same stimulation parameters as were used for bladder emptying by the patients.

Pressure recordings in response to stimulation were performed twice to ensure reproducibility.

Pudendo-anal reflex

Prior to each study the latency of the pudendo-anal reflex (Smith and Varma, 1984; Varma et al, 1986) was measured to ensure the neurogenic integrity of the conus medullaris and its afferent and efferent pathways (Vereecken et al, 1982). This reflex was elicited by electrical stimulation of the dorsal nerve of the penis with a felt bipolar surface stimulating electrode (type LBS 53051, Medelec, U.K.) and recording the reflex contraction of the external anal sphincter with a bipolar surface stainless-steel anal plug electrode (type 13K78, DISA, Copenhagen) using the Medelec MS92a evoked response unit. Details of the methodology are described in Section 2.3.

External sphincter EMG

The electromyographic response of the external anal sphincter to sacral root stimulation was monitored by a standard concentric needle EMG electrode (type 13L49 DISA, Copenhagen) inserted into it at a site 1 cm posterior to the anal orifice to a depth of approximately 2.5 cm (Figure 30). This was connected via preamplifiers to an oscilloscope (Medelec MS92a, Woking, Surrey, U.K.). Electrical

activity of the sphincter was continuously monitored using a time base of 100 ms/cm with the gain at 100μV/cm and filter settings of 20Hz - 10kHz). Permanent recordings were obtained of electrical activity at rest and on root stimulation. The electrical activity was also heard as amplified sound via a loudspeaker incorporated in the equipment.

Manometry (Figure 30)

Fasted patients were assisted in emptying their bowel on the morning of the study by digital evacuation and a saline rectal washout if necessary but laxatives were not used. Digital rectal examination and limited sigmoidoscopy using a paediatric instrument were performed to ensure that the rectum was reasonably empty and for tube placement in the left lateral position.

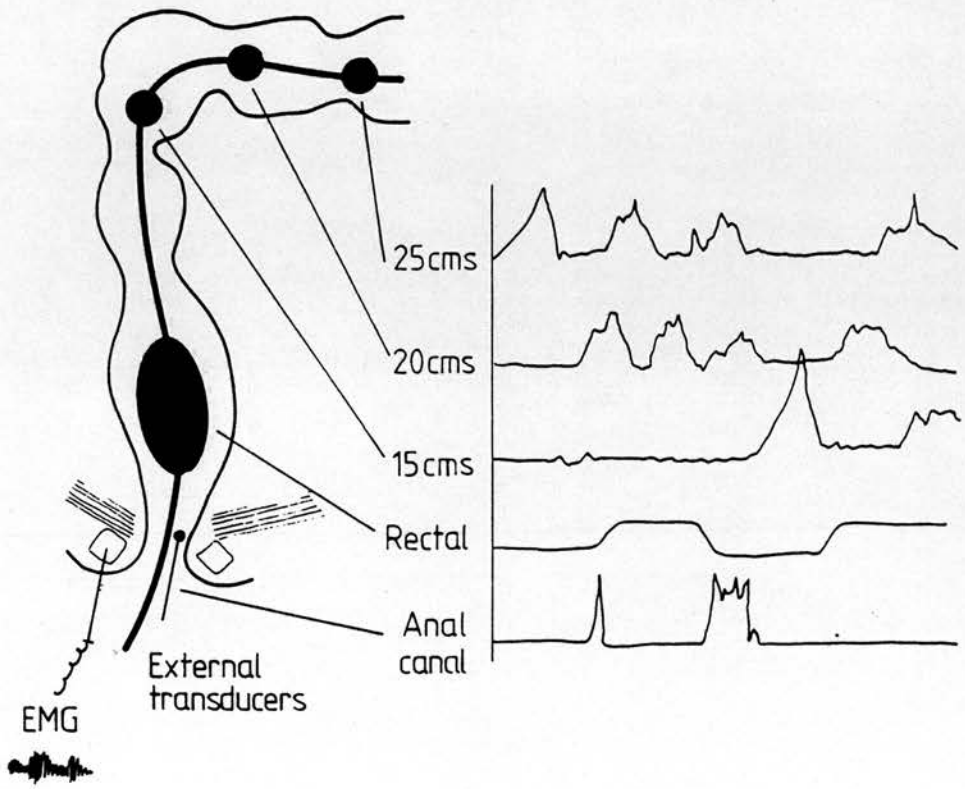
Maximum basal anal canal pressure and the response to root stimulation was recorded by a conventional technique using a waterfilled microballoon connected to an external transducer via fine tubing (Varma and Smith, 1984; section 2.1). This was held in place by adhesive tape.

Proctometrograms (Varma et al, 1986; Section 2.2) were performed to determine the volumes at maximal distension, and rectal compliance. Thereafter the large proctometrogram balloon was emptied and refilled with 200 ml of water and the pressure responses of the rectum to root stimulation recorded.

Motility of the sigmoid colon was monitored in the basal state and following root stimulation by three waterfilled balloons made of soft rubber (HSC1, Precision Dippings Ltd., UK) connected to external

FIGURE 30

Diagrammatic representation of the techniques for monitoring colorectal and pelvic floor responses to sacral anterior root stimulation



transducers by fine tubing. The balloons were placed sigmoidoscopically at distances of 15, 20 and 25 cm from the anal verge (Figure 30). Following completion of the colonic motility responses all three balloons were withdrawn into the rectum (to lie at 5,10 and 15 cm from the anal verge) and its motility assessed by this method also.

RESULTS

Pudendo-anal reflex

The reproducible latencies of this electrophysiological reflex in the five patients are shown in Table 12. These were considered to be within the normal range (Varma et al, 1986).

Anal sphincter responses

Figure 31 illustrates typical anal canal pressure tracings obtained during stimulation of sacral anterior roots S2, S3 and S4
There is a successive increment in pressures with stimulation of the more caudad roots. S4 stimulation also produces a more sustained contraction of the external anal sphincter. Figure 32 shows the sequential pressure increments in all five patients. These manometric responses were confirmed electromyographically by simultaneous EMG traces from the external anal sphincter. The resting 'tonic' electrical activity of this muscle appeared to be diminished in most patients.

FIGURE 31

Anal canal pressure tracings (redrawn). Note the sustained response to S4 stimulation

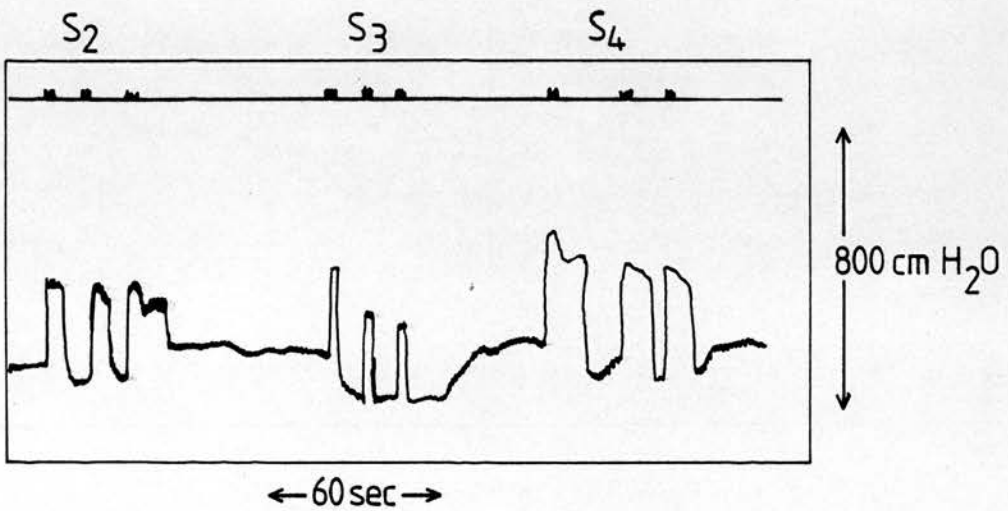


FIGURE 32

Graphical representation of maximal anal canal pressure increments in respose to sequential sacral anterior root stimulation in five patients. Each point represents the mean of two experiments

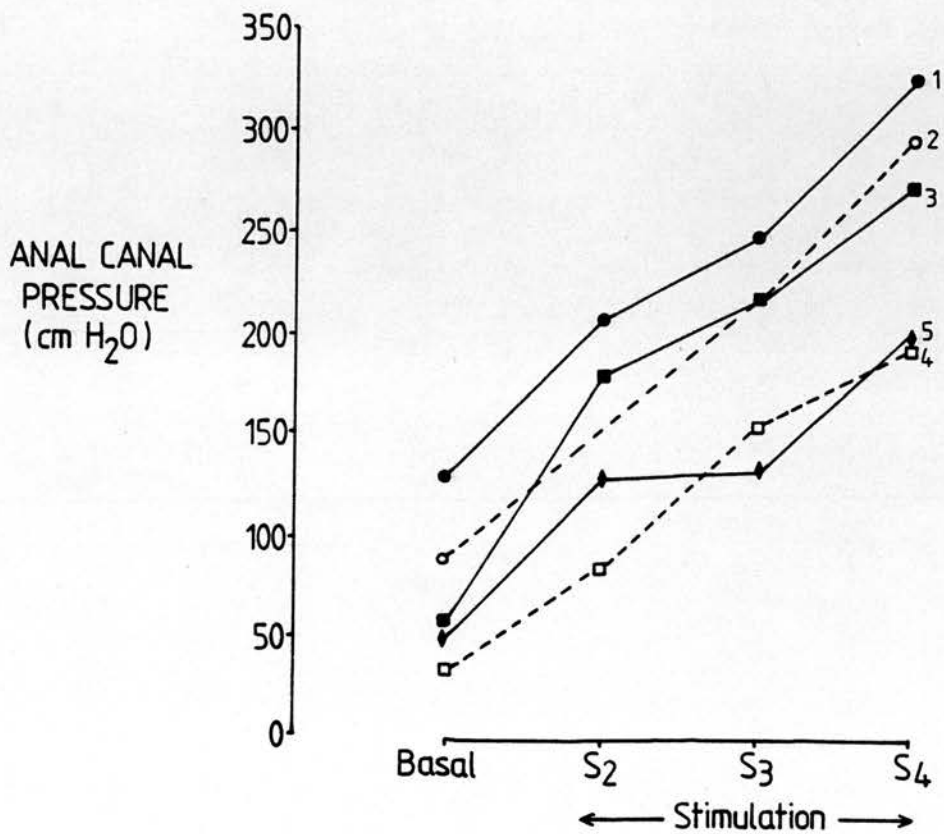


FIGURE 33

Effect of S3 train stimulation on anal canal pressure

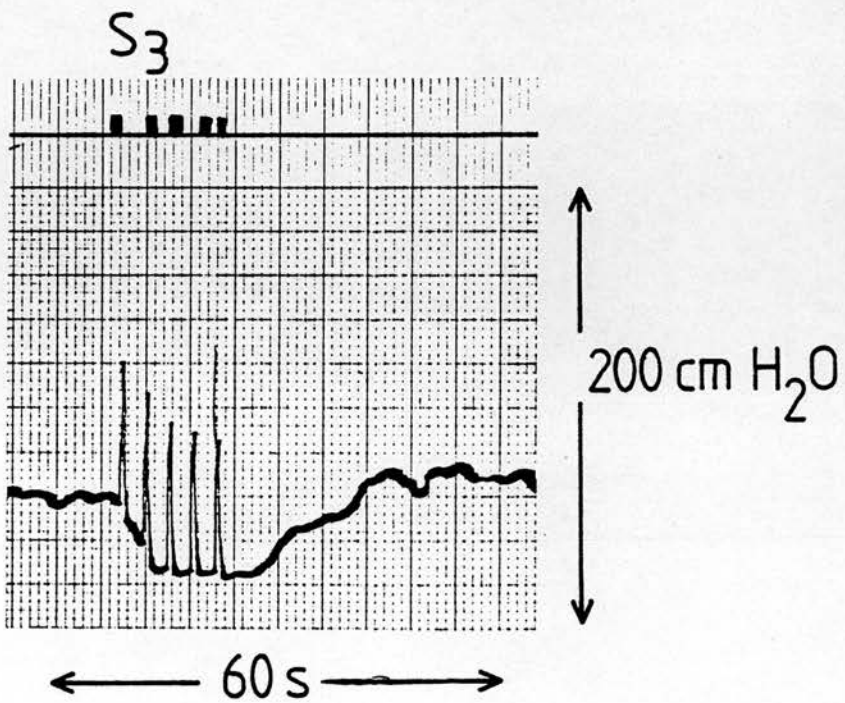


Figure 33 shows the effect of repeated S3 stimulation on anal canal pressures.

Rectal responses

None of the patients had any perception of rectal distension during the proctometrograms. Rectal compliance and the maximal volumes and pressures recorded are shown in Table 12. Two patients (1 and 4) had normal compliance, two had reduced compliance (2 and 5) and patient 3 had markedly increased compliance (Varma and Smith, 1985, 1986). Three patients (Patients 1,2 and 5) expelled the proctometrogram balloon at the maximal volume. This phenomenon is not seen in normal subjects (Varma and Smith, 1986).

Figure 34 illustrates rectal motility responses to sacral root stimulation using the large proctometrogram balloon. S3 stimulation produced the most prominent contractions. In contrast S4 stimulation produced relatively low-pressure 'square-wave' type of responses suggesting an intrarectal pressure rise possibly due to pelvic floor contraction, the pressure dropping immediately with cessation of stimulation. S2 root stimulation also resulted in low-pressure rectal contractions superimposed on pelvic floor-induced rectal pressure rises. These effects became more apparent when the sigmoid colon motility balloons were withdrawn into the rectum (Figure 35), these responses being qualitatively similar to those of the sigmoid colon. Intrarectal pressures in the resting state and in response to sequential stimulation are depicted in Figure 36.

TABLE 12

Electrophysiological and manometric data in five patients with spinal cord injury and in control subjects

No	PAR latency	RC	MTV	Balloon expulsion
1	48	9.5	550	Yes
2	40	5.5	235	Yes
3	39.2	18.5	>800	No
4	32.4	10.4	409	No
5	44	6.4	355	Yes
Control (Mean±SD)	38.5 ± 5.8	9 ± 1.6	509 ± 80	None
Reference Section	2.3	2.2	2.2	2.2

FIGURE 34

Rectal pressure tracings illustrating the various motility responses to low and high frequency sacral anterior root stimulation. Pressures recorded in a proctometrogram balloon filled with 200 ml H20

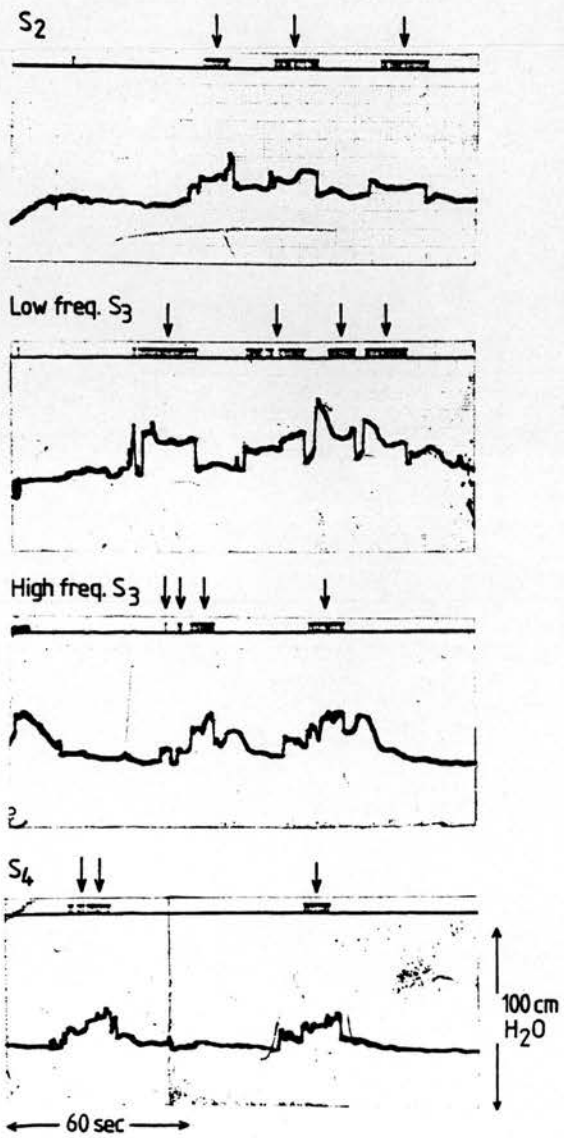


FIGURE 35

Rectal pressure tracings illustrating the various motility responses to low and high frequency sacral anterior root stimulation. Pressures recorded via three small waterfilled balloons.

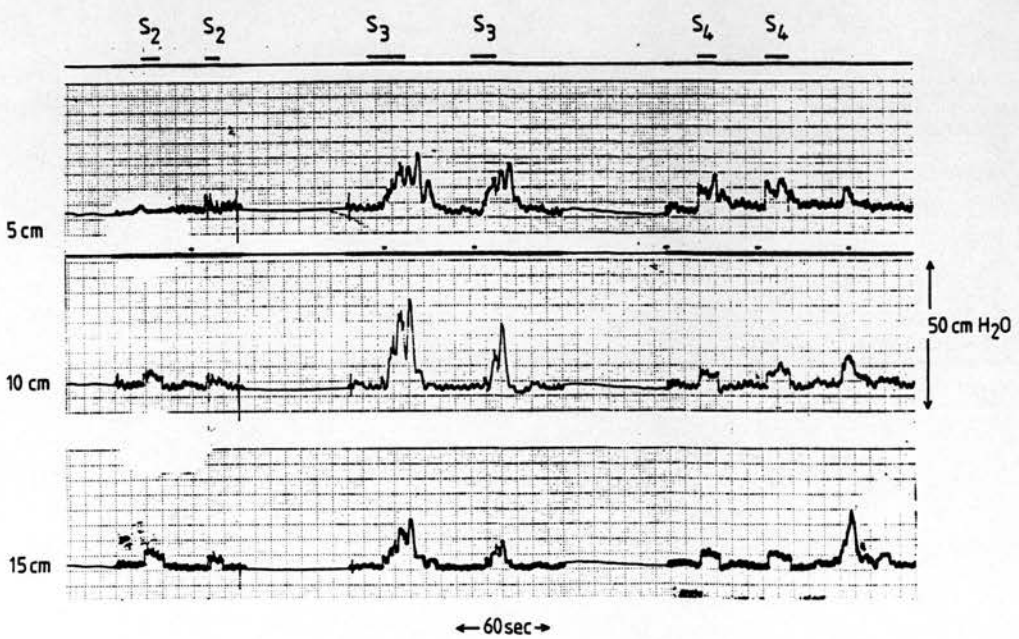
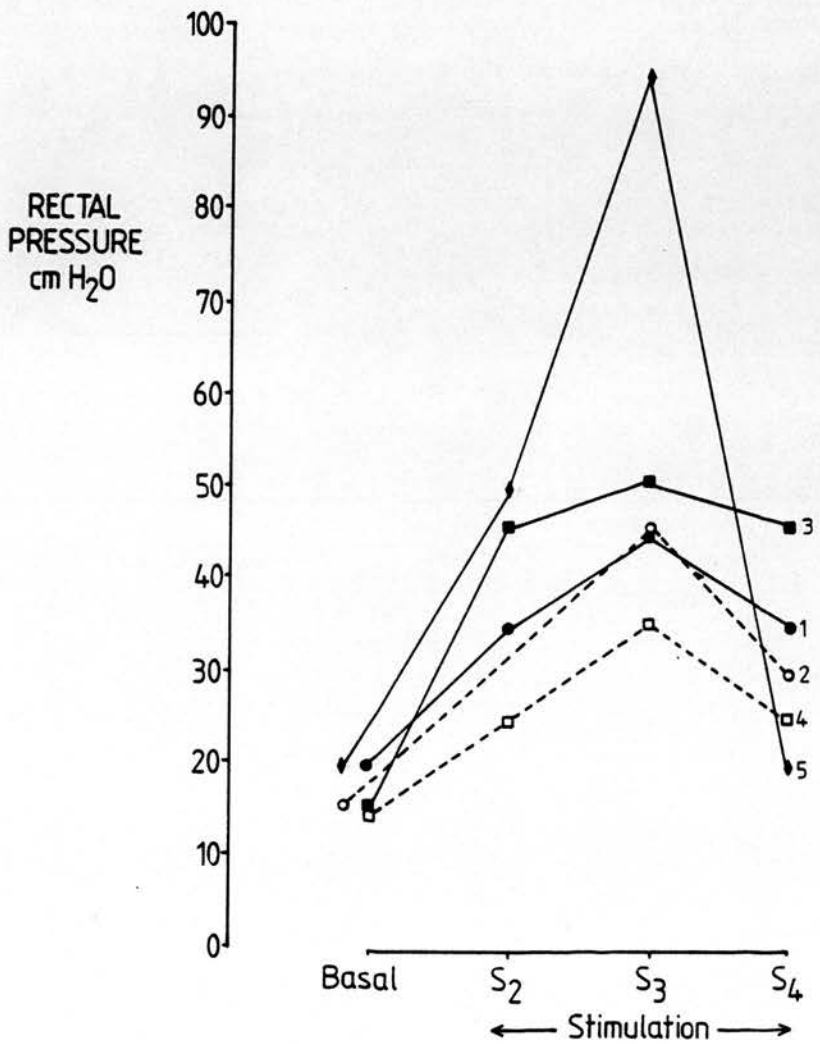


FIGURE **36**

Graph depicting maximal rectal pressures following sequential sacral anterior root stimulation in five patients. Each point represents the mean of two experiments



Sigmoid colon motility

Figures 37 — 40 illustrate the striking motility responses of the sigmoid colon to sacral anterior root stimulation. These are qualitatively similar to those of the rectum but more exaggerated. In particular, S3 root stimulation produced complex high-pressure phasic contractions reminiscent of peristaltic activity. This response appeared to be be facilitated and increased in amplitude by successive stimuli and continued for some time following their cessation. Furthermore, stimulation at the higher frequencies produced more prominent contractions. The quantitative sequential pressure increments in all five patients are shown in Figure 41.

Reproducibility of data

The latency of the pudendo-anal reflex was completely reproducible (Varma et al, 1986). The data obtained from the proctometrogram was very reliably reproducible (mean coefficient of variation less than 8%, Varma and Smith, 1986; Section 2.2).

Pressure recordings in the anal canal, rectum and sigmoid colon in response to to stimulation (Figures 32,36,41) had a mean coefficient of variation of less than 10%. Within patients, the qualitative type of response obtained (Figures 31,33-35,39,40) was always the same.

FIGURE 37

Sigmoid colon pressure tracings at various distances from the anal verge to illustrate the response to S2 anterior root stimulation

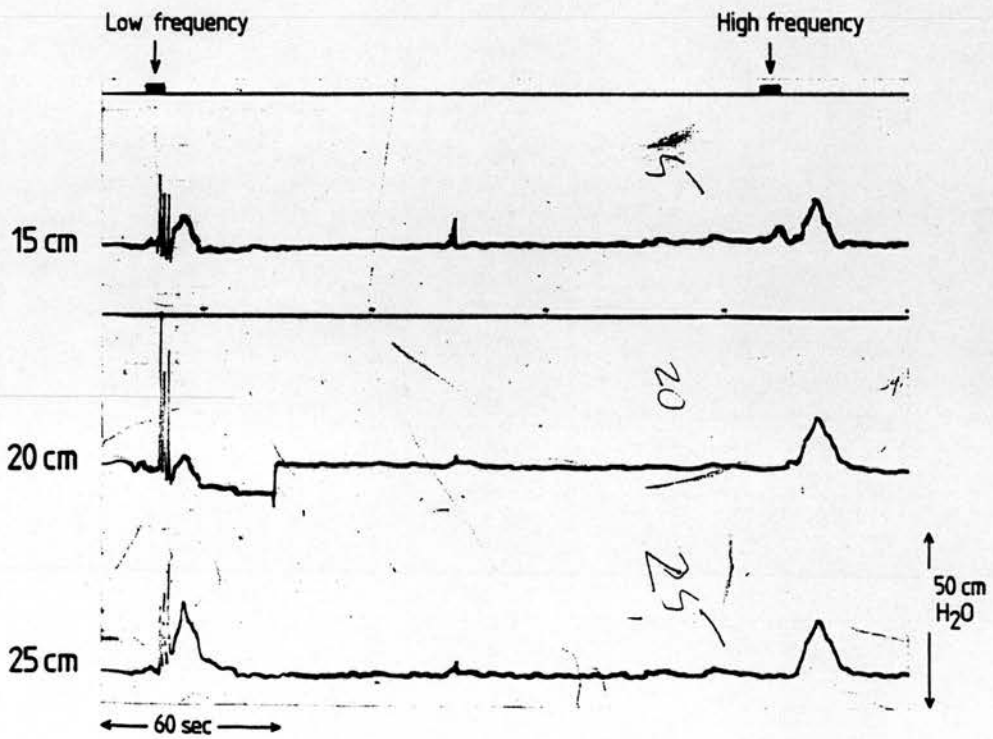


FIGURE 38

Sigmoid colon pressure tracings at various distances from the anal verge to illustrate the response to S3 anterior root stimulation (slow paper speed)

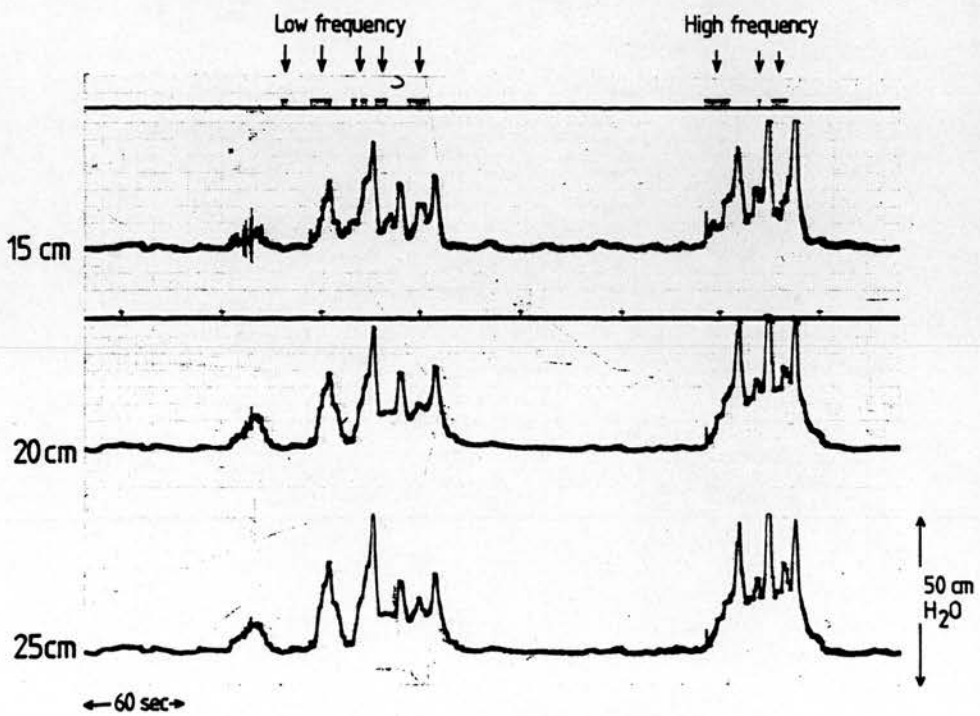


FIGURE 39

Sigmoid colon pressure tracings at various distances from the anal verge to illustrate the response to S3 anterior root stimulation (fast paper speed)

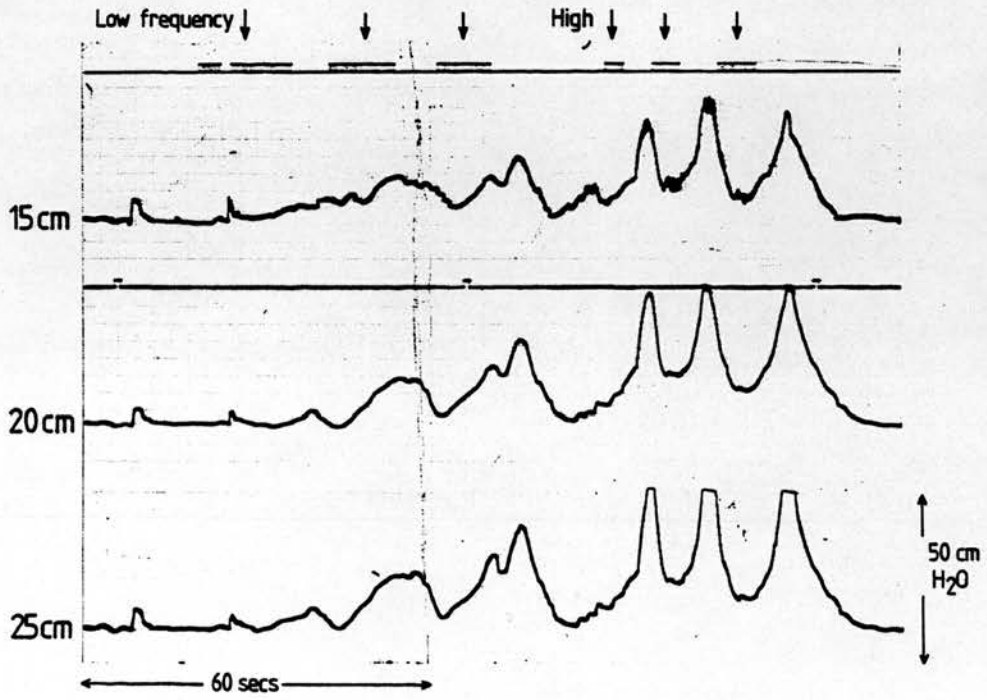


FIGURE 40

Sigmoid colon pressure tracings at various distances from the anal verge to illustrate the response to S4 anterior root stimulation

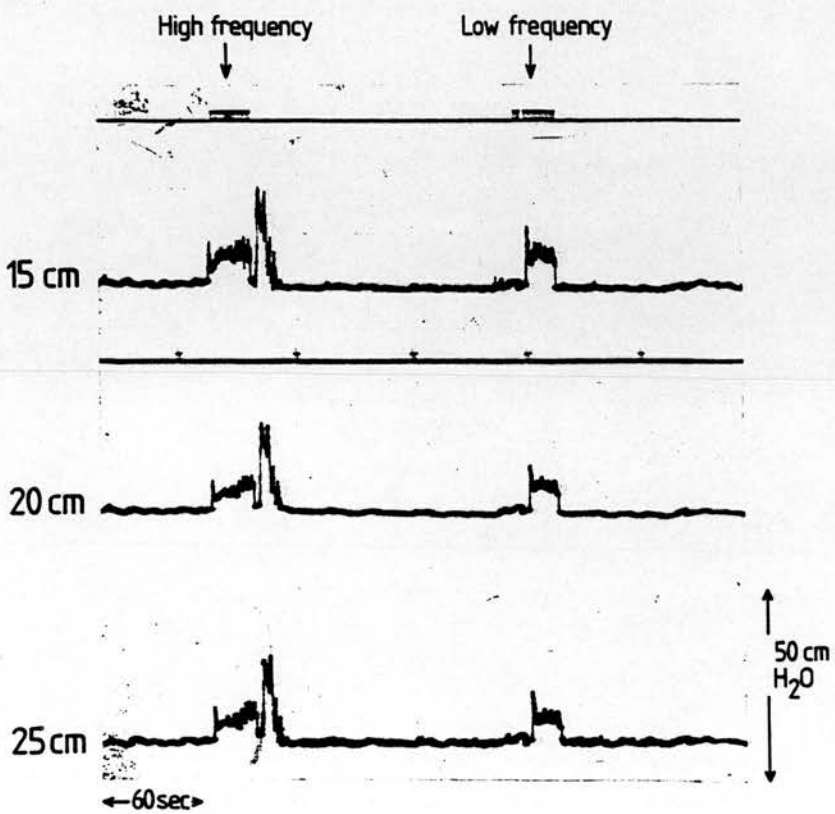
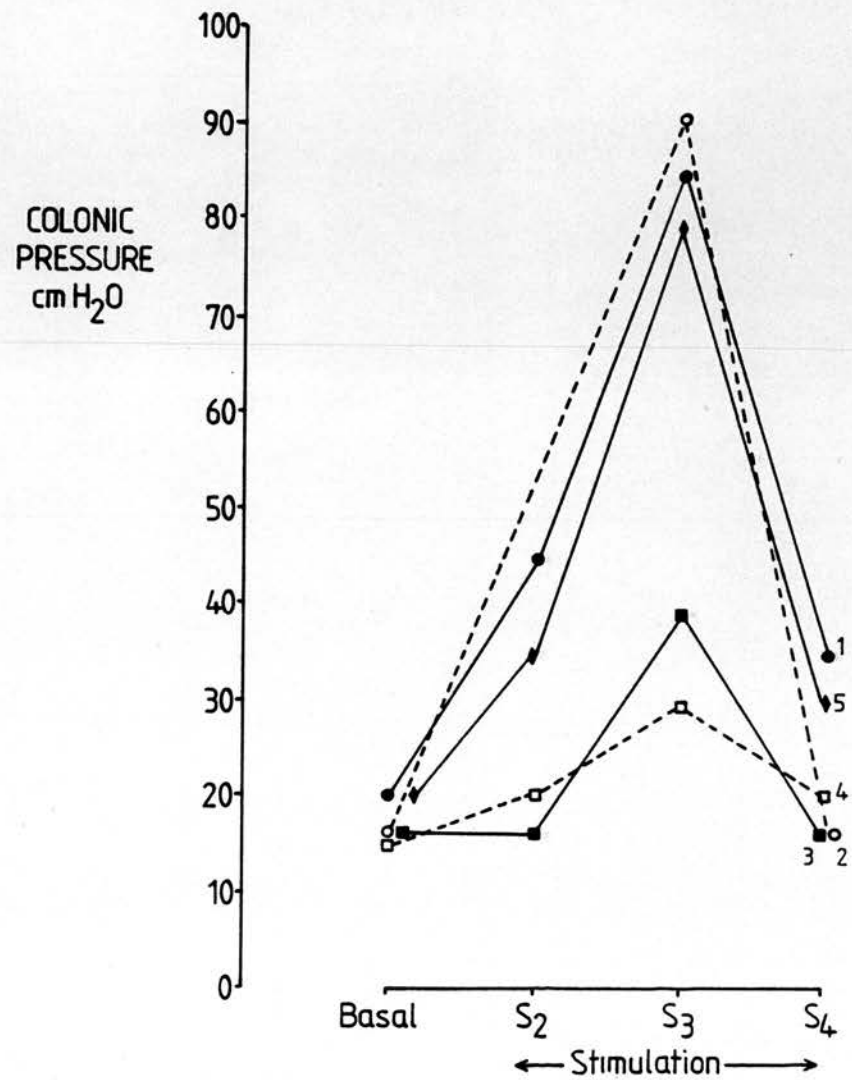


FIGURE 41

Graphical representation of maximal pressure responses in the sigmoid colon (25 cm from the anal verge) to sequential sacral anterior root stimulation; each point represents the mean of two experiments



DISCUSSION

Experimental studies in animals have for long suggested that the motility of the gastrointestinal tract can be altered by lesions of the spinal cord (Lister, 1958; Bayliss and Starling, 1900; Elliott and Barclay-Smith, 1904; Garry,1933; Scott and Cantrell, 1969; Meshkinpour et al, 1985). Evidence also exists for changes in colonic motility in man following spinal cord injury. White, Verlot and Ehrentheil (1940) recorded the pressure curve of the colon during slow filling with water. They found a hypertonic response in those patients with 'high' lesions of the spinal cord, and a hypotonic response in patients with lesions involving the sacral spinal cord or cauda equina. Connell et al (1963) found that the resting, unstimulated motility of the pelvic colon was diminished in patients with high cord transection but was significantly increased in those with low cord lesions. Weber et al (1985) provided evidence for the pons as a possible supraspinal level of control of colonic and anorectal motility. Meshkinpour et al (1983) demonstrated poor colonic compliance in patients with thoracic spinal cord injury. These patients also failed to demonstrate the normal increase in postprandial motor and myoelectrical activity of the colon (Glick et al, 1984). Menardo et al (1984), using transit studies, showed that following spinal transection the left colon and rectum were the main sites of stasis. Haldeman et al (1982) demonstrated abnormal colonmetrograms in patients with multiple sclerosis affecting the supra-sacral segments. These abnormalities in colorectal motility

following injury to the spinal cord often result in troublesome constipation which is usually treated empirically.

These and other (Denny-Brown and Robertson, 1935; Roman and Gonella, 1981; Delbro et al, 1984) studies have suggested that the mechanisms controlling defaecation are mediated through the sacral segments of the spinal cord and its peripheral ramifications. It is now recognised that the sacral anterior roots carry the parasympathetic outflow to the left colon, rectum and internal anal sphincter (Devroede and Lamarche, 1984; Schuster et al, 1963). In addition they convey the somatic innervation to the striated anal sphincter musculature which is intimately involved in the control of continence and defaecation (Sherrington, 1892).

Brindley et al utilised this knowledge to promote bladder emptying and urinary continence following spinal cord injury by controlled electrical stimulation of the sacral anterior roots with satisfactory long-term results (Brindley et al, 1982; Cardozo et al, 1984). Patients with such implants hence present a unique physiological opportunity to study directly the neurogenic influence of the sacral outflow on anal sphincter and colorectal motility. Furthermore, this information could prove beneficial in the treatment of disorders of colorectal motility. These points are addressed in the present study.

The manometric and electrophysiological observations on the external anal sphincter simply confirm its innervation from these sacral roots (Sherrington, 1892 ; Percy et al, 1981; Snooks et al, 1985). Our evidence suggests that the S4 roots supply the principal part of this innervation. Although the puborectalis is now thought to receive a nerve supply separate from the external anal sphincter (Percy et al,

1981; Snooks et al, 1985), their root innervation is similar (Sherrington, 1892). Brindley et al (1982) did not observe any response in the anal sphincter musculature during S2 stimulation . However, their observations did not include manometric or EMG data. 'Tonic' basal electrical activity was present in all the patients in this study although it was thought to be diminished in comparison to that found in normal subjects (Parks et al, 1962; Ala et al, 1965; Varma and Smith, 1985). This resting activity is mediated through reflexes via the conus medullaris (Parks et al, 1962; Ala et al, 1965; Melzak and Porter, 1964; Frenckner, 1975) and further confirm its integrity. Although most of the pressure increase in the anal canal on sacral root stimulation is attributable to contraction of the striated anal sphincter musculature, some effects on the internal anal sphincter must also occur as is suggested by the smooth muscle responses of the rectum and sigmoid colon. However, it is difficult to quantify the differential activity of the internal sphincter alone. The phenomenon observed in Figure 33 suggests relaxation of the internal anal sphincter following repetetive S3 stimulation (decrease in basal sphincter pressure). Lubowski et al (1987) demonstrated a fall in anal canal pressure following peroperative stimulation of the sympathetic) presacral nerves.

The effects of S3 stimulation on the sigmoid colon and rectum are similar to those on the detrusor smooth muscle described by Brindley et al (1982) and Cardozo et al (1984). In a larger number of patients they found only slight variation in the motor innervation of this organ. However, it appeared to be more responsive to S4 than S2 stimulation. In the colon and rectum there is little difference in the

quantitative pressure responses obtained on stimulation of these two roots but the type of responses are quite different. The S4 root simply increases the pressure in the lower bowel during the stimulation phase. It seems likely that this 'tonic' pressure response is due to the contraction of the pelvic floor resulting in a rise in intra-abdominal pressure. However, no such effects were observed on S3 stimulation which also causes contraction of the pelvic floor. As in the urinary bladder, facilitation and enhancement of the colorectal contractions seems to occur after repeated stimuli, resulting in complex, peristaltic type of waves (Figures 39,40). This is hence the site of stimulation that may best benefit patients with faecal stasis. Nevertheless, it must be realised that the stimulation parameters used in this study were limited to those used for detrusor contraction (Brindley et al, 1982). Further studies are needed to clarify the optimum stimulation parameters to achieve the most effective motility responses. For example, simultaneous stimulation of S2 and S3 may prove more effective than S3 alone in increasing colonic motility. Supplementary data by recording myoelectric activity of the distal bowel would further help to elucidate this.

The decrease in rectal compliance seen in some of our patients is in keeping wih the findings of Meshkinpour et al (1983). One patient, however, appeared to have an 'atonic' rectum, its aetiology being uncertain. Balloon expulsion seems to occur more easily in those patients with reduction in rectal compliance. Other factors such as loss of rectal proprioception and the amount of resting activity in the external sphincter must also contribute to this phenomenon which is of practical importance in the context of automatic evacuation (

Ala et al, 1965; Melzak and Porter, 1964; Frenckner, 1975). It is conceivable that sacral root stimulation might be utilised to initiate contraction of the terminal colon and rectum resulting in movement of faeces caudally into the anal canal. This might further initiate the complex reflex relaxation of the pelvic floor muscles to allow unresisted evacuation of the rectum (Parks et al, 1962). Although anorectal incontinence is usually not a major problem following spinal cord injury, continuous weak sacral root stimulation could also be used to improve anal continence in the same way as that demonstrated for nocturnal control of urinary continence (Brindley, 1982). We have already observed beneficial effects of sphincter stimulation on rectal mucosal prolapse in some of these patients.

Further studies are needed to determine the long-term effects of sacral anterior root stimulation on colorectal function in spinally-injured patients.

4.2 CONSTIPATION IN THE ELDERLY

SUMMARY

Colorectal motility was studied in 25 elderly patients with chronic constipation and compared to an asymptomatic control group (n=17). Proctometrograms were performed to measure rectal volumes at sensory threshold and maximal tolerance, and rectal compliance. Anal sphincter pressures and reflexes were measured by conventional techniques. Indices of colonic motility were also assessed.

Significant impairment of rectal sensory threshold was apparent in constipation. Six patients presenting with impaction demonstrated functional megarectums. The remaining 19 showed a significant reduction in maximal rectal volume and rectal compliance and 14 extruded the balloon. Basal sphincter pressures were reduced in constipation although there were no differences in sphincter length or presence of the rectosphincteric reflex. Four patients had an absent pudendo-anal reflex and the remainder significant prolongation. Total gastrointestinal transit times were prolonged in the constipation group, mainly distally due to rectal stasis. In 2 patients bisacodyl failed to elicit a sigmoid motor response.

Constipation in elderly patients is not merely due to delayed transit. Neurogenic deficits of sacral spinal cord function may be responsible for abnormalities in rectal motor and sensory function.

INTRODUCTION

Although constipation is a recognised problem in elderly patients (Exton-Smith, 1973; Geboes and Bossaert, 1977), its pathophysiology is poorly understood. It is particularly distressing when associated with faecal impaction and incontinence (Read et al, 1985; Read and Abouzekry, 1986; Tobin and Brocklehurst, 1986; Young, 1973). Some such patients may respond to empirical measures such as change of diet, mobilisation and colonic stimulants (Exton-Smith, 1973; Brocklehurst and Khan, 1969; Tobin and Brocklehurst, 1986; Irvine 1986). In others, however, the condition becomes intractable and difficult to treat and may be related to basic abnormalities of colorectal physiology (Read et al, 1985; Newman and Freeman, 1974). The aim of this study was to attempt to evaluate the various underlying physiological abnormalities of colorectal motor function in elderly patients which may result in chronic constipation.

PATIENTS AND METHODS

Fifteen female and 10 male elderly patients (age 68 - 95 years, mean 78.2 years) were studied. All had longstanding constipation (range 8 months - 32 yrs, mean duration 4 years). The frequency of bowel motions ranged from once every four days to once every ten days with the aid of laxatives, enemas etc. (mean once per week). This proved difficult to treat despite dietary and drug adjustments: eight

patients were on lactulose, four on Dorbanex, three on Dulcolax and two on Laxoberal; nine patients required regular enemas. Associated anorectal incontinence was present in 3 male and 4 female patients. Occasional urinary incontinence was present in 6 male and 5 female patients; in one female patient chronic urinary retention necessitated an indwelling catheter. Six patients (4 male, 2 female) were observed to be faecally impacted on admission.

Seventeen control hospital patients (8 female, 9 male) with no anorectal symptoms were studied to compare data (Section 2.2). The age range of this group was 35 - 85 years (mean 52.4 years). Six patients in the control group were over 60 years of age. Although the patients and controls were not age-matched, this was not considered essential as it has been demonstrated that anorectal manometry is not significantly affected by age (Loening-Baucke and Anuras, 1985). This premise was further tested by dividing the control group into a 'young' (age range 26-45 years, mean 67 years) and 'old' (age range 52-85 years, mean 67 years) group to compare the effect of age on various parameters of anorectal manometry. The latency of the pudendo-anal reflex and gastrointestinal transit time have also been shown to be unaffected by age (Varma et al, 1986; Eastwood, 1972).

Manometry

This was performed in the fasted state in the morning. Bowel preparation was achieved by saline washouts if necessary on the day before. All except the most essential medications were withdrawn 72 hours prior to the motility investigations.

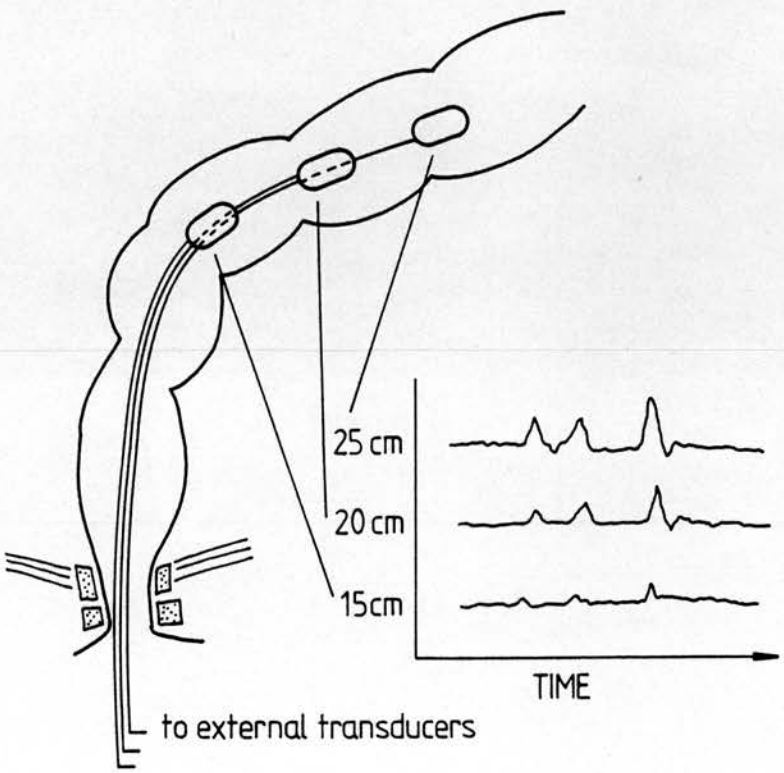
The tests were performed in the left lateral position using conventional techniques (Varma and Smith, 1984; Section 2.1). Basal anal sphincter pressure and length and the presence of the rectosphincteric reflex were determined in 23 of the patients and all the controls. Squeeze pressures were not measured as they are unlikely to be reliable due to poor patient co-operation. Sensory threshold of the rectum to distension was estimated by the amount of air necessary to inflate the rectal balloon for the patient to declare the first sensation of rectal distension.

Proctometrograms (Varma and Smith, 1986; Section 2.2) were performed by continuous fluid distension of a soft-rubber, highly compliant rectal balloon. This produced a pressure-volume graph to measure rectal compliance and the volumes and pressures at maximal distension.

Motility of the sigmoid colon was recorded as intraluminal pressure events in 15 constipated and 10 control subjects. Three 2 x 1 cm water-filled soft rubber balloons (HSC1, Precision Dippings Ltd, Bristol, UK) were placed sigmoidoscopically at 15, 20 and 25 cm. from the anal verge and connected by fine tubes to external transducers (Figure 42). After a 5 minute basal period, bisacodyl solution (3 ml, 2.74 mg/ml, Boehringer Ingelheim Ltd) was instilled intraluminally via a fourth channel with its opening adjacent to the 25 cm balloon. The motility response of the sigmoid colon was then monitored over a further 15 minutes (Preston and Lennard-Jones, 1985).

FIGURE 42

Diagrammatic representation of the method of monitoring colonic intraluminal pressure events in response to surface stimulation with bisacodyl



Intestinal transit

Total gastrointestinal transit time was measured by the method of Kirwan and Smith (1974), monitoring the progress of an isotope capsule through the colon with a scintillation counter. Fifteen constipated elderly patients and 10 control subjects underwent this investigation.

Electrophysiology

The neurogenic integrity of the sacral spinal cord was examined by measuring the latency of the pudendo-anal reflex (Varma et al, 1986; Section 2.3). This was performed in 15 patients and 15 controls.

Radiology

All patients had a plain supine abdominal X-ray to assess the extent of faecal loading.

Statistics

All the statistical analyses were performed by the Wilcoxon rank sum test for unpaired data.

RESULTS

Table 13 examines the effect of age on anorectal manometry. Table 14 lists the manometric, electrophysiological and transit data in the two groups.

Effect of age on anorectal manometry in the control group

The difference in age between the 'young' and 'old' control groups was statistically significant ($p < 0.01$). However, the only parameter of anorectal manometry measured in this study that was significantly affected by age was the basal sphincter pressure (Table 13).

Sphincter manometry

Basal anal sphincter pressures were significantly reduced in the constipated group. However, no differences were apparent in the length of the physiological sphincter or in the demonstration of the manometric rectosphincteric reflex between the constipated and control groups.

Rectal sensation

Rectal sensory threshold to distension with air was significantly increased in the constipated patients as compared to the control group. Six constipated patients but none of the controls had a sensory

TABLE 13

Variations in some parameters of anorectal manometry with age in asymptomatic subjects

Parameter	Age 26–45 yrs (Mean 36±6.9) n=8	Age 52–85 yrs (Mean 67±11.3) n=9	p
MRP (cm H2O)	129±6.4	102±6.8	<0.05
HPZ (cm)	3.4±0.18	3.3±0.14	>0.1
STV (ml air)	51±15	58±11	>0.1
MTV (ml H2O)	519±24	500±31	>0.1
RC (ml/cm H2O)	8.9±0.6	8.6±0.6	>0.1

All measurements Mean±SEM

TABLE 14

Manometric, electrophysiological and transit data in the elderly constipated compared with control subjects

Parameter	Constipation	Control	p
MRP (cm H2O)	79±5.6 (n=23)	115±5.6 (n=17)	<0.01
HPZ (cm)	3.1±0.18 (n=23)	3.4±0.12 (n=17)	>0.1
STV (ml air)	135±16 (n=25)	51±7 (n=17)	<0.01
MTV (ml H2O)	358±28(n=19) 827±57(n=6, MR)	509±19 (n=17)	<0.01 <0.01
RC (ml/cm H2O)	5.5±0.5(n=19) 16.4±1.3(n=6, MR)	8.7±0.4 (n=17)	<0.01 <0.01
PAR latency (ms)	43.7±2.6 (n=15, 4 absent)	39.4±1.1 (n=16)	<0.02
Total transit time (days)	4.3±0.7 (n=15)	1.7±0.5 (n=10)	<0.01

All measurements Mean±SEM

MR=Megarectum

RSR present in all patients and controls

threshold in excess of 200 mls of air (Figure 43).

Proctometrograms

From control measurements (Table 13) it was determined that maximum tolerable volumes in excess of 650 mls represented a functional megarectum. This was demonstrable in 2 female and 4 male patients. These patients had been observed to be faecally impacted on admission. In the other 19 patients rectal volume and compliance were significantly reduced. Extrusion of the proctometrogram balloon occurred in 13 of these 19 patients (none with megarectum), but not in the control subjects.

Colonic motility

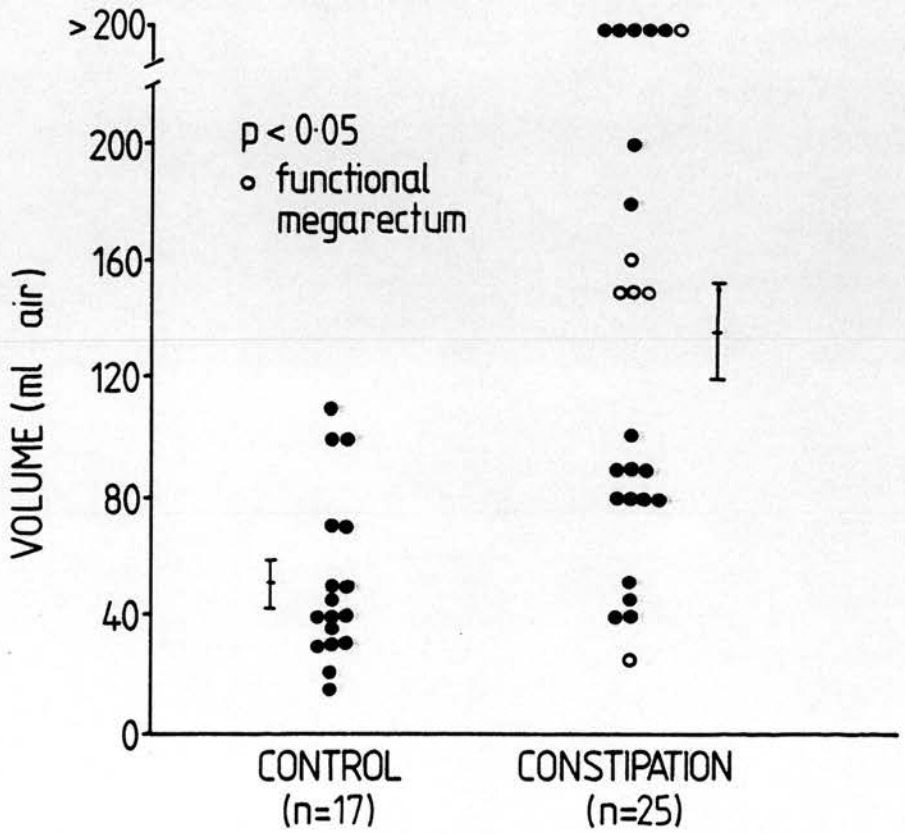
Two patients with constipation (among the 15 tested) had an absent colonic motility response to intraluminal bisacodyl. These patients had decreased maximal rectal volumes and compliance. The ten control subjects similarly tested had a normal increase in motor activity following instillation of bisacodyl.

Intestinal transit

Total gastrointestinal transit time was significantly prolonged in the elderly constipated group. In several patients the delay in colonic transit appeared to occur mainly due to delay in evacuation of the capsule from the rectum (Table 14).

FIGURE 43

Rectal sensory deficit in constipation in the elderly. Six patients had a severely impaired threshold in excess of 200 ml air. Bars represent Mean±SEM



Pudendo-anal reflex

The pudendo-anal reflex was absent in 4 of the constipated patients (one with megarectum), and significantly prolonged in the remainder compared to control values (Figure 44).

Radiology

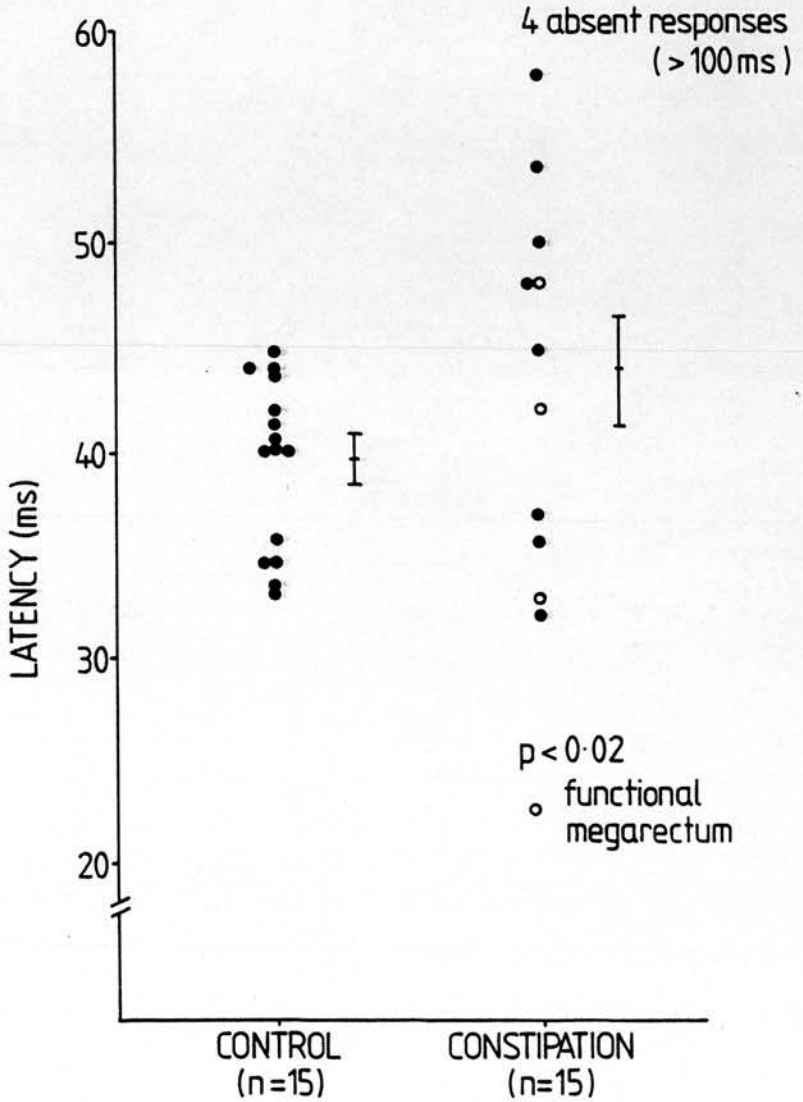
Plain supine abdominal films appeared normal in five patients and were remarked upon as showing excess faecal loading in the remainder. These x-rays were generally not helpful in determining which patients had functional megarectum with impaction.

DISCUSSION

Exton-Smith (1973) emphasised the common prevalence and difficulties in management of constipation in the elderly. Geboes and Bossaert (1977) recorded constipation as a common condition in elderly patients admitted to hospital. Forty-nine percent of their patients were taking laxatives before hospitalization. Brocklehurst and Khan (1969) and Gurll et al (1975) have emphasised the need for prevention of colonic stasis, impaction and incontinence in the elderly. Others (Young, 1973; Sutton and Blake, 1984) have stressed the possible serious complications of faecal impaction. Read et al (1985,1986) were able to describe some of the abnormalities of anorectal physiology in elderly patients that lead to faecal impaction and

FIGURE 44

Electrophysiological latency of the pudendo-anal reflex in elderly constipated and control patients. Note the 'absent' responses (latency >100 ms). Bars represent Mean±SEM



leakage. Newman and Freeman (1974) reported a progressive rise with age in defaecatory sensation, especially in those patients who were constipated. However, the functional abnormalities leading to constipation in the elderly are poorly understood (Exton-Smith, 1973). The purpose of this study was to attempt to further define the physiological abnormalities that may predispose to constipation in the elderly, with possible clinical implications in their treatment.

Although the groups in this study were not age-matched, the comparisons remain valid because anorectal manometry seems essentially unaffected by age in health (Loening-Baucke and Anuras, 1985; Table 13). Similarly, it has been demonstrated that the latency of the pudendo-anal reflex (Varma et al, 1986) and gastrointestinal transit time (Eastwood, 1972) are not age-dependent.

The diminution in basal anal sphincter pressures is probably a manifestation of both internal and external anal sphincter weakness that is recognised in this age group (Percy et al, 1982) and is present in both elderly patients and controls (Tables 13,14). It is likely to be a reflection of multiparity and chronic straining at stool (Henry and Swash, 1985). However, it is significant that functional sphincter length is unaffected and the rectosphincteric reflex was demonstrable in all the constipated patients. Weakness of the anal sphincters, although present, is therefore unlikely to result in the constipation observed in these patients.

Both groups of patients appear to suffer from defects of rectal proprioception (Figure 43) which is probably mediated by receptors in the striated pelvic floor muscles and/or pararectal tissues (Lane and Parks, 1977). This sensory deficit is more severe in megarectum (

Porter, 1961; Callaghan and Nixon, 1964; Meunier et al, 1976) and probably contributes to the rectal dyschezia and impaction observed in such patients as suggested by Read et al (1985,1986) with resultant leakage of mucus and faeces. Rectal proprioception is important in initiating the complex cycle of events that results in defaecation, involving interaction of rectum and anal sphincters (Parks et al, 1962; Denny-Brown and Robertson, 1975). Many of these patients also have anal and peri-anal sensory deficits (Read et al, 1985,1986) further compromising the 'sampling' reflex involved in defaecation (Duthie, 1975). This sensory deficit may be partly reflected in the electrophysiological abnormalities of the pudendo-anal reflex (Figure 44).

This study defines two main groups of elderly patients with chronic constipation - those with a functional megarectum (and possibly megacolon) and those with a hypertonic or 'irritable' type of distal bowel. The abnormalities of rectal distensibility in the group with reduced rectal compliance are similar to those observed in the irritable bowel syndrome in younger patients (Varma and Smith, 1984). The inadvertent expulsion of the proctometrogram balloon by many of these patients are probably a consequence of bowel hypertonicity with the rectal sensory deficit and anal sphincter weakness being contributory factors. Their constipation takes the form of difficult passage of hard, pellety faeces. The precise aetiology of this hypertonicity remains unknown but there are apparent implications in the treatment of these patients as opposed to those with the megarectum syndrome. In those patients identified by the proctometrogram to have a megarectum, it is important to prevent

faecal impaction and incontinence by regular emptying of the rectum, e.g. by means of suppositories and/or enemas. It is noteworthy that a somewhat similar grouping has been observed in younger patients with chronic idiopathic constipation (Lanfranchi et al, 1984; Meunier, 1986).

The isotope transit studies performed suggest that in many patients the delay in colonic transit follows from stasis in the rectum. In a few patients, however, abnormalities of colonic motility must also contribute as suggested by the absence of stimulation with intraluminal bisacodyl which is a surface-acting colonic stimulant (Preston and Lennard-Jones, 1985). This abnormality may reflect either a primary disorder of the myenteric plexus or a secondary, possibly laxative-induced abnormality (Smith, 1967, 1968). The same abnormality may be responsible for the colonic hypertonicity observed in these patients (Alvarez, 1949). Abnormalities of colonic motility may also exist in megacolon (Connell, 1961). The transit differences are not simply due to the ageing process as other studies have demonstrated no difference in transit in the elderly (Eastwood, 1972; Connell et al, 1965).

The abnormalities of the pudendo-anal reflex demonstrated in this study simply reflect a neurological deficit in these patients. This deficit presumably comprises a combination of sensory, central and motor abnormalities of the pathways involved in defaecation and continence (Varma et al, 1986). They may be related to the observed manometric abnormalities. There is some evidence for a central or peripheral neurogenic aetiology in megarectum and faecal impaction (Read et al, 1985, 1986; Adamson and Aird, 1932; White et al, 1940;

Scott and Cantrell, 1969; Varma and Smith, 1985) and for colonic hypertonicity (White et al, 1940). Furthermore, the accompanying urological symptoms in many of these patients are in keeping with a generalised or central neurogenic disorder being the common aetiology (Abdel-Rahman et al, 1981; Watier et al, 1983; Lawrence and Bannister, 1985). In this age group, concomitant diseases such as dibetes mellitus may further impair bowel function by secondary effects (Schiller et al, 1982; Wald and Tununguntla, 1984; Rogers et al 1987).

4.3 CHRONIC IDIOPATHIC CONSTIPATION OF YOUNG WOMEN

SUMMARY

Fifteen women with intractable chronic idiopathic constipation were investigated by anorectal manometry and electrophysiological evaluation of the conus medullaris and external anal sphincter. The data was compared to similar investigations in 25 asymptomatic control subjects. Urological disturbances were common amongst the constipated in 5 of whom lumbosacral spinal dysraphism was incidentally observed on X-rays.

No differences in sphincter pressures or the rectosphincteric reflex were demonstrable between the two groups. Rectal defaecatory sensation was blunted in constipation. The latency of the pudendo-anal reflex was significantly prolonged in idiopathic constipation, 2 women having an absent reflex (>100 ms). Mean motor unit potential duration of the external anal sphincter did not seem to be significantly prolonged in the eight constipated women tested.

A central neurogenic deficit is postulated in some women with this disorder.

INTRODUCTION

Constipation is a common complaint in gastroenterology clinics and meant by the patient to imply a variety of symptoms (Moore-Gillon, 1984; Lennard-Jones, 1985; Preston and Lennard-Jones, 1986). Although some of these patients respond to a high fibre diet and judicious use of laxatives (Devroede, 1983; Thompson and Heaton, 1980; Turnbull et al, 1986), a small proportion have constipation that is severe and persistent and remains unresponsive to all forms of treatment except enemas and large doses of cathartics. They may ultimately require a colectomy to relieve the situation (Preston et al, 1984). Severe constipation in young to middle-aged adults is almost entirely confined to women (Watier et al, 1979; Preston and Lennard-Jones, 1985,1986; Krishnamurthy et al, 1985; Read et al, 1986; Roe et al, 1986). A variety of physiological abnormalities have been postulated and described and attempts to correct them surgically have met with limited success (Barnes et al, 1984; Roe et al, 1986).

Many of these women have a failure of voluntary relaxation of the striated pelvic floor musculature during defaecation resulting in an outlet obstruction (Barnes and Lennard-Jones, 1985; Preston and Lennard-Jones, 1985; Womack et al, 1985). The observation that many of these patients also have functional urological abnormalities (Abdel-Rahman et al, 1981; Watier et al, 1983; Lawrence and Bannister, 1985) prompted this physiological investigation into anorectal and sacral spinal cord function in constipation.

PATIENTS

Fifteen women with intractable idiopathic constipation (age range 19-54 years, mean 32 years) were entered into this study. All gave a history of severe constipation starting in adolescent years. The duration of the constipation ranged from 5 to 45 years (mean 19.8 years). Almost all patients described 'dyschezic' symptoms. None of these patients had had previous abdominal or pelvic surgery. Full clinical examination and routine investigations including biochemical and haematological screening, sigmoidoscopy and barium enema had failed to define a cause for the constipation. Their symptoms were inconsistent with the irritable bowel syndrome. Hirschprung's disease had been excluded by anorectal manometry in all the patients and by full-thickness rectal biopsy in six. At the time of this study the frequency of the bowel movements of the constipated patients ranged from once per week to once every 5 weeks (mean once every 19 days). Dietary and drug adjustments had been of little benefit. Three patients had to have regular enemas to encourage defaecation. All the patients were on some form of laxative, the commonest being Dorbanex. Urological symptoms were able to be elicited in 12 of the fifteen patients studied. Frequency, urgency, urge and stress incontinence were the commonest. Two patients had recurrent urinary tract infections and three nocturnal enuresis. the pattern of voiding was urgent but many admitted to some difficulty in voiding by volition. Twenty-five female hospital patients with no bowel symptoms consented to manometric and electrophysiological investigations for the purpose

of obtaining control data. Their ages ranged from 23-60 years (mean 40 years). These patients had been admitted to hospital for investigations or surgery outwith the alimentary tract.

METHODS

Radiology

All the patients had a standard double contrast barium enema to exclude an obvious organic cause for the constipation.

Manometry

All the patients and subjects were requested to refrain from taking all but the most essential medications for 48 hours prior to the manometric and electrophysiological investigations.
Anal sphincter manometry was performed using a conventional microballoon tehnique (Varma and Smith, 1984; Section 2.1) to measure physiological sphincter length, basal and squeeze pressures. In addition, the presence of the rectosphincteric reflex was confirmed in all patients and controls. Proctometrograms (Varma and Smith, 1986; Section 2.2) were performed in 10 patients and a similar number of approximately age-matched controls. Rectal volumes at sensation threshold, defaecatory sensation and maximal tolerance were measured and rectal compliance accordingly calculated.

Electrophysiology

Measurement of the electrophysiological latency of the pudendo-anal reflex was performed by the averaging method described in Section 2.3. The sensory threshold and stimulation voltages, amplitude, and duration of the reflex contraction of the external anal sphincter as determined by this method were also noted.

Mean motor unit potential duration of the external anal sphincter musculature was measured by the method described in Section 5.1. This was able to be performed in eight patients and compared to data gathered from 15 control women.

RESULTS

Radiology

In two patients barium enema was reported to show some redundancy of the sigmoid colon. No other colonic abnormality was detectable in any patient. However, in five of the fifteen patients spinal dysraphism was incidentally noted on this examination (Figure 45); in several patients, however, satisfactory views of the lumbosacral spine were not available on the enema films to exclude this disorder.

The spinal bony defects included defective closure of the dorsal neural arches of the first or second sacral vertebrae in three patients and of the fifth lumbar vertebra in two patients.

FIGURE 45

Spina bifida occulta (L5) in a young woman with severe idiopathic constipation

Manometry

The manometric data is listed in Table 15. The rectosphincteric reflex was demonstrable in all the patients and controls. No significant differences in sphincter pressure or length exist between the two groups.

Rectal compliance was increased in constipation. There appeared to be no deficit of rectal sensory threshold although the volume at which the desire to defaecate was perceived was significantly increased in constipation, as was the maximal tolerable volume.

Electrophysiology

Table 16 lists the electrophysiological measurements. In two patients the pudendo-anal reflex was absent (>100 ms). The remainder showed significant prolongation (Figure 46). Other electrophysiological parameters of the pudendo-anal reflex remained unchanged. The mean motor unit potential duration of the external anal sphincter appeared to be somewhat prolonged in the constipated group although this did not reach statistical significance.

TABLE 15

Manometric data in young women with intractable idiopathic constipation

Parameter	Chronic constipation	Control	p
	(n=15)	(n=25)	
MRP (cm H2O)	101±4.6	107±5.6	>0.1
HPZ (cm)	3.1±0.1	3.2±0.1	>0.1
MVC (cm)	159±8	167±7	>0.1
	(n=10)	(n=10)	
STV (ml H2O)	348±56	230±35	>0.1
CSV (ml H2O)	444±40	300±28	<0.02
MTV (ml H2O)	699±49	510±22	<0.01
RC (ml/cm H2O)	14.4±1	8.5±0.6	<0.01

RSR present in all patients and controls

All measurements Mean±SEM

TABLE 16

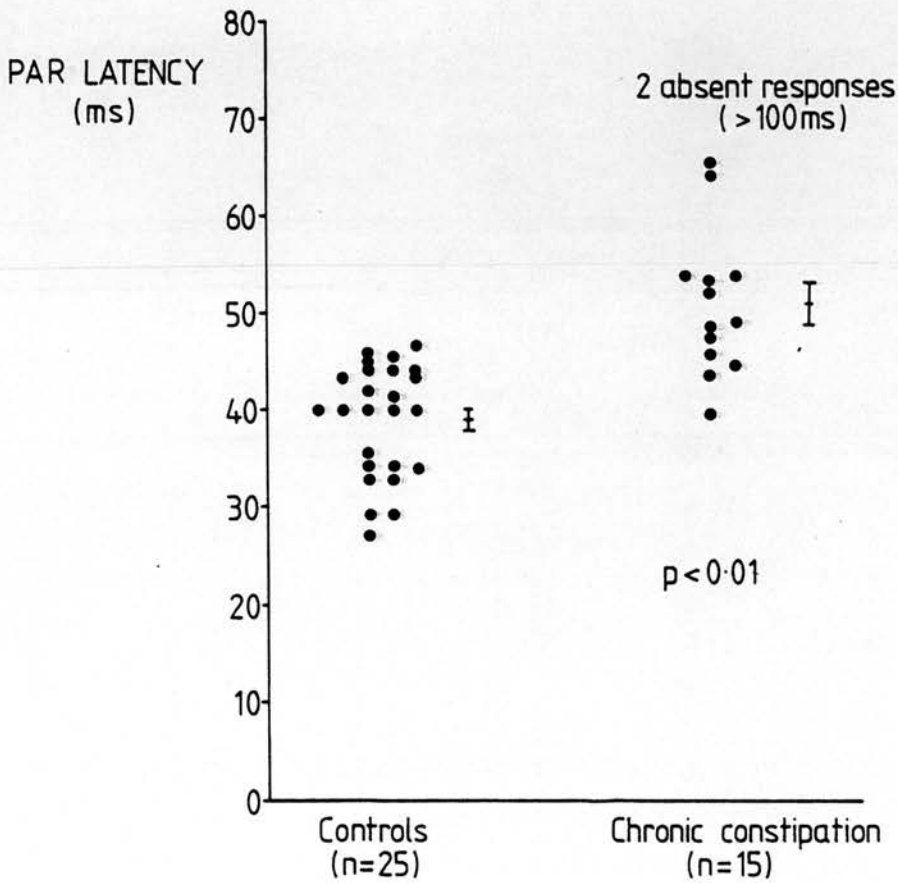
Electrophysiological data in young women with intractable idiopathic constipation

Parameter	Chronic constipation	Control	p
	(n=15)	(n=25)	
Sensory threshold, PAR (Volts)	32.7±1.5	35.2±2.9	>0.1
Stimulation strength, PAR (Volts)	103±5	112±6.6	>0.1
Latency PAR (ms)	39±1.2	50.7±1.9 (2 absent)	<0.01
Amplitude PAR (μV)	7.1±1.78	4.5±0.68	>0.1
	(n=8)	(n=15)	
MUPD EAS (ms)	10.1±0.7	8.7±0.36	>0.1

All measurements Mean±SEM

FIGURE 46

Scattergram demonstrating abnormalities of the latency of the pudendo-anal reflex in idiopathic constipation. Bars represent Mean±SEM



DISCUSSION

There is no consensus regarding the pathophysiology of constipation, a disorder which may often tax the most patient proctologist. The disease is deceptively uninteresting, yet both Hurst (1919) and Avery-Jones (1972), giants of British gastroenterology, wrote extensively about it. Studies have suggested that it may be related to abnormally high sphincter pressures (Watier et al, 1979, 1983; Meunier et al, 1979), an internal anal sphincter that fails to relax on rectal distension (Meunier et al, 1979; Martelli et al,1978; Orr et al, 1981), impaired rectal sensitivity (Meunier et al, 1979), failure of relaxation or paradoxical contraction of the pelvic floor musculature (Preston and Lennard-Jones, 1981,1985), reduced colonic propulsion (Ritchie, 1968), myenteric plexus abnormalities (Krishnamurthy et al, 1985), a functional obstruction of the sigmoid colon (Chowdury et al, 1976), or a combination of these abnormalities. Conflicting data has often accrued due to the heterogeneity of the groups studied, making interpretation difficult. This study has examined a fairly well-defined young to middle-aged group of women with severe 'idiopathic' constipation. The sex and age distribution resembles that reported from other studies (Read et al, 1986; Roe et al, 1986) but is different from the sex distribution found in elderly patients with chronic constipation (Varma et al, 1985; Section 4.2).

Manometric anal sphincter data in this study did not throw much light on the aetiology of this type of constipation. This data is in

agreement with other recent reports in a similar group of patients (Read et al, 1986; Roe et al, 1986). We were sufficiently confident of the exclusion of Hirschprung's disease by the manometric and radiological investigations and, in some patients, by the histological demonstration of normal ganglion cells in the myenteric plexus of the lower rectum. These simple investigations, nevertheless, do not exclude the paradoxical contraction of the pelvic floor musculature on attempted defaecation that have been described by other workers (Preston et al, 1985; Womack et al, 1986). Transit studies were not performed because of the obvious clinical severity of the constipation and the 'dyschezic' nature of most patients' symptoms.

Although the proctometrogram in ten patients did not demonstrate any increase in the initial sensation of rectal distension, the 'constant' sensation at which the urge to defaecate was perceived appeared to be blunted. This is in keeping with the findings of Read et al (1986) who postulated different sensory pathways for these sensory modalities. Other workers have also described abnormalities of rectal sensation in such patients (Preston et al, 1984; Roe et al, 1986). The increase in rectal compliance and maximal tolerable volume in the constipated group was in contradiction to the findings of Roe et al (1986) who, however, used a much faster rate of infusion. It is also uncertain as to their method of bowel preparation which can effect the proctometrogram results (Varma and Smith, 1986). Nevertheless, it is noteworthy that increase in rectal compliance and maximal tolerable volume in association with sensory deficits has been described in patients with spinal cord injury (White et al, 1940) and following pelvic nerve damage (Scott and Cantrell, 1969; Varma and Smith,

1985).

Our studies suggest that some of these patients have a 'functional' megarectum that is often not obvious radiologically (Preston and Lennard-Jones, 1983). This may be the combined effect of the outlet obstruction that has been described in many such patients (Preston et al, 1985) and the coexistent sensory deficit of rectal perception of distension. A similar phenomenon has been described in some elderly patients with constipation and impaction (Varma et al, 1985; Read et al 1985), although there are probably many other factors involved in that group (Section 4.2).

The electrophysiological results described in this study do not suggest any abnormality of the sensory side of the pudendo-anal reflex as both the threshold and stimulation parameters did not significantly differ from control measurements (Table 16), although voltage is less accurate than current in quantifying this parameter. This finding is in accordance with that of other workers (Roe et al, 1986) using a more accurate technique, in contrast to patients with neurogenic faecal or urinary incontinence who have abnormalities of both sensory and motor (Varma et al, 1986; Section 5) pathways.

It is recognised that denervation of the striated anal sphincter musculature can result from chronic straining at defaecation (Kiff et al, 1984). The patients in whom mean motor unit potential duration of the external anal sphincter was assessed in this study did show a relative prolongation in this parameter although this did not achieve statistical significance compared to the control group. In contrast, the latency of the pudendo-anal reflex was grossly prolonged in constipation and was indeed in excess of 100 ms in two patients. This

finding suggests a significant neurological disturbance in the central part of this reflex arc, its sensory and motor limbs apparently intact (Varma et al, 1986). It is conceivable that interneuronal connections to Onuf's nucleus (Onuf, 1901) are at fault. Both the patients with the 'absent' reflexes had a sacral spina bifida occulta. However, the external sphincter MUPD was not greatly prolonged in these two patients. It should be noted that there is a clear relationship between the latency of the PAR and the MUPD of the external anal sphincter in neurogenic incontinence (Section 5.1). The conus medullaris is intimately concerned in the modulation of colorectal motility and pelvic floor innervation (Section 4.1; Varma et al, 1986; Onuf, 1901) and in the control of micturition (Denny-Brown and Robertson, 1933; Mahony et al, 1977). The urological disturbances noted in our patients are further pointers to a possible occult neurogenic sacral spinal cord deficit in this constipated group. These abnormalities have been noted by other workers (Lawrence and Bannister, 1985). Galloway and Tainsh (1985) described abnormal somatosensory nerve studies in urologically symptomatic patients with minor bony defects of the sacrum. Fidas et al investigated neurophysiological abnormalities in primary adult enuretics (1985), acute female urinary retention (1987) and detrusor instability (1985). Fowler et al (1985) demonstrated abnormalities of urethral sphincter electromyography in women with urinary retention, suggesting impaired relaxation of this muscle similar to those seen in the striated anal sphincter musculature of some young women with chronic constipation (Womack et al, 1986). Yip et al (1985) and Jakobsen et al (1985) emphasised the importance of urodynamic evaluation in

spinal dysraphism. In a large series of patients Fidas et al (1987) reported spina bifida occulta in 50% of patients with stress urinary incontinence compared with an incidence of only 17% in asymptomatic control female subjects. In this series more than 30% of the patients had lower spinal dysraphism incidentally observed on barium studies of the colon and rectum. It is likely that the true incidence is much higher and may be a likely explanation for the neurophysiological abnormalities described. Myelography may shed further light on this subject (Brooks et al, 1981).

The surgical treatment of this group of patients remains controversial. The present methods often lack theoretical rationale. It is of interest that functional urological abnormalities secondary to the 'tethered cord syndrome' have improved following neurosurgical intervention (Pang and Hoffman, 1980). It will be of interest to study the results of biofeedback in such patients.

Many of our patients were treated by subtotal colectomy and ileo-rectal anastomosis with acceptable results, similar to those described by other centres (Preston et al, 1984).

SECTION 5

NEUROGENIC ASPECTS OF INCONTINENCE

5.1 NEUROGENIC FAECAL INCONTINENCE

SUMMARY

Electrophysiological measurements on the pudendo-anal reflex (PAR) were evaluated in 25 asymptomatic control female subjects and in 20 women with neurogenic faecal incontinence. This was supplemented by determination of the mean motor unit potential duration (MUPD) of the external anal sphincter and conventional anorectal manometry. The manometric results confirmed significant weakness of the anal sphincter musculature. The reflex latency of the PAR in the control group was 39±5.8 (SD) ms. Three patients with faecal incontinence had 'absent' reflexes (latency >100 ms); the remainder showed significant prolongation of latency (56±12.2 SD ms) and diminution of amplitude of the PAR. MUPD was prolonged in incontinence and showed significant correlation with the corresponding reflex latency determination ($\tau = 0.56$, $p < 0.001$). The latency of this polysynaptic spinal reflex hence provides a reliable index of neuropathy of the external anal sphincter.

INTRODUCTION

There has been much interest and controversy about the electrically evoked reflex activity of the external anal sphincter, particularly in relation to faecal incontinence of neurogenic origin (Pedersen et al, 1978; Henry and Swash, 1978; Swash, 1982; Pedersen et al, 1982; Swash, 1982; Bartolo et al, 1983; Wright et al, 1985). Swash et al suggested that the latency of the classical anal reflex measured electrophysiologically was significantly increased in idiopathic faecal incontinence (Henry et al, 1978; Swash, 1982; Neill et al 1981). However, studies by other workers did not confirm the usefulness of the latency of this reflex as an index of pelvic floor neuropathy (Bartolo et al, 1983; Wright et al, 1985), and raised doubts about the interpretation of the earlier latency measurements. It has since become clear that electrical stimulation of the perianal skin results in direct stimulation of the terminal innervation of the external anal sphincter. This produces the 'early' or short-latency responses (Pedersen et al, 1982; Swash, 1982; Bartolo et al, 1983; Wright et al, 1985; Vodusek et al, 1983) that had previously been erroneously interpreted as spinal cord reflexes (Neill et al, 1981). These inconsistencies have limited the usefulness of the classical anal reflex for studying the clinical neurophysiology of the pelvic floor. This Section evaluates the usefulness of the pudendo-anal reflex (Section 1.4)in the investigation of patients with neurogenic faecal incontinence.

PATIENTS AND METHODS

The control group consisted of 25 female subjects (age range 23 - 75 years, mean 43 years). They were hospital patients who had been admitted for minor surgery outwith the alimentary tract and none had any anorectal symptoms. The group with neurogenic faecal incontinence comprised 20 women (age range 37 - 79 years, mean 59.9 years). The duration of anal incontinence ranged from 6 months to 10 years (mean 1.9 years). Systemic causes of neuropathy and direct sphincter trauma were excluded from this group.

All subjects underwent anorectal manometry and measurement of the latency of the pudendo-anal reflex. Determination of the mean motor unit potential duration of the external anal sphincter was performed in all the incontinent patients and in 15 control subjects.

Manometry

Patients were requested to empty their bowel on the morning of the study. The investigations were performed with the patient in the left lateral position. Basal and squeeze sphincter pressures and sphincter length were measured with a conventional water-filled microballoon and external transducer using a 0.5 cm station-pullthrough method (Varma and Smith, 1984; Section 2.1).

Latency of the pudendo-anal reflex (PAR)

This was measured by the methodology descibed in section 2.3 (Varma et al, 1986)

Determination of the Mean Motor Unit Potential Duration (MUPD) of the external anal sphincter

A modification of the method described by Bartolo et al (1983) was used. A standard concentric needle EMG electrode (surface area 0.07 mm^2, type 13L49 DISA, Copenhagen) was inserted into the external anal sphincter without anaesthetic via a puncture site 1cm. lateral to the anal orifice to a depth of approximately 250 mm This was connected via preamplifiers to an oscilloscope (Medelec MS92a, Woking, Surrey, U.K.). The tonic electrical activity of the sphincter was monitored using a time base of 10 ms/cm with the gain at 100μV/cm and filter settings of 20Hz - 10kHz). Single motor units firing at a steady rate were identified using the delay and trigger facilities incorporated in the apparatus. A saline-soaked felt strap wrapped around the right thigh was used as the ground electrode. Approximately 100 consecutive action potentials of the same motor unit were digitally averaged on one channel of the oscilloscope and the process repeated on the second channel. When two identical traces were obtained on both channels, the action potential duration for that motor unit was measured from the first deflection from the baseline to the return of the action potential to the baseline. Stable late components were thus easily

identified (Bartolo et al, 1983). Permanent recordings were obtained of at least twenty action potentials from the external anal sphincter representing approximately ten recordings from each side of the sphincter. This was made possible by minor movements of the tip of the needle electrode in the sphincter. The arithmetic mean of the twenty recorded potential durations was calculated and represented the mean motor unit potential duration for that sphincter. This was used as an index of neuropathy (Buchtal and Pinelli, 1953).

Statistics

Non-parametric methods were used. Differences in the manometric and electrophysiological measurements between the two groups were analysed by the Wilcoxon rank sum test. Correlation between the latency of the PAR and mean motor unit potential duration of the external sphincter was performed by Kendall's rank correlation. A linear correlation was also calculated.

RESULTS

Manometry

Table 17 compares the manometric parameters measured in the two groups. There is a significant reduction in the physiological sphincter length, maximum resting pressure and the squeeze pressure of the external anal sphincter in the incontinent group.

TABLE 17

Anal sphincter manometry in neurogenic faecal incontinence

Parameter	Control (n=25)	F.I. (n=25)	p
MRP (cm H2O)	100±28	60±24.6	<0.01
SP (cm H2O)	167±35	86±32.6	<0.01
HPZ (cm)	3.2±0.5	2.2±0.9	<0.01

All measurements Mean±SD

Electrophysiology

Reproducible reflex responses were confirmed in all subjects. Reversal of the polarity of the stimulating electrode simply resulted in reversal of the stimulus artefact without altering the shape or latency of the evoked response. 'Bifid' responses were observed in some patients and controls, i.e. responses with late components. In these cases the latency of the PAR was taken from the onset of the first response because this represents the shortest measurement. Figure 47 illustrates typical traces obtained from healthy and incontinent subjects.

Table 18 compares the electrophysiological data between the control and incontinent groups. There were no differences in the voltage at sensation threshold and that used for maximal stimulation. However, the latency of the PAR was significantly prolonged and its amplitude reduced in the incontinent group (Figure 48). In three of these patients the reflex could not be elicited despite several attempts. No differences were apparent in the duration of the reflexly evoked anal sphincter response between the two groups.

The mean MUPD of the external anal sphincter was significantly increased in the incontinent patients. Figure 49 illustrates typical averaged motor unit potentials from control and incontinent patients. Figure 50 illustrates the high correlation between the latency of the PAR and the mean MUPD of the respective external anal sphincter (τ = 0.56, $p < 0.001$; for linear correlation $r = 0.69$, $p < 0.001$). Taking only the incontinent patients, $\tau = 0.4$, $p < 0.02$ (for linear

FIGURE 47

Typical traces of the pudendo-anal reflex

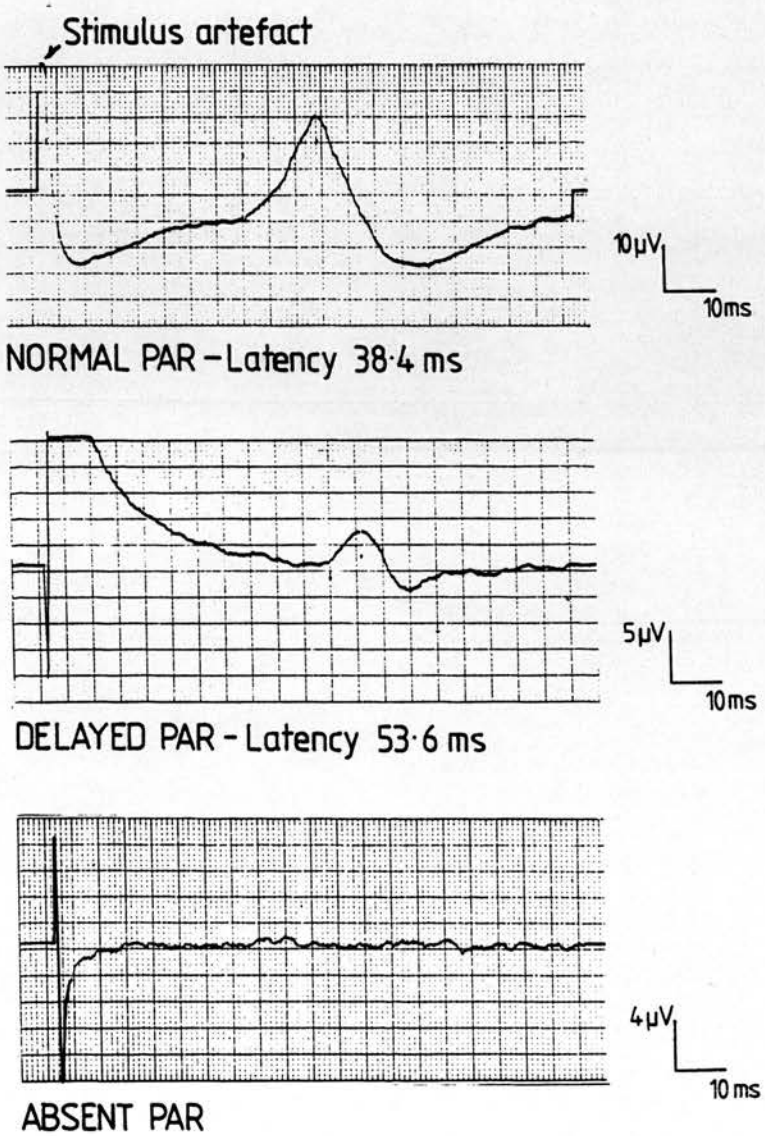


TABLE 18

Electrophysiological anal sphincter data in neurogenic faecal incontinence

Parameter	Control	Faecal incontinence	p
	(n=25)	(n=20)	
PAR stimulation threshold (Volts)	35.2±14.5	31±8.9	>0.1
PAR stimulation strength (Volts)	112±33	96.8±20.1	>0.05
Latency of PAR (ms)	39±5.8	56±12.2 (3 absent)	<0.01
Amplitude of PAR (μV)	4.5±3.4	1.95±1.9	<0.01
Duration of PAR (ms)	16.9±7	15.4±5.4	>0.1
	(n=15)	(n=20)	
MUPD of external anal sphincter (ms)	8.66±1.38	12.23±1.83	<0.01

All measurements Mean±SD

FIGURE **48**

Graphical representation of the prolongation of the latency of the pudendo-anal reflex in neurogenic faecal incontinence. Bars represent Mean±SEM

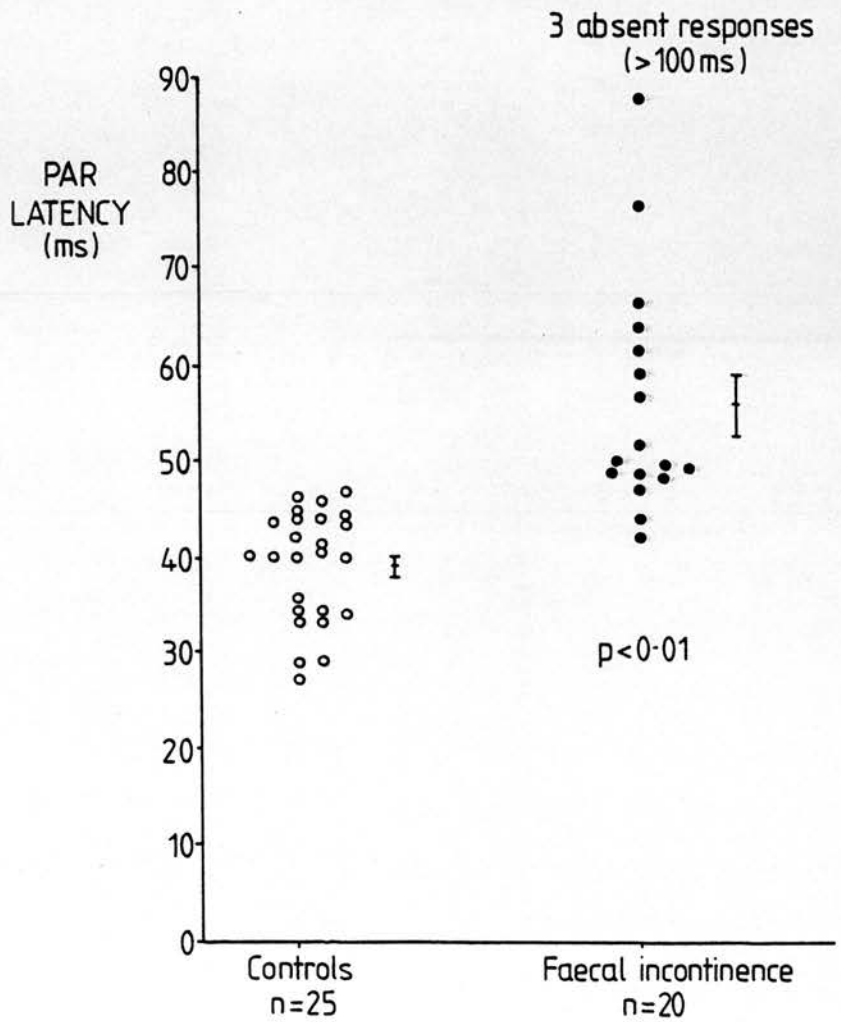


FIGURE 49

Typical motor unit potential traces showing the prolongation in neurogenic incontinence

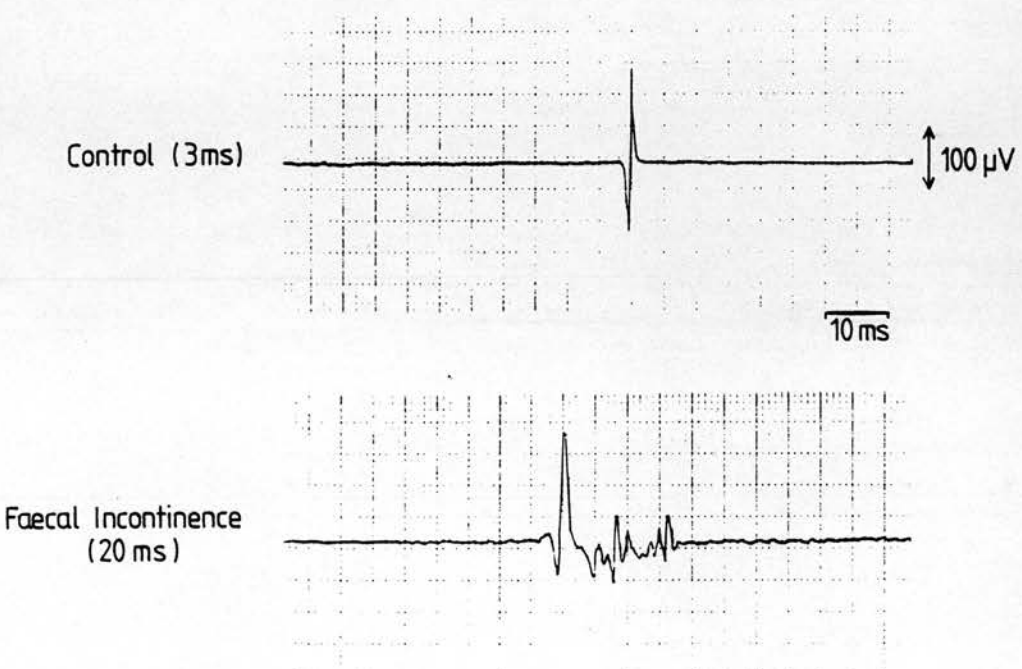
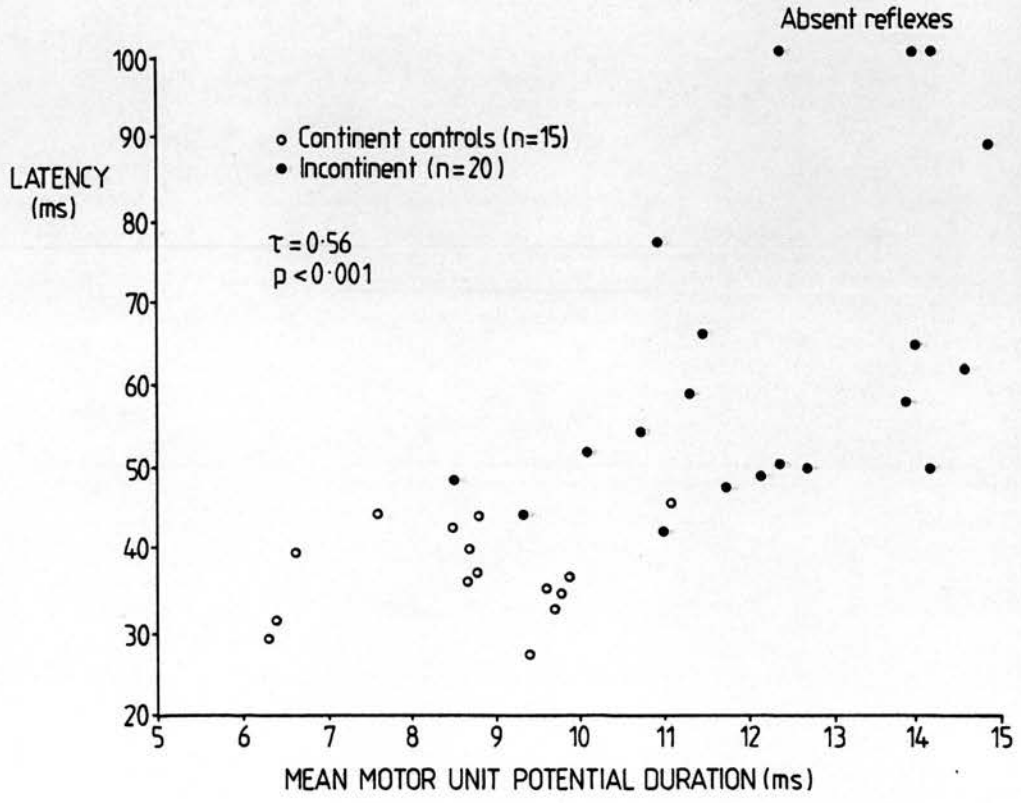


FIGURE 50

Scattergram showing the significant correlation between the MUPD of the external anal sphincter and the corresponding latency of the pudendo-anal reflex



correlation, $r = 0.5$, $p < 0.05$).

DISCUSSION

Reflexes involving the perineal muscles have stimulated much interest in the neurological evaluation of the conus medullaris and its afferent and efferent connections. These studies are considered to be of particular value in disorders of the genito-urinary system and the pelvic floor musculature (Rossolimo, 1891; Lapides and Bobbitt, 1956; Bors and Blinn, 1985; Ertekin and Reel, 1976,1979; Pedersen et al, 1978,1982; Henry and Swash, 1978; Siroky et al, 1979; Krane and Siroky, 1980; Neill et al, 1981; Swash, 1982; Marsden et al, 1982; Vereecken et al, 1982; Haldeman et al, 1982; Bartolo et al, 1982; Vodusek et al, 1983; Bilkey et al, 1983; Smith and Varma, 1984; Wright et al, 1985; Galloway and Tainsh, 1985; Fidas et al, 1985,1987). Since the description of the classical anal reflex by Rossolimo in 1891 using mechanical stimulation of the perianal skin, the reflex has been extensively investigated by more sophisticated electrophysiological methods (Pedersen et al, 1978; Swash, 1982; Bartolo et al, 1983; Wright et al, 1985; Vodusek et al, 1983; Vereecken et al, 1982). Henry and Swash described a latency for this reflex of 8.3+1.7 SD ms in 13 normal subjects (1978) and suggested that it was prolonged in faecal incontinence and rectal prolapse (Neill et al, 1981; Swash, 1982). The presence of these short-latency responses has been observed by other workers who also noted later responses of longer duration (Pedersen et al, 1982; Vodusek et al,

1983; Haldeman et al, 1982). The early reactions have a uniform electrical pattern and show no sign of fatigue. They are not abolished by spinal anaesthesia (Pedersen et al, 1982; Wright et al, 1985) and their latencies are too short for a spinal reflex (Pedersen et al, 1982; Swash, 1982; Marsden et al, 1982). They have therefore been attributed to direct activation of the terminal innervation of the anal sphincter (Wright et al, 1985, Vodusek et al, 1983). Some of the intermediate responses may be due to antidromic stimulation with interaction between neighbouring α-motoneurones in Onuf's nucleus (Onuf, 1901) hence resulting in 'oligosynaptic' latencies (Pedersen et al, 1982). The 'classical' polysynaptic anal reflex is now recognised to have a latency of 50+10.5 SD ms (Pedersen et al, 1978). These variable factors have made the precise determination of the latency of the anal reflex difficult and its interpretation controversial (Pedersen, 1985). This study evaluates the usefulness of the pudendo-anal reflex (Section 2.3) in the investigation of 'neurogenic' faecal incontinence.

The rather startling prolongation of PAR latencies observed in neurogenic faecal incontinence (i.e. more than expected by a delay in the efferent limb only), and the reduction in the amplitude of the response, suggests that in these patients the afferent impulse has some difficulty in stimulating the spinal α-motoneurones to generate a potential and hence evoke a response from the external anal sphincter. This may be due to a reduction in the number of such neurones innervating the sphincter as is reflected by the larger size of the motor units in these patients suggesting re-innervation (Bartolo et al, 1983). A smaller motoneurone pool must also result in

less interaction between them (Gogan et al, 1977), further 'magnifying' the latency differences between normal subjects and patients with defects of sphincter innervation. Although there is much evidence for the presence of a lesion in the efferent side of the reflex arc (Snooks et al, 1985; Kiff et al, 1984) it has been suggested that abnormalities may also exist in the afferent limb (Roe et al, 1986; Womack et al, 1985) similar to those seen in stress urinary incontinence (Varma et al, 1987; Section 5.2). The analogy is clearly with multiple sclerosis in which the latency of the visual evoked response at the cortex is far longer than that expected for any delay in conduction in the optic nerves, thus indicating that the nervous system experiences difficulty in generating the potential. Despite the wide range in health, the marked increase in latencies in incontinence are clearly of value as indices of neuropathy. Almost all the incontinent patients had latencies in excess of 50 ms (normal range 27.2 - 46.8 ms; Section 2.3). The high correlation of latencies with MUPD is further direct evidence of the value of the PAR as a predictor of neuropathy of this muscle. Additional evidence of a sphincteric cause of faecal incontinence in the patients in this study is provided by the manometric results (Neill et al, 1981, Table 17). Causes of nerve damage other than a stretch injury of the terminal innervation of the sphincter musculature can result in increased latencies. Thus, following glans stimulation, Rushworth (1967) found reflexes with a latency of 120 ms in a patient with polyneuritis and Vereecken et al (1982) recorded a latency of 180 ms in a patient with T12 fracture. Pedersen et al (1978) described latencies of upto 200 ms after perianal stimulation in cases where disc protrusion had

caused a cauda equina syndrome. Ertekin et al (1979) described abnormalities of the bulbocavernosus reflex in 40 patients with traumatic or compressive lesions of the conus medullaris or cauda equina. Similar observations were made by Rockswold and Bradley (1977).

The polysynaptic nature of the pudendo-anal reflex and its reproducibility also render it a suitable tool for the electrophysiological exploration of the sacral spinal cord in the absence of neuropathic changes in the external anal sphincter. Hence, it has been used in the investigation of patients with neurogenic disorders of the urinary bladder and of sexual function (Ertekin and Reel, 1976; Galloway et al, 1985; Fidas et al, 1985). Many of these patients often have radiological evidence of lumbo-sacral spinal dysraphism (Galloway et al, 1985; Fidas et al, 1987). Similar observations have been made in some patients with intractable constipation of idiopathic origin (Varma and Smith, 1984; Section 4.3).

Electrophysiological measurement of the PAR latency provides a simple and reliable method of evaluating pelvic floor neuropathy. It also provides information of the neurogenic function of the sacral conus. Its diagnostic value is increased when supplemented by other functional investigations. These include anorectal manometry, EMG (duration of motor units, number of polyphasic potentials, fibre density) and measurement of conduction velocity in the motor innervation of the pelvic floor (Snooks et al, 1985).

5.2 GENUINE FEMALE STRESS URINARY INCONTINENCE

SUMMARY

Perineal sensory and motor function was evaluated in 28 women with genuine stress incontinence of urine and compared to a control group. The incontinent patients showed diminution of resting urethral sphincter EMG pattern with poor recruitment. Electrosensitivity of the dorsal nerve and urethral mucosa was significantly diminished in these patients. Three different reflex latency measurements (dorsal nerve to external anal sphincter, dorsal nerve to urethral sphincter, urethral mucosa to external anal sphincter) were prolonged in incontinence (14 absent reflexes). Mean motor unit potential duration of the external anal sphincter was also prolonged, reflecting an early neuropathy.

Anorectal manometry detected significantly weaker squeeze pressures in stress incontinence although other parameters were unaffected.

Following a course of pelvic floor exercises (n=11), 7 patients showed no clinical improvement while 4 patients admitted to early improvement. Repeat anorectal manometry failed to detect any improvement in pressures.

INTRODUCTION

Stress incontinence of urine in women is a relatively common and distressing condition (Thomas, 1984). As there are often no overt neurological signs, the condition had for long been attributed to 'pelvic floor weakness', its precise aetiology remaining poorly defined (Green, 1975). There is now some evidence for an abnormality of motor innervation of the urethral sphincter musculature in this disorder (Snooks et al, 1985), similar to that seen in neurogenic faecal incontinence (Henry and Swash, 1985). It is conceivable that sensory abnormalities of the perineum also exist and exacerbate the urodynamic and clinical disturbances in stress urinary incontinence. These various factors may influence the results of conservative or surgical treatment of this condition (Green, 1975). The aim of this study was to further evaluate perineal sensory and motor abnormalities in such patients using new electrophysiological techniques (Abrams et al, 1986). In addition, anorectal function was studied manometrically to evaluate the effects of physiotherapy on the pelvic floor.

PATIENTS

Twenty-eight female patients with urodynamically proven genuine stress incontinence of urine were entered into the study. Their age range was 24-63 years (mean 41 yrs). Duration of symptoms ranged from 6 weeks to 23 months. Twenty-four of the patients were multiparous and 4 nulliparous. Four patients dated their incontinence to an abdominal

hysterectomy, a total of seven patients having had this operation. Three patients had previously had an anterior colporrhaphy. For purposes of comparison, 28 approximately age-matched hospital controls (age range 18-75 years, mean 44 yrs) with no urological symptoms were also studied. They were patients who were being investigated for minor colorectal and urological conditions such as polyps, bleeding etc. and had given informed consent for this study. The control patients did not undergo urodynamic investigations.

METHODS

Urodynamics

All 28 symptomatic patients had undergone clinical examination and conventional videocystometry to ascertain the diagnosis of genuine stress urinary incontinence (Bates et al, 1976; Godec et al, 1980).

Anorectal manometry

This was performed in 11 patients using conventional techniques (Varma and Smith, 1984; Section 2.1) to determine basal and (sustained) squeeze anal sphincter pressures, the functional sphincter length and the presence and amplitude of the rectosphincteric reflex. The rectal sensory threshold to distension was also measured (ml air) by slow inflation of the rectal balloon. It was defined as the amount of air necessary to for the patient to perceive the first sensation of rectal distension. These parameters were measured before

and after a course of pelvic floor exercises including faradic stimulation and interferential therapy in an attempt to improve their stress incontinence.

Electrophysiology

The sixth report of the Inernational Continence Society has standardised the terminology of procedures related to neurophysiological investigation of the lower urinary tract (Abrams et al, 1986). The procedures used in this study are described below.

Sphincter EMG

Resting and contracting anal and urethral sphincter electromyographic activity was recorded by a surface anal plug and urethral catheter-mounted electrode (DISA, Copenhagen) respectively, and assesed as normal or diminished. The same electrodes were used to record reflex sphincteric responses.

Reflex responses

The electrophysiological latency of the reflex contraction of the external anal and urethral sphincters in response to stimulation of the dorsal genital nerve was determined by a digitally averaging method. The dorsal nerve was stimulated by a felt surface electrode and the reflex responses recorded by surface ring electrodes, those within the urethra being mounted on a urinary catheter. This urethral

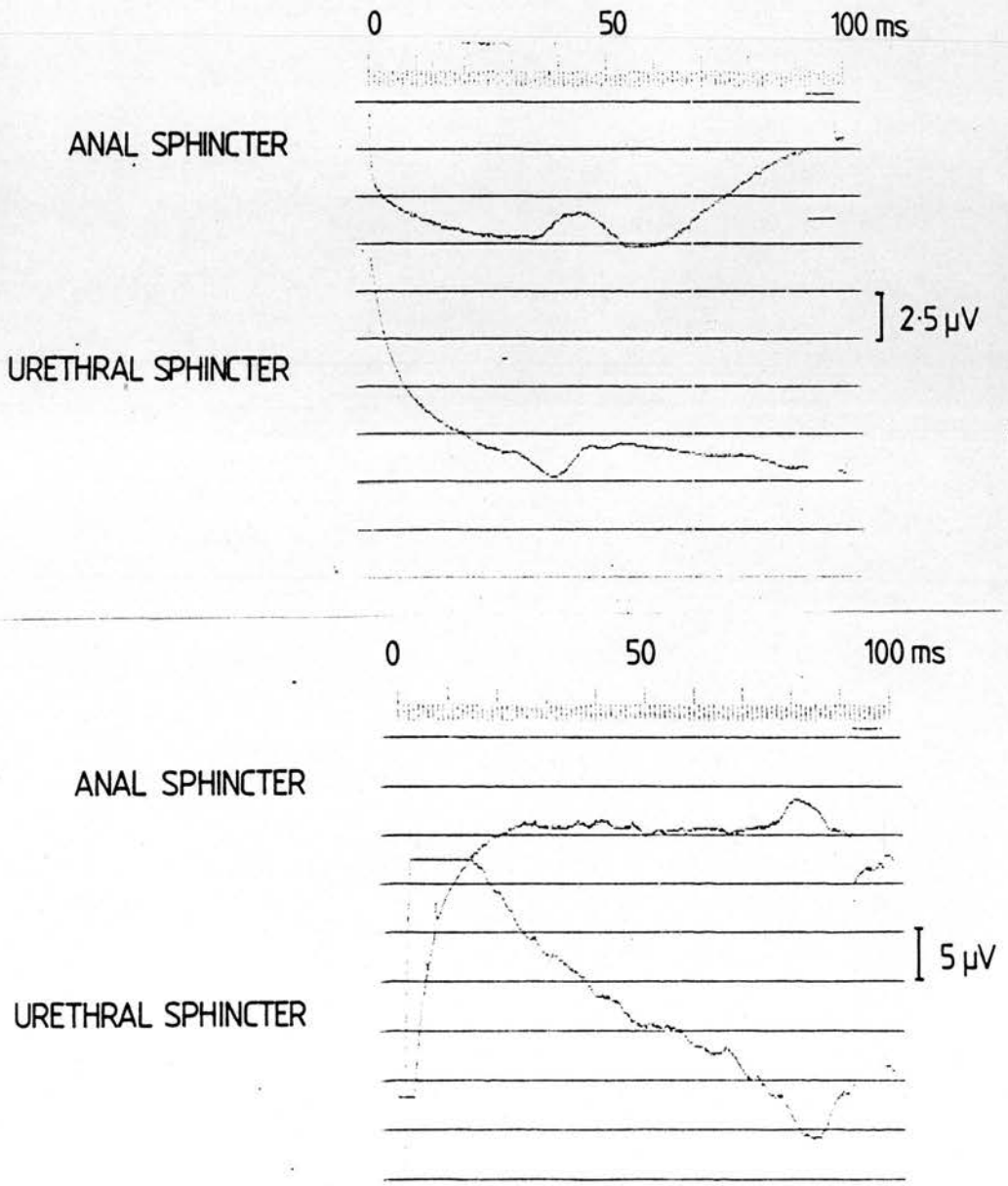
electrode was also used as a stimulating electrode to record the urethra to anal sphincter reflex latency. The details of the methodology are as described by Smith and Varma (1984), Galloway et al (1984), Fidas et al (1985), and Varma et al (1986; Section 2.3). The dorsal nerve to anal sphincter reflex latency was measured (sweep 100 ms) in all the patients and controls. The dorsal nerve to urethral sphincter latency was measured (sweep 100 ms) in 15 patients and 19 controls. The urethral mucosa to anal sphincter latency was measured (sweep 200 ms) in 15 patients and 16 controls. Figure 51 illustrates some typical anal and urethral sphincter responses to dorsal nerve stimulation.

Electrosensitivity

Electrosensitivity of the dorsal nerve and the urethral mucosa was determined by use of the same stimulating electrodes as used for the reflex responses. The principle is based on the method described by Kieswetter (1977) and Powell (1980). Sensory threshold was recorded in milliamperes (maximum 70 mA) and was defined as the first sensation of 'tapping' (threshold) perceived by the patient on increasing the stimulating current via the constant-current generator (DISA, Copenhagen). The dorsal nerve electrosensitivity was measured in 15 patients and 22 controls. The electrosensitivity of the urethral mucosa was determined in 16 patients and 17 control subjects.

FIGURE 51

Normal (upper traces) and delayed (lower traces) latencies of reflex contraction of the anal and urethral sphincters following dorsal nerve stimulation.



Mean motor unit potential duration

Mean motor unit potential duration of the external anal sphincter was measured by a the technique described by Varma et al (1986; Section 5.1), being a modification of the method described by Bartolo et al (1983). A total of 20 motor units (10 from each side of the sphincter) were studied using a concentric needle electrode, and their mean calculated. This was used as an index of neuropathy of the external anal sphincter (Buchtal and Pinelli, 1953). This investigation was performed in thirteen patients and 15 controls.

Pelvic floor physiotherapy

Eleven patients underwent a course of intensive pelvic floor exercises in the Physiotherapy Department lasting 8-10 weeks in an attempt to improve muscle function (Wilson et al, 1984). These exercises were started in the 'at rest' position and gradually promoted to doing these exercises through more provocative procedures such as jogging on the spot etc. In addition, mid-stream stopping and starting was encouraged during micturition. In those patients with clinically poor pelvic floor tone and proprioceptive deficits, the pelvic floor exercises were aided by faradic and/or interferential stimulation therapy. These 11 patients underwent repeat anorectal manometry at the completion of their treatment to detect any improvement in pelvic floor function. They were also assessed clinically.

Statistics

Comparisons between control and incontinent were made by Wilcoxon's test for unpaired data. A paired test was used for analysing the effects of pelvic floor physiotherapy on anorectal manometry.

RESULTS

Table 19 summarises the electrophysiological and manometric data in patients with stress incontinence and enables comparison with control patients. Table 20 lists the effects of pelvic floor physiotherapy on anorectal manometry in 11 patients.

Sphincter EMG

In general, several patients showed poor resting EMG pattern and poor recruitment compared to control observations.

Reflex response latencies

Reproducible results were obtained for all latency measurements. The three reflex response latencies were increased compared to the control group. Many of the reflexes from incontinent patients were noted to be of low amplitude (Varma et al, 1986). In addition, a total of 14 reflexes out of 58 were 'absent' (Figure 52).

TABLE 19

Electrophysiological and manometric data in stress urinary incontinence

Parameter	Stress incontinence	Control	p
DN - EAS latency (ms)	49.6±2.2 (3 absent, n=28)	39.7±1.1 (n=28)	<0.01
DN - US latency (ms)	60±2.7 (4 absent, n=15)	40.5±1.2 (n=19)	<0.01
UM - EAS latency (ms)	83±5.7 (7 absent, n=15)	69.6±2.1 (n=16)	<0.01
DN electro-sensitivity (mA)	8.8±0.8 (2 insensitive, n=15)	6.1±0.2 (n=22)	<0.01
UM electro-sensitivity (mA)	13.8±2.5 (6 insensitive, n=15)	8.3±0.5 (n=18)	<0.01
EAS MUPD (ms)	11.3±0.5 (n=13)	8.7±0.4 (n=15)	<0.01
	(n=11)	(n=11)	
HPZ (cm)	3.4±0.2	3.3±0.5	>0.1
MRP (cm H2O)	93±9	108±5	>0.1
SP (cm H2O)	36±6	75±13	<0.02
STV (ml air)	44±10	55±8	>0.1
Ampltude RSR (ml H2O)	48±7	42±4	>0.1

All measurements mean±SEM

TABLE 20

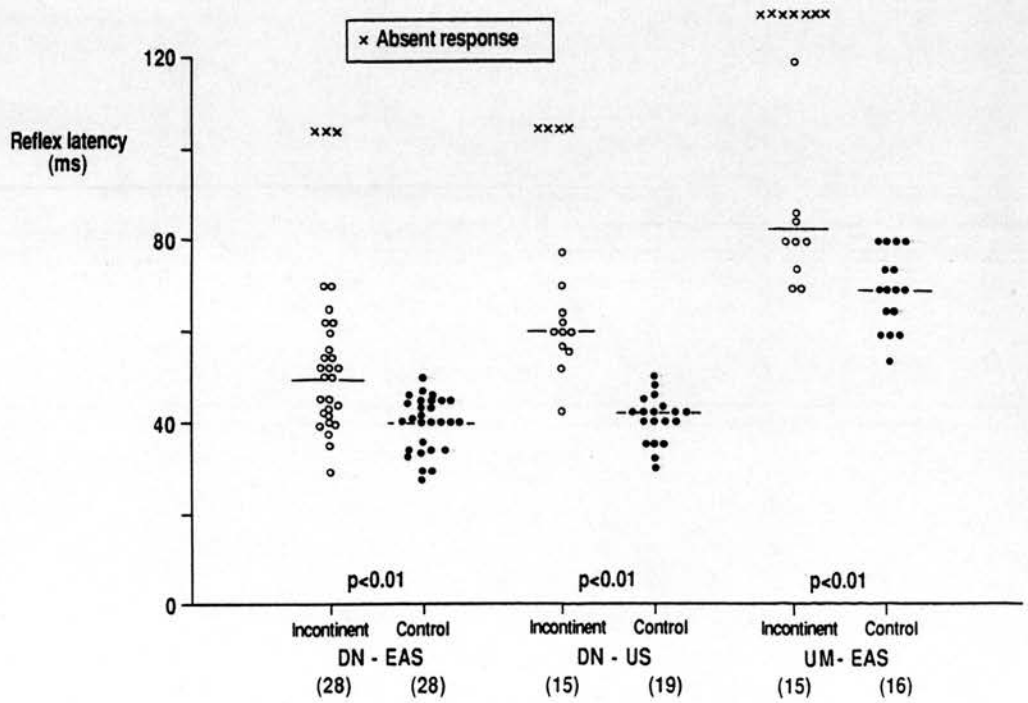
Changes in anorectal manometry following a course of pelvic floor physiotherapy for stress urinary incontinence (n=11)

Parameter	Pre-treatment	Post-treatment	p
HPZ (cm)	3.4±0.2	3.3±0.2	<0.05
MRP (cm H2O)	93±9	90±9	>0.1
SP (cm H2O)	36±6	42±7	>0.1
Sustained squeeze time (s)	10±2.5	9±3.3	>0.1
STV (ml air)	44±10	45±10	>0.1
Amplitude RSR (ml H2O)	48±7	53±8	>0.1

All measurements Mean±SEM

FIGURE 52

Scattergram comparing three different reflex latencies in incontinent and control subjects. Bars represent Mean values. Numbers in brackets denote numbers of patients studied



Dorsal nerve and urethral mucosal electrosensitivity

Reproducible measurements were confirmed at both sites. Dorsal nerve and urethral mucosal electrosensitivity was diminished in incontinent patients (Figure 53). Nine out of 31 patients had thresholds in excess of the maximum obtainable output (>70 mA). They were described as 'insensitive'.

External anal sphincter MUPD

Patients with stress urinary incontinence (n=13) had prolonged MUPD of the external anal sphincter compared to control patients (n=15; Table 19). This difference was significant ($p < 0.01$).

Anorectal manometry

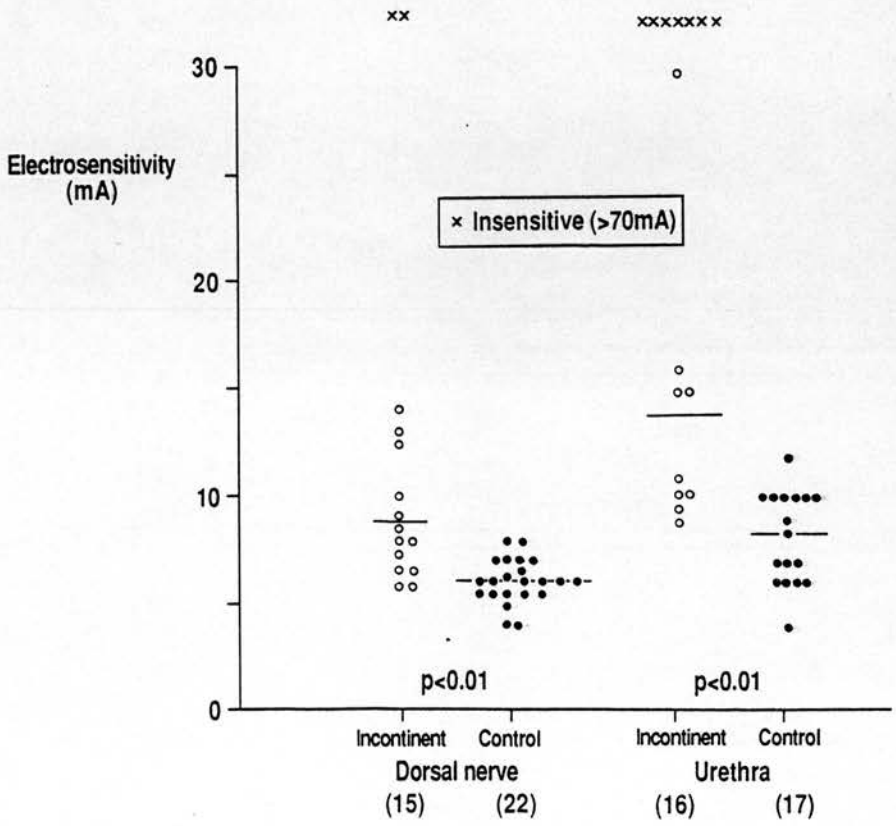
The only significant difference that could be detected between control and stress incontinent patients by conventional anorectal manometry was a reduction in voluntary sphincter contraction pressures in the latter (Table 19).

Pelvic floor physiotherapy

Following a course of pelvic floor exercises in 11 patients, there was no significant change in manometric measurements apart from a minimal change in sphincter length (Table 20). Only four of these patients

FIGURE 53

Scattergram comparing dorsal nerve and urethral mucosal electrosensitivity in incontinent and control subjects. Bars represent Mean values. Numbers in brackets denote numbers of patients studied



reported symptomatic improvement following physiotherapy.

DISCUSSION

Genuine stress incontinence of urine is defined as the involuntary loss of urine when intravesical pressure exceeds maximum urethral pressure due to an elevation of intra-abdominal pressure and in the absence of detrusor contraction (Bates et al, 1976). It is predominantly a female disorder common in the older multiparous patient (Thomas, 1984; Yarnell et al, 1981) but not inevitably so (Wolin, 1969). Like other forms of incontinence, it is distressing for the sufferer and often restricts her social life.

Urethral continence at rest is dependent primarily on the bladder neck and intramural striated sphincter (external sphincter) composed of slow twitch muscle fibres which exhibit 'tonic' activity at rest (Gosling, 1981). These are supplied directly by the pelvic nerves from the sacral segments S2-S4 (Gil Vernet, 1968). The periurethral striated muscle sphincter functions reflexly to augment urethral closure during 'stress' events which elevate intra-abdominal pressure such as coughing, laughing, straining etc. This muscle receives its motor innervation from the perineal branch of the pudendal nerve (Gosling, 1981,1985; Donker et al, 1976; Snooks and Swash, 1984). The reflex activation of the peri-urethral musculature is mediated via excitation of its innervating α-motoneurones in the conus medullaris (S2-S4) by sensory afferents in the bladder, urethra and pelvic floor. The sensory innervation of the urethral mucosa derives

predominantly from the perineal branch of the pudendal nerve (Warwick and Williams, 1980). A direct branch from the motor roots of S3 and S4 reaching the pelvic floor via its visceral surface also carries sensory fibres from the posterior urethra and anal canal (Lawson, 1974). The inferior rectal nerve, a direct branch of the pudendal nerve, supplies the external anal sphincter, the lining of the lower part of the anal canal and skin around the anus (Warwick and Williams, 1980). Anatomical or functional deficits in the sensory, central or motor pathways of reflexes involving the urethral sphincter may, therefore, compromise urinary continence.

Better understanding of these basic physiological mechanisms has renewed interest in the functional neurophysiology of the pelvic floor musculature in relation to the maintenance of faecal and urinary continence (Henry and Swash, 1985). So-called 'idiopathic' faecal incontinence is now recognised to be of neurogenic origin secondary to traumatic or chronic stretch injury to the innervation of the puborectalis and/or the external anal sphincter muscles. With the sophistication of electrophysiological techniques there has been accumulating evidence in favour of similar damage to the motor innervation of the striated urethral and peri-urethral muscles in stress urinary incontinence (Godec et al 1980; Snooks et al, 1985). These techniques are usually supplemented by urodynamic investigations. Recent studies have been able to demonstrate abnormalities of somatosensory reflex latencies in patients with other functional disorders of the lower urinary tract (Ertekin and Reel 1976; Rockswold and Bradley, 1977; Seth and Fam, 1978; Ertekin et al, 1979; Siroky et al, 1979; Krane and Siroky, 1980; Blaivas et al, 1981;

Haldeman et al, 1982; Vereecken et al, 1982; Bilkey et al, 1983; Galloway et al, 1984; Fidas et al, 1985; Galloway and Tainsh, 1985). Direct needle electromyography of the urethral sphincter muscles (Chantraine, 1973; Godec et al, 1980; Fowler et al, 1984; Anderson et al, 1984) or measurement of the conduction velocity of their innervation (Jelasic et al, 1975; Snooks and Swash, 1984) has also been of value in detecting neurogenic motor abnormalities. It is, however, conceivable that the physiological disturbance in such patients is further compromised by sensory deficits of the perineum. Indeed, such an abnormality has been demonstrable in some patients with idiopathic faecal incontinence (Roe et al, 1986). The precise understanding of such physiological abnormalities may have implications for the treatment of stress urinary incontinence. This study has addressed the precise nature of these abnormalities and attempted to relate them to the results of conservative treatment of this disorder.

The methods of measuring reflex response latencies used in this study test the integrity of the entire reflex pathway and therefore have obvious advantages over other methods that measure motor latencies only (Jelasic et al, 1975; Snooks et al, 1985) or the integrity of the sphincters by electromyography (Chantraine, 1973; Henry and Swash, 1985; Anderson et al, 1984; Fowler et al, 1984). These other methods when used in conjunction with 'cumulative' reflex latency measurements are of value in the differential analysis of neurogenic incontinence. The additional investigation of mucosal electrosensitivity helps to further elucidate the nature and extent of neurological deficit.

This study has been able to demonstrate sensory and motor perineal abnormalities in women with genuine stress urinary incontinence. It is not possible from the results of this study alone to incriminate 'central' neurogenic defects in Onuf's nucleus (Onuf, 1901) for at least some of these abnormalities. Other studies, however, suggest that this may sometimes be the case in fuctional bowel and bladder disturbances (Galloway and Tainsh, 1985; Bonnesen et al, 1981; Vereecken et al, 1982; Varma and Smith, 1984; Jakobsen et al, 1985; Yip et al, 1985; Kondo et al, 1986; Hellstrom et al, 1986). The motor abnormalities of the urethral sphincter musculature would in itself explain the inability to cope with stress situations and the resultant leakage of urine. Sensory deficits of the urethral mucosa as demonstrated in this study will further compromise continence by the inability of the urethra to detect involuntary leakage past the sphincters and therefore initiate their reflex and/or voluntary contraction to stop further escape of urine.

Isolated electromyographic abnormalities of the external anal and urethral sphincters and of their motor innervation have been previously described in urinary incontinence (Fowler et al, 1984; Anderson et al, 1984; Snooks et al, 1985). This comprehensive study has examined the perineum by a combination of electrophysiological methods to evaluate sensory impairment at two sites and reflex sphincter contraction by three different methods at both the anal and urethral sphincters. This was supplemented by direct needle EMG of the external anal sphincter and by manometric data. Reflex sphincter function is considered functionally more informative than the isolated electrophysiological abnormalities demonstrated by other methods

because it mimicks the 'physiological' stress response.

The external anal sphincter is undoubtedly a more accesssible site for direct needle EMG studies compared to the urethral sphincters and provides comparable information because of its similarity of innervation. In this study a manometric abnormality of the external anal sphincter was demonstrable in stress urinary incontinence, although these patients had no anorectal symptoms. This is not surprising because of the larger muscle bulk of the anal sphincter, its differential innervation, and the supplementation to the maintenance of faecal continence by the substantial puborectalis muscle with its different innervation directly from the pelvic nerves (Percy et al, 1981). Other studies have not found a reduction in anal sphincter pressures, although they certainly exist in double incontinence (Henry and Swash, 1985). These differences may simply represent the degree of neuropathy in the patient group studied. Nevertheless, it was thought justifiable to use anal canal pressures to monitor the response to pelvic floor exercises rather than repeat urodynamic studies (Godec and Cass, 1980; Bonnesen et al, 1986; Mouritsen and Toftdahl, 1984). In our study this therapy was not effective in improving objective pelvic floor function and this finding is substantiated by only 4 patients out of 11 achieving subjective short-term benefit. Different results have been reported using various conservative treatments, essentially reflecting the degree of pelvic floor neuropathy (Erikson and Mjolnerod, 1986; Klarsov et al, 1984; Castleden et al, 1984; Plevnik et al, 1985; Wilson et al, 1984).

The possible adverse effects of hystererectomy on vesico-urethral

dysfunction have been well-documented (Woodside and McGuire, 1982; Yalla and Andriole, 1984; Farghaly et al, 1986; Hamley, 1969; Smith et al, 1969; Godec et al, 1980) and were probably responsible for precipitating stress urinary incontinence in at least four patients. This study establishes a neurogenic basis for stress urinary female incontinence. The electrophysiological methods described and their results should be of value in the management of such patients.

SECTION 6

SUMMARY AND CONCLUSIONS

The following paragraphs summarise the principal findings and conclusions drawn from results of the studies described in the previous Sections.

1. The use of a microtransducer in anorectal manometry avoids many of the drawbacks of conventional fluid-filled systems. The data obtained is highly reproducible and probably more accurate.

2. The proctometrogram provides a reproducible and useful method of evaluating the pressure-volume distension characteristics of the rectum in health and disease. The expected correlation between compliance and volume is confirmed. There do not appear to be significant variations in rectal volume or compliance with age in healthy subjects.

3. The electrophysiological latency of the pudendo-anal reflex in health is 38.5±5.8 ms (Mean±SD, n=38). It is completely reproducible and does not appear to vary with age or sex.

4. In symptomatic chronic radiation anorectal injury:

4.1 The manometric function of the internal anal sphincter is compromised with diminution in sphincter length, basal pressure and abnormalities of the rectosphincteric reflex.

4.2 The external anal sphincter remains manometrically normal. Its mean motor unit potential duration is increased although the latency of the pudendo-anal reflex is unaffected. These findings suggest possible minor damage to its terminal innervation.

4.3 The volume and compliance of the rectum are severely diminished, there being a significant positive correlation between these parameters. The manometric changes correlate well with symptomatic and sigmoidoscopic findings.

5. Following colo-anal sleeve anastomosis for severe chronic radiation injury to the rectum the organic complications are resolved but some of the functional abnormalities persist. These are in part due to:

5.1 Persisting internal anal sphincter dysfunction.

5.2 External anal sphincter dysfunction on rectal distension and defaecation straining.

5.3 Persisting severe reduction in rectal volume and compliance.

5.4 Reduction in rectal sensory threshold volume, although rectal 'proprioception' remains intact.

6. Some of the sphincteric and rectal manometric and symptomatic disturbances in chronic radiation injury and those following colo-anal sleeve anastomosis may be secondary to damage to the myenteric plexus which is histologically demonstrable.

7. Following complete transection of the spinal cord above the sacral segments, severe constipation may result. The differential effects on colorectal and pelvic floor motility of sacral anterior root stimulators in five such patients may be summarised as follows:

7.1 There is an increasing influence on striated pelvic floor muscle activity from S2 to S4.

7.2 S2 stimulation results in occasional low pressure phasic colorectal contractions.

7.3 S3 stimulation results in high-pressure phasic colorectal contractions reminiscent of peristaltic activity. This response is frequency dependent.

7.4 S4 stimulation results in tonic pressure increases in the colon and rectum. These may simply be the cosequence of increase in intra-abdominal pressure due to pelvic floor contraction.

8. Two groups of elderly patients who suffer from chronic constipation are identifiable as defined by the proctometrogram. One group has a significantly increased rectal capacity and compliance - a 'megarectum' syndrome. The second group shows significant reduction in rectal volume and compliance demonstrating hypertonicity of the distal bowel. both groups have blunting of rectal sensation to distension. Increased gastrointestinal transit times seem mainly due to rectal stasis. Abnormalities of the pudendo-anal reflex suggest that neurogenic deficits of the sacral spinal cord may contribute to these disturbances of colorectal function.

9. Electrophysiological studies in young women with chronic idiopathic constipation suggest the possibility of a neurogenic deficit in the conus medullaris in the presence of normal sphincteric innervation.

10. In neurogenic faecal incontinence the latency of the pudendo-anal reflex is significantly prolonged and its amplitude diminished. It may be absent in some patients. A significant correlation exists between the latency of the reflex and the corresponding mean motor unit potential duration of the external anal sphincter. These findings confirm the its usefulness as an index of neuropathy in neurogenic faecal incontinence.

11. In genuine female stress urinary incontinence the latency of the pudendo-anal reflex is significantly prolonged, as are the latencies of two other polysynaptic sacral reflexes (dorsal nerve to urethral sphincter, urethral mucosa to external anal sphincter). The electrosensitivity of both the dorsal nerve and urethral mucasa is significantly blunted. These observations point to a strong neurogenic element in this disorder. The clinical and manometric response to pelvic floor physiotherapy is disappointing.

SECTION 7

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Varma JS, Smith AN. The sacral evoked response - a useful index of neuropathy in faecal incontinence. Gut 1984; 25: 1170.

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Varma JS, Smith AN. Anorectal function following colo-anal sleeve anastomosis for chronic radiation injury to the rectum. Br J Surg 1986; 73: 285-89.

Varma JS, Smith AN. Intractable constipation following hysterectomy is characterised by disordered colorectal motility. Association of Surgeons of Great Britain and Ireland Meeting, April 1986.

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SECTION 8

APPENDIX

8.1 PAPERS READ TO LEARNED SOCIETIES

The following presentations resulted from the work described in this thesis:

Anorectal manometry. University Department of Medicine Research Seminar Edinburgh, November 1983

The proctometrogram in rectal disorders. Caledonian Society of Gastroenterology, Glasgow, 2.3.84

The value of measuring rectal compliance in anorectal disorders. Edinburgh Surgical Meeting, 25.2.84

Making sense of anal incontinence. Surgical Seminar for General Practitioners, Edinburgh, 14.3.84

Anorectal function after pelvic irradiation. University Department of Surgery / Urology Meeting, Edinburgh, 21.3.84

Rectal distensibility in the irritable bowel syndrome. Scottish Society for Experimental Medicine, Aberdeen, 1.6.84

Rectal function after pelvic irradiation. British Society of Gastroenterology, Manchester, 27.4.84

Internal anal sphincter damage in radiation proctitis. British Society of Gastroenterology, Manchester, 27.4.84

Coloanal sleeve anastomosis - Five years on. Caledonian Society of Gastroenterology, Dundee, 1.6.84

The microtransducer in anorectal manometry. Surgical Research Society, Birmingham, 13.7.84

Abnormal sacral spinal cord function in chronic idiopathic constipation. British Society of Gastroenterology, Liverpool, 14.9.84

The sacral evoked response - a useful index of neuropathy in faecal incontinence. British Society of Gastroenterology, Liverpool, 14.9.84

Abnormalities of rectal distensibility in the irritable bowel syndrome. British Society of Gastroenterology, Liverpool, 14.9.84

The sacral evoked response - a new method of evaluating neuropathy in faecal incontinence. Meeting of the University Departments of Scotland and Newcastle, Dundee, 28.9.84

Anorectal function after coloanal sleeve anastomosis for radiation injury to the rectum. Tripartite meeting of the Surgical Research Society, Boston, Mass., U.S.A., 5.2.85

The latency of the pudendo-anal reflex in man. Proceedings of the Physiological Society, London, 10.11.84

The influence of the sacral spinal cord on colonic motility in conscious man. Caledonian Society of Gastroenterology, Edinburgh, 9.11.84

A text for the New Year from Samson Wright. Department of Medicine Clinical Staff Round, Western General Hospital, Edinburgh, 9.1.85

Colonic inertia and adult megacolon. Grand Rounds, Royal Infirmary, Edinburgh, 16.1.85

Technique, definition and clinical applications of latency measurement of the pudendoanal (sacral evoked) reflex in man. Scottish Society for Experimental Medicine, Edinburgh, 25.1.85

Sleeved coloanal anastomosis - longterm results. Edinburgh Surgical Meeting, 23.2.85

Motility disorders of the distal bowel in man. Gastrointestinal Unit Grand Rounds, Western General Hospital, Edinburgh, 27.2 85

Colorectal function in the elderly constipated. British Society of Gastroenterology, Brighton, 20.3.85

Abnormalities of colorectal function in intractable constipation following hysterectomy. British Society of Gastroenterology, Brighton, 20.3.85

Differential effects of sacral anterior root stimulation on colorectal and pelvic floor motility in man. Scottish Society for Experimental Medicine, Dundee, 11.5.85

Functional changes after mucosal proctectomy with colo-anal sleeve anastomosis for chronic radiation rectal injury. British Society of Gastroenterology, Newcastle, 20.9.85

Longterm results of colo-anal sleeve anastomosis for radiation rectal injury and 'stable' distal ulcerative colitis. Seminar to commemorate the retirement of Dr. W. Sircus and Mr. W.P. Small, Gastrointestinal Unit, Western General Hospital, Edinburgh, 24.9.85

Mechanisms of colorectal dysfunction in elderly patients. British Geriatric Society, Falkirk, Scotland, 11.10.85 (co-author)

Experience of a colorectal / pelvic floor physiology Unit over two years. Caledonian Society of Gastroenterology, Edinburgh, 8.11.85

Differential effects of sacral anterior root stimulation on colorectal motility in spinal man. Surgical Research Society, Manchester, 9.1.86

Faecal Incontinence. Symposium on Recent Advances in Proctology. Royal College of Surgeons of Edinburgh, 4.2.86

Colorectal dysfunction following hysterectomy. Edinburgh Surgical Meeting, 15.2.86

Colorectal function and constipation in the elderly. Joint meeting of the Belgian Society of Gerontology and Geriatrics and the Flemish Association of Gastroenterology, Ostend, 22.2.86

Radiation intestinal injury. Grand Rounds, Royal infirmary, Edinburgh, 26.2.86

Intractable constipation following hysterectomy is characterised by disordered colorectal motility. Association of Surgeons of Great Britain and Ireland, London, 4.4.86

Correlation of latency of the pudendo-anal reflex and mean motor unit potential duration of the external anal sphincter in neurogenic faecal incontinence. British Society of Gastroenterology, Lancaster, 11.4.86

Differential effects of sacral anterior root stimulation on colorectal motility in spinal man. Proceedings of the Physiological Society, Sheffield, 19.4.86

Electrophysiological assessment of neurogenic faecal incontinence by the pudendo-anal reflex. Third European Symposium on Gastrointestinal Motility, Bruges, Belgium, 19-21 June 1986

Abnormalities of colorectal motility in elderly patients with constipation. Third European Symposium on Gastrointestinal Motility, Bruges, Belgium, 19-21 June 1986

The effects of sacral anterior root stimulation on colonic and rectal motility following spinal cord injury. Third European Symposium on Gastrointestinal Motility, Bruges, Belgium, 19-21 June 1986

The Wilfrid Card Lecture 1986. Motility disorders of the human distal bowel : some new concepts. Edinburgh, 17.10.86

Does resection with colo-anal anastomosis have a place in the treatment of distal ulcerative proctocolitis ? Caledonian Society of Gastroenterology, Glasgow, 7.11.86

Neurophysiological abnormalities in female stress urinary incontinence. Surgical Research Society, Guildford, Surrey, 9.1.87

Neurophysiological evaluation in neurogenic faecal incontinence. Clinical and scientific meeting of the Royal College of Surgeons, Edinburgh, with the Association Francaise de Chirurgie and the Egyptian Surgical Society, Edinburgh, 27.5.87.

Clinical investigations in faecal incontinence. Symposium on understanding the incontinent bladder and bowel. Biological Engineering Society, Rehabilitation Engineering Group, Edinburgh, 10.7.87.

Radiation rectal injury. Scientific Programme Session, James IV Association of Surgeons Meeting, Edinburgh 4.9.87.

Rectal compliance. Tripartite SRS Colon Club Workshop on Anorectal Physiology. Bristol, U.K., 5-6th July 1988.

Anal reflexes. Tripartite SRS Colon Club Workshop on Anorectal Physiology. Bristol, U.K., 5-6th July 1988.

Neurophysiological dysfunction in young women with intractable constipation. XIIth Biennial Congress of the International Society of University Colon and Rectal Surgeons, Glasgow, U.K., 10-14 July 1988.

8.2 PUBLICATIONS

The following publications resulted from the work described in this thesis.

Varma J.S., Smith A.N. Rectal function after pelvic irradiation. Gut 1984; 25: 554

Varma J.S., Smith A.N. Internal anal sphincter damage in radiation proctitis. Gut 1984; 25: 564

Varma J.S., Smith A.N. Anorectal profilometry with the microtransducer. Br J Surg 1984; 71: 867-869

Varma J.S., Smith A.N. Rectal distensibility in the irritable bowel syndrome. Scott Med J 1984; 29: 201

Varma J.S., Smith A.N. Abnormalities of rectal distensibility in the irritable bowel syndrome. Gut 1984; 25: 1169

Varma J.S.,Smith A.N. Abnormal sacral spinal cord function in chronic idiopathic constipation. Gut 1984; 25: 1149

Varma J.S., Smith A.N. The sacral evoked response - a useful index of neuropathy in faecal incontinence. Gut 1984; 25: 1170

Smith A.N., Varma J.S. The latency of the pudendo-anal reflex in man. J Physiol 1985; 360: 48P

Varma J.S., Smith A.N. Technique and clinical applications of latency measurement of the pudendo-anal (sacral evoked) reflex in man. Scott Med J 1985; 30: 190-91

Varma J.S., Smith A.N., Smith R.G., Bradnock J. Colorectal function in the elderly constipated. Gut 1985; 26: 573

Varma J.S., Smith A.N. Abnormalities of colorectal function in intractable constipation following hysterectomy. Gut 1985; 26: 581-82

Varma J.S., Smith A.N., Busuttil A. Correlation of clinical and manometric abnormalities of rectal function following chronic radiation injury. Br J Surg 1985; 72: 875-78, and Br J Surg 1986; 73: 85 (Erratum)

Varma J.S., Smith A.N., Creasey G.H., Edmond P. Differential effects of sacral anterior root stimulation on colorectal and pelvic floor motility in man. Scott Med J 1985; 30: 193

Varma J.S., Smith A.N. Reproducibility of the proctometrogram. Gut 1986; 27: 288-92

Varma J.S., Smith A.N., Busuttil A. Function of the anal sphincters after chronic radiation injury. Gut 1986; 27: 528-33

Varma J.S., Smith A.N., Busuttil A. Functional changes after mucosal proctectomy with colo-anal anastomosis for chronic radiation rectal injury. Gut 1985; 26: 1155

Varma J.S., Smith A.N. Anorectal function following colo-anal sleeve anastomosis for chronic radiation injury to the rectum. Br J Surg 1986; 73: 285-89

Smith A.N., Varma J.S. A unit for the physiological assessment of colonic and anorectal disorders - its activities over a two-year period. Scottish Health Bulletin, March 1986; 44/2: 85-90

Varma J.S., Binnie N., Smith A.N., Creasey G.H., Edmond P. Differential effects of sacral anterior root stimulation on anal sphincter and colorectal motility in spinally injured man. Br J Surg 1986; 73: 478-82

Varma J.S., Smith A.N., McInnes A. Electrophysiological observations on the human pudendo-anal reflex. J Neurol Neurosurg Psych 1986; 49: 1411-16

Varma J.S., Smith A.N. Correlation of latency of the pudendo-anal reflex and mean motor unit potential duration of the external anal sphincter in neurogenic faecal incontinence. Gut 1986; 27: 625

Binnie N., Creasey G.H., Edmond P., Smith A.N., Varma J.S. Differential effects of sacral anterior root stimulation on colorectal motility in spinal man. J Physiol 1986; 378: 38P

Varma J.S. Some new concepts in motility disorders of the human distal bowel (The Wilfrid Card Lecture, 1986). Edinburgh Medicine, 1986; 41: 13-16

Browning G.G.P., Varma J.S., Smith A.N., Small W.P., Duncan W. Late results of mucosal proctectomy and colo-anal sleeve anastomosis for chronic radiation rectal injury. Br J Surg 1987; 74: 31-34

Varma J.S., Browning G.G.P., Smith A.N., Small W.P., Sircus W. Mucosal proctectomy and colo-anal anastomosis for distal ulcerative proctocolitis. Br J Surg 1987; 74: 31-34

Fidas A., Galloway N.T.M., Varma J.S., McInnes A., Chisholm G.D. Sacral reflex latency in acute retention in female patients. Br J Urol 1987; 59: 311-313

Varma J.S., Fidas A., Longmore J., McInnes A., Smith A.N., Chisholm G.D. Neurophysiological observations in genuine female stress urinary incontinence. Br J Surg 1987; 74: 541.

Varma J.S., Smith A.N., Neurophysiological dysfunction in young women with intractable constipation. Gut 1988; In Press.

Varma J.S., Bradnock J., Smith R.G., Smith A.N., Constipation in the elderly - a physiological study Dis Colon Rectum 1988; In Press.

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Varma J.S., Smith A.N., Clinical anatomy and pathophysiology of the anorectum and pelvic floor. In Surgical Science for Physicians. Proc Roy Coll Phys Edin 1988; In Press.

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