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**EFFECTS OF MAJOR RESECTION OF THE SACRUM  
Clinical studies on urogenital and anorectal function  
and a biomechanical study on pelvic strength**

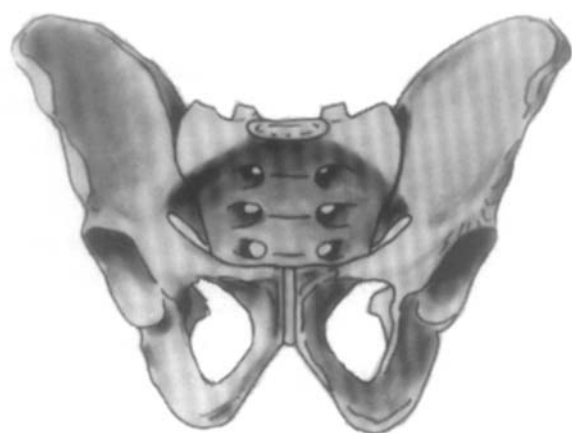
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## INTRODUCTION

The main indication for a major resection of the sacrum is a life-threatening tumour. The symptoms of tumours in this region are often vague such as low-grade, sometimes periodic, pain in the sacral region and only in advanced cases may there be more obvious disturbances like pressure on the rectum or impairment of lumbosacral nerve function, not seldom interpreted as being caused by disc protrusion. Thus, tumours in this area are often detected only when they have reached a considerable size, causing hesitation and irresolution when surgical treatment is considered.

The reasons for this are threefold: (1) expected technical difficulties during the operation, (2) doubts as to the postoperative function of the bladder, genitalia and ano-rectum, and (3) uncertainty concerning the strength of the remaining sacroiliac regions.

Surgical procedures and factors limiting surgery in cases of tumours of the retrorectal or sacral regions are not well established. Not even in a modern handbook of surgery of the spine is sacral resection mentioned although both lumbar and coccygeal surgery are described (Rathke and Schlegel 1974). An abdominosacral approach is proposed by Freier et al. (1971) in the management of most retrorectal lesions greater than 5 cm in size, regardless of histological type. Steckler and Martin (1974) point out that the second sacral segment is the factor limiting the extent of resection since removal of this segment would lead to permanent and severe neurological damage. Resections more extensive than the three lower sacral segments are said to result in instability and collapse of the pelvis and descent of the lumbar spine (Pearlman and Friedman 1970). Nevertheless, Bowers (1948), MacCarty et al. (1952), Hays (1953), and Localio et al. (1967) have demonstrated the possibility of removal of the lower four segments of the sacrum and, in the case of Hays, even half the first sacral vertebra, without serious disabling consequences to pelvic stability. However, dislocation of the pubic symphysis was found in one of the cases reported by MacCarty et al., but this patient had a recurrence of fibrosarcoma only 2 months after discharge from hospital which might have influenced pelvic stability. Wilson (1972) has described a unilateral resection of the upper part of the sacrum, including the articular surfaces of the sacroiliac joint, with bridging of the gap with a bone graft consisting of the posterior third of the ipsilateral ilium. No insufficiency of the supporting function of the graft developed in this young patient.

In the case described by Bowers, as well as that reported by Hays and in four cases presented by Localio et al., all sacral nerves except for the first were sacrificed bilaterally. In the two cases reported by MacCarty et al., in which the resection comprised the lower four sacral segments, curiously enough, only »the lower two or three sacral nerves» were sacrificed bilaterally in one case and only the lower two sacral nerves in the other.

The patients with bilateral loss of all sacral nerves except for the first had in the cases reported by Bowers and Hays definite urinary incontinence requiring a penile clamp or an incontinence bag, while in the cases described by Localio et al. urinary function was described as »satisfactory» except in one patient who had stress incontinence and emptied the bladder with the help of abdominal wall contraction. The patient presented by MacCarty et al., who possibly lacked the third in addition to the fourth and fifth sacral nerves bilaterally, had »satisfactory» urinary control but could not feel the urine being voided. The other patient, who lacked the lower two sacral nerves bilaterally, was »voiding normally» after a transurethral resection. Cystometry was performed in two of the cases reported by Localio et al., revealing »good emptying» and »hypotonicity», respectively.

The anorectal function in these eight patients described in the literature was evaluated only by history and described as adequate or satisfactory in four cases. Bowers' patient who had paralysis of the »rectal» sphincter managed his anorectal problem with a constipating diet. One of the patients of MacCarty et al. had poor rectal control. Two patients had colostomy.

The sexual function was not mentioned by any of the authors.

During recent years a number of patients have been operated upon for tumour by Professor Bertil Stener, Head of the Department of Orthopædic Surgery II, the Sahlgren Hospital, Göteborg, with major amputation or unilateral resection of the sacrum, in several cases including substantial parts of adjacent iliac bone. Radical tumour excision was always attempted which meant that the incision was carried through healthy tissues surrounding the tumour all the way. Extreme care was taken not to sever the sacral nerves unnecessarily and thus the inevitable sacrifice of nerves was ascertained and recorded. These cases led to the idea of investigating the consequences of the well-defined sacral nerve losses with reference to urinary, sexual and anorectal function. The neurophysiology of the bladder, genitalia, and anorectum has been thoroughly studied by numerous authors. Present knowledge is, however, partly based on animal experimentation, and it was thought that an investigation of these patients might contribute to a better understanding of the role of the sacral nerves as well as to confirmation of prevailing conceptions.

Further, the question rose of to what degree the pelvic ring is weakened by a major amputation of the sacrum and what residual strength is retained in the posterior arch of the pelvis. Is there any risk of pelvic failure upon full weight-bearing at an early stage postoperatively? A biomechanical study was therefore undertaken concerning pelvic strength after major sacral amputation.

The motor function of the lower extremities in our patients will not be presented in detail in this work. After sacral amputation no patient had any obvious impairment of the muscular function in the lower extremities referable to the operative sacrifice of sacral nerves. The leg function was impaired in three patients in whom a unilateral resection of the sacrum had been carried out. In one of these patients the sciatic nerve has been extirpated, in another the bone graft which is bridging the gap after an extensive sacroiliac resection does not yet permit full weight-bearing, and in the third hemipelvectomy has been done along with the sacral resection.

In cases of tumours necessitating sacral resection to varying extent it is as a rule possible, by preoperative examinations of various kinds, and careful planning, to calculate the necessary sacrifice of nerves and skeletal parts. Therefore, through our studies, we hoped to be able to collect data permitting, for example, prediction of the degree of urogenital and anorectal disability and the risks of standing and walking with full weight-bearing that these patients would encounter postoperatively.

## CLINICAL STUDIES ON UROGENITAL AND ANORECTAL FUNCTION

### Brief reviews of relevant present concepts on urogenital and anorectal function with special reference to segmental innervation

Several textbooks and reviews on these concepts have been published and the reader is referred to these for further details (e.g. Bors and Comarr 1960, Schuster 1968, Kerremans 1969, Hotchkiss 1970, Bors and Comarr 1971, Duthie 1971, Carlsson and Sundin 1974).

#### Urinary continence and voiding

The anatomical arrangement of the structures round the bladder neck provides a »passive» continence mechanism. The striated pelvic floor muscles, including the external urethral sphincter, innervated by the pudendal nerves (S 2 - S 4), are necessary for this continence only during brisk increases of the intraabdominal pressure, as for instance during coughing. »Active» continence, which means voluntary inhibition of micturition, is achieved by contraction of the external urethral sphincter. The mechanism of adaptation of the bladder wall during bladder filling, i.e. how an increase in the bladder pressure is counteracted, has not been fully explored. At moderate and large bladder volumes adaptation is thought to be achieved via afferent impulses in the pelvic nerves and efferent inhibitory impulses in the sympathetic hypogastric nerves (T 11 - L 2), bringing about a bladder relaxation. During filling of the bladder a first sensation of fullness is experienced at about half the bladder capacity and a desire to void when the bladder is nearly full. These sensory impulses are mediated via the pelvic nerves. Micturition may be voluntarily suppressed or facilitated. In the latter case a co-ordinated reflex activity is elicited so that the distension of the detrusor, which initiates its contraction (the micturition reflex), is accompanied by relaxation of the striated muscles of the urethra. The micturition reflex has its afferent and efferent pathways in the pelvic nerves (S 2 - S 4) while the relaxation of the urethral striated muscles is brought about through pelvic afferents and pudendal efferents. The co-ordination of afferent and efferent impulses of both autonomic and somatic systems at conscious and sub-conscious levels is responsible for the ability of the adult human to inhibit and initiate voiding irrespective of the degree of bladder filling. Receptors in the bladder mucosa are able to recognize painful but not tactile stimulation. The afferent pathways mediating pain impulses from the bladder have not been established with certainty. The de-

trusor part of the bladder mucosa is said to be supplied mainly by thoracolumbar and the trigone predominantly by sacral afferents. The existence of thermæsthesia of the bladder mucosa is the subject of controversy.

### **The sex act**

The events of the sex act are comparable in both sexes if the embryological development of the respective structures is taken into account. *Erection* of the penis in the male, analogous to the tumescence of the clitoris and labiæ minora in the female, is brought about by psychogenic and/or reflexogenic stimuli which accomplish arterial dilatation in the corpora. The impulses are mediated by the parasympathetic pelvic nerves (S 2 - S 4). In addition, sympathetic impulses from thoracolumbar segments may be responsible as has been shown in animals and confirmed by clinical findings. *Emission* of semen in the male by contraction of the vasa and seminal vesicles corresponds in the female to the contraction of the smooth musculature of the tubes and uterus and the expulsion of the contents of the glands of Skene. It is dependent on impulses travelling in the fibres of the sympathetic thoracolumbar outflow. *Ejaculation* in the male corresponds in the female to rhythmic contractions of the musculus sphincter cunni (the equivalent of the ischiocavernosus and bulbocavernosus muscles in the male). Emission triggers off afferent impulses from the prostatic and membranous urethra travelling in the pudendal and possibly pelvic nerves to the sacral cord (S 2 - S 4) where they elicit efferent impulses mediated by the pudendal nerves, which effect clonic contractions of the pelvic floor muscles. The smooth muscles of the vesical neck contract in response to efferent impulses from thoracolumbar segments to prevent regurgitation of the ejaculate into the bladder. *Detumescence* of the corpora in the male and the clitoris and labiæ in the female is accomplished by sympathetic impulses causing vasoconstriction. *Orgasm* precedes and accompanies emission and ejaculation. It may be retained in one form or another as long as either the autonomic innervation of the adnexa or the somatic innervation of the pelvic floor musculature remains intact.

### **Fæcal continence and defæcation**

Continence depends partly on the configuration of the anorectal region and partly on the action of muscles. The main factors are the angulation between the rectum and the anal canal, maintained by the pull of the puborectalis muscle (innervated by the pudendal nerves, S 2 - S 4), the anteroposterior slit of the anal canal which accounts for a »flutter valve» mechanism, and the tonic activity of the internal anal sphincter (excitatory impulses via the hypogastric nerves and inhibitory impulses through the parasympathetic pelvic nerves). Additional support is provided by the external anal sphincter (innervated by the pudendal nerves) whose main function is to give emergency protection voluntarily for up to one minute. The entry of fæces from the sigmoid colon

into the rectum causes sensory stimulation in the rectum and upper part of the anal canal (afferent fibres in the pelvic and pudendal nerves, S 2 - S 4). In response to the rectal distension the internal anal sphincter relaxes reflexively (pathways most probably intramural), and a reflex contraction of the external anal sphincter is elicited (afferent pathways in the pelvic nerves and efferent in the pudendal nerves). If the faeces entering the rectum are small the basal activity of the sphincters is restored and the individual is no longer conscious of the contents in the ampulla. Further filling of the rectum evokes stronger sensory stimulation experienced as a need to defaecate. Eventually the internal sphincter becomes constantly relaxed and the basal activity of the external sphincter is depressed leaving voluntarily induced contraction responsible for the closure of the anal canal. The closure of the anal canal permits build-up pressures within the rectum so that subsequent sphincteric inhibition results in expulsion of stools, facilitated by rectal contraction (efferent fibres in the pelvic nerves). When emptying is complete a rebound contraction of the anal sphincters occurs.

## **MATERIAL**

Altogether ten patients were studied, six with bilateral and four with unilateral sacrifice of sacral nerves (Table I). The nerves were identified and cut during operations for radical extirpation of tumours in the sacrum or its vicinity. In no patient has any sign of local tumour recurrence been observed.

Studies of urinary and sexual function were carried out in nine patients and studies of anorectal function in seven. Details of diagnosis, sex, age, investigations performed, and postoperative time in years are given in Table I.

## **METHODS**

### **Urinary function (I)**

After taking the patient's history the following studies were carried out: clinical examination, cystometry, cystoscopy including testing of the sensibility of the bladder and urethra, intravenous pyelography and urinary culture.

For cystometry two plastic catheters (sonde a nutrition K-32, no. 5 Fr., Pharmaseal) were introduced into the bladder through the urethra. Isotonic saline at room temperature was infused at a rate of about 50 ml per min through one of the catheters. The other catheter was connected, via a pressure receptor and an amplifier, to a kymograph (Mingograf, Elema-Schönander), providing a continuous recording of the intravesical pressure. The pressure receptor was placed at a level of 5 cm below the pubic symphysis to avoid negative pressure recordings. The intrarectal pressure was recorded

**Table I. Patients subjected to Clinical Studies of Urogenital and Anorectal Function.**

The investigations performed in each patient are indicated.

Ur = urological study, Sex = study of sexual function, An = anorectal study, Investigation performed: + , not performed: -.

Patient no.	Sacral nerves divided		Diagnosis	Age at op.	Sex	Ur	INVESTIGATIONS				
	R	L					Postop. time	Sex	Postop. time	An	Postop. time
1	4,5	4,5	Chordoma	61	F	+	5 3/12	+	5 9/12	-	
2	3,4,5	3,4,5	Ganglioneuroma	20	F	+	5 6/12	+	6 7/12	-	
3	3,4,5	3,4,5	Chordoma	68	F	+	1 6/12	+	2 2/12	+	2 2/12
4	3,4,5	2,3,4,5	Chordoma	57	M	+	1 8/12	+	2 9/12	+	2 8/12
5	2,3,4,5	2,3,4,5	Chordoma	57	M	+	1 2/12	+	3 5/12	-	
6	2,3,4,5	2,3,4,5	Chordoma	64	F	-		-		+	6/12
7		2,3,4,5	Chondromyxoid fibroma	21	M	+	4/12	+	11/12	+	11/12
8	1,2,3,4,5		Malignant Schwannoma	28	M	+	5/12	+	2 2/12	+	1 2/12
9		1,2,3,4,5	Giant-cell tumor	34	F	+	1 10/12	+	2 6/12	+	2 6/12
10		1,2,3,4,5	Fibrosarcoma	42	M	+	3 6/12	+	4 7/12	+	4 7/12

continuously via a balloon catheter. This pressure was electronically subtracted from the intravesical pressure. The pressure increase caused by an intra-abdominal pressure increase was thereby eliminated, and in the subtraction curve the «true» intravesical pressure was recorded. Early during bladder filling the calibration of the rectal pressure was changed so as to give an exact elimination in the subtraction curve of a pressure increase caused by straining. Thus, the numerical value of the rectal pressure cannot be considered as correct.

The sensibility of the bladder mucosa was tested only by electrocoagulation in the patients with bilateral loss of sacral nerves. In the patients with unilateral loss of sacral nerves a more elaborate investigation of the sensibility of the bladder mucosa was performed. Thus, the sensibility of the mucosa was tested by electrocoagulation, light touch with a ureteral catheter and by forcing the catheter more vigorously against the bladder wall. When thermæsthesia was tested the bladder was filled with 200 - 300 ml of physiological saline at room temperature. Then 10 - 15 ml saline at 0°C or +60°C, was injected as a jet against the bladder wall through a ureteral catheter with an end-hole, introduced into the bladder through a cystoscope. In all patients the sensibility of the urethra was tested only by pin-pricking.

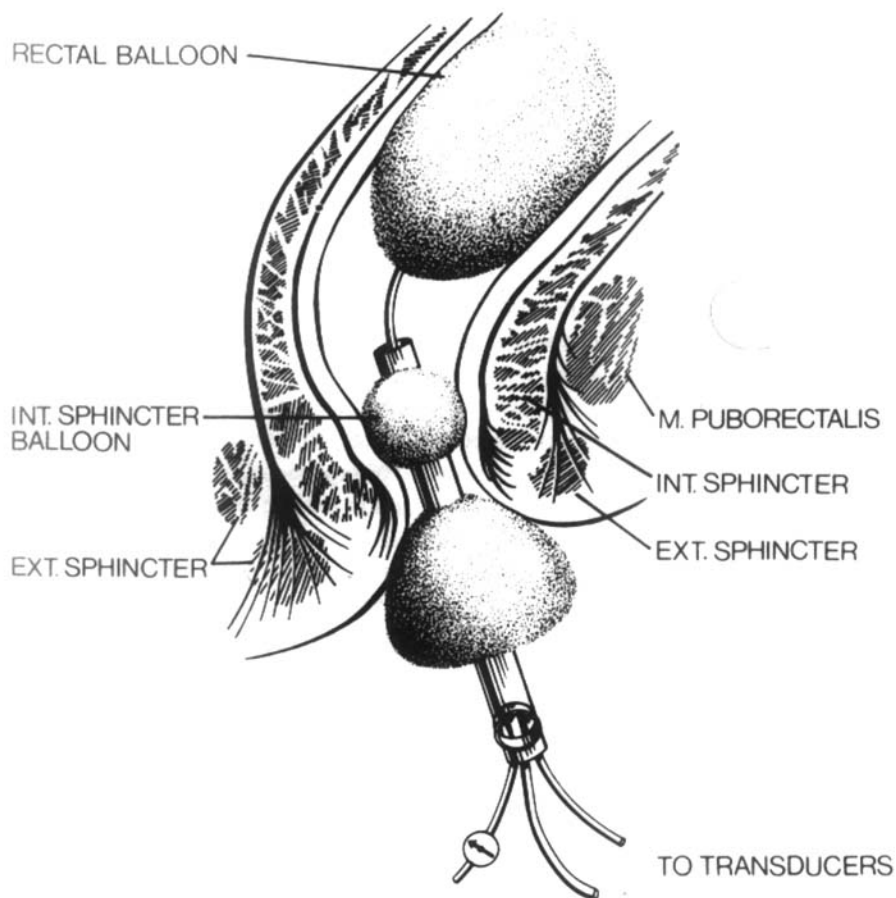
### **Sexual function (II)**

The history was taken by personal interview and a questionnaire. Skin sensibility and the sensibility of the glans penis were tested by touching with cotton-wool and pin-pricking. The male patients, except for one who refused, were also submitted to an electromyographic investigation in attempt to record myoelectric signals from the external urethral and anal sphincters during ejaculation.

For the electromyographic study the patient was placed in a modified lithotomy position after having emptied his bladder. Co-axial needle electrodes of 0.5 mm external diameter were inserted percutaneously into the striated urethral and anal sphincters according to a technique described previously (Petersén and Stener 1970). The positioning of the needles was monitored by an oscilloscope and a loud speaker connected to the electromyograph. A three-channel type Disa electromyograph was used for the registration. When the electrodes were in place the subject was left in solitude to bring about ejaculation by masturbation. Of the four patients investigated only one could bring about ejaculation (no. 8). The electromyographic investigation was not repeated in the failure cases.

### **Anorectal function (III)**

The history was taken. The sphincter tone was estimated by palpation. The anal reflex (contraction of the anal sphincter on drawing a needle across the perianal skin) was



**Fig. 1.** Schematic drawing of the pressure-sensing device in the rectum and the anal canal. Distension of the rectal balloon provides the stimulus for reflex responses from the internal and external sphincters. Separate pressures are obtained from the rectal balloon and the internal sphincter balloon. The external balloon was used as an aid to keep the device in place.

tested bilaterally by observation. The sensibility of the anal canal, below the dentate line, and perianal skin was tested by tactile, painful and thermal stimuli. The rectum and internal anal sphincter were investigated with a pressure recording device (Fig. 1) suggested by Schuster et al. (1965). Electromyography of the external anal sphincter was made on both the left and the right side simultaneously with the pressure recordings. Thus, the relationships between rectal volumes and pressures, pressure changes in the internal sphincter region and the myoelectric activity in the external sphincter were established.

The pressure recording device consisted of a hollow metal cylinder (external diameter 7 mm) with two surrounding balloons, approximately 1 cm apart. The inner, somewhat smaller, balloon was connected via polyethylene tubing to a pressure recording unit (Grass Model 7 B Polygraph, paper speed used 50 mm per min) while the outer balloon was used to keep the device in place. A third balloon of thin latex (5 cm long, 2 cm wide when inflated with 10 ml of water) was inserted through the hollow core of the recording device and was also connected via polyethylene tubing to the pressure recording unit. The pressure receptor was placed at the level of the anal orifice. The myoelectric activity of the external anal sphincter was picked up by concentric needle electrodes (Disa) of 0.65 mm diameter. The signals were amplified on a Disa electromyograph and recorded on tape using an FM tape-recorder (Philips Ana-log 7). Graphic recordings were obtained by means of an ink-jet recorder (Mingograf, Siemens-Elementa) at a reduced tape speed playback. The quantitative signal analysis was performed on an analyzer (Örtengren 1975) entailing continuous recordings of the fullwave rectified and smoothed, »integrated», total signal. The output from the detector was presented on a logarithmic, decibel scale with arbitrary reference.

### *Procedure*

The needle electrodes were placed bilaterally in the external anal sphincter with the patients in the lithotomy position. Recordings were made of the spontaneous myoelectric activity, during voluntary contraction of the sphincter, and during coughing. The thin latex balloon was then placed in the ampulla recti and the hollow metal cylinder with its two surrounding balloons was inserted into the anal canal so that the internal balloon when inflated with 4 ml of water (+37°C) was surrounded by the internal anal sphincter. The external balloon, used for keeping the device in place, was inflated with 15 ml of air. The rectal balloon was straightened out by filling it with a small volume of water which was then removed. The registrations then started and the rectal balloon was filled with 20 ml of water (+37°C) followed by a further 30 ml after approximately 30 seconds. The rectal balloon was then intermittently filled with 50 ml of water every 30 - 60 seconds until the patient reported an almost intolerable sensation, i.e. the maximum tolerable volume was reached. In cases in which such a

sensation could not be obtained the balloon was filled with a maximum of 500 ml. The rectal balloon was then emptied in the same stepwise manner. During the whole procedure pressure recordings from the rectal balloon and the balloon placed in the anal canal were made as well as electromyograms from the external anal sphincter. Pressure/volume curves (rectometrograms) were constructed for each patient. This was done by subtracting the pressures of the rectal balloon obtained at various volumes in free air from the pressures obtained at the same volumes with the balloon in the ampulla recti as described by Ihre (1974).

## RESULTS

### Bilateral loss of sacral nerves (I, II, III)

#### *S 4, S 5*

This patient (no. 1) had slight urinary stress incontinence and used a diaper. Cystometry revealed detrusor activity. She had no residual urine. Cystoscopic findings were normal as also were sensibility tests of the bladder and urethra. The pyelogram was without pathological changes. Urinary culture was positive (>100 000 bacteria/ml).

The patient considered her sexual function to be normal and enjoyed sexual intercourse regularly. She had not experienced any postoperative change of sexual perception or orgasm. The sensibility of the labiæ was normal.

In this patient the rectum had been extirpated.

#### *S 3, S 4, S 5*

Of these two women one had an indwelling catheter (Patient no. 3). The other had to strain to empty her bladder. No micturition contraction was recorded in the cystometrograms. The residual urine volume was 90 ml in the patient without a catheter. Cystoscopy revealed slight trabeculation. Painful stimuli to the mucosa of the bladder and urethra were not perceived. The pyelograms were normal. One of these patients had a urinary tract infection (no. 3).

The younger of these two patients (no. 2) reported no change of sexual behaviour or perception postoperatively and considered her sexual function to be normal. The older patient had all her life experienced minimal perception upon sexual stimulation but still had intercourse, although unfrequently. She did not recognize any alteration postoperatively. The sensibility of the labiæ was normal in these two patients.

Anorectal function was studied in the older patient (no. 3). She had no sense of defæcatory need. Soiling occurred. The patient used laxatives and visited the toilet every

day at the same time to evacuate her rectum. She needed a diaper. Sphincter tone judged by palpation was decreased. The anal reflex was absent. The sensibility of the anal region was decreased with respect to tactile and painful stimulation, and lacking as regards thermal stimulation. The patient became continuously conscious of rectal distension at a volume of 350 ml (87 mm Hg). The rectum had a maximum tolerable volume of at least 500 ml (>105 mm Hg). She felt a dull, uncomfortable sensation in the lower abdomen at these substantial rectal volumes. The internal anal sphincter reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at a volume of 200 ml (46 mm Hg). EMG revealed weak spontaneous activity in the external anal sphincter. Attempts to contract the sphincter voluntarily resulted in a small increase of the myoelectric activity. Denervation potentials were recorded in the electromyogram. The external anal inflation reflex (transient contraction of the external anal sphincter at rectal distension) was not observed. The weak spontaneous myoelectric discharge disappeared at a rectal volume of 400 ml (105 mm Hg).

*Right side: S 3, S 4, S 5. Left side: S 2, S 3, S 4, S 5*

This patient (no. 4) had urinary stress incontinence. He wore a diaper and had to strain when he wished to empty his bladder. No micturition contraction was observed in his cystometrogram. The residual urine volume was 15 ml. Cystoscopy revealed trabeculation of the bladder wall. Bladder wall sensibility was absent. Pyelography was normal. Urinary culture was negative.

Sexual function was altered postoperatively. Libido was preserved but erection weakened and insufficient for intercourse. Ejaculation occurred nightly with an orgasm-like sensation. The sensibility of the left side of the penis and glans was heavily diminished.

There was faecal incontinence if rectal contents were not solid. Defaecatory need was never experienced as it had been preoperatively. The patient was unable to discriminate between different qualities of rectal contents at defaecation, which was brought about by straining or by pressure on the rectum from behind. Sphincter tone judged by palpation was decreased. The anal reflex was absent. The sensibility of the anal region was abolished concerning all modalities on the left side and the posterior quadrant of the right side; it was weak on the anterior quadrant of the right side. The patient became continuously conscious of rectal distension at a volume of 300 ml (32 mm Hg) and had a maximum tolerable volume of at least 500 ml (60 mm Hg). The internal anal sphincter reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at a volume of 300 ml (32 mm Hg). The external sphincter displayed weak spontaneous myoelectric activity bilaterally and presence of denervation potentials. A small increase of the myoelectric activity was recorded on voluntary contraction bilaterally. The external anal inflation reflex was absent. The weak spontaneous discharge decreased but did not disappear as the rectum was progressively distended.

*S 2, S 3, S 4, S 5*

Urinary function was studied in the male patient (no. 5). He had undergone a trans-urethral bladder neck resection postoperatively. He was incontinent and wore an incontinence bag and had to strain when he wished to empty his bladder. No micturition contraction was observed in his cystometrogram. Residual urine was 50 ml. Cystoscopy revealed trabeculation. There was loss of bladder and urethral sensibility. Pyelography was normal. Urinary culture was positive.

Sexual function in this man was impaired. He had weakened libido but enjoyed sexual intercourse a few times a month. Erection occurred exclusively upon psychical stimulation and was somewhat weaker than preoperatively but sufficient to permit intercourse. »Ejaculation» was of a dripping nature. The sensation of orgasm was altered and not referred to the penis and perineum as it had been before the onset of the tumour disease. The penis and glans were anaesthetic.

Anorectal function was studied in the female patient (no. 6). She was incontinent and constipation was her only safeguard against soiling. Defaecatory need was not experienced normally and she was unable to recognize faecal quality in the anal canal. Sphincter tone was lacking on palpation. The anal reflex was not observed. The anal region was anaesthetic. The patient became aware of rectal distension at volumes of 300 ml (71 mm Hg) and when the rectal balloon had been filled to 400 ml or more it tended to protrude outside the anus without the patient being conscious of this. The internal anal sphincter reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at a volume of 250 ml (50 mm Hg). Electromyograms from the external anal sphincter displayed denervation potentials only. No external anal inflation reflex could be observed, nor was there any voluntarily induced myoelectric activity.

**Unilateral loss of sacral nerves (I, II, III)***S 2, S 3, S 4, S 5 and S 1, S 2, S 3, S 4, S 5*

Essentially the same findings were recorded in these four patients. Their urinary function was subjectively unimpaired. Micturition contractions were registered in the cystometrograms although the patients had to strain at the end of micturition. The residual volumes were 10-15 ml. The cystoscopy findings were essentially normal. Bladder wall sensibility tests revealed that light touch with a ureteral catheter could not be felt on either side. When the catheter was forced more vigorously against the bladder wall this caused pain on the intact side and diffuse discomfort on the other side, in the latter case with poor ability of lateralization. When testing the thermæsthesia, the jets of cold or hot saline were correctly recognized on the intact side but could not be felt on the denervated side. Coagulation of the mucosa of the bladder and trigone was felt as

pain on the intact side. On the denervated side such stimuli were not felt in the bladder, nor was pin-pricking felt in the urethra. Pyelography was normal except in Patient no. 8, who had right-sided hydronephrosis and hydroureter owing to postoperative fibrosis. This patient was later operated upon with reimplantation of the right ureter into the bladder. Urinary culture was positive in Patient no. 9.

The sexual function of these patients was subjectively unimpaired. The quality and degree of the reactions of the external genitalia was unchanged as also was the degree of sexual satisfaction. There was loss of sensibility on the denervated side of the penis and labiæ. EMG was recorded from the external urethral and anal sphincters in one of the male patients (no. 8) during ejaculation. Clonic contractions of both sphincters occurred alternately.

The anorectal function was also subjectively unimpaired and ability to recognize different qualities of rectal contents in the anal canal was present. Sphincter tone, judged by palpation, was normal. The anal reflex could be elicited on the intact side but not on the denervated side. The sensibility of the anal region was unimpaired on the intact side, but there was anæsthesia concerning tactile and thermal stimuli on the denervated side. Painful stimuli on this side were recognized as a weak, unpleasant sensation localized to the midline or intact side. The patients became continuously conscious of rectal distension at volumes of 150 - 200 ml (18 - 34 mm Hg) and had maximum tolerable volumes of 200 - 350 ml (36 - 52 mm Hg). The internal sphincters reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at rectal volumes of 100 - 200 ml (18 - 43 mm Hg). The external anal sphincter displayed spontaneous myoelectric activity bilaterally and there was strong increase of this activity bilaterally on voluntary contraction. During prolonged contraction (about 30 seconds) the strongly increased activity was maintained bilaterally. The external anal inflation reflex was observed bilaterally in three of these patients; in one (no. 10) the presence of the reflex was doubtful. Reflex decrease or inhibition of external sphincter activity was recorded at maximum tolerable volumes.

## **DISCUSSION**

### **Bladder and urethra**

The micturition reflex in the cystometrogram was not abolished by sacrifice of the fourth and fifth sacral nerves bilaterally, but it was abolished if the third sacral nerves were sacrificed as well. This indicates that the second sacral segment alone cannot subservise the micturition reflex and is in accordance with the observations of Markland et al. (1972) that the main motor axons of the pelvic parasympathetic nerves arise in the third and fourth sacral segments. The cystometrograms of the patients with unilateral

sacral denervation revealed detrusor activity, although these patients had to strain toward the end of micturition in order to empty their bladders. This is in agreement with the findings of several authors who in patients with lumbosacral dysraphic states with unilateral neurological impairment found normal bladder function (e.g. Ericsson et al. 1970).

The unilaterally denervated patients offered a unique possibility to investigate unsettled questions concerning bladder sensibility. Thus, detrusor mucosal pain is said to be mediated by spinal segments as high up as the L 1 to T 12 levels (Bors and Comarr 1971). Our patients with unilateral sacral denervation were unable to feel pain on the denervated side when the bladder mucosa was electrocoagulated. They could, however, feel stretching of the bladder wall on the denervated side, which is in agreement with the findings of Talaat (1937) who recorded afferent impulses from the hypogastric nerves upon distension of the bladder in dogs. Several authors (Senger and Rothfeld 1947, Nathan 1952, Bors et al. 1956) have found no thermæsthesia of the bladder mucosa and state that this sense is confined to the urethra. Pitfalls in the investigation of bladder thermæsthesia and the ability to lateralize thermal stimuli are, firstly, that temperature changes of the cystoscope or of the whole bladder content may be mediated via urethral nerves, secondly, that the stimulus might induce local detrusor contraction, making it possible to lateralize it, and thirdly, that the jet of hot or cold saline might evoke the lateralized sensation purely by mechanical stimulation of receptors. However, with the latter technique used in the present study (I) the differentiation of heat and cold and the ability to lateralize must have been conveyed in nerves from the bladder mucosa since the unilaterally denervated patients could not feel thermal stimuli at all on the denervated side of the bladder, but could recognize heat and cold on the intact side. Moreover, the jet was not felt on either side when the injection was made with saline at room temperature with the same force on both sides. The experiments thus indicate that the bladder mucosa has thermæsthesia which is most probably conveyed by the parasympathetic pelvic nerves. This is in agreement with the findings of e.g. Ray and Neill (1947), Retief (1950) and McDonald and Murphy (1959). Thermæsthesia seems, however, less well developed in the bladder mucosa than in the skin or oral mucosa, which might account for the divergent findings of different investigators.

### Genitalia

The sexual function was unaltered in the three women with bilateral loss of the fourth and fifth, or third, fourth and fifth sacral nerves. The sensibility of the labiæ appears to be mediated above the level of S 3 since both the patients who lacked the third sacral nerves had normal sensibility. The sensibility of the penis seems to be subserved mainly by the second sacral nerve. Patient no. 4 had normal sensibility on the right side

of the penis where this nerve had been spared, but strongly diminished sensibility on the left side where only the first sacral nerve was left. Patient no. 5 who lacked the second sacral nerve on both sides had an anaesthetic penis. This is in agreement with the findings of Bohm et al. (1956) who found unilateral impairment of cutaneous sensibility of the penis after selective sectioning of one dorsal root of S 2, performed in seven men.

In the male, the preservation of only the first sacral nerve on both sides is compatible with sexual activity such as reported by Patient no. 5, who had exclusively psychogenic erection, dripping »ejaculation», and orgasmic sensation referred to the lower abdomen. This case parallels one reported by Bernhardt (1888), who described the same condition in a young man with a traumatic lesion of the spinal cord with anaesthesia of the four lower sacral dermatomes. Purely psychogenic erections are known to occur in about 30 per cent of paraplegics with lower motor neuron lesions (Bors and Comarr 1960).

In the patients with total loss of sacral nerves on one side the sex act was experienced as essentially unaltered although there was unilateral anaesthesia of the penis or labiæ. The EMG from Patient no. 8 during ejaculation displayed the normal event of clonic contraction bilaterally of the external urethral and anal sphincters (Petersén and Steiner 1970), although the contractions of the two sphincters alternated which is not the case in normal subjects. We can offer no explanation of this phenomenon in our patient.

### **Rectum and anus**

Normal anorectal function, like normal bladder function, appears to be dependent on the preservation of at least one third sacral nerve as the patients who lacked this nerve on both sides were incontinent with respect to soft fæces. Moreover, these patients had difficulty in expelling solid stools. When the second sacral nerve had been spared painful and tactile stimuli could be weakly perceived in the anal canal. This sensibility of the anal canal, however, was not sufficient for recognition of the quality of stools passing the canal. The sensory perceptions from the anal canal thus seem to be mediated mainly in nerves below the S 2 level. The patient with only the first sacral nerves left bilaterally was anaesthetic in the anal region.

There was also impaired sensibility concerning rectal wall distension in the three patients with bilateral loss of sacral nerves and it may be concluded that the sensation of rectal wall distension is also to a large extent mediated via segments below the S 2 level.

In all seven patients who were subjected to the study of anorectal function, the internal anal sphincter displayed the normal events of relaxation as the rectum was distended – the internal anal inflation reflex – indicating that this is not a spinal reflex at the S 2 - S 5 levels. Denny-Brown and Robertson (1935) have reported the presence of this internal sphincter reflex in a patient with destruction of the sacral cord and in another patient with sectioned hypogastric nerves. The pathways of the reflex are unknown but an intact anorectum seems necessary (Gaston 1948, Schuster et al. 1963). Several authors (e.g. Denny-Brown and Robertson 1935, Schuster 1975) have suggested an intramural pathway which is well compatible with our findings.

The external anal sphincter also seems to be dependent to a large extent on the preservation of sacral nerves below the S 2 level, as the spontaneous myoelectric activity of this sphincter was weak in Patient no. 3, who had the second sacral nerve left on both sides, and in Patient no. 4, who had this nerve left on one side. In addition, denervation potentials were registered in these patients. In Patient no. 6, who had only the first sacral nerves left, no spontaneous activity was present in the external sphincter except for a few denervation potentials. A small increase of the myoelectric activity during attempts to contract the sphincter voluntarily was seen in the patients who had one or both second sacral nerves left. This weak sphincter contraction was, however, without obvious significance for the anorectal function. No transient reflex contraction of the external sphincter during rectal wall distension – the external anal inflation reflex – was observed in the patients with bilateral nerve sacrifice, indicating that this reflex is mediated below the S 2 level.

Unilateral sacral denervation did not imply any significant impairment of anorectal function. There was, however, a loss of sensibility on the denervated side, although this was of no significance for recognizing the quality of the rectal contents when they passed the anal canal. The sense of rectal distension seemed normal as also did the reflex pattern of the internal anal sphincter. The spontaneous activity of the external anal sphincter was of good quality bilaterally, but in some of the electromyograms a slight difference of activity between intact and denervated sides could be observed. On brisk voluntary contraction there was an essentially normal increase of myoelectric activity bilaterally and this increased activity could be maintained on prolonged voluntary contraction as may be expected in normal subjects (Kadefors and Petersén 1970). This strongly suggests an overlap distribution of motor fibres from the right and left pudendal nerves and proves the sufficiency of only unilateral innervation of the external anal sphincter. The investigations of Sherrington (1892) and Bishop (1959), who in animals produced contraction of the entire anal circumference with unilateral pudendal nerve stimulation, were thus confirmed.

Several different aspects of anorectal function were studied. The significance of any of these factors per se for continence or defaecation, however, can not be evaluated.

Even though the internal anal sphincter had a normal reflex pattern in all patients the power of this sphincter cannot be judged. It might well be that, at least in the patients with bilateral loss of sacral nerves, it had a weaker tone than ordinarily but still had the capacity to relax. All other factors studied were negatively affected in this group of patients. In spite of this heavily impaired anorectal function the patients managed astonishingly well with the help of diapers, constipating diet and regular bowel care.

## BIOMECHANICAL STUDY OF PELVIC STRENGTH (IV)

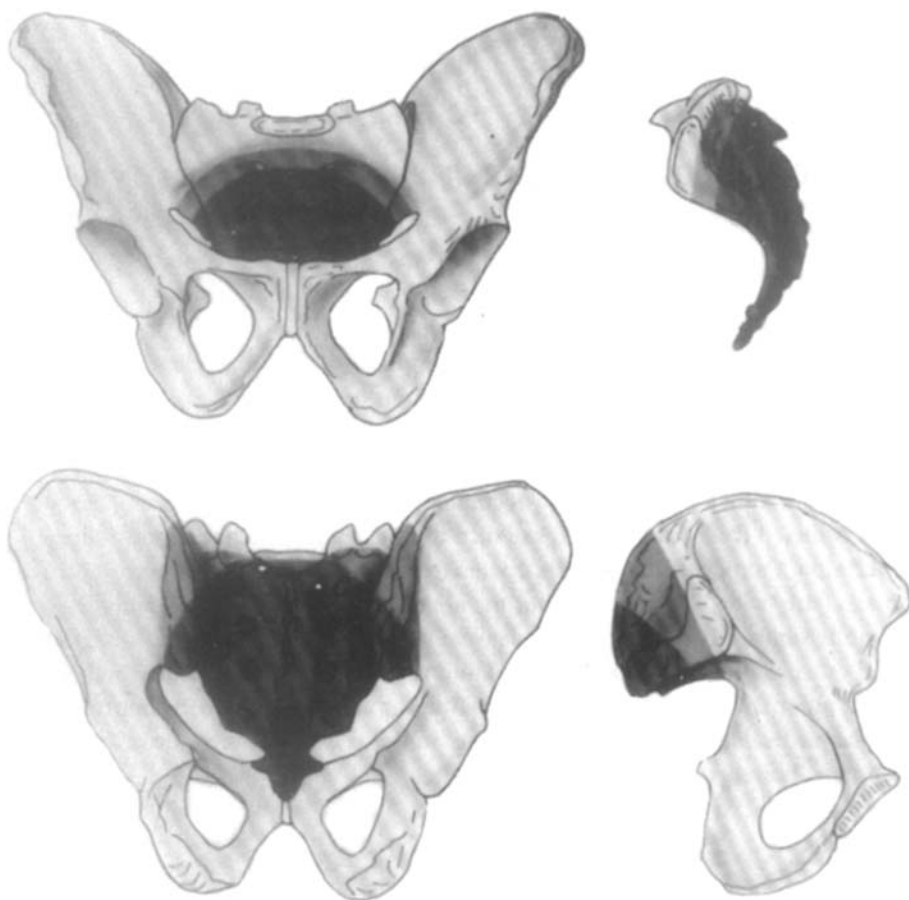
### MATERIAL

Fifteen cadaver pelvises were studied. They consisted of the pelvic ring with the fifth lumbar vertebra and were roughly cleaned from soft tissues except for the ligaments which were left intact. The specimens were kept in deep freeze and allowed to thaw at room temperature in moist wrappings 12 - 24 hours before testing. The pelvises were divided into three groups with five specimens in each. In the first group no resection was made. In the second group sacroiliac resection was performed according to alternative A (see below) and in the third according to alternative B (see below). The specimens originated from patients who had died of diseases that did not directly engage the skeleton. Cardiovascular diseases dominated the causes of death. The age distribution was fairly wide, 29 - 85 years, but the age compositions of the different groups were quite similar. Two cases of uræmia were included (unresected group and group A) and one patient had steroid-treatment during the last 6 months before death (unresected group). It was not possible to establish the exact duration of premortal bed-rest from the medical records. A major difference in this respect between the different groups was, however, not likely.

### Resection A

The resection is illustrated in Figure 2, darkest fields.

Anteriorly, the resection comprised the whole of the sacrum except for the first segment. Thus, the resection line ran between the bodies of S 1 and S 2 and through the anterior opening of the first sacral holes. Posteriorly the resection also comprised parts of the first sacral segment, including the posterior opening of the first sacral holes and the entire posterior wall of the sacral canal. From each iliac bone a posterior part, adjacent to the resected portion of the sacrum, was included. In this manner, about one-third of the sacroiliac joint with corresponding ligaments was removed on both sides.



**Fig. 2.** *Schematic drawing of resections performed in the biomechanical study on pelvic strength (IV).*

*Resection A: Darkest fields.*

*Resection B: Less dark fields also included.*

## Resection B

The resection is illustrated in Figure 2, less dark fields also included.

Anteriorly, the first sacral segment was divided about one centimetre below the promontory and the resection line ran superior to the first sacral holes. Posteriorly, the body of S 1 was divided only a few millimetres from the lumbosacral disc. A considerably larger part of each iliac bone than in Resection A was included so that only about half the sacroiliac joint with corresponding ligaments remained on each side.

## METHOD AND CALCULATIONS

The ischial tuberosities and the inferior pubic rami of the pelvises were fixed in epoxy resin (Plastic Padding<sup>®</sup>) in a metal box in a position corresponding to upright standing (Boyd et al. 1958). The specimens were loaded on the L 5 vertebra in a standard material testing machine (Alwetron Model T-2000), with a deformation speed of 5 mm/min. A strain gauge load cell transducer of 9810 N (1000 kp) with an accuracy of  $\pm 1\%$  was used. The load and the time were registered on an x-y-recorder over a measuring bridge and an amplifier. The specimens were x-rayed before and after testing.

To make it possible to judge the clinical significance of the experimental data the hypothetical loads in upright standing were calculated according to Nachemson and Elfström (1970), who have shown that the load on lumbar discs in upright standing may be calculated with the formula  $P = 6 + 2.2 W$ , where W is the part of the body weight exerting load upon the disc. This has been estimated by Ruff (1950), who found that approximately 60 per cent of the body weight lies above L 5.

Prior to failure testing two specimens in each group were loaded one to three times up to approximately twice the estimated normal load in upright standing to find out whether any permanent tissue damage occurred at these loads. Eventually all specimens were subjected to ultimate compressive loads.

## RESULTS

The preliminary tests with loading to approximately twice the estimated normal load in upright standing did not show any significant residual deformation.

In the test to failure the mean ultimate compressive load in the group of unresected pelvises was 4856 N (standard deviation 824 N). The specimens resected according to A had a mean ultimate compressive load of 3286 N (standard deviation 1971 N) and those according to B 2484 N (standard deviation 1500 N).

All specimens fractured through the lateral parts of the sacrum relatively close to the sacroiliac joints, first on one side and then on the other. The fracture localization was difficult to observe in the specimens after deloading when the sacrum returned almost to its original position due to the elasticity of the obviously uninjured sacroiliac ligaments. If the deformation was allowed to continue well past the point of failure the injuries became more obvious and in resected specimens the S 1 vertebra or its remains eventually split. Permanent dislocation of the sacroiliac joints did not occur in any specimen.

## DISCUSSION

The small number of specimens makes statistical evaluations unwarranted. Tendencies can, however, be recognized. It cannot be excluded that biological and other factors had influenced the specimens in a negative direction to weaken their strength. This would, however, be no disadvantage in this investigation as the safety margin concerning pelvic strength after major sacral resection would then in reality be greater than is shown by the study.

A slow deformation speed (5 mm/min) was chosen mainly to make it possible to follow the deformation and terminal failure of the specimens visually. Resistance to loading is lower when testing with low speeds than with high speeds (McElhaney 1966). Thus, the low testing speed might also have contributed to the registered ultimate compressive load values being minimum values.

The sacroiliac junction is very strong. Thus, the failure occurred in the lateral parts of the sacrum in unresected as well as resected specimens and the deformation curves also indicated a very low degree of permanent deformation of the soft tissues.

In this limited material the weakening of the sacroiliac region after resection according to A was approximately 30 per cent and after resection according to B approximately 50 per cent, as calculated from the mean values. Information on the normal load in vivo on the pelvic ring is needed to evaluate our results and to judge whether the resections leave sufficient residual strength in the pelvic ring to allow early postoperative weight-bearing. It should be borne in mind that the load at a certain vertebral level, because of muscular activity, is greater than the weight of the overlying part of the body. Nachemson and Elfström (1970) have shown that the load varies depending on posture, movements, etc.: ordinary slow walking increases the load by about 15 per cent, jumping on the floor and coughing by about 40 per cent, straining with erect posture by about 50 per cent and straining when seated by 5 - 35 per cent. In the cases in which information on the body weight was available (11/15) a good margin was found between the calculated load in upright standing and the load at failure. Thus, the test

strength was 4 - 8 times the calculated load in upright standing in the unresected group, 1.5 - 5 times after resection between S 1 and S 2, and about twice the calculated load after resection through S 1.

From this study it seems safe with regard to residual strength of the pelvic ring to allow patients to stand and walk with full weight-bearing at an early stage postoperatively after submaximal resection of the sacrum including adjacent iliac bone.

## SUMMARY AND CONCLUSIONS

The purpose of this work was to study the clinical effects of major resection of the sacrum, with well-defined sacrifice of sacral nerves, concerning urogenital and ano-rectal function. Moreover, an answer was sought to the question what residual strength and safety margin are retained in the pelvic ring after major amputation of the sacrum.

The **CLINICAL STUDIES** were performed in altogether 10 patients in whom sacral nerves had been sacrificed during surgical procedures for radical removal of tumours. Six patients had **bilateral** loss of sacral nerves (5 took part in the urogenital and 3 in the ano-rectal studies), and 4 had **unilateral** loss of sacral nerves (all took part in both the urogenital and ano-rectal studies).

*Urinary function* was studied by history, clinical evaluation, cystometry and cystoscopy including a test of vesical and urethral sensibility with different stimuli. *Sexual function* was evaluated by history, and one patient with total unilateral sacral denervation was subjected to an electromyographic study of the external urethral and anal sphincters during ejaculation. *Ano-rectal function* was studied by history, clinical evaluation, and simultaneous recordings of volume and pressure in the rectal ampulla, pressure changes in the internal anal sphincter region, and the myoelectric activity in the external anal sphincter.

In patients with **bilateral loss of sacral nerves** there was no active *detrusor contraction* when only the first and second sacral nerves had been spared, indicating that segments below the S 2 level are essential for the micturition reflex. This reflex was present when the third sacral nerves had been spared besides the first and second. There was loss of bladder mucosal pain when the lower three sacral nerves had been sacrificed.

*Sexual function* seemed unimpaired in women with preservation of only the first and second sacral nerves. A man with only the first sacral nerves spared had regular sexual intercourse but purely psychogenic erection, dripping »ejaculation» and a somewhat altered sensation of orgasm. The sensibility of the labiæ and penis seemed to be mediated mainly in the second sacral nerves.

*Anorectal function* was impaired when only the first and second sacral nerves had been spared. (No patient with preservation of the third sacral nerves was studied.) Soiling occurred and the sensation of rectal distension was defect as also was the sensibility of the anal canal. The internal anal sphincter displayed the normal reflex pattern even when only the first sacral nerves had been spared. There was weak spontaneous and voluntary myoelectric activity in the external anal sphincter when only the first and second sacral nerves were intact and no activity at all, except for denervation potentials, when only the first sacral nerves had been preserved.

In patients with **unilateral loss of sacral nerves** the *micturition reflex* was present even in those with total unilateral sacral denervation. The bladder mucosa was anaesthetic on the denervated side but the presence of pain and thermal sensibility was demonstrated on the intact side.

*Sexual function* was subjectively unimpaired in patients with total unilateral sacral denervation. In one patient the normal clonic contractions of the striated urethral and anal sphincters during ejaculation were recorded electromyographically, although the contractions of the two sphincters alternated for some reason. The penis or labiæ were unilaterally anaesthetic when the lower four or all sacral nerves had been sacrificed.

*Anorectal function* was subjectively unimpaired. One-sided sacral denervation implied deficient sensibility of the anal canal unilaterally but no disturbance of sphincter function.

The **BIOMECHANICAL STUDY** was performed as vertical loading tests on the L 5 vertebra of 15 pelvic specimens divided into three groups, one with no resection, one with resection of the sacrum between the first and second segments and one with resection through the first segment approximately 1 cm below the promontory. The resections also comprised substantial parts of the adjacent iliac bones. As calculated by mean values the approximate weakening of the pelvic ring by resection between S 1 and S 2 was 30 per cent and by resection through S 1 50 per cent. To make it possible to judge the clinical significance of the experimental data the hypothetical loads in upright standing were calculated according to Nachemson and Elfström (1970). There appeared to be a reasonable safety margin between the calculated loads and the loads at failure. This margin was about 4 - 8 times the calculated load in upright standing in the unresected group, 1.5 - 5 times after resection between S 1 and S 2, and about twice the calculated load after resection through S 1.

**IN CONCLUSION**, it seems necessary to spare at least one and perhaps both third sacral nerves in order to preserve normal bladder and anorectal function. The patients with bilateral loss of the lower three or four sacral nerves seemed, however, in spite of the loss of normal bladder and bowel control to manage astonishingly well with the

help of diapers, incontinence bags, constipating diet and regular toilet visits. Sexual function in women is probably unimpaired by bilateral sacrifice of the three lower sacral nerves. In the male the preservation of only the first sacral nerves is, at least in occasional cases, compatible with sexual activity and intercourse, the stimuli being purely psychogenic. Total unilateral sacral denervation leads to no significant impairment of urogenital or anorectal function.

A submaximal sacral amputation, including adjacent iliac bone on both sides, seems not to imply any great risk for failure of the pelvic ring even if the patient is allowed to stand and walk with full weight-bearing at an early stage postoperatively.

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## REFERENCES

- BERNHARDT, M. (1888) Klinischer Beitrag zur Lehre von der Innervation der Blase, des Mastdarmes und der Geschlechtsfunktion (beim Manne). Berlin Klin. Wschr. 25, 637 - 640.
- BISHOP, B. (1959) Reflex activity of external anal sphincter of cat. J. Neurophysiol. 22, 679 - 692.
- BOHM, E., FRANKSSON, C., PETERSEN, I. (1956) Sacral rhizopathies and sacral root syndromes (S II - S V). Acta chir. scand. Suppl. 216.
- BORS, E., MA, K.T., PARKER, R.B. (1956) Observations on some modalities of bladder sensation. J. Urol. 76, 566 - 575.
- BORS, E. & COMARR, A.E. (1960) Neurological disturbances of sexual function with special reference to 529 patients with spinal cord injury. Urol. Surv. 10, 191 - 222.
- BORS, E. & COMARR, A.E. (1971) Neurological urology. S. Karger AG, Basel.
- BOWERS, R.F. (1948) Giant cell tumor of the sacrum: a case report. Ann. Surg. 128, 1164 - 1172.
- BOYD, J.D. et al. (1958) Textbook of human anatomy, 1st ed., reprinted, MacMillan and Comp. Ltd., London.
- CARLSSON, C.A. & SUNDIN, T. (1974) Neurogena blåsrubbningar. Elanders Boktryckeri AB, Kungsbacka.
- DENNY-BROWN, D. & ROBERTSON, E.G.G. (1935) An investigation of the nervous control of defæcation. Brain 58, 256 - 310.
- DUTHIE, H.L. (1971) Anal continence. Gut 12, 844 - 852.
- ERICSSON, N.O., HELLSTRÖM, B., NERGÅRDH, A. & RUDHE, U. (1970) Unilateral neurological defect in myelomeningocele with normal bladder function. Acta pædiat. scand. 59, 487 - 490.
- FREIER, D.T., STANLEY, J.C. & THOMPSON, N.W. (1971) Retrorectal tumors in adults. Surg. Gynec. Obstet. 132, 681 - 686.
- GASTON, E.A. (1948) Fecal continence following resections of various portions of the rectum with preservation of the anal sphincters. Surg. Gynec. Obstet. 87, 669 - 678.
- HAYS, R.P. (1953) Resection of the sacrum for benign giant cell tumor: a case report. Ann. Surg. 138, 115 - 120.

- HOTCHKISS, R.S. (1970) Physiology of the male genital system as related to reproduction. In: *Urology*, 3rd ed., Vol. 1, Saunders Comp., Philadelphia, London, Toronto.
- IHRE, T. (1974) Studies on anal function in incontinent patients. *Scandinavian Journal of Gastroenterology*
- KADEFORS, R. & PETERSEN, I. (1970) Spectral analysis of myo-electrical signals from muscles of the pelvic floor during voluntary contraction and during reflex contractions connected with ejaculation. *Electromyography* 10, 45 - 67.
- KERREMANS, R. (1969) Morphological and physiological aspects of anal continence and defæcation. *Arscia uitgaven N.V. Brussel*.
- LOCALIO, S.A., FRANCIS, K.C. & ROSSANO, P.G. (1967) Abdominosacral resection of sacrococcygeal chordoma. *Ann. Surg.* 166, 394 - 402.
- MACCARTY, C.S., WAUGH, J.M., MAYO, C.W. & COVENTRY, M.B. (1952) The surgical treatment of presacral tumors: a combined problem. *Proc. Staff Meet. Mayo Clin.* 27, 73 - 84.
- MARKLAND, C., MERRILL, D., CHOU, S. & BRADLEY, W. (1972) Sacral nerve root stimulation: a clinical test of detrusor innervation. *J. Urol.* 107, 772 - 776.
- MCDONALD, D.F. & MURPHY, G.P. (1959) Quantitative studies of perception of thermal stimuli in the normal and neurogenic urinary bladder. *J. appl. Physiol.* 14, 204 - 206.
- MCELHANEY, J.H. (1966) Dynamic response of bone and muscle tissue. *J. appl. Physiol.* 21, 1231 - 1236.
- NACHEMSON, A. & ELFSTRÖM, G. (1970) Intravital dynamic pressure measurements in lumbar discs. *Almqvist & Wiksell, Stockholm*.
- NATHAN, P.W. (1952) Thermal sensation in the bladder. *J. Neurol. Neurosurg. Psychiat.* 15, 150 - 151.
- PEARLMAN, A.W. & FRIEDMAN, M. (1970) Radical radiation therapy of chordoma. *Amer. J. Roentgenol.* 108, 333 - 341.
- PETERSÉN, I. & STENER, I. (1970) An electromyographic study of the striated urethral sphincter, the striated anal sphincter and the levator ani muscle during ejaculation. *Electromyography* 10, 23 - 44.
- RATHKE, F.W. & SCHLEGEL, K.F. (1974) *Wirbelsäule und Becken (Band III)*. In *Orthopädisch-chirurgischer Operationsatlas*. Ed. by Hackenbroch, M. and Witt, A.N., Georg Thieme Verlag, Stuttgart.
- RAY, B.S. & NEILL, C.L. (1947) Abdominal visceral sensation in man. *Ann. Surg.* 126, 709 - 724.
- RETIEF, P.J.M. (1950) Physiology of micturition and ejaculation. *Sth afr. med. J.* 24, 509 - 512.

- RUFF, S. (1950) Brief acceleration: less than one second. In: *German Aviation Medicine, World War II*, U.S. Government Printing-Office, Washington D.C. 1, 584 - 597.
- SCHUSTER, M.M., HENDRIX, T.R. & MENDELOFF, A.J. (1963) The internal anal sphincter response: Manometric studies on its normal physiology, neural pathways and alteration in bowel disorders. *J. clin. Invest.* 42, 196 - 207.
- SCHUSTER, M.M., HOOKMAN, P., HENDRIX, T.R. & MENDELOFF, A.J. (1965) Simultaneous manometric recording of internal and external anal sphincteric reflexes. *Bull John Hopkins Hosp.* 116 no. 2, 79 - 88.
- SCHUSTER, M.M. (1968) Motor action of the rectum and anal sphincters in continence and defecation. In: *Handbook of Physiology*, sect. 6: Alimentary canal. Ed. by C.F. Code. Washington D.C. American Physiological Society.
- SCHUSTER, M.M. (1975) The riddle of the sphincters. *Gastroenterology* 69, 249 - 262.
- SENGER, F.L. & ROTHFELD, S.H. (1947) On sensation of the bladder - a preliminary report. *Urol. Cut. Rev.* 51, 454 - 456.
- SHERRINGTON, C.S. (1892) Notes on the arrangement of some motor fibres in the lumbosacral plexus. *J. Physiol., Lond.* 13, 672 - 675.
- STECKLER, R.M. & MARTIN, R.G. (1974) Sacrococcygeal chordoma. *Am. Surg.* 40, 579 - 581.
- TALAAT, M. (1937) Afferent impulses in the nerves supplying the urinary bladder. *J. Physiol.* 89, 1 - 13.
- WILSON, P.W. (1972) A clinical study of the biomechanical behaviour of massive bone transplants used to reconstruct large bone defects. *Clin. Orthop. Rel. Res.* 87, 81 - 110.
- ÖRTENGREN, R. (1975) A filter bank analyzer with simultaneous read-out for the evaluation of dynamic myoelectric signal power spectra. *Medical and Biological Engineering* 13, 561 - 569.